ADVANCED TECHNOLOGIES AND METHODOLOGIES FOR RISK MANAGEMENT IN THE GLOBAL TRANSPORT OF DANGEROUS GOODS

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Advanced Technologies and Methodologies for Risk Management in the Global Transport of Dangerous Goods

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Preface

In the last few years, logistics has become a strategic factor for development and competition. In fact, Research and Development activities have traditionally faced the management of Supply Chain and International Transport focussing on two main aspects: speed and efficiency. However, several vulnerabilities have recently been highlighted under a safety and security viewpoint. The weakness of the logistic chains has become more evident with the beginning of the new millennium. Terrorist attacks, such as 11/09 in the USA have caused the introduction of new rules and procedures, which affect the overall logistics showing the vulnerability of the global economy. So, nowadays, it would appear anachronistic to carry out an exhaustive research activity on the supply chain with no relation to the various typologies of risk, which may affect it.

CIELI, the Italian Excellence Centre on Integrated Logistics, which was founded at Genoa University in autumn 2003, studies the interactions between Logistics and Safety/Security aspects among its main lines of research, with the main specific goal of modelling the components of risk, and the relationships among various parameters and variables, depending on market evolution, on geographic position and socioeconomic and cultural appearance, on commercial practices and legislations/local regulations, on productive and technological solutions, on decision-making development for innovative analysis models of awkward risks to its connection with the optimization of logistic chain. Supply support is necessary for driving decisions oriented to moderate business choices, national politics and international regulations and, in this context, to supply some models that pass from qualitative esteem to quantitative analysis able to consider all operated choice implications.

Since CIELI aims to become a reference centre for Europe and for the overall Mediterranean area as regards research in the field of logistics and transport planning and management, CIELI has started to find research opportunities to collaborate with different relevant research actors. One important opportunity was the NATO Science for Peace Programme, where the NATO Human and Societal Dynamics Panel approved a joint proposal by CIELI and the University of Mohammedia in Morocco under the scientific contact of Professor Azedine Boulmakoul. The proposal was related to the organisation of a workshop, that was then effectively organised in Genoa on 25–26 October 2007, with the subject “Advanced technologies and methodologies for risk management in the global transport of dangerous goods”. In fact, dangerous goods transport probably represents by definition the most vulnerable aspect in global logistics and transportation activities. The workshop represented the test bed to collect different Italian, Moroccan and world experiences of the problem of dangerous goods transport, and to compare different approaches. The main result of the workshop was the creation of an international group working on this subject, whose dimension is still increasing. Some of the experiences that were collected in the workshop have been reported in this book, which may effectively represent the current status of research on dangerous goods transport. In this respect, CIELI, University of Mohammedia and all participants are grateful to NATO, and specifically to the Human and Societal Dynamics Panel, headed by Prof. Carvalho Rodrigues for being given this opportunity.

I also wish to express my gratitude to Prof. Roberto Sacile for the organization work and to all participants that attended the workshop and had the fundamental opportunity to share knowledge and practices in Genoa, a city that has a long and sound experience in traffic management as well as historical and artistic charm.

Prof. Pier Paolo Puliafito

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Introduction

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In Italy about 80% of road traffic is represented by the delivery of goods, and the overall trend in Europe seems to predict an increase of 30% within 2010. About 18% of this freight traffic is currently represented by Dangerous Good Transport (DGT), but a clear awareness of DGT world flows on road and on the other transport modes – as well as of the related security and safety aspects – is not present yet, at least from a social and economic point of view.

Over one million shipments per day are transported in North America alone and the risks associated with such transports are high (488 serious incidents resulting in 15 deaths, 35 injuries, and $37.75 million in property damage in 2003 in the USA alone). The Department of Transportation (DOT) in the US has a proper office (OHM, Office of Hazardous Material Safety, http://hazmat.dot.gov) to promulgate a national safety program that will minimize the risks to life and property inherent in commercial transportation of hazardous materials. A specific programme ("Hazardous Materials Transportation Safety Assessment", http://www.whitehouse.gov/) has been recently funded in the USA on these aspect and $27 million are programmed as funds on this project.

In Europe, DGT are subject to ONU Recommendations, published for the first time in 1957 and periodically updated, specific for the different modality of transport (IMDG Code for maritime transport, ICAO for air transport, ADR for road transport, RID for railway transport, AND for transport in rivers/canals).

ADR (European Agreement concerning the International Carriage of Dangerous Goods by Road, recently revised in 2005 and 2007) contains international regulations which itemizes DG in several categories according to their danger and chemical characteristics and quotes DG marking, labelling and packaging standards but it failed in the effective risk prevention of injuring people, damaging immovable and movables property and the environment.

To address this issue of security of the DGT, in the ADR 2005 a new chapter 1.10 was introduced. DG distribution companies since July 2005 should comply to regulations as regards the introduction of measures and control services to monitor DG vehi-

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cle to prevent its theft carrying high consequence dangerous goods or its cargo (1.10.3.3).

Due to the complexity of the problem and the new directives imposed by the ADR, some countries, such as Morocco and Italy, are also working at the development of centers to track DGT and to define the related risk, but a clear common model of risk management is not present yet.

Despite the lack of awareness, and the starting research effort in the different countries, some coordination is requested at world level in order to compare different approaches, and to verify which the requested and the requirements are from a research point of view in the near future.

In fact, DGT risks can be reduced in many different ways and advanced research can deeply contribute in this respect. The current situation and the predicted trend of DGT require a particular attention as regards methodologies to plan and to monitor deliveries, to define risk, with attention to exposure of the population and to the possible impact on the environment. In fact, several emerging Information and Communication Technologies allow a new definition of this risk, which can be more related to space and time varying factors (for example, the state of the road, of the weather, of the driver, of the dangerous good itself) which affects its degree. In addition, a common strategy to study at policies and regulations is to shift DGT from road to other safer transport modes requires support in its development. On the other hand, the possibility to get real-time information on DGT adds other new problems on the confidentiality and on the security of this information.

The general objective of the proposed ARW was to focus on DGT, verifying the validity of existent technologies and methodologies in order to enhance safety and security, and evaluating future research needs with special reference to sustainable development and risk management.

As regards technologies, special emphasis has been given to the integration of two different technological solutions to identify, detect and monitor DGT. An active tracing and tracking system installed on-board of each monitored truck and a passive detection system for the DG vehicle identification installed on the road infrastructure. As regards methodologies, special emphasis has been given to decision support systems to minimise risks in DGT, with special reference to the transport on critical infrastructures and in areas with high potential exposure. Besides, due to the particular damage caused by the different types of dangerous goods transported (explosions, toxic rubbish, corrosion, radioactivity etc.) and of the potential subjects exposed to this phenomenon (population, environment, infrastructure etc.), risk prevention and emergency management requires the availability of precise and thorough information for the various decision makers involved.

The ARW objective was to stimulate co-operation among countries by exchanging and integrating experiences among public local authorities, transport companies, infrastructure owners, stakeholders, decision makers, researchers, providers of technology and training institutions. The activities carried out during the ARW were related to: studies integration, analysis, benchmarking, mapping and dissemination to produce a clearer definition of DGT flows and related technologic and methodological management throughout the world. The main results of the ARW are:

- The definition of a Global Reference Framework (WRF) on DGT on road, and in part, in other transport modalities.
- The constitution of a DGT Working Group (DGT-WG).

Public authorities, distribution companies and other target users and key actors have attended the ARW, have presented their needs and competences as regards safety and security in DGT. They have validated the promising technologies and methodologies presented by key scientists to detect, monitor and control DGT and to prevent and manage the related risk.

This book reports this experience and is organised in the following sections. After this introduction section, there is a section oriented to the definition of the state of the art on the subject. Then, the following section includes some chapters focusing on advanced methodologies and technologies to enhance security and safety. Finally, some case studies are presented and conclusions are reported.

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Part I

State of the Art on Risk Assessment

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Assessment of Risk and Accident Impacts related to Dangerous Goods Transport in a Dense Urbanized Area

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Abstract. France and Italy are characterized by a huge flow of Dangerous Goods carried by trucks inside their own territory and between them and the European Union. It is well known that the Dangerous Goods Transport (DGT) leads risks for the population, the environment and the human activities, according to the experience feedback of the major accidents occurred during the last 30 years. Due to the particular damages caused by the different types of dangerous goods transported (explosions, toxic release, corrosion, radioactivity etc.) and of the potential subjects exposed to this phenomenon (population, environment, infrastructure etc.), risk prevention and emergency management necessitate the design and development of a Spatial Decision Support System (SDSS) dedicated to the various decision makers involved. This chapter aims to present the methodology that establishes the base of a SDSS dedicated to the risk assessment of a DGT accident and the evaluation of the consequences in order to provide to the decision makers the best information to support their decision. The first part of this chapter presents the definition of DGT accident risk on road, taking into account the specificities of the traffic flow, the weather conditions, the accident feedback in the selected infrastructure and its structural characteristics. The second part is related to an overview of the main phenomena that occur if an accident of DGT occurs, presenting the main model to estimate the effect of these phenomena on the population. The third part is the case study, in the city of Nice (French Riviera), which corresponds to the simulation of two scenarios of DGT accidents in two urbanized places and the damage assessment induced. The last part is a discussion about the interest of this methodology and its results for the public authorities, the Civil Protection and the motorway companies.

Keywords. Risk assessment, risk definition, hazardous material transport, Nice, decision support system.

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Introduction

The risk attached to the Dangerous Goods Transport by road is complex to understand as it is connected to all the road network and depends on multiple factors such as traffic density, weather conditions, the occurrences of undesired events (road accidents, natural phenomenon etc.). This risk is also strongly linked to the nature of the transported goods and to the presence of exposed humans and materials in proximity to the place of incident. For example, the transport of fuel such as petrol or GPL can provoke considerable fires or the explosion of the tankers in which it is transported, with heat, over pressures and missile effects.

Other substances have toxic properties and can be the origin of toxic gas clouds in the case of leakage due to the accidental puncturing of the tanker.

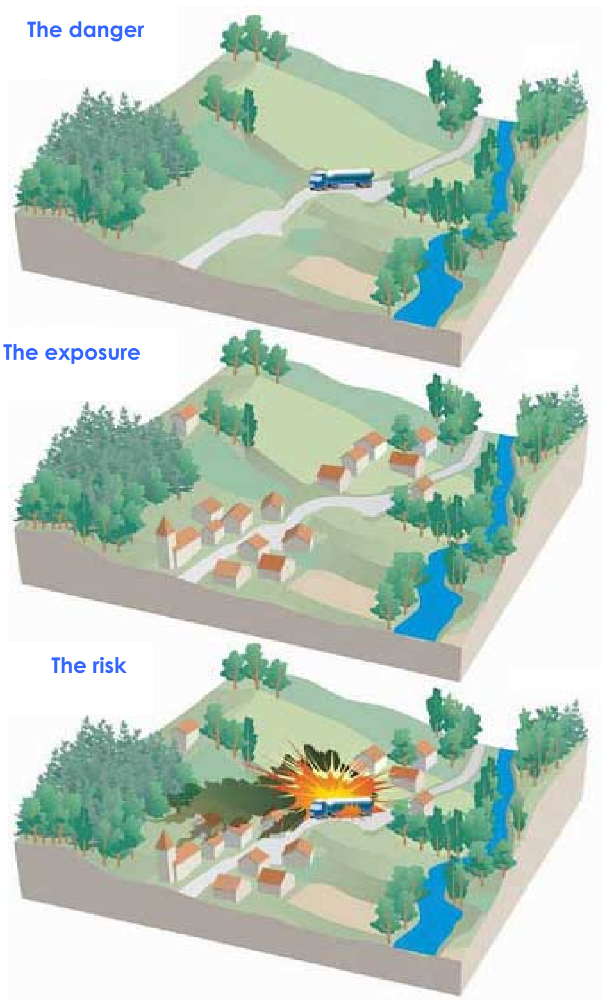

Figure 1. The risk of DGT (Source: Ministry of Ecology and Sustainable Development – France)

On a national scale it is shown that DGT accidents on the roads make up no more than 0.1% of total accidents. But, even though this risk is minimal, the consequences are important when dangerous substances are involved. In France on the 8th September 1997, the collision between a vehicle transporting hydrocarbon and a lorry caused the deaths of 13 people and injured a further 43. In Italy on 9th February 1997 in a motorway accident a collision between a lorry transporting kerosene and a tanker caused a fire and a pile-up which resulted in 1 death and 40 injured.

Despite the high level of risk, the public authorities and the management of the motorway and road infrastructure do not precisely know the nature, number and route of the dangerous goods transported on the territory. The only statistics produced are the result of manual surveys carried out in various periods of the year, furthermore, carried out by different bodies such as motorway companies, territory institutions or some state services (for example the Ministry of Transport and Infrastructure). The results show that the Dangerous Goods Transport by road represents between 5 and 10% of the flow of goods transported by lorry.

Figure 2 shows the statistics computed by the French motorway company ESCOTA regarding the numbers and categories of vehicle that cross the toll barrier at Ventimiglia (Italy). This figure shows that around 5000 lorries pass the barrier each day and that this tendency has been on the increase for more than 20 years. Based on the approximation that 10% of those vehicles transport dangerous goods, the number of DGT vehicles that cross the toll barrier at Ventimiglia is around 500 vehicles per day (13,000 vehicles per month, 156,000 vehicles per year excluding the days when lorries are not allowed (Sundays).

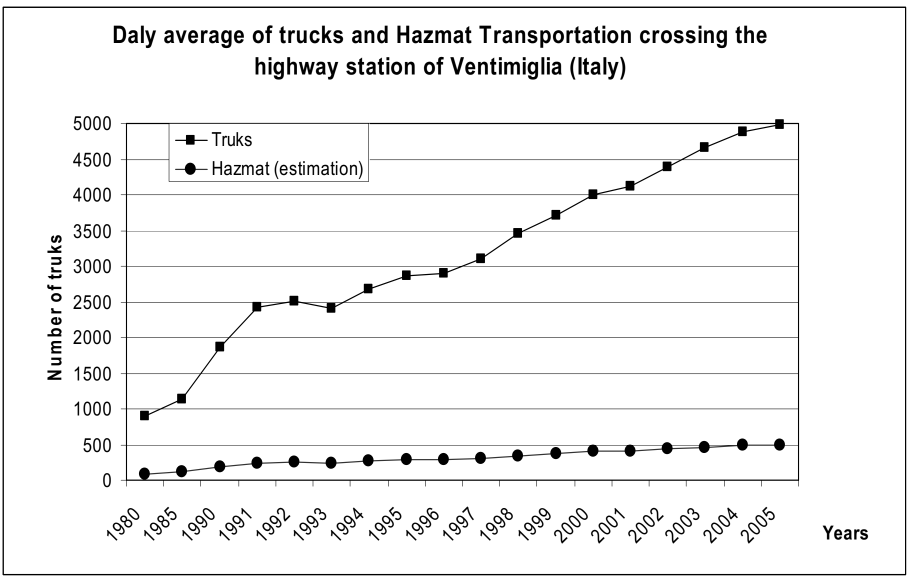

Figure 2. Number of vehicles that cross the toll barrier at Ventimiglia (Italy). Data supplied by the company ESCOTA. Source: Road Union of France.

In this context, the aim of this chapter is to propose a methodology to assess the risk of DGT accident and to evaluate its consequences in order to provide to support the decision makers in their missions of accident prevention, crisis and territory management.

1. Definition of DGT risk

In literature there are two different approaches to the definition of risk. For a detailed analysis of the literature see [1], [2], [3], [4], [5]and [6]. For the definition of risk the distinction of the following two indicators is fundamental: the individual risk and the social risk.

The individual risk is defined as the probability in a year that an exposed person, positioned at a precise distance to the source of risk, is hit by the undesired effects of the event [7]. This is formally defined by the following expression:

$$IR = P_f \cdot P_{d|f} \tag{1}$$

where:

P_f = probability of accident happening

$P_{d|f}$ = probability of death of the individual if the accident happens

The individual risk is graphically represented by the iso-risk curve which links points with identical values of individual risk.

The social risk is instead defined [7] as the relationship that exists between the number of people affected (killed) following a single accident (N) and the probability (F) that the number of people affected is exceeded.

The most convenient representation of the social risk is the F-N curve; this curve, expressed in log scale and characterized by a monotonous upwards trend, represents the frequency (F) of accidents and the number (N) of victims with N varying from 1 to the maximum possible number. There are two general methods for the construction of the F-N curve: the first is to calculate the F-N curve directly from the empirical frequency of the data of passed accidents; the second is to develop and use a probabilistic model to estimate the frequency (F).

The indicators of individual and social risk, initially defined by fixed installation and then for precise source of risk, can extend to the road links and then the linear sources, even if with notable computational effort [8].

To calculate the F-N curve associated with each it is in fact necessary to know information such as: the number of journeys per year, the frequency of accidents (F), the probability that a particular accident happens, the dimensions of the area potentially involved in the accident and the population density in the area under examination.

The approach proposed by [9] is therefore innovative as the frequency of an accident on the *i*-th stretch can be expressed by the following equations:

$$f_i = \gamma_i L_i n_i \tag{2}$$

$$\gamma_i = \gamma_0 \prod_{j=1}^{6} h_j \tag{3}$$

where:

$\gamma_i =$ frequency expected on the i-th stretch of road [accidents km-1 per vehicle]

$L_i =$ road length [km]

$n_i =$ number of vehicles [vehicles]

$\gamma_0 =$ basic frequency [accidents km-1 per vehicle]

$h_i =$ parameters of local amplification / mitigation

In their study the authors proposed gauging the parameters of the amplification and mitigation, for a stretch of the A7 motorway near Genoa (see Tables 1, 2, and 3). They were subdivided into 6 categories; in particular h1 and h2 refer to geometric characteristics of the road, h3 to the type of roadway, h4 to the weather conditions, h5 to the type and intensity of traffic, h6 to the presence or not of tunnels and bridges.

Table 1. Local amplification / mitigation parameters : factors interrelated to the intrinsic characteristics of the road [9]

Intrinsic characteristics	**h1**	**h2**	**h3**	**h6**
Direct road	1			
Curve of the road (distance> 200m)	1,3			
Curve of the road (distance < 200m)	2,2			
Level road		1		
Ascending road (gradient< 5%)		1,1		
Steeply ascending road (gradient > 5%)		1,2		
Descending road (gradient < 5%)		1,3		
Steeply descending road (gradient > 5%)		1,5		
Two lanes for every roadway			1,8	
Two lanes plus the emergency lane for every roadway			1,2	
Three lanes plus the emergency lane for every roadway			0,8	
Tunnel				0,8
Bridge				1,2

Table 2. Local amplification / mitigation parameters : factors interrelated to the weather conditions [9]

Weather Conditions	**h4**
Fine weather	1
Rain/fog	1,5
Snow/ice	2,5

Table 3. Local amplification / mitigation parameters : factors interrelated to the characteristics of traffic on the A7 motorway [9].

Traffic Characteristics	**h5**
Low intensity < 500 vehicles/hours	0,8
Medium intensity <1250 vehicles/hour with heavy traffic <125 lorries per day	1
High intensity >1250 vehicles/hour	1,4
High intensity <1250 vehicles/hour with heavy traffic >250 lorries per day	2,4

Another approach, based on the calculation of the population, is that of [3]. The authors, in this work, consider unitary segments of risk, or rather each road link is subdivided in segments of unitary length. Assuming furthermore that the risk is connected to a segment of unitary length *x*, belonging to a generic link, and to the population, that resides in the proximity of the segment next to the unitary length *y*. The risk is defined as the product between the probability, per unitary length, that is verified as an accident in segment *x* and the consequences of that accident for the population that lives in the proximity of segment *y*:

$$\sigma_x^y = P_x \cdot pop_y \cdot e^{-\alpha[d(x,y)]^2} \tag{4}$$

where:

P_x = probability that an accident happens in the stretch of unitary length x

pop_y = population in the proximity of the segment of unitary length y

$d(x,y)$ = euclidean distance between the centre of the 2 segments x and y of unitary length

α = factor of impact, dependent on the particular dangerous goods considered

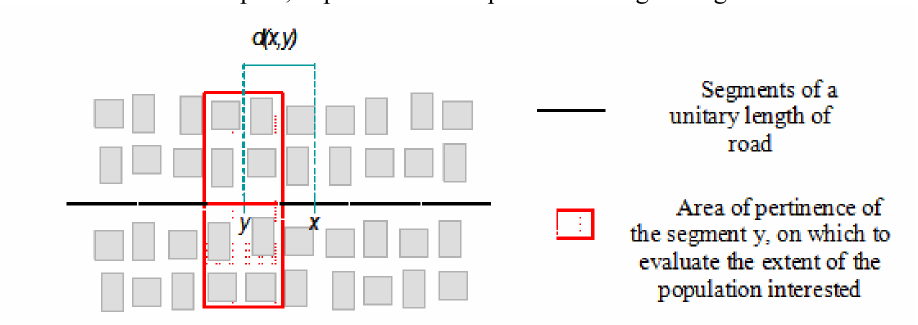

Figure 3. Representation of the area of pertinence of a segment and the distance between the centres of the two different segments

The risk σ_x associated to segment *x* for the population that lives in proximity to the considered arc can be evaluated by the comparison:

$$\sigma_x = P_x \sum_{y \in S} pop_y \cdot e^{-\alpha[d(x,y)]^2} \tag{5}$$

where S is the combination of the segments of unitary length that make up the entire network under consideration. At this point the risk associated to the link can be calculated as the sum of the risk associated to each segment of unitary length that makes up the same arc:

$$r_h = \sum_{x=1}^{q_h} \sigma_x \tag{6}$$

As already proposed in [10], combining the definition of the frequency of accidents, calculated using the approach of Fabiano *et al.* [9], with that of the population involved proposed by Carotenuto *et al.* [3], a complete definition of risk associated with a road link is obtained. This solution is displayed in figure 4.

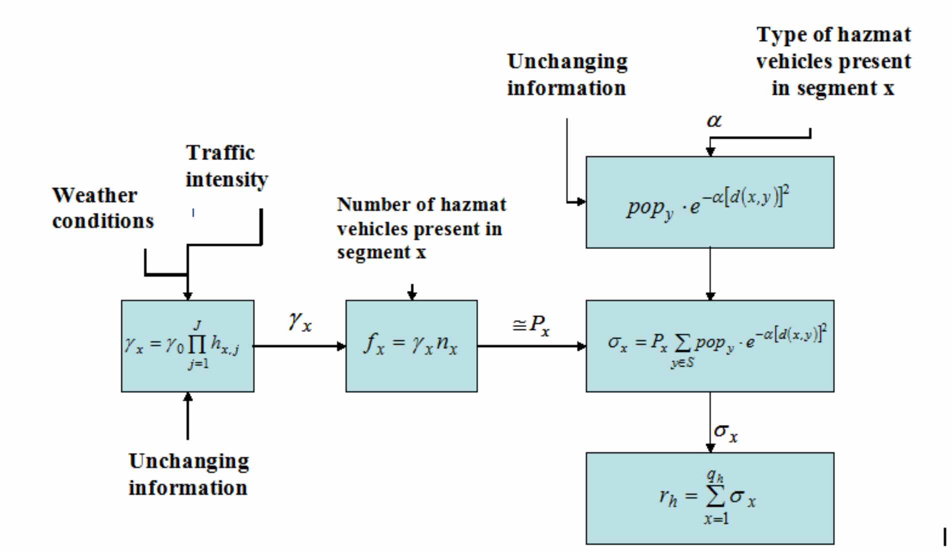

Figure 4. Summary diagram regarding the definition of risk in the DGT relative to the link *h*

The following paragraph is focused on the modelling of the effects induced by an DGT accident on road. This part show that it is dramatically important to take into account to these considerations in the aim of accident prevention and crisis management.

2. Hazardous effects induced by DGT accidents: models and simulation parameters

As previously seen to calculate the number of people involved in an accident caused by the Dangerous Goods Transport it is necessary to know, or at least estimate, the dimensions of the area affected by the accident.

The accidents that can occur during the Dangerous Goods Transport can be substantially classified into three categories:

- Release of substances which are toxic to health and the environment;
- Release of thermal energy;
- Release of pressure.

The consequences that derive depend on the type of transport, the characteristics of the vehicle, the substances transported and how the event happened. Furthermore, above all for the degree to which it concerns the transport of rubber accident scenario, the domino effect cannot be ignored, made more probable by energy releases in conditions of traffic congestion and the proximity of storage, production and distribution systems to the substances of risk.

2.1. Explosive phenomena

The release of energy that appear in an explosive phenomenon is evaluated in this part, in particular the two types of explosive events: BLEVE and UVCE.

BLEVE (Boiling Liquid Expanding Vapour Explosion) is a scenario similar to the explosion generated from the rapid expansion of inflammable vapours produced by gas substances kept under pressure in a liquid state; from this event can derive both effects of over pressure and fire balls dangerous for people and structures. This type of event entails three main dangers: the wave from the explosion, the thermal flow and projectiles.

The wave from the explosion is due to the abrupt pressure variation and consists of two phases: he wave of over pressure and the wave of depression. The thermal flow expressed in kW/m2, is often caused by the fire ball; for hydrocarbon the diameter of this is calculated by the formula:

$$D=6{,}48\ M\ 0{,}325 \qquad (7)$$

where M represents the mass of hydrocarbon measured in kg.

The thermal flow radiated from the ball of fire depends on the distance and is expressed by:

$$F = F0(R/X)^2 \qquad (8)$$

With:

- F0 = flow on the surface of the ball of fire;
- R = beam from the ball of fire in metres;
- X = distance in respect to the centre of the ball in metres.

To evaluate the effects of the thermal flow it is necessary to also know the exposure times. Through the following formula it is therefore possible to calculate the time of combustion of the hydrocarbon ball of fire:

$$t = 0{,}852.M^{0{,}26} \qquad (9)$$

With:

- M = mass of the ball of fire in kg ;
- t = duration of the ball of fire in seconds.

Finally, it is possible to calculate the area in which there is a strong possibility of lethal burns:

$$D_G = 1{,}26\ D_{BF} \tag{10}$$

Where :

- DG = area of strong possibility of lethal burns;
- DBF = diameter of the ball of fire in m.

The projectiles are the fragments generated by the tanker explosion; studies carried out on the types of tanker have demonstrated that:

- 80% of the fragments are thrown to around 250 m;
- 10% of the fragments are thrown to around 400m;
- the maximum distance of projection has been recorded as around 1200 m.

UVCE (Unconfined Vapour Cloud Explosion) is an accident scenario determined by the release and dispersion in an open area of inflammable substances in a gas or vapour state, from which can derive, if triggered, variable thermal effects and over pressure, often dangerous for man and the environment. This explosion has both thermal effects and over pressure effects that strongly depend on local conditions and, in particular, mixes of gases and weather conditions. The thermal effects are mainly due to the passage of the front of the blaze; as regards man, therefore, all people along the route of the blaze are at risk of lethal harm while the effect on structures is generally limited to superficial damage, even if at time metal structures can suffer small cracks. The effects of over pressure are, due to the size of the wave of pressure generated, directly proportional to the speed at which the front of the blaze spreads.

The model used for the UVCE simulation is, instead, that of a TNT equivalent, based on the correlation between the consequences of an explosion of a mass of a certain product, a mass of TNT would produce the same consequences at the same distances.

This relationship is defined through the combustion energy of the mass of TNT and the potential combustion energy of the mass of product released during the explosion.

$$a = \frac{M_{TNTequi} x Q_{TNT}}{M_{prod} x Q_{prod}} \tag{11}$$

With :

- a = the TNT equivalent based on the energy (adimensional)
- $M_{TNTequi}$ = mass of TNT equivalent (kg)
- M_{prod} = mass of equivalent product (kg)
- Q_{TNT} = combustion energy of TNT per unit of mass (kJ/kg)
- Q_{prod} = combustion energy of the product per unit of mass (kJ/kg)

It is noted that, in both models, information regarding the morphology of the terrain is not considered; this, which is due to the bi-dimensional nature of the models, is a limit for the simulation and the consequent evaluation of risk.

2.2. Toxic releases in the atmosphere

In case of accident during the transport and of release of dangerous substances from the tanker, the dangerous substances can be diffused in the atmosphere and provoke a toxic cloud with consequences on human health and the environment. The main objective of this study is to propose a method of evaluation of the exposure subject to the toxic risk caused by a DGT accident, starting from a tool for the simulation of the toxic releases in the atmosphere and a geographic information system (GIS).

2.2.1. The source of the release

The source of the release corresponds to all the elements that intervene in the materialisation of the phenomenon of a toxic cloud. This source of release includes the following points:

- The dangerous material for which it is important to know the reactivity with the atmosphere to evaluate if it undergoes chemical transformations, that can react violently etc. for example with contact with air or humidity, etc. Moreover, the type of storage of dangerous goods is an important parameter, in particular regarding the state of the goods themselves (liquid, gas, liquid-gas mix) which influences at the same time the kinetics of formation of the toxic clouds and their dispersion;
- The storage material, such as tankers and cylinders, of which it is necessary to know the capacity, points of possible breakage, pressure and the storage temperature, for storage compliance;
- The method of the dangerous goods release into the atmosphere. Classically two types of emissions are taken into consideration in the modelling: the instantaneous and continual release. Instantaneous release corresponds to the total destruction of the container and provokes the contact of all the dangerous goods with the atmosphere: this event results statistically improbable and therefore is not taken into consideration in the simulation. The second method regards the continual release that represents an escape starting from a pipe or hole in the shape, of variable dimensions and positioning inside the container. In this case, the smoke plume is of an elongated shape and spreads in a direction determined by the orientation of the hole or the wind direction. This type of release, closer to the real conditions of the formation of a toxic cloud in a DGT by road accident, represents the case under examination in this study.
- The method of movement of the cloud and its evolution in the atmosphere: the speed of movement of the cloud and its dilution in the atmosphere conditions the level of risk for the potential exposure. The orientation of the hole of release is fundamental to estimate the spread of the toxic cloud (high, low, lateral etc.). The pressure of the storage is also essential to determine the movement and the concentration of the cloud. In the case of the clouds being heavier than air, they will fall on the ground due to the gravitational effect and be subject to the forces of friction with the ground: therefore slowing down the progression and, often, increasing the concentration.

2.2.2. The weather conditions

The weather conditions have a fundamental role in the materialisation of a toxic cloud and in particular:

- Wind speed: this depends on the density of the cloud and influences the speed of the spreading just like the dilution in the atmosphere and the friction against the constructions present in the territory affected;
- The air temperature: this can influence the state (liquid, gas) of the dangerous goods emitted. The temperature also provokes the vertical movement of the molecules that are found in the atmosphere (thermal stratification of the atmosphere);
- The presence of a thermal inversion: this provokes the stagnation of the cloud on the lower part of the atmosphere. It can therefore be considered an aggravating factor for the consequences on the exposure because it impeded the fast dilution of the toxic cloud, particularly when considering light gases;
- The air moisture can be just as important because the toxic substances can react with the water vapour or, to the contrary, be captured by the drops of water that reduce the speed of progression of the cloud in the atmosphere;
- The cloud state: certain chemical substances react with sun light (photochemical reactions) and therefore this element should also be taken into consideration.
- Precipitation: this, in the form of rain or snow etc., reacts as a barrier that limits the progression of the toxic cloud in the atmosphere.

2.2.3. Surrounding environment

The notion of the natural environment subject to the diffusion in the atmosphere of a toxic cloud includes the following elements:

- The irregularity of the ground with the presence or not in the space of obstacles of various shapes, dimensions and nature. The progression of the toxic cloud will be different according to where it is situated outside, without large obstacles as in a plain, or in a closed area full of buildings, trees etc.;
- The topography: this influences the progression of the cloud according to the extent of inclination of the slopes and wind strength. The presence of breezes and slopes is also a factor in the movement of a toxic cloud;
- Thermal effects of the elements of the territory: according to the type of ground use (cultivated fields, forests, asphalted areas, built up areas, water areas etc.) different thermal effects can occur to the toxic cloud that is disturbed by sea breezes and disturbances caused by thermal rises.

Only the models that consider the three dimensions of the space allow the precise representation of the influence of the topography and the obstacles to the movement of the toxic cloud. The two dimensional classic models use assessment values to represent the influence upon the surrounding environment.

2.2.4. The main models of atmospheric dispersion

The atmospheric dispersion of a toxic cloud includes the study of its journey and the consequent diffusion in the atmosphere [11]. Three main models are usually used for the simulation of the toxic releases ([12]; [13]):

- The gaussian models: these apply to the clouds having a density close or the same as that of air and their molecular diffusion is presumed to be zero. In this case, only the action of the wind (at least 1 m/s) and the atmospheric turbulences distributed in classes of stability condition the movement of the gas molecules in the atmosphere. For these models, the turbulence and the wind speed are presumed to be constant for the total route of the cloud. These models do not take into consideration the irregularity of the territory and are not valid for distances of less than 100 m or more than 10 km. The calculation of the gas concentration released if the more often expressed like the following equation :

$$C_{(x,y,z,t)} = \frac{Q}{2\pi u \sigma_y \sigma_z} \exp\left(-\frac{(y-y_0)^2}{2\sigma_y^2}\right)\left[\exp\left(-\frac{(z-z_0)^2}{2\sigma_y^2}\right) + \alpha \exp\left(-\frac{(z+z_0)^2}{2\sigma_z^2}\right)\right] \quad (12)$$

with:

$C_{(x,y,z,t)}$ = concentration in kg/m^3;

Q = mass of product released in kg;

x_0, y_0, z_0 = coordinates of the source in m;

x, y, z = coordinates of the calculation point for the product concentration in m;

σ_x, σ_y, σ_z = standard deviation of the Gaussian distribution of the Q quantity of gas with regards to its location a the t time expressed in m;

u = average speed of wind in m/s;

t = gas release duration expressed in minutes.

- The whole models: these are used when the volumetric mass of dangerous substances is more sensitive than air and allows the consideration of the turbulence generated by the release at a high speed, of the effects of gravity generated by the heavy gases and of the floatation effects of the light gases. The various types of release source are examined by these models and the calculation of distances of release is based on the simplified equations of the process of the fluids. The simulations are valid on distances less than or equal to 10 km generally;
- The three-dimensional CFD (Computational Fluid Dynamics) models: these models consider the complexity of the atmospheric phenomenon due to the three-dimensional space.The use of these models requires a good experience and precise data of the environment and the atmospheric conditions of the area where the release occurred. The modelling in this case is more complex in the definition of the scenario for the effective calculation of the dispersion distances.

The simulations that are described concern the accidents that involve dangerous goods and are established from the ALOHA model of the software CAMEO that uses a gaussian model for the neutral gas with a density similar to air, and a whole model for other types of gas. These simulations are presented for the different case studies on the territory of the city of Nice, French Riviera.

3. Damage assessment in a dense urbanised area: case study in the city of Nice, French Riviera

The city of Nice is crossed to the North and to the West by the motorway A8, on which numerous (between 250 and 300) vehicles carrying dangerous goods pass. Often, the types of goods that are carried are unknown to the authorities. The simulation of accidents causing the release of ethylene oxide has been put into practice in two different areas of the city. This has been done in order to bring further elements of reflection to the managers of the motorways, the public and local bodies regarding the planning of assistance.

3.1. Areas surveyed

The territories on which the simulations of releases of toxic elements have been performed have been chosen following the frequency of truck accidents recorded by the Departmental Direction of Infrastructures (DDE) of the Alpes-Maritimes in the period stretching from 1998 to 2005. Such areas are on the Saint-Isidore and Nice sector stretches.

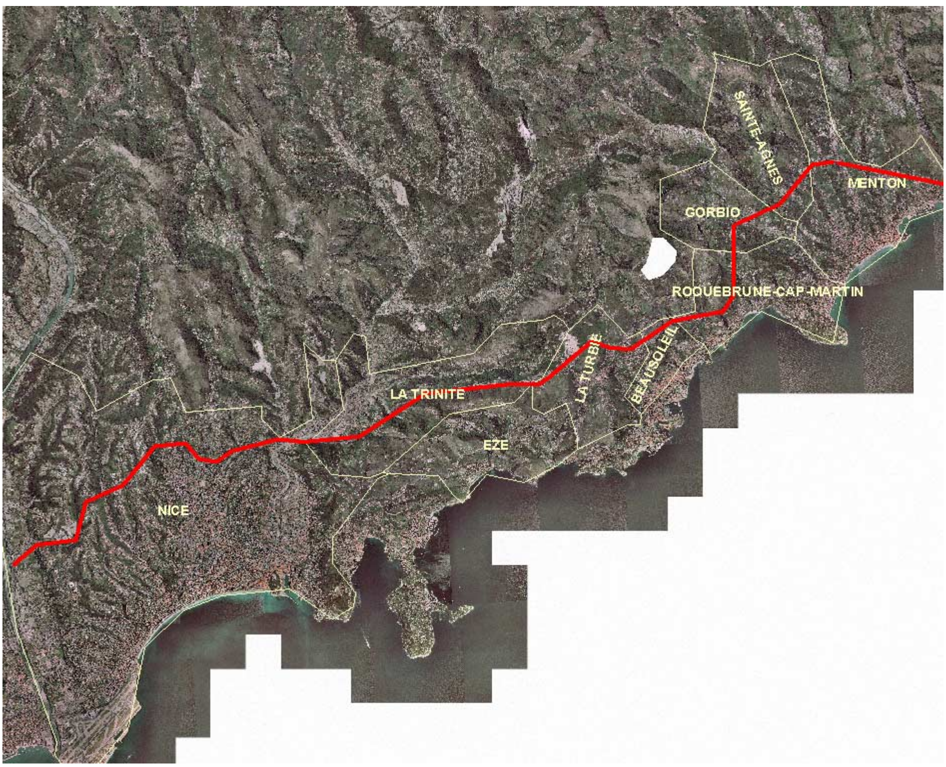

Figure 5. Communities crossed by the A8 motorway between Nice and Mentone: the ortho-photo shows the study areas of Saint Isidore and North Nice (source: BD ORTHO et ROUTE 500 IGN CRIGE PACA).

3.1.1. Saint Isidore sector

This sector of the A8 motorway presents four main types of exposure:

- Agricultural land (1);
- An important industrial and commercial area (2);
- Small dwellings and small capacity residence complexes, hotels, business activities, public buildings such as town halls, schools, churches etc (3);
- A platform of logistic activities (PAL) for the transport of goods (4).

In this sector there are many shopping centres such as Lingostière that is situated upon an area of 30 hectares. In particular it includes a supermarket, commercial activities, restaurants, a multi-screen cinema etc.

Further south are other shopping centres, car concessionaries etc. but also the administration offices of the Alpes-Maritimes (CADAM), the Alpes-Maritimes prefecture and General Council, the Nikaïa building (multi-function room) and the offices of the Nice-Matin newspaper.

Figure 6. Photograph of the main vulnerable stakes in the Saint Isidore sector.

3.1.2. North Nice

The North Nice sector has a population of more than 60,000 inhabitants that are spread throughout many areas: Ray, Borriglione, Saint Sylvestre, Gorbella, le Vallon des Fleurs, le Rouret, Las Planas, Gairault, Saint Pancrace.

This densely urbanised sector (5), includes large capacity type HLM (dwellings with moderate rent) buildings, distributed in hills with difficult access (6). There are also small dwellings situated in the hills. In the proximity of the A8 motorway there is also a small football stadium with a capacity of more than 15,000 places.

Figure 7. Photographs of the main exposed elements in the North Nice sector.

Furthermore, at present at Las Planas, some metres from the exit of the A8, there is a stop of the Nice tram. Finally, shopping centres, commercial activity, schools, gardens and public parks etc are distributed throughout all the North Nice sector.

3.2. Architecture of the SDSS for damages estimation

It must be assured that the communication methods between the services and the interveners are active and functioning perfectly. The Spatial Decision Support System (SDSS) for the estimation of damage in case of a DGT accident (Figure 8, [14]and [15]), uses the information supplied by the prototype of identification and monitoring of the DGT. This information is in fact archived in the common database (1) that includes historical data, data acquired in real time on the transport and vital statistics for the vehicles equipped for the monitoring system.

A set of queries on the common database (2) were implemented to extract the useful information for the decision makers. For example, it is possible to know, in a given time horizon, the dangerous materials that are transported in the specified territory, as well as the dangers that are connected to them. In the proposed case study, the frequency of the vehicles which transport ethylene oxide was identified in the common database and a module of extraction of the associated data was implemented.

The knowledge of the frequencies of the passage of the vehicles that transport dangerous goods under consideration, allows the consideration of possible accident scenarios in the specific territory and, thanks to the software module ALOHA, the ability to determine the atmospheric dispersion (3) of the toxic substances that can be in the form of a gas at room temperature and at atmospheric pressure. The software module ALOHA to help the simulation of the atmospheric dispersion and UVCE is presented in detail in the next paragraph. The dispersion distances are evaluated based on the variable toxicity threshold according to the worries of the decision makers regarding the chosen exposed elements, human population, animals, vegetation etc., and the considered consequences (mortality, reversible physiological problems). This modelling is supported by the weather parameters that at the time of an accident influence the dispersion of the gas, such as air temperature, wind speed, atmosphere moisture, etc.

The results of the simulation of the atmospheric dispersion of toxic substances are then integrated in the GIS module to allow the geographical representation in the considered territory (4).

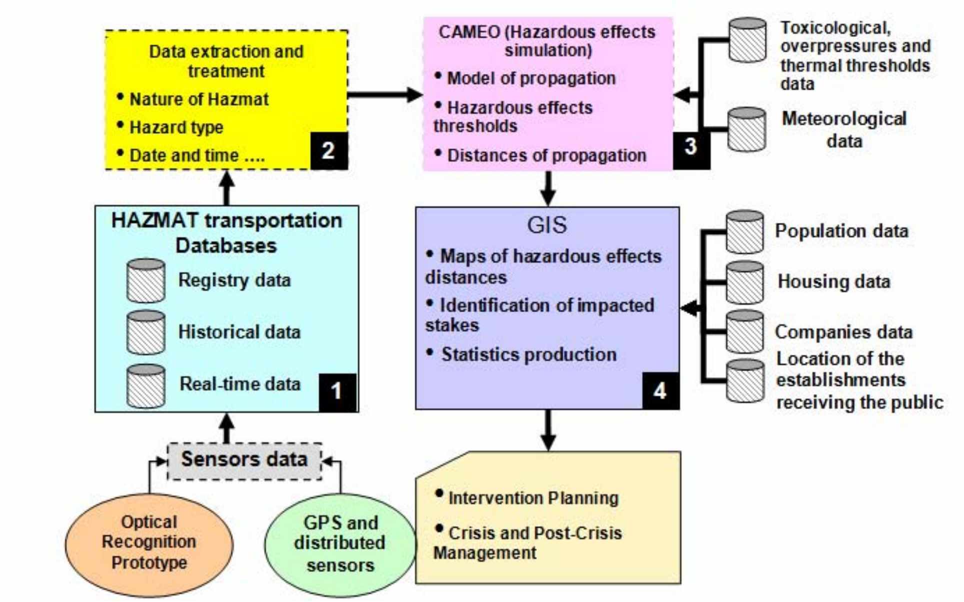

Figure 8. Architecture of the SDSS of estimation of the damage following a DGT accident.

- The GIS include the following information (figure 9), that allows the characterisation of the territory and was made available by the city of Nice in this study:
- The total population included in the ILOTS: this data comes from the ILOTS data banks of the INSEE (Istituto Nazionale della Statistica e degli Studi Economici) and often represent an urban sector dense in inhabitations, potentially separated in the case of council or canton limits that pass through a district, or small group of inhabitations;
- The “roads” theme of the CARTO database of the IGN (Istituto Geografico Nazionale): represents the roads of communication (motorways, roads etc) of the territory studied;
- The “construction” theme of the CARTO database of the IGN (Istituto Geografico Nazionale): this theme allows the representation of the building that are found on the territory studied;
- The ICPE theme (Installazioni Classificate per la Protezione dell'ambiente naturale): this theme includes the localization of the ICPE carried out by the services of the city of Nice;
- The ERP theme (Fixed used for public events): deals with the localization of the ERP (schools, hospitals, churches, roads, museums etc) carried out by the city of Nice.

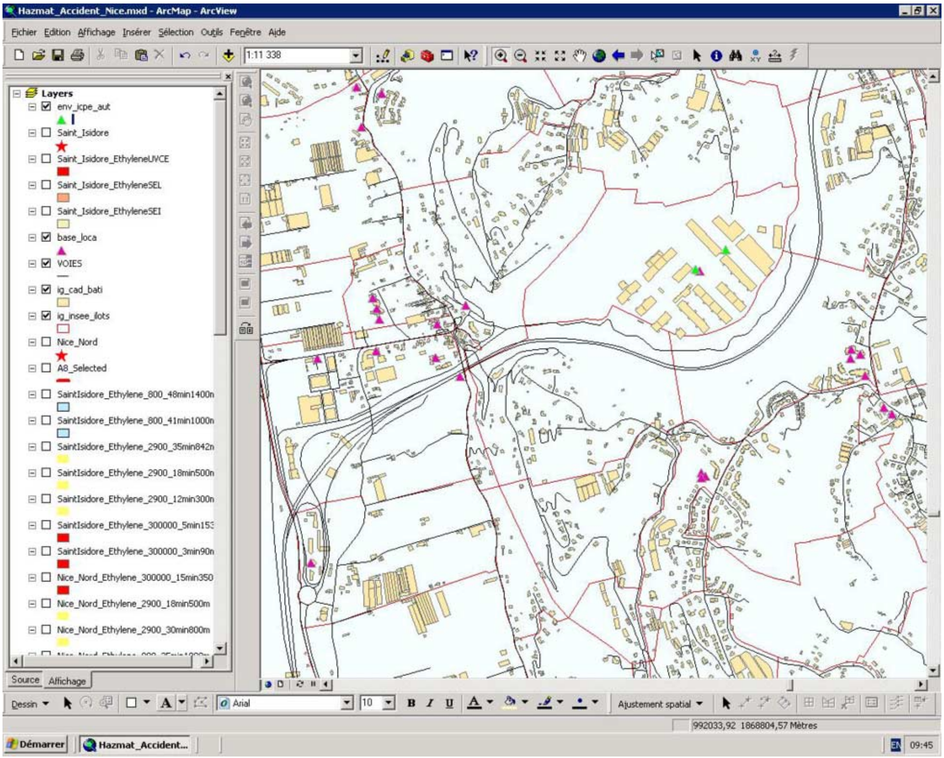

Figure 9. Layer of the data on the territory of St'Isadore: the outline of the ILOTS limits (red – dark grey - lines); the roads (black lines); the buildings (beige – grey - polygons); the ERP (pink – light grey - triangles); the ICPE (green – medium grey - triangles).

The overlapping of the maps of dispersion of toxic substances with the maps of the allocation of the exposed allows the identification of the portion of the population and the buildings exposed to the toxic cloud.

The atmospheric dispersion corresponds to the physical phenomenon of the mixing of a gas product (toxic cloud) with the air and its evolution in time and space [13]. The conditions of atmospheric dispersion of a toxic cloud depends mainly on the characteristics of the release source (molecular mass of the substance, reactivity with water or the sun, conditioning in a closed or open tanker, thickening, an escape hole opening, first and next phase pollution etc.), of the weather conditions (atmospheric temperature, moisture level, direction and strength of the wind, presence of atmospheric inversion etc.), and of the irregularities of the natural environment in the proximity of the release source (relief, buildings, cultivated fields, forests etc.). According to this information the dispersion can be completely different for each product, territory and instant of time etc.

Furthermore, different models of atmospheric dispersion exist, that allow the estimation of the spread distances of the toxic clouds. The main types of models are present in the next paragraphs, with particular attention to those used for the estimation of exposure in case of accident. The following paragraphs present the main parameters that are included in the phase of the simulation of toxic atmospheric emissions and in the case of the occurrence of a UVCE.

3.3. Accident scenario and Hazardous phenomena simulation

To evaluate the elements potentially exposed to the consequences of a DGT accident on the A8 motorway, the foreseen scenario takes into consideration two types of event connected to the nature of the transported dangerous goods: the explosion of a unconfined vapour cloud (UVCE) and the toxic release in the form of a gas cloud that spreads in the atmosphere.

In this part, the accident of the DGT vehicles is assumed to have happened and caused the start of a fire in the vehicle's tanker. Parallel to this fire, an escape of the dangerous goods occurred from the cistern. The simulation of the toxic releases was carried out with the ALOHA module of the CAMEO software developed by NOAA (National Oceanic And Atmospheric Administration).

ALOHA is software for atmospheric dispersion of polluting substances that in 2007 integrated the possibility of building models of the effects of BLEVE and UVCE. This software is recognised by the Civil Protection of the United States for its consistency in the estimation of the diffusion of polluting substances. It was recently used in the construction of models for industrial or chemical accidents ([16]; [17]; [18]).

In France, the Ecole des Mines d'Alès recommends the ALOHA software after having carried out a study comparing various simulation software for polluting release [19]. Furthermore, the evaluation of the ALOHA module for INERIS, [20], underlines that it can be useful in the operative phase (at the moment of accident) for the emergency services, in particular for:

- The ergonomics of the user interface of the software that is simple to use;
- It reduces the time to introduce the parameters of modelling and the calculation time;
- The consistency of the results of modelling.

ALOHA allows the taking into consideration of the main parameters for the simulation of toxic atmospheric release. These parameters are stated below with the values attributed to the reference scenarios:

- The type of product: the ethylene oxide were selected for the case study in Nice;
- The atmospheric parameters: the values come from the information acquired at METEO-FRANCIA (pluvio-thermometrical observation) and the work of [21] for the department of the Maritime Alps. That study examined:

1. the wind speed: equal to 1 m/s and corresponding to the worst scenario for atmospheric dispersion of toxic products;
2. the wind direction: in this study with the wind direction not being known beforehand , it is assumed that the release forms a circular cloud;
3. the height of the concentration of the toxic cloud (height by shortcoming equal to 3m);
4. the irregularity of the land, defined as "urban or forest";
5. cloud cover expressed in percentage: the parameter chosen, by shortcoming, was entitled "partially cloudy";
6. air temperature: 20°C ;
7. the stability of the atmosphere: class B was selected (class by shortcoming), (moderate day wind), from six meteorological categories;
8. the presence of thermal inversion with a defined height: this case was not considered in this study;
9. the percentage of humidity: the value 50% was selected;

10. the type of storage: ALOHA allows the representation of a cistern of a DGT vehicle in the form of a horizontal cylinder with a length of 6m and a diameter of 2m. The theoretical volume is estimated by the software and corresponds to 18.8 m3. It is possible to specify the state of the goods transported according to the temperature of the tank: in this case it was a liquid at a temperature of 20°C. ALOHA leaves the user to define the level of the tank: in this case the tank was considered to be full (100% of the theoretical volume);
11. the type of escape: ALOHA takes into consideration the shape (circular or rectangular) and the dimensions of the hole: in the reference scenario the hole is circular with a diameter of 10cm. The height of the emission source is 10cm from the base of the cistern.

After having introduced these parameters, ALOHA calculates the spread distances according to the concentrations of the dangerous goods expressed in pmm for the risk calculation of UVCE, of the thresholds of lethal effects and irreversible effects. The following figure (figure 10) presents the form of a cloud and the spread distances according to the parameters previously set in the simulation. The following table presents the spread distances of the ethylene oxide according to the predetermined effect thresholds, UVCE (Unconfined Vapour Cloud Explosion), TEL (threshold of lethal effects) and TEI (threshold of irreversible effects, as well as the formation time of the cloud for each concentration.

Table 4. Distances and kinetics of the formation of toxic clouds under the reference thresholds.

Distances (m) and kinetic (min)			
Dangerous Good	UVCE	TEL	TEI
Ethylene oxide	225 – 15	525 – 25	849 – 40

Due to the weak speed of the wind, the toxic cloud of ethylene oxide move slowly and assumed an elongated shape that caused an ample toxic front (a kilometre for the concentration for the formation of a UVCE, a kilometre and a half for the threshold of the lethal effects and almost 2 kilometres for the threshold of irreversible effects).

It is also possible to determine the kinetics (concentration and dispersion speed) of the spread of the cloud by clicking on a specific point on the graphics in the interface of the ALOHA simulation.

The following figure presents the kinetics of the spread of a cloud of 225m with a concentration curve in the atmosphere (red curve) for the three chosen thresholds. This curve shows that 15 minutes pass for the conditions of formation of a UVCE of 225m to be satisfied.

The blue dotted line curve represents the concentration of toxic gas in a building assumed to be closed and not ventilated. This concentration remains lower than the considered thresholds: underlining that the confinement of the population would allow the avoidance of product inhalation. In counterbalance the risk of UVCE, that is characterised by an explosion that has thermal and over pressure effects, would have an influence upon the population in the perimeter of the cloud. This information is therefore particularly interesting for the public bodies that must intervene in an accident in the organisation of assistance and the decision of strategies of protection of the population (confinement or clear).

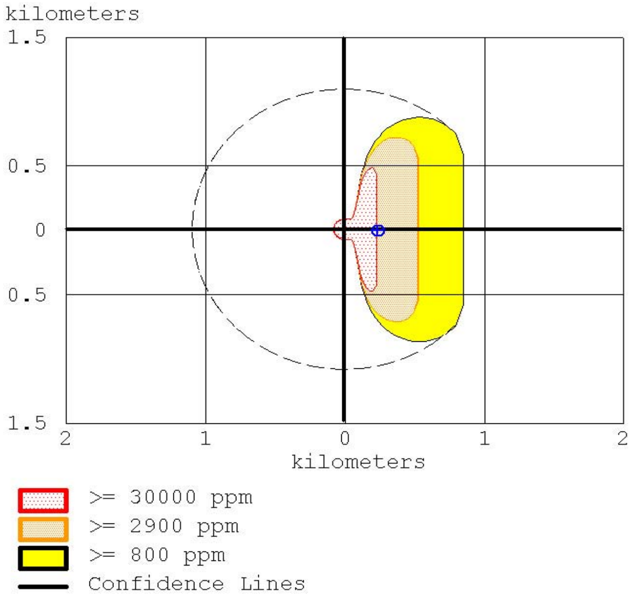

Figure 10. Graphic representation of the shape and the spread distances of a toxic cloud according to the formation of UVCE (30,00 ppm, red area), the thresholds for the lethal effects (2,900 ppm, orange area) and the thresholds for the irreversible effects (800 ppm, yellow area).

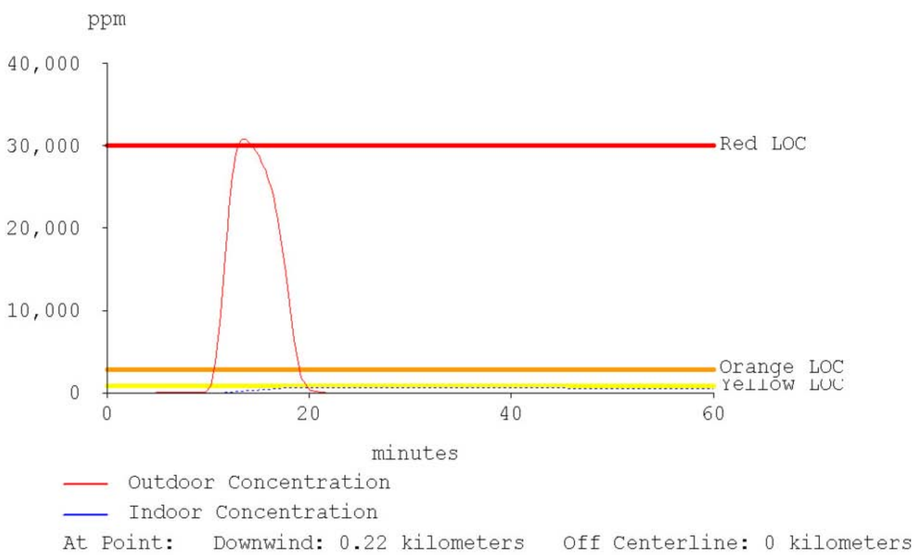

Figure 11. Kinetics of spread of a toxic cloud at 225m. 15 minutes is needed for the toxic cloud to reach the concentration of 30,000 ppm at this distance.

The following figure presents the spread kinetics of a toxic cloud of 525m. Around 25 minutes is needed for the cloud to reach the concentration of 2,900 ppm that corresponds to the lethal effects threshold.

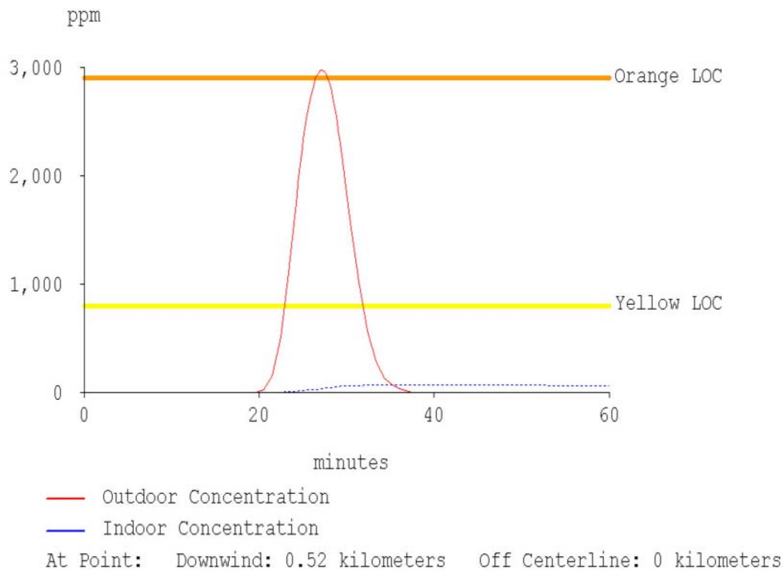

Figure 12. Kinetics of spread of a toxic cloud at 525m. 25 minutes is needed for the toxic cloud to reach the concentration of 2,900 ppm at this distance

The following figure presents the spread kinetics of a toxic cloud with a concentration of 800 ppm that corresponds to the threshold of irreversible effects in the space of 40 minutes.

Once the distances and spread kinetics of the toxic cloud are determined the spread distance is represented on a GIS (Geographical Infomation System) to be compared with the data on the exposed elements to determine the report of the a DGT accident risk.

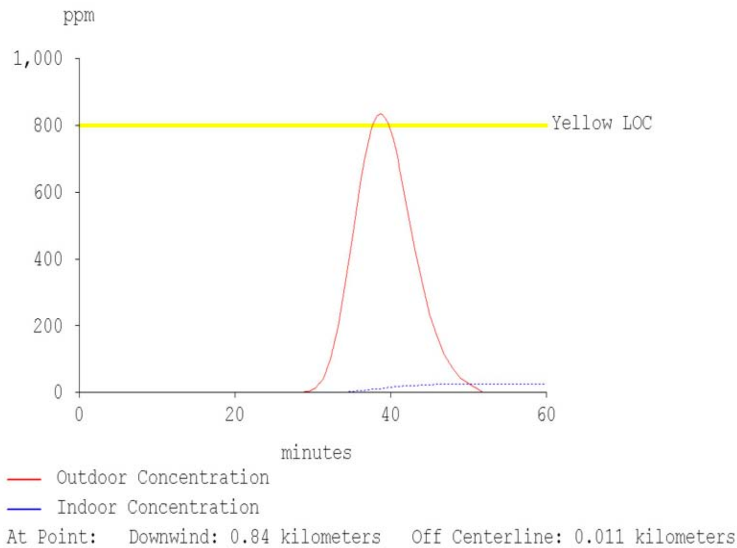

Figure 13. Kinetics of spread of a toxic cloud at 849m. 40 minutes is needed for the toxic cloud to reach the concentration of 800 ppm at this distance.

3.4. Simulations results

The diffusion parameters of the polluting substance are geographically represented by the GIS ArcGIS, in the form of concentric rings from the point of release regarding the chosen concentrations. These rings, comparable to polygons, allow the evaluation of the probable impacts on the population and the real estate in the case of a DGT vehicle accident. Each concentration is the object of a cartographic representation and the crossing with data regarding the potential exposure.

The first step consists in placing the "polluting substance" layer that represents the diffusion parameter of dangerous goods such as ethylene oxide according to the reference concentrations (UVCE, SEL, SEI), upon the layers that represent the exposure, that is the data supplied by the city of Nice (ISOLE, structure, ICPE, ERP). Since the population data is supplied on the scale of the ILOTS polygons, it was necessary to calculate the average number of people per building to define precisely the potential population exposed in case of an accident for the heterogeneity of the division of the same in the space in the study areas. It was also necessary to calculate the number of habitations potentially subject to the release.

The next step was to extract the data connected to the potential exposure of an atmospheric release: in this case a simple intersection between the areas of substance pollution and the various exposed elements (buildings, ICPE and ERP) was carried out and allowed the extraction of data regarding the areas situated under the "polluting elements" layer.

The last step corresponds to the publication of the results of the estimations of the exposed building elements: the number of people and dwellings therefore depended on the number of buildings subject to the consequences of the toxic cloud in the study sectors. The number of ICPE and ERP was directly deduced from the geo-localisation.

For each result a map presents the diffusion of the toxic cloud on the relevant territory represented by a orthophoto (BD ORTHO of IGN, in agreement with the CRIGE PACA and the city of Nice).

3.4.1. Results for the Saint Isidore Sector

The following figure presents the danger parameters of the ethylene oxide around the toxic substance release point (red star) with the three concentrations taken into consideration: in red the concentration of the formation of a UVCE (30,000 ppm), in pink the SEL SEL concentration (2,900 ppm) and in green the SEI concentration (800 ppm). In each circumference there are the relative maximum values of the spread for each concentration and the time of the formation of the cloud.

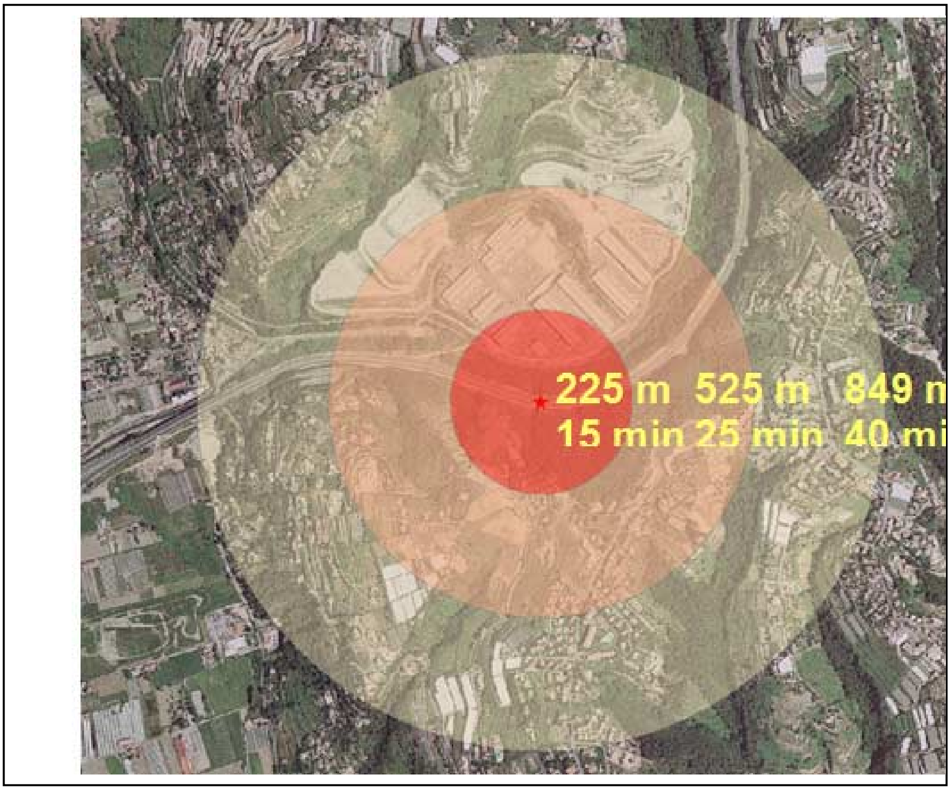

Figure 14. Cartography of the ethylene oxide cloud in the Saint Isidore sector (cartographic aid: IGN BD, ORTHO, CRIGE PACA, City of Nice).

The following table presents the estimation of the exposure (population, buildings, lodgings and ERP – reception structures) for a release of ethylene oxide in the Saint Isidore sector. This table shows the 15 lodgings that would be affected by the toxic cloud while the remaining part represents the deposits such as those found in the platform of logistics activity (PAL). In the case of the SEL, 800 people would be exposed and 8 of those would die after an exposure of one minute. Furthermore, 8 ERP would also be exposed to this toxic cloud. In the SEI case, 1,100 people would be exposed and in the ERP 14.

Table 5. Estimation of the elements exposed in the toxic atmospheric release of ethylene oxide in the Saint Isidore sector for the reference thresholds

Ethylene oxide					
Thresholds	Population exposed	Deaths	Buildings exposed	Apartments exposed	ERP exposed
UVCE	35	35	36	15	0
SEL	800	8	620	370	8
SEI	1100	0	860	500	14

3.4.2. Results for the North Nice Sector

The following figure presents the atmospheric release of ethylene oxide in North Nice, a highly urbanised area where there are a large number of buildings and ERP such as shopping centres, schools, a sports complex etc.

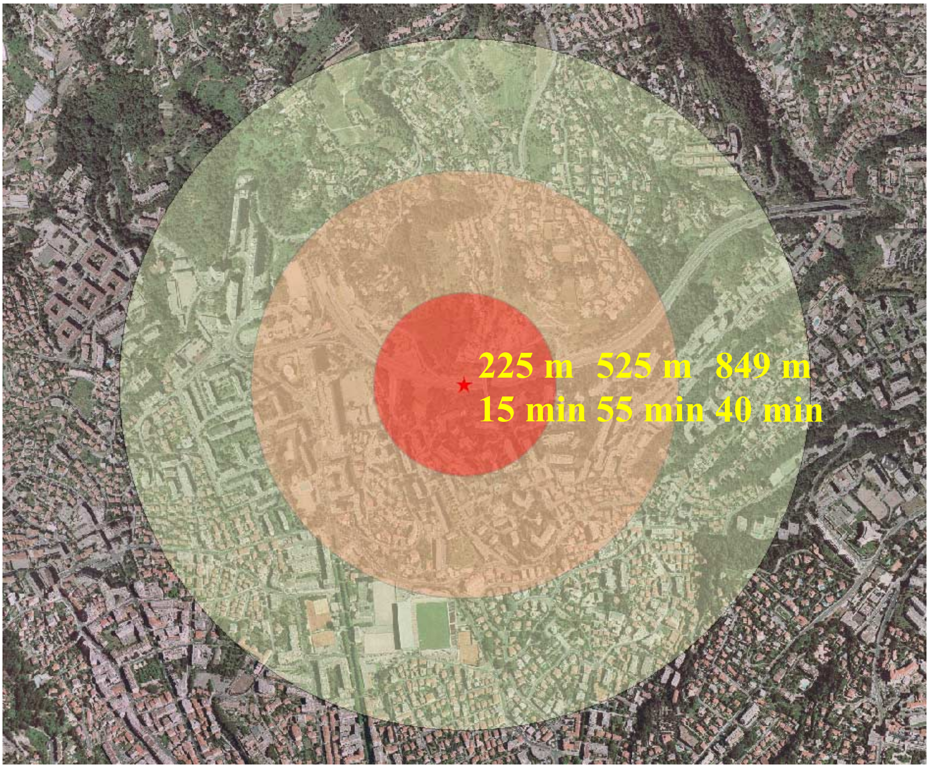

Figure 15. Cartography of a ethylene oxide cloud in the North Nice sector (Cartographic aid: IGN BD ORTHO, CRIGE PACA, City of Nice)

The estimation of the number of the population exposed shows a great difference to the Saint Isidore sector scenarios. In fact in this case the involvement of people is almost 30 times greater than at the Saint Isidore sector if exposed to a UVC, 10 times for the SEL and 16 times for the SEI.

Table 6. Estimation of the elements exposed to the atmospheric release of the ethylene oxide at North Nice for the reference thresholds

Ethylene oxide					
Thresholds	**Population exposed**	**Deaths**	**Buildings exposed**	**Apartments exposed**	**ERP exposed**
UVCE	1000	1000	113	570	9
SEL	9000	90	1300	5200	55
SEI	18000	0	2600	10000	110

These results supply the public bodies with the information that is important to define the operative strategies in the case of an accident, preparing for this and, in the case of a crisis, defining the strategy of emergency management. In the following paragraph the elements for the support of the assistance organisations are described.

4. Risk and Damage assessment and decision support for emergency organization

In an accident involving the transport of type "M" dangerous goods, the Inter-Ministerial Direction of Defence and Civil Protection of the Prefecture of the Alpes-Maritimes has defined a Plan of Specialised Support (PSS). The first version was published in 1991. The last was approved on 30th November 2006.

This DGT PPS is an element that allows the identification of DGT risks in the Department territory and the definition of the organisation method of assistance in case of emergency. This document also explains the allocation of duties and authority of the different public and private participants in the case of the DGT PSS. The plans for the giving of the alarm and the assistance management are presented in the following.

4.1. General plan of the alert activation

The emission of the "DGT motorway accident" alert can be constructed as shown in Figure 16.

The alarm to the emergency services (fire department, police etc.) is given by an accident witness or the driver of the affected DGT vehicle. The emergency services are given the role of establishing safety parameters and informing the Prefect and the relevant mayors of the affected area.

The CMIC (mobile chemical intervention unit) is alerted to intervene, if necessary, with the tanker and re-absorb any released product. The prefecture, even the sub-Prefect, must be alerted of the event.

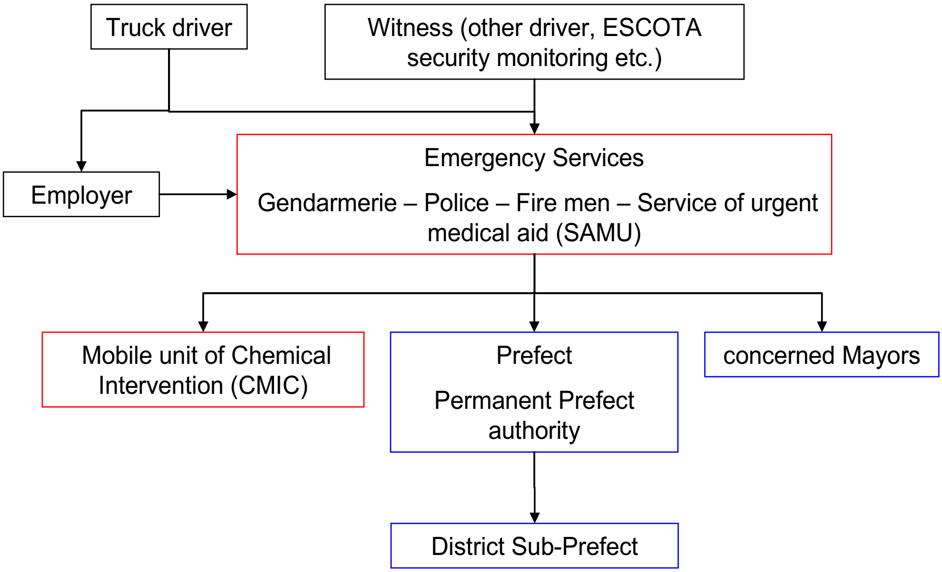

Figure 16. General plan of alert for "DGT accident on the A8 motorway"

4.2. Organisation of the assistance

Once the alarm is given and the immediate and probable consequences of the event are assessed by the emergency services, the PSS DGT is begun by the Prefect who also informs the Area Prefect. It is therefore up to the Prefect, according to the severity of the event, to inform the threatened population and communicate the safety regulations to follow such as confinement of the population, prohibition to drink tap water and/or leave the home etc.

As shown in the following figure, the number of bodies required in the management of a crisis caused by a DGT accident is important. The crisis management is not only associated with public bodies, such as the emergency services, the Prefecture, the services separated from the State etc. but also with private subjects such as the A8 motorway management companies that, according to the case, can intervene with their own emergency assistance.

The role of the Prefecture is to undertake the management of the emergency operation, assuring that all means are in service, and the management of the mass media (Public Relations Office and the Press).

The interdepartmental management for defence and civil protection must tell the relevant service directors, averting the relevant mayors and guaranteeing the function of the services that create support groups for "informing families, the public, local bodies and public authorities".

The departmental service of the information and communication systems must activate the means of telecommunication and information technology in the departmental operative centre and the support groups for families. It must furthermore assure that the means of communication between the services and those that intervene at the accident site are active and working perfectly.

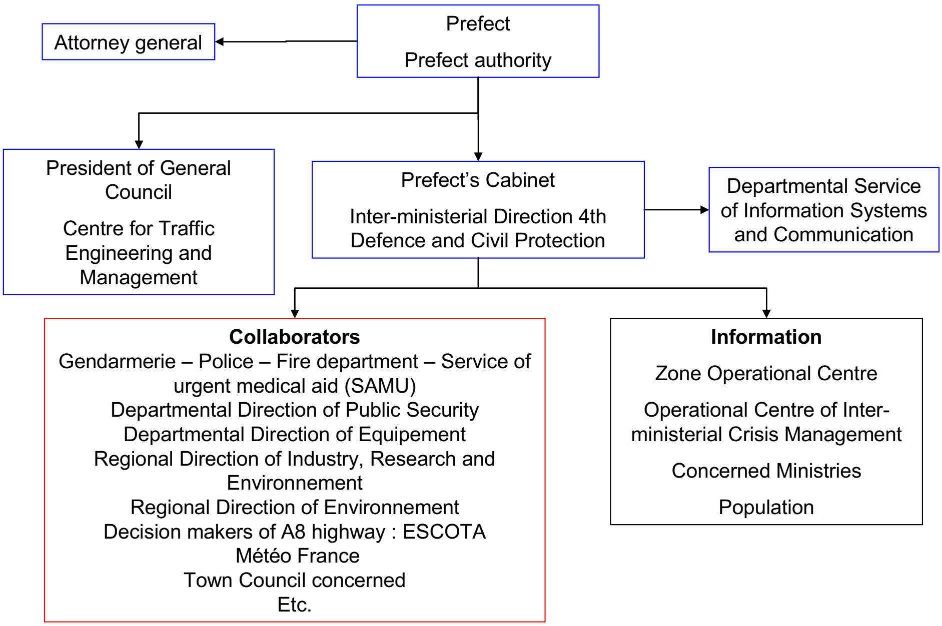

Figure 17. General operative plan for the PSS DGT alert for the A8 motorway

The General Council must supply the emergency plans necessary to guarantee, as much as possible, the management of the traffic. The affected town councils must register the people who were exposed and who require particular aid. The mayors must also inform their staff of their duty and begin the Communal Safeguard Plan.

The emergency services (traffic police, police, fire department, SAMU) must intervene on the accident site to limit the consequences on the population, the environment and the infrastructure, actively combating damage and fixing safety parameters. They must evaluate the different necessary technical means such as intervention by the CMIC. They also have the role of carrying out the rescue procedure of victims and guaranteeing the strategy of crisis management by confinement and clearing. They must also guarantee the maintenance of public order, the protection of goods and people, and aid the sending for further help, checking identity etc. the services separated from the State must participate in the evaluation of the impact on the environment and the infrastructure, the clearing operation, the defining of the cause of the accident etc.

The A8 motorway management company ESCOTA must inform the police chief of the accident site and the police of the danger parameter, and follow the orders of the head of the assistance operation. If the personnel of ESCOTA intervene before the emergency services they must transmit the information to the prefecture and move away from danger while waiting for assistance.

When the phase of crisis management is completely finished, it is necessary to proceed with the post-accident organisation with the aim of guaranteeing the return to a normal state. This phase consists in the evaluation of technical, sanitary, economical, social and legal aspects such as the characterisation of the contamination, the procedure of decontamination of the environment, the management of contaminated goods, the management of the population of the affected area, the calculation of victims, the management of people evacuated, from a physiological and psychological point of view etc.

4.3. Interest of the public bodies in the SDSS of impact assessment

Based on crisis management aspects and the results supplied by the SDSS for impact estimation, the decision support system can be foreseen in three levels:

- To help the formalization of the assistance plans and the activity of the assistance: the knowledge of the dangerous goods transported by road allows the forecast of other DGT accidents that involve hydrocarbon in a liquid or gas state, the bases, the acids, the oxidants etc. that can cause toxic gas clouds, UVCE or BLEVE. This information on the dangerous goods comes from the fixed and aboard identification and monitoring systems proposed in the prototype developed in the project. The results of the simulation carried out with dangerous goods supply the public bodies maps of danger which are useful to evaluate and measure the emergency assistance needed. These results can act as reflection for the creation of emergency simulations;
- To help crisis management: for the proportion that the assistance could determine the type of dangerous goods in a DGT accident, the estimation SDSS for the potential exposure can be used directly by the emergency services (who direct emergency assistance) and by the departmental operative centre. In fact the ergonomics of the ALOHA software allows the carrying out of simulations of toxic release, of UVCE or of BLEVE in a few minutes. The coupling of the GIS with these simulations allows the evaluation of the potential damage. This information can serve to generate an intervention strategy, in particular the definition of the safety parameters, and to decide the measures to adopt;
- To help the post accident management: the results can also be useful to manage post-event, in particular the support of the cartography of the contaminated sectors allows the relevant public organisms (regional environment management, departmental management of social affairs and sanitation, departmental management of agriculture and forests etc.) to proceed with the clearing and decontamination of the land etc.

4.4. Development outlook

The Spatial Decisions Support System (SDSS) for the estimate of the damages and the consequences of an accident involving DGT vehicles uses statistical data on the exposure that does not take into account the dynamic aspect of the time-space division of the population and the vehicles on the relevant roads. Since the population flow varies greatly according to the day/night period and the area, this information favours the intervention and management of the services in case of a serious accident. It is therefore necessary in future to attempt to evaluate dynamically these population flows in the relevant territory.

These developments were carried out in the territory of the agglomeration of the hevraise region (Bourcier et Mallet, 2006) with the PRETE-RESSE model (Population Réaliste dans l’Espace et le Temps sur le bassin de Risques majeurs de l’EStuaire de la SEine). This model was founded on the estimation of population fluctuations between day and night periods on a structure scale. This model therefore considers the migration of the commuters (day/night) with the aim of quantifying the population when at home, at work or in leisure time.

The construction of a module that allows the consideration of the population flow will require a more thorough competence in the data sources already available. But also the carrying out of information campaigns and questionnaires with collaboration with public bodies and services separated from the State to complete this information.

References

[1] V. Akgün, A Parekh, R. Batta, C.M. Rump, 2007. Routing of a hazmat truck in the presence of weather systems. Computers & operations research, 34(2007), 1351-1373.

[2] A. Ang, J. Briscoe,1989. Development of a systems risk methodology for single and multimodal transportation systems. Final Report, Office of University Research, US DOT, Washington, DC.

[3] P. Carotenuto, S. Giordani,., S. Ricciarelli,.2007. Finding minimum and equitable risk routes for hazmat shipments. Computers & Operations Research, 34 (2007), 1304-1327.

[4] E. Erkut, V. Verter, 1995. A framework for hazardous materials transport risk assessment. Risk Analysis 15 (1995), 589-601.

[5] J. Zhang, , J. Hodgson, E. Erkut, 2000. Using GIS to assess the risks of hazardous materials transport in networks, European Journal of Operatinal Research , 121 (2000), 316-329.

[6] K.G. Zografos,., K.N. Androutsopoulos., 2004. A heuristic algorithm for solvine hazardous materials distribution problems. European Journal of Operatinal Research 152 (2004), 507-519.

[7] B.J.M. Ale,., 2002. Risk assessment practices in the Netherlands. Safety Science, 40 (2002), 105-126.

[8] P. Leonelli,., S. Bonvicini, G..Spadoni, 2000. Hazardous materials transportation: a risk-analysis-based routing methodology. Journal of Hazardous Materials 71 (2000), 283–300.9

[9] Fabiano, B., Currò, F., Palazzi,E., Pastorino,R., 2002. A framework for risk assessment and decision-making strategies in dangerous good transportation. Journal of Hazardous Materials 93 (2002) , 1–15.

[10] Benza M., Bersani C., Casazza R., Garbolino E., Giglio D., Olampi S., Sacile R., Trasforini E., 2006.Definizione, progettazione e realizzazione prototipale di un sistema informativo distribuito per l'identificazione, il monitoraggio e la gestione dei flussi veicolari di merci pericolose. Proceedings of VGR 2006 - Valutazione e Gestione del Rischio negli Insediamenti Civili e Industriali - ISBN 88-6019-061-4.

[11] National Oceanic and Atmospheric Administration and the U.S. Environmental Protection Agency, 2007.- ALOHA : user's manual.- 195p.

[12] J.C. Couillet., 2002.- Méthodes pour l'évaluation et la prévention des risques accidentels (DRA-006). Dispersion atmosphérique. (Mécanismes et outils de calcul).- INERIS.- 61p.

[13] MEDD, 2006.- Compréhension des phénomènes et modélisation : la dispersion atmosphérique.- 12p.

[14] E. Garbolino., R. Sacile, S. Olampi., C. Bersani. A, Tomasoni., N. Alexandre., E. Trasforini., M. Benza., D.Giglio., 2007a.- A Spatial Decision Support System prototype for assessing road HAZMAT accident impacts on the population in a dense urban area: a case study of the city of Nice, French Riviera. Chemical Engineering Transactions, Icheap-8 conference, 24-27 june, Ischia.

[15] E. Garbolino., R. Sacile., S. Olampi., A Tomasoni., C. Bersani., N. Alexandre., E. Trasforini., M. Benza., D. Giglio., 2007b.- Definition of a Spatial Decision Support System for public authorities, civil protection and highway companies dedicated to the crisis management in the case of a Hazmat Transportation road accident in a dense urbanized area in the French Riviera. AIRO 2007, September 5-8, Genoa.

[16] R. Bellasio. and R.. Bianconi, 2005.- On line simulation system for industrial accidents.- Environnemental Modelling and Management, vol. 20, Issue 3 : 329-342.

[17] P.H. Martin., E.J. LeBoeuf., E.B Daniel., J.P. Dobbins and M.D Abkowitz., 2004.- Development of a GIS-based Spill Management Information System. Journal of Hazardous Material, B112 : 239-252.

[18] D. Mundy., 2002.- Local Emergency Planning Committees: Working together to increase chemical safety in our communities. Chemical Health and Safety, Vol. 9, Issue 6 : 31-34

[19] J. G. Tixier Dusserre,., S. Rault-Doumax., J..Ollivier and C. Bourely., 2002.- OSIRIS: Software for the consequence evaluation of transportation of dangerous goods accidents. Environmental Modelling and Software, vol. 17: 627-637.

[20] J..M. Lacombe., G. Vincent., A. Baulig., M.A. Kordek., F. Fontaine and S. Tissot, 2006.- Examen de l'utilisation du logiciel ALOHA-CAMEO en situation d'urgence. INERIS, Direction des Risques Accidentels.- 41p.

[21] J. Kessler et A Chambraud., 1990.- Météo de la France. Tous les climats localité par localité. JC Lattès.- 391p.
[22] Préfecture des Alpes-Maritimes, 2006.- Plan de Secours Spécialisés Transport de Matières Dangereuses non radioactives P.S.S. – T.M.D. Direction Interministérielle de Défense et de Protection Civile, Bureau de la Protection Civile.- 69p

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Hazardous Materials Transportation: a Literature Review and an Annotated Bibliography

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Abstract. The hazardous materials transportation poses risks to life, health, property, and the environment due to the possibility of an unintentional release. We present a bibliographic survey on this argument paying particular attention to the road transportation. We attempt to encompass both theoretical and application oriented works. Research on this topic is spread over the broad spectrum of computer science and the literature has an operations research and quantitative risk assessment focus. The models present in the literature vary from simple risk equations to set of differential equations. In discussing the literature, we present and compare the underlying assumptions, the model specifications and the derived results. We use the previous perspectives to critically cluster the papers in the literature into a classification scheme.

Keywords: hazardous material transportation, risk assessment, minimum crash frequency, catastrophe minimization

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Introduction

The attention to HAZardous MATerials transportation (HAZMAT) research dates back 1980's, mainly due to growing safety concerns in developed countries (see, e.g., [1-18]). After a slight slow-down mainly caused by the difficulty of gathering accurate and relevant data, it has recently gained emphasis again (see, e.g., [19- 41]).

This renewed interest is also owed to two factors that have acquired more and more importance in the recent years: sustainability and equity.

Sustainability is a systemic concept that, according to World Commission on Environment and Development, relates to the continuity of economic, social, institutional and environmental aspects of human society. Hence, sustainability is the long-term compatibility between the economic and the environmental and the social dimensions of development (see, e.g., [42]).

According to [4] equity regards the public sensitivity to HAZMAT as the beneficiaries from these shipments are usually those who live near production facilities or the delivery points, yet also the populations living along HAZMAT routes are also exposed to transportation risks (see, e.g., [15];[43];[44]). This lack of burden-benefit concordance is typical source of public opposition to hazardous material shipments. The shipment of nuclear fuel, also spent, offers a good example of equity-based public opposition (see, e.g., [1]; [45]; [46]; [47]; [48]; [49]; [50]; [51]; [52];[53]).

The hazardous materials transportation requires a risk management process that involves set of crucial logistic decisions referring to, as an example, the organization of the emergency response operations. In fact, the logistical decisions on the routing of HAZMAT vehicles and the emergency response must be integrated (see, e.g., [54]).

Quantification of risk of the "en-route" hazardous materials accidents is difficult because probabilities for traffic accidents are low and those involving hazardous materials are even lower. However, as the consequences of an accident involving hazardous materials can be enormous, researchers are whetted to model the risk associated with this shipment to propose various methods to design suitable routes that present interesting trade-offs between transportation costs and accident risks.

This article is based on an idea of the first author, who is also Operations Director of S.p.A. Autovie Venete, to make an attempt to encompass both theoretical and application oriented papers from disparate areas related to the commercial transport of hazardous materials. S.p.A. Autovie Venete is an important Italian motorway concessionaire and safety is its main priority. Its operators manage HAZMAT transportation following different strategies and using different technologies to detect vehicles, to give the alarm and to properly intervene in case of accidents.

This review takes into account the framework and the method of the former article [28]. The present article develops such a work, completes it with the most recent literature and it is organized as follows. In Section 1, we introduce some important concepts about risk, the main factor that differentiate HAZMAT logistic problems from other logistic problems. We also review different models of risk assessment. In Section 2, we offer a high-level view of HAZMAT logistics literature and we propose a classification scheme. In Section 3, we cluster and discuss the papers available in the literature according to the proposed scheme and we suggest directions for future research. Finally, we draw some concluding remarks in Section 4.

1. Hazardous Materials and Risk

In this section we initially define the concept of hazardous material and point out the possible sources of risk in their transportation. Then we introduce a classification of the basic risk assessment models.

1.1. What hazardous materials are

According to the US Department of Transportation [55], a hazardous material is defined as any substance or material capable of causing harm to people, property, and the environment. There are nine major hazardous material classes:

Class 1– Explosives (dynamite, caps)
2– Gases (propane, anhydrous ammonia, chlorine, oxygen)
3– Flammable Liquids (gasoline, oil, tars, diesel, kerosene)
4– Flammable Solids (plastics, asphalt shingles)
5– Oxidizing Substances (peroxides)
6– Poisonous and infectious substances (herbicides, pesticide)
7– Radioactive materials
8– Corrosives (acids)
9– Miscellaneous (PCB's, dangerous wastes).

The en-route hazardous materials involuntary accidents have low probability: [56]; [57] estimate as a typical accident rate the value of 3.0×10^{-6} accidents/vehicle-km. Nevertheless, the potentially catastrophic impacts attributed to such incidents and the large number of hazardous shipments raises serious fears to all stakeholders involved in and affected by the HAZMAT process i.e. governmental authorities, carriers, the local societies and social groups, and shippers. Yet some risk is imposed on the population living along the major highways or railways, who are asked to assume the risk with no clear benefits to them. For this reason, if the same main route segment is selected for shipments from multiple origins, the objection of people living along this route would increase considerably. These people are likely to prefer alternate routings that would spread the risks. Public opposition to hazardous material shipments has increased in recent years, due to fears of terrorist attacks on HAZMAT vehicles.

In the event of an accident, it is important for first responders to know the nature of the hazardous materials involved. Hence, for example, vehicles transporting hazardous materials must display unified placards describing the class and the nature of the cargo. On the other hand, making HAZMAT vehicles easy to identify through placards exposes them to another kind of risk: sabotage or misuse as weapons of mass destruction or of convenience.

The possibility of accidents requires the development of integrated safety management systems to implement mitigation activities, which seek the reduction of the vulnerability, and prevention activities, which try to reduce the hazard [58]. Theoretically, risk management activities can be oriented to deal with specific and defined risk and manage it optimally. Unfortunately, reality is far too complex and resources far too scarce to deal with each risk event individually, as often one hazardous event is linked or related to one or more other hazardous events. Some events triggered others. As an example [59], urban degradation caused, e.g., by unplanned urban growth, bad construction practices, or immigration of people from the rural areas, tends to disturb the balance in the urban system, influences the interaction process between different hazards and vulnerabilities increasing vulnerability levels, and then creates new hazards factors.

1.2. Risk assessment

Risk assessment is included in risk management. The key elements of risk management are divided into two phases: the pre-disaster phase and the post-disaster phase. The pre-disaster phase includes risk identification, risk mitigation, risk transfer, and preparedness; the post-disaster phase is devoted to emergency response and rehabilitation and reconstruction. Table 1 divides the key components of disaster risk management into actions required in the pre-disaster phase and actions needed in the post-disaster period [60]). A comprehensive risk management program addresses all these components: they are an integrated, cross-sector network of institutions addressing all the above phases of risk reduction and disaster recovery. Activities that need support are policy and planning, reform of legal and regulatory frameworks, coordination mechanisms, strengthening of participating institutions, national action plans for mitigation policies, and institutional development.

Risk assessments are an essential part of the process of integrating natural disaster programs with overall development objectives. These assessments identify sources of risk, vulnerable groups, and potential interventions. Risk assessment allows policymakers to specifically define the objectives of the risk management programs and to establish vulnerability reduction targets.

In the context of HAZMAT transportation, risk is characterized by two aspects: occurrence probability of an event and consequences of an occurring event. According to Alp [61], "risk is a measure of the probability and severity of harm to an exposed receptor due to potential undesired events involving a HAZMAT whereas the exposed receptor can be a person, the environment, or properties in the vicinity". The undesired events are the accidents that could lead to a release of a HAZMAT. Risk assessment connotes a systematic approach to organizing and analyzing scientific knowledge and information for potentially hazardous activities or for substances that might pose risks under specified circumstances [62]. Risk assessment can be qualitative or quantitative. Qualitative risk assessment regards the identification of possible accident scenarios and attempts to estimate the undesirable consequences (see, e.g., [63]). Quantitative Risk Assessment (QRA) tries to assess the risk in terms of the value of some indicators to be used to actively manage risk, to identify and prioritize technology needs and decision making and, finally, to evaluate regulatory alternatives (see, e.g., [64]; [65]).

Table 1. Key Elements of Risk Management

Pre-disaster phase				Post-disaster phase	
Risk identification	Mitigation	Risk transfer	Preparedness	Emergency response	Rehabilitation and reconstruction
Hazard assessment (frequency, magnitude, and location)	Physical/ structural mitigation works	Insurance and reinsurance of public infrastructure and private assets	Early warning systems and communication systems	Humanitarian assistance	Rehabilitation and reconstruction of damaged critical infrastructure
Vulnerability assessment (population and assets exposed)	Land-use planning and building codes	Financial market instruments (catastrophe bonds and weather indexed hedge funds)	Contingency Planning (utility companies and public services)	Clean-up, temporary repairs, and restoration of services	Macroeconomic and budget management (stabilization and protection of social expenditures)
Risk assessment (a function of hazard and vulnerability)	Economic incentives for promitiga-tion behavior	Privatization of public services with safety regulation (energy, water, and transportation)	Networks of emergency responders (local and national)	Damage assessment	Revitalization for affected sectors (exports, tourism, and agriculture)
Hazard monitoring and forecasting (GIS, mapping, and scenario building)	Education, training and awareness about risks and prevention	Calamity Funds (national or local level)	Shelter facilities and evacuation plans	Mobilization of Recovery resources (public, multilateral, and insurance)	Incorporation of disaster mitigation components in reconstruction activities

[66] define risk on the basis of historical data, that is, as:

$$Risks = \frac{Events}{Exposure} \tag{1}$$

where Exposure is an exposure measure, such as truck miles, and Events is the weighted number of releases or vehicular accidents. Here, the weight associated to an event expresses the level of its severity. The strength of indicators as (1) is that they represent an integrated comprehensive measure of both frequency and severity of the past undesired events, and for this reason they are frequently used in literature to assess the risk. On the other hand, the subjectivity, in defining the value of the weights that account for the severity of the events, is an unavoidable weakness of these indicators. In addition, such indicators may be not suitable to assess the risk of potential future occurrences, in presence, e.g., of technological advances. Different studies try to overcome this latter limitation (see, e.g., [67]; [68]; [69]).

As these studies are usually focused on releases that occur on the road or, in a lesser extent, along railways, they assesses the risk by taking into consideration different factors such as population density, facility type, material to be shipped and exposure. The challenge is to convert these factors into quantitative values that allow to express the probability of a hazardous materials accident and a measure of the associated consequences (e.g. expected population exposure) to apply to the links of the road (rail) network so that the best (safest) routes can be determined.

QRA involves the following key steps: (1) hazard and exposed receptor identification; (2) frequency analysis; and (3) consequence modeling. In addition, examination of risks on different types of exposed receptor is essential to cover different response characteristics in the risk assessment. Also, given the fact that public opposition is a function of perceived risks, perhaps more attention should be paid to quantifying and modeling of perceived risks.

Each step of QRA presents some difficulties. For example, the consequence modeling step requires as inputs the territorial distribution of the population exposed to the consequences of an accident. Differently, many past studies roughly assumed uniform population density along transport links.

1.2.1. Frequency analysis

According to Ang [70], the frequency analysis involves:

1. determining the probability of an undesirable event;
2. determining the level of potential receptor exposure, given the nature of the event;
3. estimating the degree of severity, given the level of exposure.

Each stage of this assessment requires the calculation of a probability distribution. As an example [71], for each unit road segment, determine the joint probability of type of accident, release, incident, and consequence as follows. Let *A* be the accident event that involves an HAZMAT carrier, *M* the release event, and *I* the incident event; finally, let *D* be indicate the type of damage to an individual. Then, using Bayes' theorem, we obtain the probability of an injury resulting from an accident related to the HAZMAT is:

$$p(A, M, I, D) = p(D|A.M, I)p(I|A, M)p(M|A)p(A) \tag{2}$$

where $p(.)$ denotes the probability of the event and $p(.|.)$ the associated conditional probability.

If S_{lm} denote the number of shipments of HAZMAT *m* on road segment *l* per year, then the product $S_{lm} \cdot p_l(A, M_m, I, D)$ corresponds to the frequency of the occurrence of the hazardous release event with consequence *D* for a person in the neighbourhood of road segment *l*.

In assessing the risk, the literature makes a distinction individual and societal risk. Such a distinction is justified as, if few people are present around the hazardous activity, the societal risk may be close to zero, whereas the individual risk may be quite high.

- Individual Risk: [72] defines the individual risk as the yearly death frequency for an average individual at a certain distance from the impact area. The analytical expressions for individual risk are often mathematically complex and their value can only determined numerically. As an example, [73] and [74] propose a model that requires the following high level variables to assess the individual risk: 1) frequency of release, 2) probability of final outcome given a release, 3) wind probability, and 4) vulnerability. Then the individual risk is expressed as

$$\text{Individual Risk} = \sum_j f_{rel}(l,v,j)\int_L Risk_{unit} \tag{3}$$

Being

$$Risk_{unit} = \sum_i p^{out}(i)\sum_k \int_o^{2\pi} p_{wind}(j,k,\theta)\cdot V(i,k,\theta) \tag{4}$$

where *frel* (l,v,j) is the release frequency for link l, vehicle typology v in season j; $p^{out}(i)$ is the probability of final outcome i given a release; $p_{wind}(j,k,\theta)$ is the probability for meteorology condition k, season j, wind direction θ; $V(i,k,\theta)$ is the vulnerability for outcome i, meteorology condition k, wind direction θ. Note the correspondence between $f_{rel}(l,v,j)$ in (*3*) and the previously introduced product $S_{lm}\cdot p_l(A,M_m,I,D)$ by [28].

- Societal Risk: R_{lm} on road segment l of hazmat m is usually defined (see, e.g., [13]; [75]) as

$$R_{lm} = S_{lm}\iint_L p_l(D_{xy}\,|A,M_m,I)p_l(I,A.M_m)p_l(M_m\mid A)p_l(A)POP_l(x,y)\cdot dxdy \tag{5}$$

Where $p_l(D_{xy}\mid A,M_m,I)$ is the probability that individuals on location (x,y) in the impact area L will be dead due to the incident on a route segment l and $POP_l(x,y)$ is the population density on location in the neighborhood of road segment l. By assuming that each individual in the affected population will incur the same risk, R_{lm} can be simply expressed as

$$R_{lm} = S_{lm}p_l(D\mid A,M_m,I)p_l(I\mid A,M_m)p_l(M_m\mid A)p_l(A)POP_l \tag{6}$$

An alternative way to describe the societal risk is the use of the so-called *FN*-curves, (see, e.g., [76] and [77]), where F is the cumulative frequency of an accident with N or more either fatalities or evacuated people. Such *FN*-curve are drawn by computing, the probability that a group of more than N persons would be impacted due to an HAZAMAT accident, for each (reasonable) value of N [78].

Expressions from (2) to (6) allow to assess the risk in the assumption that just one type of accident may happen. However, more than one type of accident, release, incident, and consequence can occur during the HAZMAT transport activity. For example, a release of flammable liquid can lead to a variety of incidents such as a spill, a fire, or an explosion. To accommodate this, [28] suggest assessing the risk as follows. Let A, M, I, and C denote respectively the set of possible accidents, releases, incidents, and consequences that may occur on road segment l. Suppose that all consequences (injuries and fatalities, property damage, and environmental damage) can be expressed in monetary terms. Then, the hazardous materials transport risk associated with road segment l can be expressed as

$$R_l = \sum_{a \in A} \sum_{m \in M} \sum_{i \in I} \sum_{c \in C} S_{lm} \cdot p_i\left(A_a, M_m, I_i, C_c\right) \cdot CONS_c \qquad (7)$$

Where, $CONS_c$ is the possible c-type consequence.

In practice, researchers frequently neglect conditional probabilities and simplify the analysis by considering the expected loss (or the worst-case loss) as the measure of risk. The expected value is calculated as the product of the probability of a release accident and the consequence of the incident [79]. Hence the HAZMAT risk associated with a road segment l is expressed as

$$R_l = \sum_{m \in M} S_{lm} \cdot p\left(M_m\right) \cdot c_{lm} \qquad (8)$$

where, c_{lm} is the undesirable consequence due to the release of hazmat m on road segment l. This risk model is sometimes referred to as *the technical risk* [71].

1.2.2 Security

The risk assessment methodologies introduced in the previous section may need reviewing in the next future due to the new concern for security in HAZMAT transportation. The terrorist attacks in the USA in 2001 have focused attention on what other targets terrorists may choose. It was quickly recognized that HAZMAT vehicles could be desirable targets for terrorists, and certain HAZMAT vehicles were designated as *weapons of mass destruction*, see [80]; [81]. Such concerns changed the way the HAZMAT industry operates. For example, the US Federal Government now requires HAZMAT truckers to submit to fingerprinting and criminal background checks [82].

The security issue, however, has not yet received much attention from the operations research (OR) literature. However, there is potential for OR studies, for example as below indicated.

- **Rerouting around major cities** - The risk of terrorist attacks made it very undesirable to route HAZMAT vehicles (particularly trains) through major population centres. In particular, [83] show that significant risk reductions are possible through rerouting, and [84] develop new methodology for routing with a catastrophe-avoidance objective.

- **Changes in the modeling of incidence risks -** The traditional risk assessment for HAZMAT assumes incidents are caused by traffic accidents or human error. We now know that there is a nonzero probability of a terrorist attack or a hijack. This fact increases the incident probabilities and requires a new way of modeling consequences since the impact may no longer be limited to the planned route. Furthermore, attack probabilities are unlikely to be uniform. For example, a tunnel, a bridge, or trophy buildings are likely to have higher attack probabilities than a remote and unpopulated area. In contrast, sparsely populated areas may be associated with a higher hijack probability. A hijacked vehicle's future route is unpredictable and special precautions may have to be taken to prevent it from having an incident in a densely populated area. As a result, traditional risk assessment-based route planning is no longer adequate. There are few papers on these subjects, but see [85] for probabilistic modeling of terrorist threats, and [86] and [40] for incorporation of security concerns in route planning.
- **Changes in route planning methodology -** Past HAZMAT routing literature focuses on finding a minimum risk route. Unfortunately, the use of quantitative measures and selecting routes accordingly make the routes predictable by terrorists. To minimize the probability of a successful terrorist attack or hijacking, shippers should use alternative routes. A game theory approach can be applied determine the best way of either alternating the routes or switching from one to other ones en-route time to minimize predictability. In this context, video surveillance, global positioning systems and communication equipment installed on all HAZMAT vehicles allow the precise tracking of vehicles, but also allow the implementation of such real-time decision making (see, e.g., [82]; [87]).

2. HAZMAT logistics literature

The book chapter [28] offers a relatively comprehensive of the literature up to 2005 on risk assessment, location, and routing.

2.1. Special issues of journals

Hazmat logistics has been a very active research area during the last twenty years.

- Management Science Management Science published a special issue on Risk Analysis in 1984 (Vol.30, No.4) where five papers dealt with HAZMATs and hazardous facilities. This issue was followed by a number of special issues of refereed academic journals that focus on HAZMAT transportation or location problems.
- Transportation Research Record published two special issues on HAZMAT transportation in 1988 (No.1193) that included four papers and 1989 (No.1245) that included six papers.

- Transportation Science devoted an issue to HAZMAT logistics in 1991 (Vol.25, No. 2) that contained six papers.
- Journal of Transportation Engineering published a special section on HAZMAT transportation in the March/April 1993 issue that included four papers.
- INFOR published a special double-issue on hazardous materials logistics in 1995 (Vol.33, No.1 and 2) with nine papers.
- Location Science published four papers included in a special issue dealing with HAZMATs in 1995 (Vol.3, No.3).
- Transportation Science produced a second special issue with seven papers on HAZMAT logistics in 1997 (Vol.31, No.3).
- Studies in Locational Analysis published a special issue on undesirable facility location in April 1999 (Vol.12) that contained seven papers.
- Computers & Operations Research have published a HAZMAT logistics special issue in 2007 which contains results of the most recent research in the area in 13 papers.

2.2. Books

The following books are a good starting point for those who wish to familiarize with the terminology and the problem context.

1. *Transportation of Hazardous Materials* (1993) - This book, edited by L. N. Moses and D. Lindstrom, Kluwer Academic Publishers, issues in Law, Social Science, and Engineering. It contains 18 articles presented at HAZMAT Transport '91, a national conference held at Northwestern University on all aspects of HAZMAT transport. While only a few of the articles use OR models and techniques, the book offers a multi-dimensional treatment of the subject and it is good reading for new researchers in the area.
2. *Institute for Risk Research*, University of Waterloo (1992) - Three books were produced by this Institute as a result of the First International Consensus Conference on the Risks of Transporting hazardous materials, held in Toronto, Canada in April, 1992.
3. *Transportation of hazardous materials: Assessing the Risks* (1993) - This book, edited by F.F. Saccomanno and K. Cassidy, contains 30 articles which are organized into five main chapters: Application of QRA models to the transport of hazardous materials; Analysis of hazardous materials Accident and Releases; Application of Simple Risk Assessment Methodology; Uncertainty in Risk Estimation; Risk Tolerance, Communication and Policy Implications.
4. *Comparative Assessment of Risk Model Estimates for the Transport of hazardous materials by Road and Rail* (1993) - This book, edited by F.F. Saccomanno, D. Leming, and A. Stewart, documents the assessment of a corridor exercise involving the application of several risk models to a common transport problem involving the bulk shipment of chlorine, LPG and gasoline by road and rail along predefined routes. The purpose of the corridor exercise was to provide a well defined transportation problem for analysis in order to

examine the sources of variability in the risk estimates. Seven agencies in six countries participated in this exercise.

5. *What is the Risk* (1993) - This book, edited by F.F. Saccomanno, D. Leming, and A. Stewart, book documents the small group discussions and consensus testing process from the corridor exercise conducted as part of the international consensus conference.
6. *Hazardous materials transportation risk analysis* (1994) - This book, edited by Rhyne WR, Van Norstrand Reinhold, develops a quantitative approaches for truck and train and it explains the QRA methodologies and their application to HAZMAT transportation. It also provides an extended example of a QRA for bulk transport of chlorine by truck and train. This detailed example explores every step of the QRA from preliminary hazards analysis to risk reduction alternatives. This book is a valuable reference for HAZMAT transportation risks, and it is intended for practitioners. It is not an OR book, but it provides useful information for OR research in HAZMAT transportation modeling and analysis.
7. *Guidelines for chemical transportation risk analysis* (1995) - This book, edited by American Institute of Chemical Engineers, Center for Chemical Process Safety (CCPS) New York, completes two other books in the series of process safety guidelines books produced by CCPS: Guidelines for Chemical Process Quantitative Risk Analysis (CPQRA, 1989) and Guidelines for Hazard Evaluation Procedures (HEP, 2nd edition, 1992). It is intended to be used as a companion volume to the CPQRA and HEP Guidelines when dealing with a quantitative transportation risk analysis (TRA) methodology. This book offers a basic approach to TRA for different transport modes (pipelines, rail, road, barge, water, and intermodal containers). It can be useful to an engineer or manager in identifying cost effective ways to manage and reduce the risk of a HAZMAT transportation operation.
8. *Quantitative Risk Assessment of Hazardous Materials Transport Systems* (1996) - This book, edited by M. Nicolet-Monnier and A.V. Gheorge, Kluwer Academic Publishers, contains a comprehensive treatment of the analysis and assessment of transport risks due to HAZMAT transport on roads, rail, by ship, and pipeline. It contains European case studies as well as a discussion of computer-based decision support system for HAZMAT transport problems. It is a useful reference book in the area.

2.3. Classification

The rest of this chapter deals mainly with the academic literature consisting of refereed journal articles. The number of papers published between 1982 and 2007s in this area of research has peaked in mid 1990s and has declined somewhat since 2004.

In 2007 there is again a grow-up of the importance of the matter and of the number of articles. Given the large number of papers in these last twenty years, the articles deal with different aspects of the problem and can be classified as summarized in Tab.2

Table 2. Main subjects in HAZMAT transportations literature

1. Risk assessment	3. Combined facility location and routing
2. Routing	4. Network design

According to [28], we believe in a simple classification that can be useful in providing some structure to the rest of the chapter. One possible classification is the following (in no particular order):

C: with security consideration; DSS: Decision Support System model; G: using GIS; M: Multiobjective; S: Stochastic; T: Time-varying; U: Survey/Annotated Bibliography

Table 3 - A Classification of Hazmat Transportation Models

Risk assessment	Road	Jonkman, et al. (2003), Nardini et al. (2003), Martinez-Alegria et al. (2003)[G,] Rosmuller and Van Gelder (2003), Abkowitz (2002)[C], Fabiano et al. (2002), Kimberly and Killmer (2002), Saccomanno and Haastrup (2002)[tunnels], Hollister (2002), Hwang et al. (2001), Abkowitz et al. (2001), Verter and Kara (2001)[G], Efroymson and Murphy (2000), ICF Consulting (2000), Leonelli et al. (1999), Zhang et al. (2000)[G], Pet-Armacost et al. (1999), Cassini (1998), Mills and Neuhauser (1998), Cutter and Ji (1997), Groothuis and Miller (1997), Lovett et al. (1997)[G], Pine and Marx (1997), Alp and Zelensky (1996), Ertugrul (1995), Sissell (1995), Chakraborty and Armstrong (1995), Erkut and Verter (1995a)[U], Erkut and Verter (1995b), Moore et al. (1995), Spadoni et al. (1995), Verter and Erkut (1995)[U], Gregory and Lichtenstein (1994), Macgregor et al. (1994), Hobeika and Kim (1993), Sandquist et al. (1993), Harwood et al. (1993), Abkowitz et al. (1992), Glickman (1991), Grenney, et al. (1990)[DSS], Kunreuther and Easterling (1990), Chow et al. (1990), Abkowitz and Cheng (1989), Ang and Briscoe (1989), Harwood et al. (1989), Abkowitz and Cheng (1988), Hillsman (1988), Horman (1987), Keeney and Winkler (1985), Scanlon and Cantilli (1985), Pijawka et al. (1985), Kunreuther, et al. (1984), Philipson et al. (1983), Keeney (1980), Shappert et al. (1973)
	Rail	Anderson and Barkan (2004), Barkan et al. (2003), Fronczak (2001), Orr et al. (2001), Dennis (1996), Larson (1996), Glickman and Golding (1991), McNeil and Oh (1991), Saccomanno and El-Hage (1991), Saccomanno and El-Hage (1989), Glickman and Rosenfield (1984), Glickman (1983),
	Marine	Douligeris, et al. (1997), Roeleven et al. (1995), Romer et al. (1995)
	Air	LaFrance-Linden et al. (2001)

	Road + Rail	Brown and Dunn (2007), Milazzo et al. (2002), Bubbico et al. (2000), Neill and Neill (2000), Deng et al. (1996), Leeming and Saccomanno (1994), Purdy (1993), Saccomanno, and Shortreed (1993), Saccomanno, et al. (1989), Vanaerde et al. (1989), Glickman (1988), Swoveland (1987)	
	Road + Rail + Marine	Andersson (1994)	
	Road + Rail + Marine + Air	Kloeber et al. (1979)	
Routing	Local Routing	Road	Akgün et al. (2007), Duque et al. (2007), Erkut and Ingolfsson (2005), Huang and Cheu (2004)[C], G, Huang et al. (2003)[C], M, Kara et al.(2003), Luedtke and White (2002)[C], Paté-Cornell (2002), Marianov et al. (2002), Frank et al. (2000), Erkut and Ingolfsson (2000), Leonelli et.al. (2000), Zografos et al. (2000)[DSS], Erkut and Verter (1998), Tayi et al. (1999)[M], Bonvicini et al. (1998), Marianov and ReVelle (1998)[M], Verter and Erkut (1997), Sherali et al. (1997)[M], Nembhard and White (1997)[M], Erkut and Glickman (1997), Jin and Batta (1997), Verter and Erkut (1997), Erkut (1996), Jin et al. (1996), Ashtakala and Eno (1996)S, Beroggi and Wallace (1995), Boffey and Karkazis (1995), Erkut (1995), Moore et al. (1995), Karkazis and Boffey (1995), Glickman and Sontag (1995)[M], McCord and Leu (1995)[M], Sivakumar et al. (1995), Beroggi (1994), Beroggi and Wallace (1994), Ferrada and Michelhaugh (1994), Patel and Horowitz (1994)G, Lassarre et al. (1993)[G], Sivakumar et al. (1993), Turnquist (1993)[M], S, Wijeratne et al. (1993)[M], Lepofsky et al. (1993)[G], Beroggi and Wallace (1991), Miaou and Chin (1991), Gopalan et al. (1990a), Chin and Cheng (1989)[)M], Zografos and Davis (1989)[M], Abkowitz and Cheng (1988)[M], Batta and Chiu (1988), Vansteen (1987), Cox, and Turnquist (1986), Belardo et al. (1985), Saccomanno and Chan (1985), Urbanek and Barber (1980), Kalelkar and Brinks (1978)[M]
		Rail	Verma and Verter (2005), McClure et al. (1988), Coleman (1984), Glickman (1983)
		Marine	Iakovou (2001), Li et al. (1996), Haas and Kichner (1987)

		Road + Rail	Glickman (1988)
		Road + Rail + Marine	Weigkricht and Fedra (1995) ^{DSS}
	Local Routing and Scheduling (on Road)	Zografos and Androutsopoulos (2004)^{M}, Zografos and Androutsopoulos (2002)^{M}, Miller-Hooks and Mahmassani (2000)^{S,T}, Bowler and Mahmassani, (1998)^{T}, Miller-Hooks and Mahmassani (1998)^{S,T}, Sulijoadikusumo and Nozick (1998)^{M,T}, Nozick et al. (1997)^{M,T,} Smith (1987)^{M}, Cox and Turnquist (1986)	
	Global Routing	Road	Carotenuto et al. (2007a,b), Dell'Olmo et al. (2005), Akgün et al. (2000), Marianov and ReVelle (1998), Lindner-Dutton et al. (1991), Gopalan et al. (1990a, b), Zografos and Davis (1989)
		Marine	Iakovou et al. (1999)
Combined facility location and routing	Alumur and Kara (2007), Cappanera et al. (2004), Berman et el. (2000), Giannikos (1998)^{M}, Helander and Melachrinoudis (1997), List and Turnquist (1998), Current and Ratick (1995)^{M}, Jacobs and Warmerdam (1994), Boffey and Karkazis (1993), Stowers and Palekar (1993), List and Mirchandani (1991)^{M}, List, et al. (1991)^{U}, Revelle et al. (1991), Zografos and Samara (1989), Peirce and Davidson (1982), Shobrys (1981)		
Network design	Erkut and Alp (2007a,b), Berman et al. (2007), Erkut and Gzara (2005), Verter and Kara (2005), Kara and Verter (2004)		

Although we have offered this simple classification, it is fair to say that numerous papers deal with problems that lie at the intersection of the above areas and such problems are receiving increasingly more attention in the literature. Table 3 suggests that the HAZMAT transportation problems on highways received the most attention from the operations researchers. In contrast, HAZMAT transportation via air or pipeline, as well as intermodal HAZMAT transportation has received almost no attention.

3. Literary review of problems and models

In Table 2, we suggest a schematic classification of the academic literature of HAZMAT that now we review. Rather than giving a detailed separate presentation of each work, we outline the most relevant guidelines emerging from the literature. We consider separately risk assessment and routing, combined facility location and network design.

3.1. Risk Assessment

Risk is defined as a measure of human injury, environmental damage, or economic loss in terms of both the incident likelihood and the magnitude of the loss or injury [88]. Risk is an integral part of the hazardous materials transportation literature. The majority of articles are operations research studies for minimizing risk on a transport route. The risk equations in the OR studies tend to be relatively simple and are often variations on the release probability or the product of release probability and consequences. Other articles focus on calculating risk as part of QRA studies [23]. These latter articles are typically written by environmental, civil, and chemical engineers who incorporate demographic, meteorological, and chemical databases in calculating risk. These OR and QRA studies are focused on releases that occur on the road or along railways. There is not a focus on transport-support activities, such as loading or unloading of containers. Although there are differences in the accident scenarios surrounding these two activities, many of the variables and associations and hence the general Bayesian network structures are the same.

The great majority of existing studies attempt to minimize or calculate the risk of potential future occurrences. The HAZMAT literature does not seem interested in modeling the past release incidents to determine the influence of the relevant variables. One notable exception is a study by [89] in which various sociological, behavioural, and perceptual variables affect the impact of an HAZAMAT release, was depicted using an influence diagram. From this perspective, the decision model suggested by Burns and Clemen is unique within the HAZMAT transport literature by virtue of its exploratory, statistical nature. In general, this literature lacks a focus on data-driven analysis of outcomes relative to the influencing variables.

A possible reason of this lack is owed to the fact that past data are not very reliable. Using general truck accident data for HAZMAT trucks overestimates the accident probabilities. What makes matters worse is that there is no agreement on general truck accident probabilities and conflicting numbers are reported by different researchers. Furthermore, applying national data uniformly on all road segments of similar type is quite problematic since it ignores hot spots such as road intersections, highway ramps, and bridges. Researchers need to have access to high quality accident probability data and empirical or theoretical research that leads to improvements in the quality of such data should be welcome. [23] describe a quantitative risk assessment approach for hazardous materials transportation that employs considerable statistical data from past incidents. They illustrate application of this method to evaluating distances to which the public should be protected immediately following an accidental release of toxic materials that pose an inhalation hazard. While this paper focuses on emergency response aspects of the problem, the framework that they describe has applications to societal risk estimation and routing optimization for a wide variety of hazardous materials.

Typically, accident and release probabilities have been estimated for a given road and area type using averaged values, which have limited sensitivity in specific situations (see, e.g., [90]). Differently, some recent empirical works suggest the use of fuzzy logic to determine the accident frequency (see, e.g., [91]). Additional exploratory work on accident probabilities is still needed. There is a lack of agreement on how HAZMAT transport risk should be represented [71].

Risk is described at least from seven different perspectives:

- Accident or Release Probability [92]
  - Probability of a vehicular accident of the HAZMAT truck [93]
  - Probability of a vehicular accident that leads to release [94]
  - Probability of a release [71]

- Consequences [95]
- Consequence Probability
  - Individual Risk [96]
  - Societal Risk [71]
- Numerical Indices [88].
- Exposure and Product of Exposure [97]
- Expected Value [41]
- Variations on Expected Value [74]

However, as already described in Section 2.2 risk is usually assessed in terms of the following high-level variables: 1) accident or release probability, 2) consequence level, 3) population count, and 4) exposure amount, such as amount of HAZMAT transported.

Several authors whose risk equations are limited to these high level variables characterize their risk models as simple (see e.g. [98]; [44]. More complex formulations [19] for risk assessment include the above high-level variables along with variables such as 5) wind probability or 6) fatality probability, also known as vulnerability. In turn, the latter variables are often specified in terms of sub-variables, or input parameters [99]. However, the numerical relationships of the sub-variables to the higher level variables or outcomes are not provided to the reader and are therefore not a discussion focus [73]. For example, [74] suggest that the release probability calls for the use of vehicle type and material type as sub-variables. However, they neither discuss nor provide in the article the exact numerical relationship of vehicle type or material type to release probability.

3.2. Route Optimization for Hazardous Materials Transport

In the following we briefly introduce some of the most relevant work dealing with route optimization for HAZMAT.

[95] focus on the damage induced to the population in case of an accident. In this research study attention is given to the dispersion of the HAZMAT through air. Therefore, the impact area is not defined by a given bandwidth, but is a function dependent on the type of material transported and the meteorological conditions at the moment of the accident.

[100] made research study that has considered a simplified approach to quantify risk. This research study focuses in the development of a spatial decision support system for the selection of route for the transport of HAZMAT within the United States of America. The element at risk considered is the population located in the impact area of the possible accident. The impact area is located alongside the route and it extents to both sides of the route up to a predefined bandwidth.

[74] introduce a methodology based on the quantification of individual and societal risk indexes for the selection of optimal route for the transport of HAZMAT. The hazard considered is the accident probability of a HAZMAT transport unit, and the population is considered as the element at risk, being affected in the case of an accident. The population value results from aggregating the population travelling on the transport network and the population located adjacent to the transport network. In a previous article [73] mention that the use of individual and societal risk can give an accurate

indication of risk, however to calculate these values, a great amount of data and programming effort is required. Due to this, a number of other simplified risk quantification techniques have been adopted in other research studies some of these are mentioned above.

[41] consider the population as the element at risk. In this study the population located inside the impact area is assumed to have the same vulnerability value, namely one. The risk for the population is then defined as the product of the individual risk and the total population. Individual risk is assessed only on hazards, vulnerability, and element at risk. The previous results could be generalized assessing the individual risk on the basis of also the accident probability of a HAZMAT transport unit, and the population is considered as the element at risk, being affected in the case of an accident as proposed by [73].

[101] describe a method for finding nondominated paths for multiple routing objectives in networks where the routing attributes are uncertain, and the probability distributions that describe those attributes vary by the time of day. This problem is particularly important in routing and scheduling of shipments of very hazardous materials. The method developed extends and integrates the work of several previous authors, resulting in a new algorithm that propagates means and variances of the uncertain attributes along paths and compares partial paths that arrive at a given node within a user-specified time window. The comparison uses an approximate stochastic dominance criterion.

[102] study the problem of determining a path for a shipment of hazardous materials between a pre-specified origin-destination pair on the plane taking into account minimization of risks during the transportation and cost of the path. Given a source point a, a destination point b, a set S of demand sites (points in the plane) and a positive value I, the authors want to compute a path connecting a and b with length at most I such that the minimum distance to the points in S is maximized. They propose an approximate algorithm based on the bisection method to solve this problem and the technique reduces the optimization problem to a decision problem, where one needs to compute the shortest path such that the minimum distance to the demand points is not smaller that a certain amount r. To solve the decision task, Diaz-Banez, Gomez and Toussaint transform the problem to the computation of the shortest path avoiding obstacles. This approach provides efficient algorithms to compute shortest obnoxious paths under several kinds of distances.

[35] study the determination of optimal routes for hazardous material transportation trying to find trade-off solutions among many conflicting objectives in the analysis, such as travel cost, population exposure and environmental risk or security concerns. The authors use as generalized objective the product of the different objective functions and solve a complex shortest path problem that often present several “efficient" solutions. A case study with 8 objective functions has been carried out on a road network in Singapore. A geographical information system is used to quantify road link attributes, which are assumed linear and deterministic for the sake of simplicity. The proposed algorithm derives four significantly different routes, which conform to intuition.

[36] propose a novel vehicle routing and scheduling problem in transporting hazardous materials for networks with multiple time-varying attributes. It actually aims to identify all nondominated time-varying paths with fixed departure times at the origin and fixed waiting times at intermediate nodes of the paths for each given pair of origin and destination. Three kinds of practical constraints must also respected: limited

operational time period, limited service time, and limited waiting time window at each node. Based on the assumption of linear waiting attributes at a node, the proposed problem can be transformed into a static multiobjective shortest path problem in an acyclic network reconstructed by the space-time network technique. An efficient dynamic programming method is then developed.

[103] analyzes the possible use of telegeomonitoring in HAZMAT transportation. The author proposes a telegeomonitoring system that uses a geographic information system to represent civil infrastructure (urban network, land use, industries, etc.) and a decision support systems technology to asses the risk and to evaluate the K-best paths that minimize transportation risk. To this end, routing algorithms on graphs are extended to deal with fuzzy risk; in particular, the K-best fuzzy shortest paths.

[104] proposes a model of flow propagation, assuming "packets" of vehicles and uniformly accelerated movement. Such an approach allows the author to propose a mesoscopic model of the HAZMAT vehicles movements that appears lifelike in the representation of outflow dynamics and easy polinomiale to solve.

[31] study the problem of routing hazardous material on a multimodal network with time-varying link travel times and intermodal options. The problem is formulated as a Dynamic Program and an intermodal/multimodal shortest path algorithm is modified to compute minimum risk paths by combining the available transport modes, while accounting for transfer delays and transportation costs. The algorithm is implemented on a test network to observe changes in the solution under different scenarios. Computational performance is evaluated on networks of different sizes and the algorithm's efficient running time makes it appropriate for use on realistic networks for both planning and real-time operations.

[19] focus on the effects of weather systems on HAZMAT routing. They start by analyzing the effects of a weather system on a vehicle traversing a single link. This helps characterize the time-dependent attributes of a link due to movement of the weather systems. This analysis is used as a building block for the problem of finding a least risk path for HAZMAT transportation on a network exposed to weather changes. Several methods are offered to solve the underlying problem, and computational results are reported. Two conclusions are drawn from this paper: (1) it is possible to determine the time-dependent attributes for links on a network provided that some assumptions on the nature of the weather system are made; (2) heuristics can provide effective solutions for practical size problems while allowing for parking the vehicle to avoid weather system effects; technologies (4) how to route waste residues to disposal centres. The model has the objective of minimizing both the total cost and the transportation risk.

[20] propose a new multiobjective location-routing model that is object of a large-scale implementation in the Central Anatolian region of Turkey. The aim of the proposed model is to answer to the following questions: (1) where to open treatment centres and with which technologies, (2) where to open disposal centres, (3) how to route different types of hazardous waste to which of the compatible treatment technologies (4) how to route waste residues to disposal centres. The model has the objective of minimizing both the total cost and the transportation risk. The model proposed is manageable for a realistic problem in the Central Anatolian region of Turkey. Given that the hazardous waste management problem is a strategic one that will be solved infrequently, the authors believe that the computational effort is reasonable for problems with up to 20 candidate sites and that the application is a few orders of magnitude better than other applications in the literature. Most of the papers

present applications for small problems such as with 10 or 15 generation nodes and with 3 or 4 candidate sites, whereas Alumur and Kara applied their model with 92 generation nodes and with 15 and 20 candidate sites. As another research direction, the authors suggest that they can include other objectives of the hazardous waste management problem in their model. For example, one can maximize the energy production after the incineration process. Differently, one can minimize the risk due to the location of the treatment facility. When multiple objectives are considered, the model can be managed with different multi-objective solution techniques. Alumur and Kara propose a relatively simple multi-objective solution technique for ease of application. Apart from the different objectives, one can expand the mathematical model so that the locations of the recycling facilities and the corresponding routing strategies are also determined. Lastly, a multi-period version of the model can be used to schedule the processing of different types of waste. In this case, the compatibility constraint will gain more importance. That is, any new model should not allow wastes that are not compatible with each other to be transported or incinerated at the same time.

[22] study how undesirable consequences of hazardous materials incidents can be mitigated by quick arrival of specialized response teams at the accident site. They present a novel methodology to determine the optimal design of a specialized team network so as to maximize its ability to respond to such incidents in a region. They show that this problem can be represented via a maximal arc-covering model. They discuss two formulations for the maximal arc-covering problem, a known one and a new one. Through computational experiments, the authors establish that the known formulation has excessive computational requirements for large-scale problems, whereas the alternative model constitutes a basis for an efficient heuristic. The methodology is applied to assess the emergency response capability to transport incidents, which involve gasoline, in Quebec and Ontario. [105] point out the possibility of a significant improvement via relocation of the existing specialized teams, currently stationed at the shipment origins.

[24] study the problem of managing a set of HAZMAT requests in terms of HAZMAT shipment route selection and actual departure time definition. For each HAZMAT shipment, a set of minimum and equitable risk alternative routes from origin to destination points and a preferred departure time are given. The aim is to assign a route to each HAZMAT shipment and schedule them on the assigned routes in order to minimize the total shipment delay, while equitably spreading the risk spatially and preventing the risk induced by vehicles travelling too close to each other. This HAZMAT shipment scheduling problem is modelled as a job-shop scheduling problem with alternative routes. No-wait constraints arise in the scheduling model as well, since, supposing that no safe area is available, when a HAZMAT vehicle starts travelling from the given origin it cannot stop until it arrives at the given destination. A tabu search algorithm is proposed for the problem, which is experimentally evaluated on a set of realistic test problems over a regional area, evaluating the provided solutions also with respect to the total route risk and length.

[26] consider the problem of designating HAZMAT routes in and through a major population centre. Initially, they restrict the attention to a minimally connected network (a tree) where we can predict accurately the flows on the network. They formulate the tree design problem as an integer programming problem with an objective of minimizing the total transport risk. Such design problems of moderate size can be solved using commercial solvers. Then they develop a simple construction heuristic to expand the solution of the tree design problem by adding road segments. Such

additions provide carriers with routing choices, which usually increase risks but reduce costs. The heuristic adds paths incrementally, which allows local authorities to trade off risk and cost. Erkut and Alp use the road network of the city of Ravenna, Italy, as a case study.

[27] consider an integrated routing and scheduling problem in HAZMAT transportation when accident rates, population exposure, and link durations on the network vary with time of day. They minimize risk subject to a constraint on the total duration of the trip and allow for stopping at the nodes of the network. The authors consider four versions of this problem with increasingly more realistic constraints on driving and waiting periods, and propose pseudo-polynomial dynamic programming algorithms for each version. They use a realistic example network to experiment with theirs algorithms and provide examples of the solutions generated. The computational effort required for the algorithms is reasonable, making them good candidates for implementation in a decision-support system.

The en-route stops allow us to take full advantage of the time-varying nature of accident probabilities and exposure and result in the generation of routes that are associated with much lower levels of risk than those where no waiting is allowed.

4. Synthesis and Conclusions

4.1. Synthesis

Ethics is not a substitute for a fundamentally sound business strategy, and so it is important to provide value-added tools for companies to help them manage all aspects of sustainable and socially responsible business practices in the HAZMAT area. In general, the studies in the HAZMAT transport literature do not have an exploratory modelling focus. Rather, various analytical equations for risk are used in route optimization or quantitative risk assessment research. The lack of focus on exploratory modelling of risk in terms of its important variables presents a gap or opportunity in the HAZMAT literature.

[28] reflected on the state-of-the-art as of 2005, and pointed out a number of directions for future research. In the following two years, some of the problem areas proposed in [106][107]and in [28] were investigated by researchers, whereas many others remained relatively unexplored. From the methodological perspectives, global routing problems on stochastic time-varying networks received no attention despite their relevance and application potential.

HAZMAT transportation network design problem which considers all involved parties (government and the carriers) is a relatively young research topic. The most obvious extension of the existing models in this area is to incorporate uncertainty and consider multiple objectives as the HAZMAT transportation problems are highly stochastic in nature and involve multiple criteria (and players). There is an increase on utilizing geographic information systems either for data input or combined with optimization models to conduct more realistic risk assessment. We believe that there are still many important OR problems in HAZMAT transportation. Researchers can find additional important references in [108-266]. However, we think the focus will shift from a priori optimization toward real-time adaptive decision making for several reasons, such as the availability of the necessary technology and data, as well as security concerns. While it is rather unfortunate that terrorist attacks can and do happen, their possibility opens up a new frontier for operations researchers in general, and HAZMAT transport researchers in particular.

4.2. Conclusions

- Researchers need to have access to high quality accident probability data and empirical or theoretical research that leads to improvements in the quality of such data would be welcome.
- Applying national data uniformly on all road segments of similar type is quite problematic since it ignores hot spots such as road intersections, highway ramps, and bridges.
- There is no agreement on general truck accident probabilities and conflicting numbers are reported by different researchers.
- Given the limitation of QRA, and the fact that public opposition is a function of perceived risks, perhaps more attention should be paid to quantifying and modeling of perceived risks. We believe more work is needed to improve our understanding of how perceived risks change as a function of the hazardous substance, the distance to a hazardous activity, and the volume of the activity.
- More work is needed to improve understanding of how perceived risks change as a function of the hazardous substance, the distance to a hazardous activity, and the volume of the activity.
- Geographic information systems make it possible to use more precise population information. However, using census-based population data for daytime HAZMAT movements makes little sense since census data is residence-based and most residents are not at home during the day. Researchers need to take the next step and incorporate day versus night population distributions, as well as high-density population installations such as schools and hospitals. While this is done relatively easily for QRA of a single route, it is more complicated to generate the necessary data for an entire transportation network.

References

[1] L.B. Shappert, W.A. Brobst, J.W. Langhaar, J.A. Sisler, 1973. Probability and consequences of transportation accidents involving radioactive-material shipments in the nuclear fuel cycle. Nuclear Safety 14(6), 597-604.

[2] A. Kalelkar, R. Brinks, 1978. Use of multidimensional utility functions in hazardous shipment decisions. Accident Analysis and Prevention 10, 251-265.

[3] S. Wirasinghe, 1978. Determination of traffic delays from shock-wave analysis. Transportation Research 12, 343-348.

[4] R. Keeney, 1980. Equity and public risk. Operations Research 28, 527-534.

[5] G. Urbanek, E. Barber, 1980. Development of criteria to designate routes for transporting hazardous materials. Final Report, FHWA-RD-80- 105, Federal Highway Administration, Washington DC.

[6] D. Shobrys, 1981. A model for the selection of shipping routes and storage locations for a hazardous substance. PhD thesis, Johns Hopkins University, Baltimore.

[7] J. Peirce, G. Davidson, 1982. Linear programming in hazardous waste management. Journal Environmental Engineering 108(5), 1014-1026.

[8] T. Glickman, 1983. Rerouting railroad shipments of hazardous materials to avoid populated areas. Accident Analysis and Prevention 15(5), 329-335.

[9] L. Philipson, H. Napadensky, M. Maxey, 1983. Hazardous materials transportation risk assessment. Transportation of Hazardous Materials: Toward a National Strategy, Volume 2 TRB Special Report 197, 43-57.
[10] J. Coleman, 1984. Railroad - highway crossings and route selection for transporting hazardous materials. Public Roads 48(2), 63-71.
[11] T. Glickman, D. Rosenfield, 1984. Risks of catastrophic derailments involving the release of hazardous materials. Management Science 30(4), 503-511.
[12] H. Kunreuther, J. Linnerooth, J. Vaupel, 1984. A decision-process perspective on risk and policy analysis. Management Science 30(4), Risk Analysis 475-485.
[13] P. Slovic, S. Lichtenstein, B. Fischhoff, 1984. Modeling the societal impact of fatal Accidents. Management Science 30(4) 464-474.
[14] S. Belardo, J. Pipkin, J. Seagle, 1985. Information support for hazardous materials movement. Journal Hazardous Materials 10(1), 13-32.
[15] R. Keeney, L. Winkler, 1985. Evaluating decision strategies for equity of public risks. Operations Research 33(5), 955-970.
[16] K.D. Pijawka, S. Foote, A. Soesilo, R.D. Scanlon, E.J. Cantilli, 1985. Improving transportation of hazardous materials through risk assessment and routing. Technical Report PB-86-112471/XAB; TRB/TRR-1020, National Research Council, Washington, DC.
[17] F. Saccomanno, A. Chan, 1985. Economic evaluation of routing strategies for hazardous road shipments. Transportation Research Record 1020, 12-18.
[18] R. Scanlon, E. Cantilli, 1985. Assessing the risk and safety in the transportation of hazardous materials. TRB, National Research Council, Washington, D.C. Transportation Research Record 1020, 06-11.
[19] V. Akgün, A. Parekh, R. Batta, C. Rump 2007. Routing of a hazmat truck in the presence of weather systems. Computers & Operations Research 34, 1351-1373.
[20] S. Alumur, B. Kara, 2007. A new model for the hazardous waste location-routing problem. Computers & Operations Research 34, 1406-1423.
[21] C. Barkan, S. Ukkusuri, S. Waller, 2007. Optimizing the design of railway tank cars to minimize accident-caused releases. Computers & Operations Research 34, 1366-1286.
[22] O. Berman, V. Verter, B. Kara 2007. Designing emergency response networks for hazardous materials transportation. Computers & Operations Research 34, 1374-1388.
[23] D. Brown, W. Dunn 2007. Application of a quantitative risk assessment method to emergency response planning. Computers & Operations Research 34, 1243-1265.
[24] P. Carotenuto, S. Giordani, S. Ricciarelli 2007a. Finding minimum and equitable risk routes for hazmat shipments. Computers & Operations Research 34, 304-1327.
[25] P. Carotenuto, S. Giordani, S. Ricciardelli, S. Rispondo 2007b. A tabu search approach for scheduling hazmat shipments. Computers & Operations Research 34, 1328-1350.
[26] E. Erkut, O. Alp, 2007a. Designing a road network for dangerous goods shipments. Computers & Operations Research 34, 1389-1405.
[27] E. Erkut, O. Alp, 2007b. Integrated routing and scheduling of hazmat trucks with stops en-route. Transportation Science 41(1), 107-122.
[28] E. Erkut, S. Tjandra, V. Verter, 2007. Hazardous materials transportation: In C. Barnhart and G. Laporte (Eds.) Transportation, Handbook in OR & MS Vol. 14, Elsevier, 539-621.
[29] J. Duque, A. Barbosa-Pvoa, A., Novais, 2007. Synthesis and optimization of the recovery route for residual products under uncertain product demand. Computers & Operations Re-search 34(5), 1463-1490.
[30] M. Verma, V. Verter, 2007. Rail transportation of dangerous goods: population exposure to airborne toxins. Computers & Operations Research 34, 1287-1303.
[31] E. Floros, A. Ziliaskopoulos, E. Chang, 2006. Intermodal hazmat transportation problem with time-dependent travel risk. TRB 2006 Annual Meeting.
[32] P. Dell'Olmo, M. Gentili, A. Scozzari, 2005. On finding dissimilar Pareto-optimal paths. European Journal of Operational Research 162, 70-82.
[33] E. Erkut, F. Gzara, 2005. A bi-level programming application to hazardous material transportation network design. Research Report Department of Finance and Management Science, University of Alberta School of Business, Edmonton, Alberta, Canada T6G 2R6.
[34] E. Erkut, A. Ingolfsson, 2005. Transport risk models for hazardous materials: revisited. Operations Research Letters 33(1), 81-89.
[35] B. Huang, P. Fery, 2005. Aiding route decision for hazardous material transportation. TRB 2005 Annual Meeting.
[36] Q. Meng, D. Lee, R. Cheu, 2005. Multiobjective vehicle routing and scheduling problem with time window constraints in hazardous material transportation. Journal Of Transportation Engineering 131(9), 699-707.

[37] V. Verter, B. Kara, 2005. A path-based approach for the hazardous network design problem. Working paper, Faculty of Management, McGill University.
[38] P. Cappanera, G. Gallo, F. Maffioli, 2004. Discrete facility location and routing of obnoxious activities. Discrete Applied Mathematics 133, 3-28.
[39] B. Kara, V. Verter, 2004. Designing a road network for hazardous materials transportation. Transportation Science 38(2), 188-196.
[40] B. Huang, R. Cheu, 2004. Gis and genetic algorithms for hazmat route planning with security considerations. International Journal Geographical Information Science 18(00), 1-19.
[41] K. Zografos, K. Androutsopoulos, 2004. A heuristic algorithm for solving hazardous materials distribution problems. European Journal of Operational Research, 152(2), 507-519.
[42] G. Atkinson, (2000) "Measuring Corporate Sustainability", Journal of Environmental Planning and Management, Vol. 43, pp. 235-252.
[43] M.Marsh, D. Schilling, 1994. Equity measures in facility location analysis: a review and framework. European Journal of Operations Research 74(1), 1-17.
[44] J. Current, S. Ratick, 1995. A model to assess risk, equity, and efficiency in facility location and transportation of hazardous materials. Location Science 3, 187-202.
[45] W. Vesely, E. Goldberg, N. Roberts, D. Haasl, 1981. Fault tree handbook, U.S. Nuclear Regulatory Commission. NUREG-0492.
[46] S. Chin, P. Cheng, 1989. Bi-criterion routing scheme for nuclear spent fuel transportation. Transportation Research Record 1245, 60-64.
[47] T. Chow, R.M. Oliver, G.A. Vignaux, 1990. A Bayesian escalation model to predict nuclear accidents and risk. Operations Research 38(2), 265-277.
[48] T. Glickman, D. Golding, 1991. For a few dollars more: Public trust and the case for transporting nuclear waste in dedicated trains. Policy Studies Review 10 4, 127-138.
[49] S. Miaou, S. Chin, 1991. Computing k-shortest path for nuclear spent fuel highway transportation. European Journal of Operational Research 53(1), 64-80.
[50] G.M.Sandquist, J.S. Bennion, J.E. Moore, D.M. Slaughter, 1993. A route-specific transportation risk assessment model. Transactions of the American Nuclear Society (ANS) annual meeting 20-24 Jun 1993; San Diego, CA (United States) l(68), 151-153.
[51] J. Ferrada, R. Michelhaugh, 1994. Development of an expert system for transportation of hazardous and radioactive materials. International Topical Meeting on Nuclear and Hazardous Waste Management, Spectrum '94, Atlanta, American Nuclear Society, American Nuclear Society, Inc., l.2, 997-1002.
[52] J. Moore, G. Sandquist, D. Slaughter, 1995. A route-specific system for risk assessment of radioactive materials transportation accidents. Nuclear Technology 112(1), 63-78.
[53] H. Neill, R. Neill, 2000. Transportation of transuranic nuclear waste to wipp: A reconsideration of truck versus rail for two sites. Natural Resources Journal 40(1), 93-124.
[54] K.G. Zografos, G.M. Vasilakis, I.M. Giannouli, 2000. A methodological framework for developing a decision support systems (DSS) for hazardous material emergency response operations. Journal of Hazardous Materials 71(1-3), 503-521.
[55] U.D., 2004. List of hazardous materials. The Office of Hazardous Materials Safety, U.S. Department of Transportation, Washington, DC.
[56] A. Gheorghe, M. Nicolet-Monnier, 1995a. Integrated regional risk assessment-volume1: continuous and non-point source emissions: Air, water, soil.
[57] A. Gheorghe, M. Nicolet-Monnier, 1995b. Integrated regional risk assessment-volume2: consequence assessment of accidental releases.
[58] A. Lavell, 2000. An approach to concept and definition in risk management terminology and practice. Latin American Social Science Faculty (FLACSO) and the Network for the Social Study of Disaster Prevention in Latin America-LA RED.
[59] N.A. Pons, O.J. Pejon, L.V. Zuquette, 2007. Use of geoprocessing in the study of land degradation in urban environments: the case of the city of São Carlos, state of São Paulo, Brazil. Environmental Geology, 53(4), 727-739.
[60] C.M. Lewis, K.C. Murdock, 1999. Alternative Means of Redistributing Catastrophic Risk in a National Risk-Management System. The Financing of Catastrophe Risk, edited by K.A. Froot, 51-85. Chicago: National Bureau of Economic Research.
[61] E. Alp, M. Zelensky, 1996. Risk quantification for meteorology-and direction-dependent hazards due to point and linear risk sources. Journal of Loss Prevention in the Process Industries 9(2), 135-145.
[62] S.L. Ellinas, 1999. Risk assessment-an insurer's perspective. Journal of Hazardous Materials, 65(1-2), 123-130.
[63] R. Gregory, S. Lichtenstein, 1994. A hint of risk-tradeoffs between quantitative and qualitative risk-factors. Risk Analysis 14(2), 199-206.

[64] S. Kaplan, J. Garrick, 1991. On the quantitative definition of risk. Risk Analysis 1(1), 11-27

[65] B. Bottelberghs, 2000. Risk analysis and safety policy developments in the Netherlands. Journal of Hazardous Materials 71(1), 59-84

[66] D. Harwood, E. Russell, J. Viner, 1989. Characteristics of accidents and incidents in highway transportation of hazardous materials. Transportation Research Record 1245, 23-33.

[67] R. Batta, S. Chiu, 1988. Optimal obnoxious paths on a network: transportation of hazardous materials, Operations Research 36(1), 84-92.

[68] G. Beroggi, W. Wallace, 1991. Closing the gap-transit control for hazardous material flow. Journal of Hazardous Materials 27(1), 61-75.

[69] C. Barkan, T. Treichel, G. Widell, 2000. Transportation research record 1707. Reducing hazardous materials releases from railroad tank car safety vents, 27-34.

[70] A. Ang, J. Briscoe, 1989. Development of a systems risk methodology for single and multimodal transportation systems. Final Report, Office of University Research, US DOT, Washington, DC.

[71] E. Erkut, V. Verter, 1998. Modeling of transport risk for hazardous materials. Operations Research 46(5), 625-642.

[72] J. Mumpower, 1986. An analysis of the de minimis strategy for risk management. Risk Analysis 6, 437-446.

[73] P. Leonelli, S. Bonvicini, G. Spadoni, 1999. New detailed numerical procedures for calculating risk measures in hazardous materials transportation. Journal of Loss Prevention in the Process Industries 12(6), 507-515.

[74] P. Leonelli, S. Bonvicini, G. Spadoni, 2000. Hazardous materials transportation: a risk analysis-based routing methodology. Journal of Hazardous Materials 71(1), 283-300.

[75] F. Saccomanno, J. Shortreed, 1993. Hazmat transport risks-societal and individual perspectives. Journal of Transportation Engineering-ASCE 119(2), 177-188.

[76] J.K. Vrijling, W. van Hengel, R.J. Houben, 1995. A framework for risk evaluation. Journal of Hazardous Materials 43(3), 245-261

[77] S. Jonkman, P. van Gelder, J. Vrijling, 2003. An overview of quantitative risk measures for loss of life and economic damage. Journal of Hazardous Materials 99(1), 1-30.

[78] CCPS Center for Chemical Process Safety, 1995. Guidelines for chemical transportation risk analysis. New York: American Institute of Chemical Engineers.

[79] G. List, P. Mirchandani, 1991. An integrated network planar multiobjective model for routing and siting for hazardous materials and wastes. Transportation Science 25(2), 146-156.

[80] M. Abkowitz, 2002. Transportation risk management: a new paradigm. Security Papers, Southeastern Transportation Center, University of Tennessee, 93-103.

[81] TRB, 2002. Deterrence, protection, and preparation: the new transportation security imperative. Transportation Research Board, Special Report 270.

[82] M. Glaze, 2003. New security requirements for hazmat transportation. Occupational Health & Safety 72(9), 182-185.

[83] E. Erkut, T. Glickman, 1997. Minimax population exposure in routing highway shipments of hazardous materials. Transportation Research Record 1602, 93-100.

[84] E. Erkut, A. Ingolfsson, 2000. Catastrophe avoidance models for hazardous materials route planning. Transportation Science 34(2), 165-179.

[85] E. Paté-Cornell, 2002. Probabilistic modeling of terrorist threats: A system analysis approach to setting priorities among counter-measures. Military Operations Research 7(4), 5-23.

[86] B. Huang, C. Long, Y. Liew, 2003. GIS-AHP Model for hazmat routing with security considerations. IEEE 6th Int'l Conf on ITS.

[87] K. Zografos, K. Androutsopoulos, 2001. Assessing impacts from introduction of advanced transport telematics technologies in hazardous materials fleet management. Proceedings of the 80th Annual meeting of Transportation Research Board, Washington DC.

[88] CCPS Center for Chemical Process Safety, 2000. Guidelines for chemical process quantitative risk analysis. New York: American Institute of Chemical Engineers.

[89] W. Burns, R. Clemen, 1993. Covariance structure models and influence diagrams. Management Science 39(7), 816-834.

[90] D. Harwood, E. Russell, J. Viner, 1993. Procedure for developing truck accident and release rates for hazmat routing. Journal of Transportation Engineering - ASCE 119(2), 189-199.

[91] S. Bonvicini, P. Leonelli, G. Spadoni, 1998. Risk analysis of hazardous materials transportation: evaluating uncertainty by means of fuzzy logic. Journal of Hazardous Materials 62(1), 59-74.

[92] M. Abkowitz, P. Cheng, 1988. Developing a risk cost framework for routing truck movements of hazardous materials. Accident Analysis & Prevention 20(11), 38-51.

[93] N. Vayiokas, M. Pitsiava-Latinopoulou, 2004. Developing a framework for assessing risks involved in the transportation of dangerous goods. 11th International Symposium: Loss Prevention and Safety Promotion in the Process Industries, Praha, Czech Republic, 4495-4503.

[94] B. Kara, V. Verter, 2003. Accurate calculations of hazardous materials transport risks. Operations Research Letters 31(4), 285-292.

[95] J. Karkazis, T. Boffey, 1995. Optimal location of routes for vehicles transporting hazardous materials. European Journal of Operational Research 86(2), 201-215.

[96] H. Bohnenblust, P. Slovic, 1998. Integrating technical analysis and public values in risk-based decision making. Reliability Engineering & System Safety 59(1), 151-159.

[97] G. Purdy, 1993. Risk analysis of the transportation of dangerous goods by road and rail. Journal of Hazardous Materials, 33(2), 229-259.

[98] C. Revelle, J. Cohon, D. Shobrys, 1991. Simultaneous siting and routing in the disposal of hazardous wastes. Transportation Science 25(2), 138-145

[99] P. Blaikie, T. Cannon, I. Davis, 1994. At risk: natural hazards, people's vulnerability, and disasters. London, Routledge.

[100] W. Frank, J. Thill, R. Batta, 2000. Spatial decision support system for hazardous material truck routing. Transportation Research Part C - Emerging Technologies 8(1-6), 337-359.

[101] T. Chang, L. Nozick, M. Turnquist, 2005. Multi-objective path finding in stochastic dynamic networks, with application to routing hazardous materials shipments. Transportation Science 39(3), 383-399.

[102] J. Diaz-Banez, F. Gomez, G. Toussaint, 2005. Computing shortest paths for transportation of hazardous materials in continuous spaces. Journal Of Food Engineering 70(3), 293-298.

[103] A. Boulmakoul, 2006. Fuzzy graphs modelling for hazmat telegeomonitoring. European Journal of Operational Research 175(3), 1514-1525.

[104] M. Dell'Orco, 2006. A dynamic network loading model for meso-simulation in transportation systems. European Journal of Operational Research 175(3), 1447-1454.

[105] O. Berman, Z. Drezner, G. Wesolowsky, 2000. Routing and location on a network with hazardous threats. Journal of the Operational Research Society 51(9), 1093-1099.

[106] E. Erkut, V. Verter, 1995a. Framework for hazardous materials transport risk assessment. Risk Analysis 15(5), 589-601.

[107] E. Erkut, V. Verter, 1995b. Hazardous materials logistics. Facility location: A survey of applications and methods. In Z. Drezner (Eds) Ch. 20, New York.

[108] M. Abkowitz, P. Cheng, 1989. Hazardous materials transport risk estimation under conditions of limited data availability. Transportation Research Record 1245, 14-22.

[109] M. Abkowitz, J. DeLorenzo, R. Duych, A. Greenberg, T. McSweeney, 2001. Assessing the economic effect of incidents involving truck transport of hazardous materials. Transportation Research Record 1763, 125-129.

[110] M. Abkowitz, M. Lepofsky, P. Cheng, 1992. Selecting criteria for designating hazardous materials highway routes. Transportation Research Record 1333, 30-35.

[111] M.C.S. Administration, 2001. Comparative risks of hazardous materials and non-hazardous materials truck shipment accidents/incidents. Motor Carrier Safety Administration, Washington, DC.

[112] V. Akgün, E. Erkut, R. Batta, 2000. On finding dissimilar paths. European Journal of Operational Research 121(2), 232-246.

[113] E. Alp, 1995. Risk-based transportation-planning practice-overall methodology and a case example. INFOR 33(1), 4-19.

[114] R. Anderson, C. Barkan, 2004. Railroad accident rates for use in transportation risk analysis. Transportation Research Record 1863, 88-98.

[115] S. Andersson, 1994. Safe transport of dangerous goods- road, rail or sea- a screening of technical and administrative factors. European Journal of Operational Research 75(3), 499-507.

[116] S. Arya, 1999. Air pollution meteorology and dispersion. Oxford University Press.

[117] N. Arystanbekova, 2004. Application of Gaussian plume models for air pollution simulation at instantaneous emissions. Mathematics and Computers in Simulation 67(4-5), 451-458.

[118] B. Ashtakalaand, L. Eno, 1996. Minimum risk route model for hazardous materials. Journal of Transportation Engineering - ASCE 122(5), 350-357.

[119] A. Balakrishnan, T. Magnanti, P. Mirchandani, 1994. Modeling and heuristic worst-case performance analysis of the two-level network design problem. Management Science 40(7), 846-867.

[120] C. Barkan, C. Dick, R. Anderson, 2003. Railroad derailment factors affecting hazardous materials transportation risk. Transportation Research Record 1825, 64-74.

[121] R. Bellman, 1958. On a routing problem. Quarterly of Applied Mathematics 16, 87-90.

[122] G. Beroggi, 1994. A real-time routing model for hazardous materials. European Journal of Operational Research 75(3), 508-520.

[123] G. Beroggi, W. Wallace, 1994. Operational risk management - a new paradigm for decision -making. IEEE Transactions on Systems Man and Cybernetics 24(10), 1450-1457.
[124] G. Beroggi, W. Wallace, 1995. Operational control of the transportation of hazardous materials: An assessment of alternative decision models. Management Science 41(12), 1962-1977.
[125] B. Boffey, J. Karkazis, 1993. Models and methods for location and routing decisions relating to hazardous materials. Studies in locational analysis 4, 149-166.
[126] B. Boffey, J. Karkazis, 1995. Linear versus nonlinear models for hazardous materials routing. INFOR 33, 114-117.
[127] L. Bowler, H. Mahmassani, 1998. Routing of radioactive shipments in networks with timevarying costs and curfews. Technical Report ANRCP - 1998 - 11, Amarillo National Resource Center for Plutonium, TX (United States).
[128] R. Boykin, R. Freeman, R. Levary, 1984. Risk assessment in a chemical storage facility. Management Science 30(4), 512-517.
[129] R. Bubbico, C. Ferrari, B. Mazzotta, 2000. Risk analysis of LPG transport by road and rail. Journal of Loss Prevention in The Process Industries 13(1), 27-31.
[130] P. Cappanera, 1999. A survey on obnoxious facility location problems. University of Pisa Technical Report: TR - 99 - 11.
[131] G.A. Corea, V.G. Kulkarni, 1993. Shortest paths in stochastic networks with arc lengths having discrete distributions. Networks 23, 175-183.
[132] R. Cox, M. Turnquist, 1986. Scheduling truck shipments of hazardous materials in the presence of curfews. Transportation Research Record 1063, 21-26.
[133] S. Cutter, M. Ji, 1997. Trends in us hazardous materials transportation spills. Professional Geographer 49(3), 318-331.
[134] M. Dell'Amico, F. Maffioli, S. Martello, 1997. Annotated bibliographies in combinatorial optimization. Eds John Wiley and Sons, Chichester, 1997- 495 pp.
[135] C. Deng, S. Oberg, J. Downs, 1996. Risk assessment for transportation of radioactive material within the state of Idaho. Health Physics, 70(6).
[136] S. Dennis, S 1996. Estimating risk costs per unit of exposure for hazardous materials transported by rail. Logistics and Transportation Review 32(4), 351-375.
[137] C. Douligeris, E. Iakovou, L. Yudhbir, 1997. Maritime route risk analysis for hazardous materials transportation. Proceedings of the 8th IFAC/IFIP/IFORS Symposium on Transportation Systems Chania, Crete, Greece, 574-579.
[138] J. Duque, A. Barbosa-Pvoa, A. Novais, 2007. Synthesis and optimization of the recovery route for residual products under uncertain product demand. Computers & Operations Research 34(5), 1463-1490.
[139] R. Efroymson, D. Murphy, 2000. Ecological risk assessment of multimedia hazardous air pollutants: estimating exposure and effects. Science of the Total Environment 274, 219-230.
[140] E. Erkut, 1990. The discrete p-dispersion problem. European Journal of Operational Research 46, 48-60.
[141] E. Erkut, 1993. Inequality measures for location problems. Location Science, 1(3), 199-217.
[142] E. Erkut, 1995. On the credibility of the conditional risk model for routing hazardous materials. Operations Research Letters 18, 549-52.
[143] E. Erkut, 1996. The road not taken. OR/MS Today, 22-28.
[144] E. Erkut, S. Neuman, 1989. Analytical models for locating undesirable facilities. European Journal of Operational Research 40, 275-291.
[145] B. Fabiano, F. Curro, E. Palazzi, R. Pastorino, 2002. A framework for risk assessment and decision-making strategies in dangerous good transportation. Journal of Hazardous Materials 93(1), 1-15.
[146] H. Frank, 1969. Shortest paths in probabilistic graphs. Operations Research 17, 583-599.
[147] L. Fu, L. Rilett,1997. Real-time estimation of incident delay in dynamic and stochastic networks. Transportation Research Record 1603, National Research Council Washington DC.
[148] L. Fu, L. Rilett, 1998. Expected shortest paths in dynamic and stochastic traffic networks. Transportation Research Part B, 32(7), 499-516.
[149] M. Gendreau, G. Laporte, I. Parent, 2000. Heuristics for the location of inspection stations on a network. Naval Research Logistics 47(4), 287-303.
[150] A. Gheorghe, D. Vamanu, 2002. Integrated risk assessment and safety management; transportation of dangerous goods. International Journal of Risk Assessment and Management, 3(2-4), 99-112.
[151] I. Giannikos, 1998. A multi-objective programming model for locating treatment sites and routing hazardous wastes. European Journal of Operational Research 104(2), 333-342.
[152] T. Glickman, 1988. Benchmark estimates of release accident rates in hazardous materials transportation of rail and truck. Transportation Research Record 1193, 22-28.

[153] T. Glickman, 1991. An expeditious risk assessment of the highway transportation of flammable liquids in bulk. Transportation Science 25(2), 115-123.
[154] T. Glickman, M. Sontag, 1995. The tradeoffs associated with rerouting highway shipments of hazardous materials to minimize risk. Risk Analysis 15(1), 61-67.
[155] G.M. Sandquist, J.S. Bennion, J.E. Moore, D.M. Slaughter, 1993. A route-specific transportation risk assessment model. Transactions of the American Nuclear Society (ANS) annual meeting 20-24 Jun 1993; San Diego, CA (United States) l(68), 151-153.
[156] R. Gopalan, R. Batta, M. Karwan, 1990a. The equity constrained shortest path problem. Computers & Operations Research 17(3), 297-307.
[157] R. Gopalan, K. Kolluri, R. Batta, M. Karwan, 1990b. Modeling equity of risk in the transportation of hazardous materials. Operations Research 38(6), 961-975.
[158] W. Grenney, D. Stevens, W. Doucette, 1990. Decision support model for hazardous-waste application rates at land treatment systems. Civil Engineering Systems, 7(4), 219-228.
[159] L. Grenzeback, W. Reilly, P. Roberts, J. Stowers, 1990. Urban freeway gridlock study: decreasing the effects of large trucks on peak-period urban freeway congestion. Transportation Research Record 1256, 1626.
[160] P. Groothuis, G. Miller, 1997. The role of social distrust in risk-benefit analysis: a study of the siting of a hazardous waste disposal facility. Journal of Risk and Uncertainty 15(3), 241-257.
[161] T. Haas, J. Kichner, 1987. Hazardous materials in marine transportation-a practical course. Journal of Chemical Education 64(1), 34-35.
[162] R. Hall, 1986. The fastest path through a network with random time-dependent travel times. Transportation Science 20(3), 182-188.
[163] S. Hanna, J. Chang, D. Strimaitis, 1993. Hazardous gas model evaluation with field observations. Atmospheric Environment, 27A(15), 2265-2285.
[164] P. Hansen, 1980. Bi-criterion path problems. in: G. Fandel and T. Gal (eds.). Multiple criteria decision making: Theory and applications. Lecture notes in Economics and Mathematical Systems 177, Springer-Verlag, Berlin, 109-127.
[165] M. Helander, E. Melachrinoudis, 1997. Facility location and reliable route planning in hazardous material transportation. Transportation Science 31(3), 216-226.
[166] E. Henley, H. Kumamoto, 1981. Reliability engineering and risk assessment. Prentice Hall, Englewood Cliffs, New Jersey.
[167] E. Hillsman, 1988. Estimating population at risk from release of hazardous materials. Seminar on multipurpose land information systems: Application of information technology for natural resource planning, management, and monitoring. Univ. of Wisconsin Oct.24,1986, Inst. For Environmental Studies, Report, 32, 79-96.
[168] A. Hobeika, S. Kim, 1993. Databases and needs for risk assessment of hazardous materials shipments by trucks. in: Leon n. Moses (ed.). Transportation of Hazardous Materials.
[169] G. Hoffman, J. Janko, 1990. Travel times as a basic part of the LISB guidance strategy. Paper presented at the Third International Conference IEEE Road Traffic Control Conference 1-3 May 1990 London, UK, 6-10.
[170] K. Hollister, 2002. A risk/cost framework for logistics policy evaluation: hazardous wastemanagement. The Journal of Business and Economic Studies 8(1), 5165.
[171] R. Horman, 1987. Time/loss analysis. Technical Report EG and G Idaho, Inc., Idaho Falls, System Safety Development Center.
[172] D.C. Washington: World Bank. Hu, T., 1974. Optimum communication spanning trees. SIAM Journal on Computing 3(3), 188-195.
[173] S. Hwang, D. Brown, J.O. Steen, A. Policastro, W. Dunn, 2001. Risk assessment for national transportation of selected hazardous materials. Transportation Research Record 1763, 114-124.
[174] E. Iakovou, 2001. An interactive multi-objective model for the strategic maritime transportation of petroleum products: risk analysis and routing. Safety Science 39(1-2), 19-29.
[175] E. Iakovou, C. Douligeris, H. Li, C. Ip, L. Yudhbir, 1999. A maritime global route planning model for hazardous materials transportation. Transportation Science 33(1), 34-48.
[176] T, Jacobs, J. Warmerdam, 1994. Simultaneous routing and siting for hazardous-waste operations. Journal of Urban Planning and Development-ASCE 120(3), 115-131.
[177] H. Jin, R. Batta, 1997. Objectives derived from viewing hazmat shipments as a sequence of independent Bernoulli trials. Transportation Science 31(3), 252-261.
[178] H. Jin, R. Batta, M. Karwan, 1996. On the analysis of two new models for transporting hazardous materials. Operations Research 44(5), 710-723.
[179] A. Kimberly, H. Killmer, 2002. A risk/cost framework for logistics policy evaluation: Hazardous waste management. The Journal of Business and Economic Studies 8(1), 51-65.

[180] G. Kloeber, M. Cornell, T. McNamara, A. Moscati,1979. Risk assessment of air versus other transportation modes for explosives and flammable cryogenic liquids, volume 1: risk assessment method and results. Report No.DOT/RSPA/MTB-79/13, US DOT.
[181] H. Koutsopoulos, H. Xu, 1993. An information discounting routing strategy for advanced traveler information systems. Transportation Research Part C 1(3), 249-264.
[182] V. Kulkarni, 1986. Shortest paths in networks with exponentially distributed arc lengths. Networks 16, 255274.
[183] H. Kunreuther, D. Easterling, 1990. Are risk-benefit tradeoffs possible in siting hazardous facilities. American Economic Review 80(2), 252-256.
[184] D. LaFrance-Linden, S. Watson, M. Haines, 2001. Threat assessment of hazardous materials transportation in aircraft cargo compartments. Transportation Research Record 1763, 130-137.
[185] K.M. Larson, 1996. Hazmat on the rails: A closer look. Environmental Solutions 9(9), 36-42.
[186] S. Lassarre, K. Fedra, E. Weigkricht, 1993. Computer-assisted routing of dangerous goods for haute-normandie. Journal of Transportation Engineering, 119(2), 200-210.
[187] A. Lavell, 1996. Degradacion ambiental, riesgos urbanos y desastres. Ciudades en Riesgo. M.A. Fernandez. Peru, USAID 30.
[188] D. Leeming, F. Saccomanno, 1994. Use of quantified risk assessment in evaluating the risks of transporting chlorine by road and rail. Transportation Research Record 1430, 27-35.
[189] M. Lepofsky, M. Abkowitz, P. Cheng, 1993. Transportation hazard analysis in integrated Gis environment. Journal of Transportation Engineering-ASCE 119(2), 239-254.
[190] H. Levy, 1992. Stochastic dominance and expected utility: survey and analysis. Management Science 38(4), 555-593.
[191] H. Li, E. Iakovou, C. Douliger, 1996. A strategic planning model for marine oil transportation in the Gulf of Mexico. Transportation Research Record 1522, 108-115.
[192] L. Lindner-Dutton, R. Batta, M. Karwan, 1991. Equitable sequencing of a given set of hazardous materials shipments. Transportation Science 25, 124-137.
[193] G. List, P. Mirchandani, M. Turnquist, K. Zografos, 1991. Modeling and analysis for hazardous materials transportation-risk analysis, routing scheduling and facility location. Transportation Science 25(2), 100-114.
[194] G. List, M. Turnquist, 1998. Routing and emergency response team siting for high-level radioactive waste shipments. IEEE Transactions on Engineering Management 45(2), 141-152.
[195] G.F. List and M. Abkowitz, 1986. Estimates of current hazardous material flow patterns. Transportation Quarterly 40, 483-502.
[196] A. Lovett, J. Parfitt, J. Brainard, 1997. Using Gis in risk analysis: A case study of hazardous waste transport. Risk Analysis 17(5), 625-633.
[197] J. Luedtke, C. White, 2002. Hazmat transportation and security: survey and directions for future research. Department of Ind. & Sys. Engineering, Georgia Institute of Technology.
[198] D. Macgregor, P. Slovic, R. Mason, J. Detweiler, S. Binney, B. Dodd, 1994. Perceived risks of radioactive-waste transport through Oregon: results of a statewide survey. Risk Analysis 14(1), 5-14.
[199] O. Madsen, 1983. Methods for solving combined two level location-routing problems of realistic dimensions. European Journal of Operational Research 12(3), 295-301.
[200] T. Magnanti, R. Wong, 1984. Network design and transportation planning: models and algorithms. Transportation Science 18, 1-55.
[201] E. Mansilla, 2000. Riesgo y ciudad, la red.
[202] V. Marianov, C. Revelle, 1998. Linear, non-approximated models for optimal routing in hazardous environments. Journal of the Operational Research Society 49(2), 157-164.
[203] V. Marianov, C. Revelle, S. Shih, 2002. Anticoverage models for obnoxious material transportation. Environment and Planning B-Planning and Design 29(1), 141-150.
[204] H. Markowitz, 1987. Mean-variance analysis in portfolio choice and capital markets.
[205] R. Martinez-Alegria, C. Ordonez, J. Taboada, 2003. A conceptual model for analyzing the risks involved in the transportation of hazardous goods: Implementation in a geographic information system. Human And Ecological Risk Assessment 9(3), 857-873.
[206] T. McClure, L. Brentlinger, V. Drago, D. Kerr, 1988. Considerations in rail routing of radioactive materials. Technical Report, Office of Transport Systems and Planning, Battelle Memorial Institute, 505 King Ave, Columbus, OH 43201.
[207] M. McCord, A. Leu, 1995. Sensitivity of optimal hazmat routes to limited preference specification. INFOR 33(2), 68-83.
[208] S. McNeil, S. Oh, 1991. A note on the influence of rail defects on the risk associated with shipping hazardous materials by rail. Risk Analysis 11(2), 333-338.

[209] M. Milazzo, R. Lisi, G. Maschio, G. Antonioni, S. Bonvicini, G. Spadoni, 2002. Hazmat transport through, Messina town: from risk analysis suggestions for improving territorial safety. Journal of Loss Prevention in the Process Industries 15(5), 347-356.
[210] E. Miller-Hooks, 2001. Adaptive least-expected time paths in stochastic, time-varying transportation and data networks. Networks 37(1), 35-52.
[211] E. Miller-Hooks, H. Mahmassani, 1998. Optimal routing of hazardous materials in stochastic, time-varying transportation networks. Transportation Research Record. 1645, 143-151.
[212] E. Miller-Hooks, H. Mahmassani, 2000. Least expected time paths in stochastic, time-varying transportation networks. Transportation Science 34, 198-215.
[213] G. Mills, K. Neuhauser, 1998. Urban risks of truck transport of radioactive material. Risk Analysis 18(6), 781-785.
[214] H. Min, V. Jayaraman, R. Srivastava, 1998. Combined location-routing problems: A synthesis and future research directions. Operational Research 108(1), 1-15.
[215] P. Mirchandani, 1976. Shortest distance and reliability of probabilistic networks. Computers and Operations Research 3, 347-355.
[216] J. Morales, 1989. Analytical procedures for estimating freeway traffic congestion. TRB Research Circular 344, 38-46.
[217] T. Morin, R. Marsten, 1976. Branch-and-bound strategies for dynamic programming. Operations Research 24(4), 611-627.
[218] L.N. Moses, D. Lindstrom 1993. Transportation of Hazardous Materials: issues in Law, Social Science, and Engineering. Ed. Springer - Kluwer Academic Publishers.
[219] L. Nardini, L.,Aparicio, A. Bandoni, S. Tonelli, 2003. Regional risk associated with the transport of hazardous materials. Latin American Applied Research 33(3), 213-218.
[220] D. Nembhard, C. White, 1997. Applications of non-order-preserving path selection to hazmat routing. Transportation Science 31(3), 262-271.
[221] S. Nguyen, S. Pallottino, 1986. Hyperpaths and shortest hyperpaths. combinatorial optimization. Lecture notes in Mathematics 1403, 258-271.
[222] L. Nozick, G. List, M. Turnquist, 1997. Integrated routing and scheduling in hazardous materials transportation. Transportation Science 31(3), 200-215.
[223] W. Ogryczak, A. Ruszczynski, 2002. Dual stochastic dominance and related mean-risk models. SIAM Journal on Optimization 13(1), 60-78.
[224] M. Orr, W. Kaye, P. Zeitz, M. Powers, L. Rosenthal, 2001. Public health risks of railroad hazardous substance emergency events. Journal of Occupational and Environmental Medicine 43(9), 738-739.
[225] F. Pasquill, F. Smith, 1983. Atmospheric diffusion. Third edition, Ellis Horwood Series in Environmental Science.
[226] M. Patel, A. Horowitz, 1994. Optimal routing of hazardous materials considering risk of spill. Transportation Research Part A - Policy and Practice 28(2), 119-132.
[227] J. Pawlow, 1985. Liability for shipments by sea of hazardous and noxious substances. Law and Policy in International Business 17(2)(1985, 458-459.
[228] J. Pet-Armacost, J. Sepulveda, M. Sakude, 1999. Monte Carlo sensitivity analysis of unknown parameters in hazardous materials transportation risk assessment. Risk Analysis 19(6), 1173-1184.
[229] J. Pine, B. Marx, 1997. Utilizing state hazardous materials transportation data in hazardous analysis. Journal of Hazardous Materials 54(1-2), 113-122.
[230] E. Puliafito, M. Guevara, C. Puliafito, 2003. Characterization of urban air quality using Gis as a management system. Environmental Pollution 122, 105-117.
[231] P. Raj, E. Pritchard, 2000. Hazardous materials transportation on us railroads: application of risk analysis methods to decision making in development of regulations. Transportation Research Record 1707, 22-26.
[232] W. Rhyne, 1994. Hazardous materials transportation risk analysis. Van Nostrand Reinhold, Publishers.
[233] D. Roeleven, M. Kok, H.I. Stipdonk, W. DeVries, 1995. Inland waterway transport modeling the probability of accidents. Safety Science 19(2-3), 191-202.
[234] H. Romer P. Haastrup H.J.S. Petersen 1995. Accidents during marine transport of dangerous goodsdistribution of fatalities. Journal of Loss Prevention in the Process Industries, 8(1), 29-34.
[235] N. Rosmuller, P.V. Gelder, 2003. Hazardous materials release analysis: probabilistic input for emergency response organizations. In: Bedford & Van Gelder (Eds, Safety and Reliability.
[236] F. Saccomanno, S. El-Hage, 1989. Minimizing derailments of railcars carrying dangerous commodities through effective marshaling strategies. Transportation Research Record 1245, 34-51.
[237] F. Saccomanno, S. Elhage, 1991. Establishing derailment profiles by position for corridor shipments of dangerous goods. Canadian Journal of Civil Engineering 18(1), 67-75.
[238] F. Saccomanno, P. Haastrup, 2002. Influence of safety measures on the risks of transporting dangerous goods through road tunnels. Risk Analysis 22(6), 1059-1069.

[239] F. Saccomanno, J. Shortreed, M. Van Aerde, J. Higgs, 1989. Comparison of risk measures for the transport of dangerous commodities by truck and rail. Transportation Research Record 1245, 1-13.
[240] R. Séguin, J.Y. Potvin, M. Gendreau, T.G. Crainic, P. Marcotte, 1997. Real-time decision problems: an operational research perspective. Journal of the Operational Research Society 48(2), 162-174.
[241] H.D. Sherali, L.D. Brizendine, T.S. Glickman., S. Subramanian, 1997. Low-probability high-consequence considerations in routing hazardous materials shipments. Transportation Science 31(3), 237-251.
[242] K. Sissell, 1995. Defining risk assessment. Chemical Week.
[243] R.A. Sivakumar, R. Batta, M.H. Karwan, 1993. A network-based model for transporting extremely hazardous materials. Operations Research Letters 13(2), 85-93.
[244] R.A. Sivakumar, R. Batta, M.H. Karwan, 1995. A multiple route conditional risk model for transporting hazardous materials. INFOR 33(1), 20-33.
[245] G. Spadoni, P. Leonelli, P. Verlicchi, R. Fiore, 1995. A numerical procedure for assessing risks from road transport of dangerous substances. Journal of Loss Prevention in the Process Industries 8(4), 245-252.
[246] C. Stowers, U. Palekar, 1993. Location models with routing considerations for a single obnoxious facility. Transportation Science 27(4), 350-362.
[247] G. Sulijoadikusumo, L. Nozick, 1998. Multiobjective routing and scheduling of hazardous materials shipments. Transportation Research Record 1613, 96-104.
[248] C. Swoveland, 1987. Risk analysis of regulatory options for the transport of dangerous commodities by rail. Interfaces 17(4), 90-107.
[249] G.K. Tayi, D.J. Rosenkrantz, S.S. Ravi, 1999. Path problems in networks with vector-valued edge weights. Networks 34(1), 19-35.
[250] TRB, 1993. Hazardous materials shipment information for emergency response. Transportation Research Board, Special Report 239.
[251] M. Turnquist, 1993. Multiple objectives, uncertainty and routing decisions for hazardous materials shipments. Proceedings of the 5th International Conference on Computing in Civil and Building Engineering ASCE, New York, NY, 357-364.
[252] U. D., 1994. Guidelines for applying criteria to designate routes for transporting hazardous materials. U.S. department of transportation. Report No. FHWA-SA-94-083, Federal Highway Administration, Washington DC.
[253] U. D., 1998. Hazardous materials shipments. Office of Hazardous Materials Safety, Research and Special Programs Administration, U.S. Department of Transportation, Washington DC.
[254] U. D., 2003 Summary of hazardous materials transportation incidents. Research and Special Programs Administration, Office of Hazardous Materials Safety, U.S. Department of Transportation, Washington, DC.
[255] UN, 2001. Un recommendation on the transport of dangerous goods, model regulations, United Nations Economic and Social Council's Committee of Experts on the Transport of Dangerous Goods.
[256] J. Vansteen, 1987. A methodology for aiding hazardous materials transportation decisions. European Journal of Operational Research 32(2), 231-244.
[257] V. Verter, E. Erkut, 1995. Hazardous materials logistics: an annotated bibliography, in: Alain Haurie and Carlo Carraro (eds.). Operations Research and Environmental Management.
[258] V. Verter, E. Erkut, 1997. Incorporating insurance costs in hazardous materials routing models. Transportation Science 31(3), 227-236.
[259] V. Verter, B. Kara, 2001. A gis-based framework for hazardous materials transport risk assessment. Risk Analysis 21(6), 1109-1120.
[260] E. Weigkricht, K. Fedra,1995. Decision-support systems for dangerous goods transportation. INFOR 33(2), 84-99.
[261] A.B. Wijeratne, A.B. Turnquist, P.B. Mirchandani, 1993. Multi-objective routing of hazardous materials in stochastic networks. European Journal of Operational Research 65, 33-43.
[262] S. Yitzhaki, 1982. Stochastic Dominance, Mean Variance, and Gini's Mean Difference. The American Economic Review 72, 178-185.
[263] J. Zhang, E. Erkut, J. Hodgson, 2000). Using GIS to Assess the Risks of Hazardous Materials Transport on Networks. European Journal of Operational Research, 121(2), 316-329.
[264] K. Zografos, K. Androutsopoulos, 2002. Heuristic algorithms for solving hazardous materials logistical problems. Transportation Research Record 1783, 158-166.
[265] K. Zografos, C. Davis,1989. Multi-objective programming approach for routing hazardousmaterials. Journal of Transportation Engineering 115, 661-673.
[266] K Zografos, S. Samara, 1989. A combined location-routing model for hazardous waste transportation and disposal. Transportation Research Record 1245, 52-59.

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Hazardous Materials Transportation by Road: Trends and Problems in Risk Assessment and Emergency Planning

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Abstract. Hazardous material transportation poses obvious hazards to environment, general public and response personnel. In this context, risk reduction can be achieved by analyzing and designing correctly the routing of shipments, by proper risk assessment procedure. HazMat transportation risk management must include appropriate emergency response services, limiting accident consequences. This paper presents a quantitative risk assessment approach to HazMat transportation, starting from an historical statistical analysis on road accidents. A methodological approach for the assessment of standard vehicle and dangerous good truck flows was applied to a pilot area in the North of Italy, allowing a statistical reinforced evaluation of route intrinsic enhancing/mitigating parameters. The results evidence the distribution of the risk along the different routes and the localization of high spots, with good accuracy and precision. Preventive and mitigating risk measures are discussed in depth, with particular reference to the optimization of emergency equipment (number of prompt action vehicles) by means of an unambiguous and consistent selection criterion that allows reduction of intervention time. Different risk mitigation options, based on changing route or designing alternative slip roads, in transport corridors or tunnels, are investigated as well. The presented approach can represent a useful tool not only to estimate transport risk, but also to define strategies for the reduction of risk (i.e. distribution and limitation of ADR road traffic, improvement of highway section, design of alternative routes) and emergency management.

Keywords. accident scenario; emergency optimization; road accident statistics; road tunnel; transportation of dangerous substance

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Introduction

As all physical human activities, the transportation of hazardous goods, either to industrial facilities or to end-users, bears risks to human health and human life. By the way, notwithstanding the relative recent move towards "inherent safe" materials, the relentless drive of consumerism requires increased quantities of dangerous goods to be manufactured, transported, stored and used year on year [1]. A convenient definition of hazardous material is to regard such substance as one requiring special care to prevent harm from it (to man, environment and/or property), usually from an accident, or an unwanted event. Regulations connected to hazardous material safety generally consists of four issues, namely: hazard assessment of materials on the basis of identified risks; hazard communication by proper labeling, documentation etc.; technical and operative controls, such as specifications of tanks, trucks, compatibility, quantity limitations, exposure limits, safety training; administrative procedures.

HazMat road transportation presents a very different risk than a fixed facility: detailed information on shipments is not available on a national, regional, or local level in contrast with fixed facility inventories [2], while the transportation activity creates opportunities for the materials to be accidentally released into the environment, due to traffic accidents, equipment failures and human error. The safety and efficiency of road transport is to be considered a strategic goal in particular in those countries, like Italy, in which about 80% of goods is transported by this means with a 30% increase with reference to the 2020 forecast. Dealing with transportation risk analysis different types of study can be performed, namely:

- route selection (addressing the safest itinerary for transport);
- mode selection (focused on the modality of transport: truck, rail, pipeline, intermodal);
- facility location (addressing the best location of a new plant or warehouse).

Risk reduction in the context of HazMat transportation can be achieved by analyzing the routing of shipments through a risk assessment procedure. Several researchers have faced this issue, studying hazardous materials routing from a theoretical viewpoint, including [3], [4],[5],[6]. Applicative studies on highway best-routing were presented by [7] and [8]. Usually, a simplified risk measure consisting of the product of the accident likelihood by the number of affected people is used when routing hazardous goods, however, there is no consensus on the procedure to quantify risk in planning HazMat transportation [9].

Poor appreciation of factors related to road conditions, such as road class, designated speed limits, traffic density, as well as of the population characteristics, is likely to result in a risk assessment insensitive to route specifics and over- or under-estimating the overall level of risk [10]. The methodology presented in this paper is intended to shed light on this issue, discussing a site-oriented framework of general applicability. In fact, it was chosen to develop a high level of detail in the frequency model, by considering in-depth the traffic accident environment; a "cautious best estimate" approach was employed adopting either realistic, on-site detected assumptions, or conservative hypotheses.

Policy and risk related decision-makers could benefit from the present research, in that they can better support design or road management options at local level by means of the proposed methodology. The reminder of this paper is structured as follows. We first provide a background section including a critical overview on risk analysis and its weaknesses and a statistical analysis on road accidents. We then present a model specification section and a result section, based on the developed methodology. A discussion section includes directions for risk mitigation and emergency planning. Conclusions are drawn about the approach application to societal risk evaluation in the HazMat transportation sector, routing optimization and related emergency response aspects.

1. Background

1.1 Road transportation risk analysis

Generally speaking, risk can be defined according to a number of definitions, i.e.

- risk is a combination of uncertainty and damage;
- risk is a ratio of hazards to safeguards;
- risk is a triplet combination of event, probability and consequences [11];
- risk is a measure of economic loss or human injury in terms of both incident likelihood and the magnitudo of the loss or injury [12].

Some risk measures are derived from those commonly adopted in evaluating fixed process and chemical plants and include: individual risk, presented on an iso-risk contour plot; maximum individual risk; average individual risk of exposed people; average individual risk of total population; societal risk presented via a frequency-number curve. Other risk measures are strictly connected to the transportation risk analysis and include: risk of accident per ton and km transported; risk of death or damage per ton and km transported; risk of accident per ton transported; risk of death or damage per ton transported; risk of accident per transport trip; risk of death or damage to the public per ton transported or per transport trip.

However, we must notice that different factors can severely affect the results of a QRA study, namely affecting the frequency and the consequence assessment. Table 1 summarizes the qualitative results obtained by [13], expressed in term of increased importance from one to five stars.

Table 1. Qualitative assessment of the importance of various factors to the uncertainty in quantitative risk calculation.

Factor	**Importance**
Differences in the qualitative analysis	**
Factors affecting frequency assessment	
Frequency assessments of pipeline failures	***
Frequency assessments of loading arm failures	****
Frequency assessments of pressurised tank failures	****
Frequency assessments of cryogenic tank failures	***
Factors affecting consequence assessment	
Definition of the scenario	*****
Modelling of release rate from long pipeline	***
Modelling of release rate from short pipeline	*
Release time (i.e. operator or shut-down system reaction time)	***
Choice of light, neutral or heavy gas model for dispersion	****
Differences in dispersion calculation codes	***
"Analyst conservatism" or judgment	***

Table 2. Hazardous substance loss of containment effect calculations with various models [14]

Scenario	**Variable calculated**	**EFFECTS 4**	**PHAST**	**GASP**	**EFFECTS 5.5**	**Mean value**	**Standard deviation**
Toluene confined pool	Max evaporation rate, [kg s^{-1}]	0.21	0.15	0.11	0.21	0.17	0.05
Toluene unconfined pool	Max evaporation rate [kg s^{-1}]	3.5	1.2	1.1	3.5	2.33	1.36
	Max pool area [m^2]	2005	995	1042	2000	1510.50	568.44
LNG on water	Max evaporation [kg s^{-1}]	166	197-273	32-147	Avg. 169.5	164.08	78.38
	Max. pool area [m^2]	387	1451-1520	804-1256	385	967.17	514.84
Scenario	**Variable calculated**	**STERAD**	**PHAST**	**Int-HSE**	**EFFECTS 5.5**	**Mean value**	**Standard deviation**
Two-phase jet fire	Surface Emissive Power [kWm $^{-2}$]	230	151	184	81	161.50	62.69

Another category causing spread is consequence modeling (release rates, evaporation, dispersion and the probit damage models). Outcomes of pure physical models of release, vaporisation and dispersion can differ, with at least a factor 2. As typical example, a part of the simulation results is reproduced in Table 2 [14].

Summarising: choices, complexity, available computing time, limited knowledge and experience will contribute all to unavoidable spread. It will be clear that in case of land use planning, for new road design or licensing, the disagreement in model outcomes will cause much debate and friction amongst planners from both private and public parties.

1.2 Accident Statistics

A detailed survey on accidents occurring during the transport of dangerous goods by road and rail was performed by [15], starting from 1932 accidents recorded in the MHIDAS database. A gradual increase in the number of accidents was observed, with a significant rise in the period 1981-2000. As for the kind of land traffic, 37% of accidents occurred on railways and 67% on roads. The analysis showed that releases are the most common type of accident, appearing in 78% of cases, followed by fires in 28%, explosions in 14% and gas clouds in only 6%. As each accident may belong to one or more of the four basic incident categories, the sum exceeds 100%.

In order to validate the previously presented findings, we analyzed in depth, by standard statistical methods, transportation events in a database from TNO (2007), globally holding information on 2586 accidents from the year 1896 to nowadays.

We identified and grouped road accidents according the four basic categories reported in the following, each, with the corresponding percentage on the overall number of accidents: release (70.7%), fire (23.9%), explosion (11.1%) and BLEVE (0.8%). Again, each unwanted event may belong to one or more categories. We can observe that release and fire and explosion events show a similar percentage incidence in the two statistical analyses performed.

If we take a look at the distribution of the accidents over the time (Figure 1), we can found a significant increase in the number of accidents occurred in road transportation from the Sixties onwards. This trend is consistent with the frequency variation of accidents recorded by different authors, for chemical and process plants, as well as for different kinds of hazardous material transportation. The striking increase recorded from 1978 to nowadays can be reasonable connected to the increase of land transportation and to the wider information on accidents available in the different countries.

As shown in Figure 2, the number of fatalities, as a consequence of road transportation accidents, was grouped in categories (1-3, 4-10, 11-50, etc.). Globally, a considerable percentage of accidents (14.85%) can be categorized as high profile events, causing a minimum of one death.

As we limited the statistical analysis to road accidents, the location was investigated making reference to the specific kind of way (Figure 3). The most frequent category corresponds to highway/road (83.2%), followed by level crossing and internal moving lanes. We should notice that, even if tunnel location is characterized by a low percentage (1.0%), this category includes several high severity accidents in terms of fatalities. Table 3 summarizes high severity accidents in road tunnel from 1940 [16].

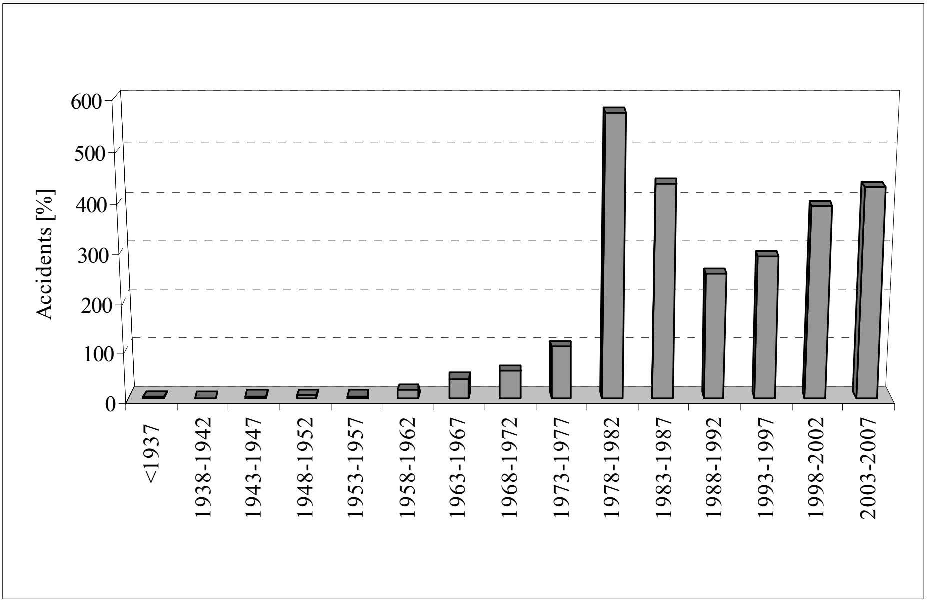

Figure 1. Trend of accidents occurred in road-transportation from 1896 to 2007.

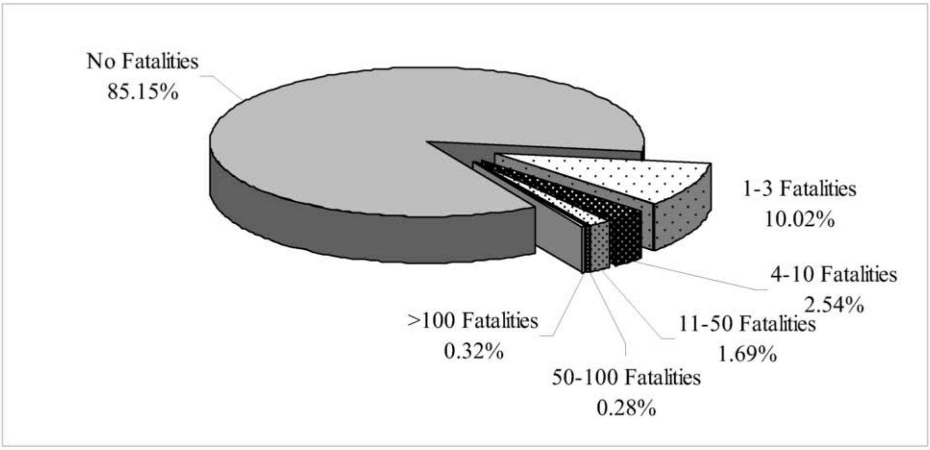

Figure 2. Consequences of accidents occurred in road-transport.

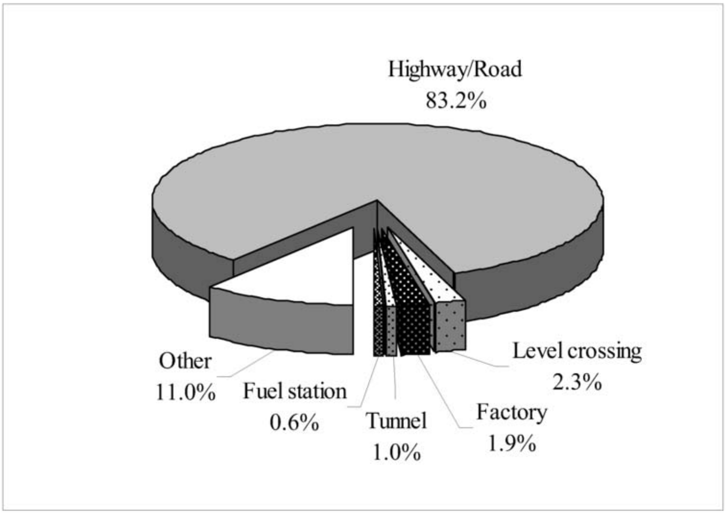

Figure 3. Location of accidents occurred in road-transport.

Key learning points from tunnel accidents can be connected to the following topics: design and operational aspects; hazard management; safety management systems and emergency response. Taking a look to road tunnel severe accidents, we must notice that the higher percentage was associated to fire scenarios, while collision was the immediate cause in a limited number of them. Heavy good vehicles are involved in a high percentage of accidents, especially if connected to the low proportion of this vehicle, compared to the light vehicles one. The most immediate threat to human health and life in accidental tunnel fire is connected to the effects of smoke inhalation, rather than to direct exposure to heat from fire. Several complex mathematical models and time consuming Computational Fluid Dynamics techniques were adopted to study the rise, deflection and spread of fire smoke.

A key factor associated with tunnel accident is represented by the emergency procedures for responding to incidents (including fire) and the adequacy of staff training for dealing with emergency situations.

From Table 3, it can be inferred that tunnel length represent an intrinsic hazard factor, even if other parameters would need investigation, e.g. height gradient along the tunnel.

Table 3. High severity accidents in road tunnel from 1940

Year	Tunnel	Length (m)	Fatalities	Injured people	Vehicle	Immediate accident cause
1949	Holland USA	2250		66	23	Load loss
1978	Velsen The Netherlands	770	5	5	6	Collision
1979	Nihonzaka Japan	1045	7	2	173	Collision
1980	Sakai Japan	459	5	5	10	Collision
1982	Caldecott USA	1028	7	2	8	Collision
1983	Pecorile Italy	600	8	22	10	Collision
1986	L'Armé France	1105	3	5	5	Collision
1987	Gumefens Svizzera	340	2		3	Collision
1993	Serra Ripoli Italy	442	4	4	16	Collision
1994	Hugouenot Sud Africa	6111	31	28	1	Pullman engine failure
1995	Pfaender Germany	6719	53	4	4	Collision
1996	I.Femmine Italy	148	5	10	20	Collision
1999	M. Bianco Italy	11600	39		26	Fire after a leak
1999	Tauren Austria	6400	12		40	Collision
2003	Vicenza Italy		6	50		Roll over

2. Methodology

The model is focused on a proper evaluation of the expected accident frequency. If the route is divided into road stretches, the expected number of fatalities, as consequence of an accident occurred on the road stretch r and evolving according to a scenario S, can be expressed as:

$$D_r = \sum_S f_r N_{r,S} P_S \tag{1}$$

where:

f_r = frequency of accident in the r-th road stretch, accident·year^{-1}

$N_{r,S}$ = number of fatalities caused by the accident evolving according to a scenario S in the r-th road stretch, fatalities accident^{-1}

P_S = probability of evolving scenarios of type S, following the accident initialiser (i.e. collision; roll-over; failure etc.).

Transportation network can be considered as a number of vertices, linked each other by a number of arcs. The vertices represent origin-destination points, tool-gates, storage areas on the transportation network and the arcs are the roads connecting vertices. An arc between two vertices is characterized by a different number of road stretches and the expected number of fatalities for the arc is:

$$D = \sum_{r}\sum_{S} f_r N_{r,S} P_S \tag{2}$$

where $N_{r,S}$ is the total number of fatalities according to eq. (3):

$$N_{r,S} = (A_S^{in} \cdot k \cdot v + A_S^{off} \cdot d_P) \cdot P_{F,S} \tag{3}$$

being the in-road and the off-road number of fatalities calculated respectively as:

$$N^{in}{}_{r,S} = A_S^{in} \cdot k \cdot v \cdot P_{F,S} \tag{4}$$

$$N^{off}{}_{r,S} = A_S^{off} \cdot d_P \cdot P_{F,S} \tag{5}$$

where:

A_S^{in} = consequence in-road area associated with scenario *S,* m^2
A_S^{off} = consequence off-road area associated with scenario *S*, km^2
$P_{F,S}$ = probability of fatality for accident scenario *S,* -
k = average vehicle occupation factor, -
v = vehicle density on the road area, vehicle·m^{-2}
d_P = population density, inhabitants,·km^{-2}

The frequency of an accident involving a scenario *S*, on the *r*-th road stretch, can be expressed as:

$$f_{r,S} = f_r \cdot P_S \tag{6}$$

$$f_r = \gamma_r L_r n_r \tag{7}$$

$$\gamma_i = \gamma_0 \prod_{j=1}^{6} h_j \tag{8}$$

where:

γ_r = expected frequency on *r*-th road stretch, accident·km^{-1}·$vehicle^{-1}$
L_r = road length, km
n_r = number of vehicles, vehicle·$year^{-1}$
$\gamma_{0,r}$ = national accident frequency, accident·km^{-1}·$vehicle^{-1}$
h_j = local enhancing/mitigating parameters, -

When considering the different concurrent scenarios *y* and *j* (i.e. toxic release and delayed ignition), in order to avoid overestimation, the total lethal area will be considered as:

$$A_{L,t}=A_y+A_j-[A_y \cap A_j] \tag{9}$$

As reported by different researchers, various factors influence the accidents: mechanical, environmental, behavioral, physical, road intrinsic descriptors. Making reference to intrinsic road factors, meteorological and traffic factors, a statistical multivariate analysis was performed, by comparing historical accident data related to the whole regional highways and data directly collected in the field on each road arc [17].

Table 4. Local enhancing and mitigating parameters.

Parameter		
INTRINSIC CHARACTERISTICS	h_1	Straight road
		Road bend (radius > 200m)
		Road bend (radius < 200m)
	h_2	Plane road
		Slope road (gradient < 5%)
		Steep slope road (gradient > 5%)
		Downhill road (gradient < 5%)
		Steep downhill road (gradient > 5%)
	h_3	Two lanes for each carriageway
		Two lanes and emergency lane for each carriageway
		Three lanes and emergency lane for each carriageway
	h_4	Well lighted straight tunnel
		Other tunnels
		Bridge
METEOR. COND.	h_5	Fine weather
		Rain
		Heavy rain
		Fog
		Snow/ice
TRAFFIC CHARACT.	h_6	Low intensity < 500 vehicle/h
		Medium intensity <1250 vehicle/h with heavy traffic <125 truck/day
		High intensity > 1250 vehicle/h
		High intensity > 1250 vehicle/h with heavy traffic > 250 truck/day

A significative ($P<0.05$) degree of correlation was highlighted making reference to following parameters: geometrical characteristics; carriageway type; traffic intensity and heavy good truck proportion; meteorological conditions. The number of accidents verified in tunnel or road bridge was rather limited, allowing to obtain numerical results which would need further investigation. It is however clear that these findings are to be considered more from the qualitative viewpoint, as well as that the results of risk modeling would be considered for the comparison of different alternatives, rather than in their absolute values.

The values of the parameters, shown in Table 4 and grouped into three categories (road intrinsic, meteorological and traffic), are in the range 0.8-2.5 [17].

3. Results

It is clear that a realistic evaluation of the accident frequency γ is to be considered an essential step in the risk assessment. As an example, an evaluation at a national level, making reference to ISTAT (National Institute of Statistics) and AISCAT (Association of Concessionary Companies for Motorways and Tunnels), referred to the year 2006 allows evaluating an overall truck accident frequency corresponding to $1.36 \cdot 10^{-7}$ accident vehicle^{-1} km^{-1} and the light vehicle accident frequency as $1.71 \cdot 10^{-7}$ accident vehicle^{-1} km^{-1}. From the same statistical sources, it can be derived the frequency of truck accidents involving damage to man (injured person or fatalities): $1.07 \cdot 10^{-7}$ accident vehicle^{-1} km^{-1}.

When dealing with a particular route, a realistic evaluation of the frequency must take into account on one side inherent factors (such as tunnels, rail bridges, height gradient, bend radii, slope, characteristics of neighborhood, meteorological conditions), on the other side factors correlated to the traffic conditions (traffic frequency of tank truck, dangerous goods trucks etc), suitable modifying the national or regional accident frequency.

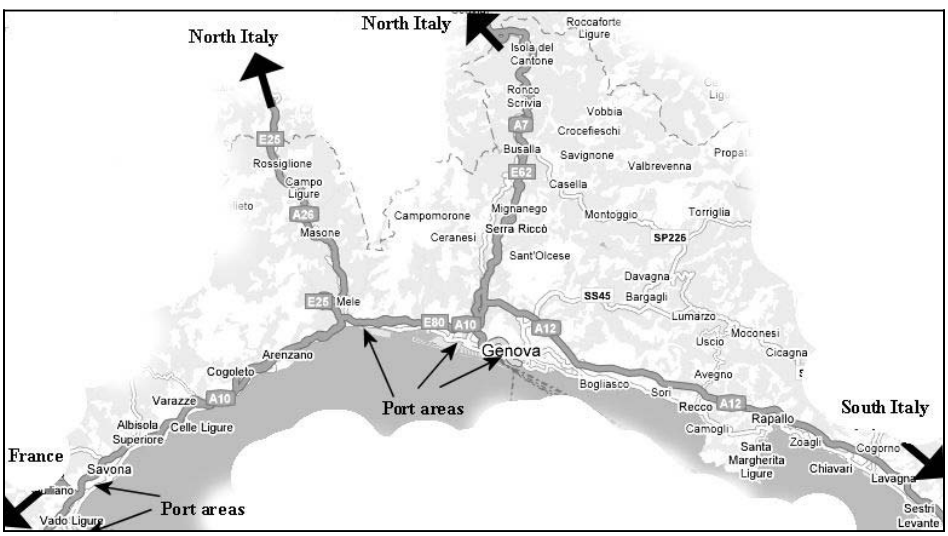

Figure 4. Pilot area

The methodology previously presented was applied to a pilot area (Figure 4), referred to the routes starting from the Genoa port area (the most important in the Mediterranean basin) towards four direction: the industrialized North Italian and Central Europe districts (Highway A26 and A7), France (A10) and South of Italy (A12). All of these highways are characterized by high truck traffic (mainly ADR) and inherent factors (such as out-of-date road construction: the year of construction of A7 is 1935) determining to a major accident risk, with reference to both individual and social risk, defined according to the Dutch limits. Historical frequencies, calculated for each highway stretch of the most hazardous highway (A7), are reported in Table 5. If compared with the historical accidents, it can be noticed that A7 highway is characterized by values similar to those for urban road and higher at least an order of magnitude than the accident frequency calculated by other researchers for certain type of load threatening accidents [18], ($6.0 \cdot 10^{-8}$ accident vehicle^{-1} km^{-1}). The results can be ascribed to the already-mentioned particular characteristics of the highway, with intrinsic hazard factors also due to its old construction time (1935).

Table 5. Accident frequency on the highway A7

Highway stretch	**Length (km)**	**Accident frequency (accident vehicle^{-1} km^{-1})**
Genova Ovest-Connection A7/A10	1.9	$8.63 \cdot 10^{-7}$
Connection.A7/A10 – Connection A7/A12	3	$4.04 \cdot 10^{-7}$
Connection A7/A12 – Bolzaneto	2.9	$6.47 \cdot 10^{-7}$
Bolzaneto – Busalla	14.3	$6.56 \cdot 10^{-7}$
Busalla – Ronco Scrivia	5	$13.4 \cdot 10^{-7}$
Ronco Scrivia – Isola del Cantone	5.8	$7.45 \cdot 10^{-7}$
Isola del Cantone – Piemonte	6.6	4.56·10-7

Table 6. Average speed on A7 highway, for the different vehicle categories

Highway stretch	**Average speed (km·h^{-1})**		
	Car	**Truck**	**Total**
Genova Ovest-Connection A7/A10	84	67	83
Connection.A7/A10 – Connection A7/A12	80	64	78
Connection A7/A12 – Bolzaneto	77	62	75
Bolzaneto – Busalla	80	64	77
Busalla – Ronco Scrivia	80	64	77
Ronco Scrivia – Isola del Cantone	80	64	77
Isola del Cantone – Piemonte	80	64	77
Connection A10/A7 – Connection A10/A26	70	60	67
Connection A10/A26 – Savona	94	74	88
Connection A12/A7 – Sestri Levante	92	68	82

As reported in Table 6, this assumption is confirmed by the average speed calculated for the different highway stretches and vehicle type, making reference to the statistics obtained from Italian Highway S.p.A.

Temporal accident distributions are important to specify appropriate meteorology determining the release evolution. In transportation risk assessment, temporal variables influence the population at risk too, as population density can appreciably change throughout the day. We investigated only one temporal variable associated to the transportation activities, namely hours of the day. The effective hour of an accident can be critical in connection with the diurnal cycle of the atmospheric boundary layer and the release evolution, for a given source term.

The statistical distribution of the accidents during the hours of the day, as resulting from on-site survey performed in cooperation with the Road Policy of Genoa district, over a span of one year, is reproduced in Figure 5.

In order to verify the existence of a correlation between accident and heavy traffic/hazardous materials transport (ADR), a statistic elaboration over the same time span was carried out, considering as well the results reproduced in Figure 6.

The study of the month of the year can be important in situation, such as this case study highway, due to climatologic effects on temperature and wind speed, which affect both the source term due to an accident and the subsequent dispersion phase. Instead, the effect on the daytime mixing height exerts its influence only on the dispersion phase of the release.

By considering the daily ADR traffic on the different highway sections, it results that the higher values of dangerous goods fluxes correspond to the intersection between the highways A10 (West Riviera) and A12 (East Riviera), in the stretch between the towns of Bolzaneto and Busalla and in the starting stretch, from the central port of Genoa (Genova Ovest tollgate) to the connection between the highways A10 and A7. Globally, the most hazardous highway (A7) can be divided into 22.63 km of straight stretch ; 9.33 km of tunnels and 7.54 km of bends.

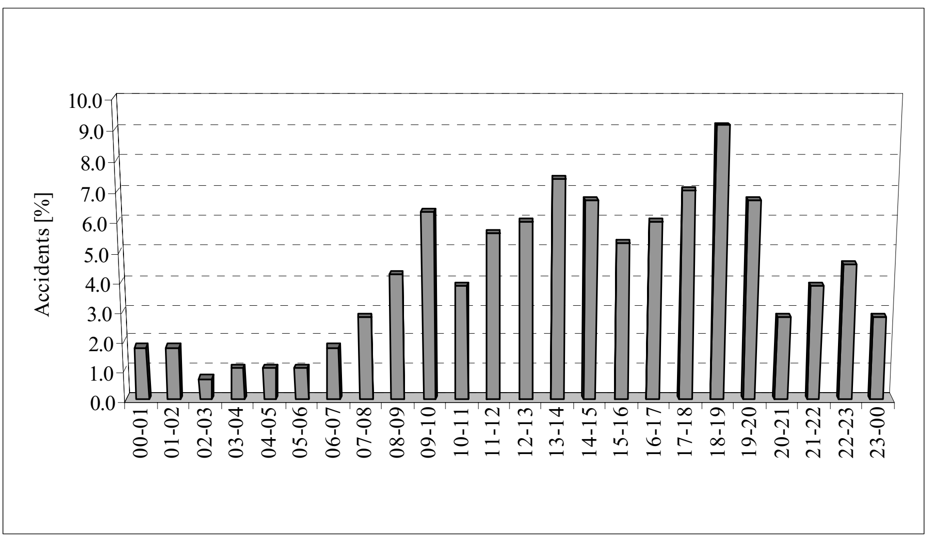

Figure 5. Accident hourly distribution on A7 highway Genova-Serravalle.

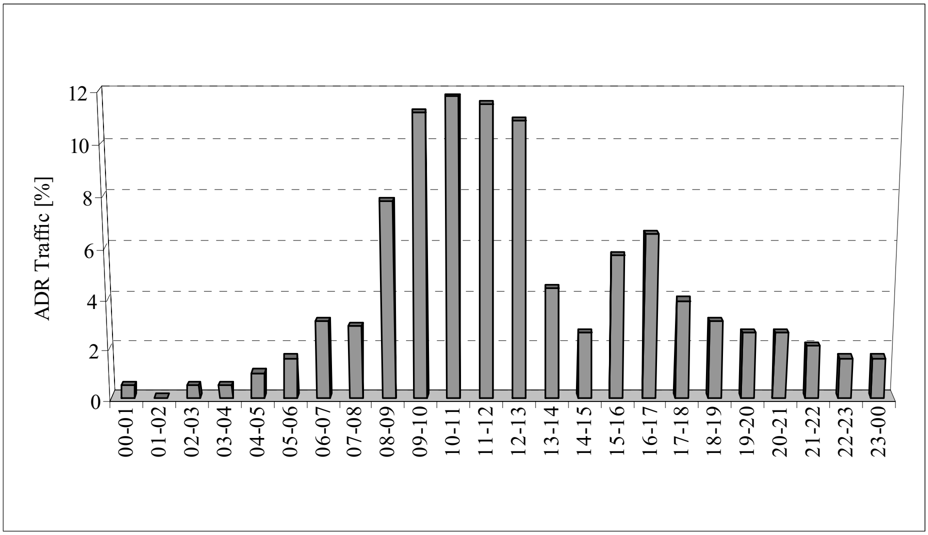

Figure 6. Percentage daily distribution of heavy traffic (ADR) on A7 highway.

As a basis of comparison, the number of accidents in Liguria for the different vehicle categories was obtained by elaborating ISTAT statistics, as follows: motorcycles: 1883; cars: 6459 trucks: 570; other: 185.

The proportion of severe accidents on A7 highway North during the years 1996-2005 is in the range 28%-41% of the total accidents, defining a severe incident as one involving death, serious injuries, a fire or explosion, or more than Euro 25.000 worth of damage. This definition is rather conservative, in fact, strictly speaking, and referring to HazMat transportation activities, the current definition of serious accident is [19]:

- a fatality or major injury caused by a release of a hazardous material;
- the evacuation of 25 or more persons, as a result of a release or exposure to fire;
- a release or exposure to fire which results in the closure of a major transportation artery;
- the release of a bulk quantity (over 450 liters or 0.4 Mg) of a hazardous material.

By elaborating the data collected on the field, over an observation time of one year, the immediate causes of the accidents on the highway A7 North, can be grouped as reported in Figure 7, in comparison with national data.

As previously remarked, both the immediate causes and the underlying causes of accidents can be connected to mechanical, environmental, behavioral, physical, or intrinsic factors.

The main points of interest resulting from Figure 7 are the high proportion of incidents due to speed, corresponding to 40.3% and the proportion due to drive errors equal to 21.7%.

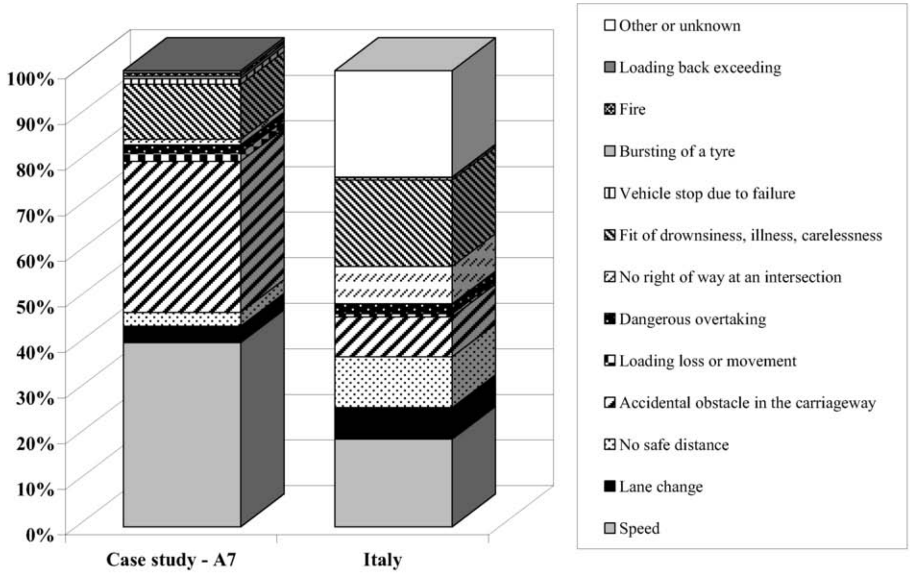

Figure 7. Immediate accident cause on A7 highway North vs. national data.

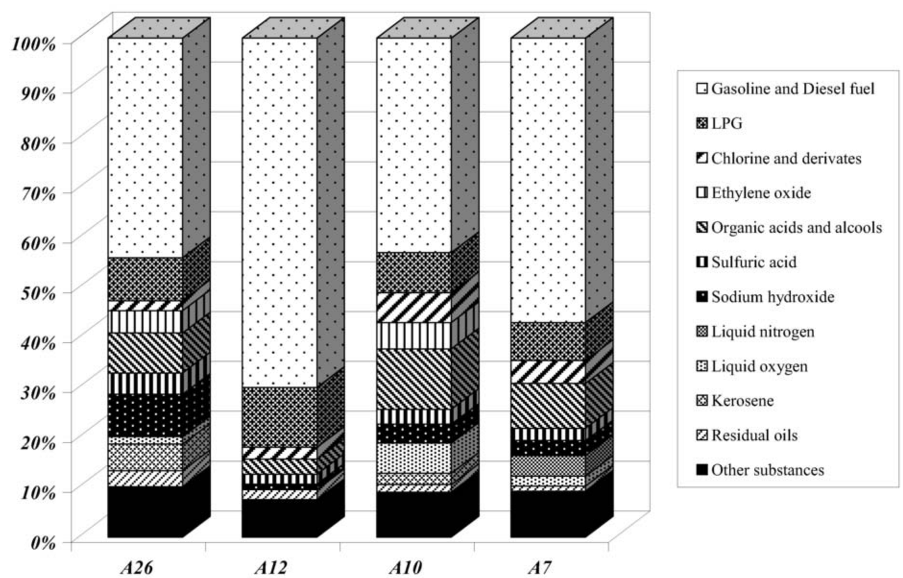

Figure 8. Inventory of hazardous material traffic (5 years statistics)

The striking high percentages of these factors are to be correlated again to the intrinsic characteristics of the analyzed highway. In fact, the high proportion of stretches with curves characterized by small radii (< 200m) and steep descent, make it necessary to respect low speed (i.e. 40 km/h), not usual on this type of road. When dealing with HazMat incidents, historical data reported by Hardwood et al. [20] show that the proportion due to traffic is 11%, while the proportion involving a failure of the truck (body, tank, valve or fitting) is as high as 44.5. It can be pointed out that, dealing with dangerous good transportation, the main difference with process industry is the need of a noteworthy improvement in the inherent safety of the system and in the human factor.

A statistical analysis on transported substances is shown in Figure 8: it is noteworthy nothing the high striking transport percentages of chlorine, LPG and ethylene oxide.

The study on the density of the population which might be exposed to hazards from HazMat transportation must include data on population density along the route and on the so-called motorist density, considering as well the proportion which may be considered particularly vulnerable or protected. Otherwise, all individuals within a threshold distance from a road stretches incur in the same risk regardless of their location. The average density on the route was calculated starting from the collected statistical data relevant to average daily traffic, average speed and geometrical data of carriageway and lanes, in each highway arc considered.

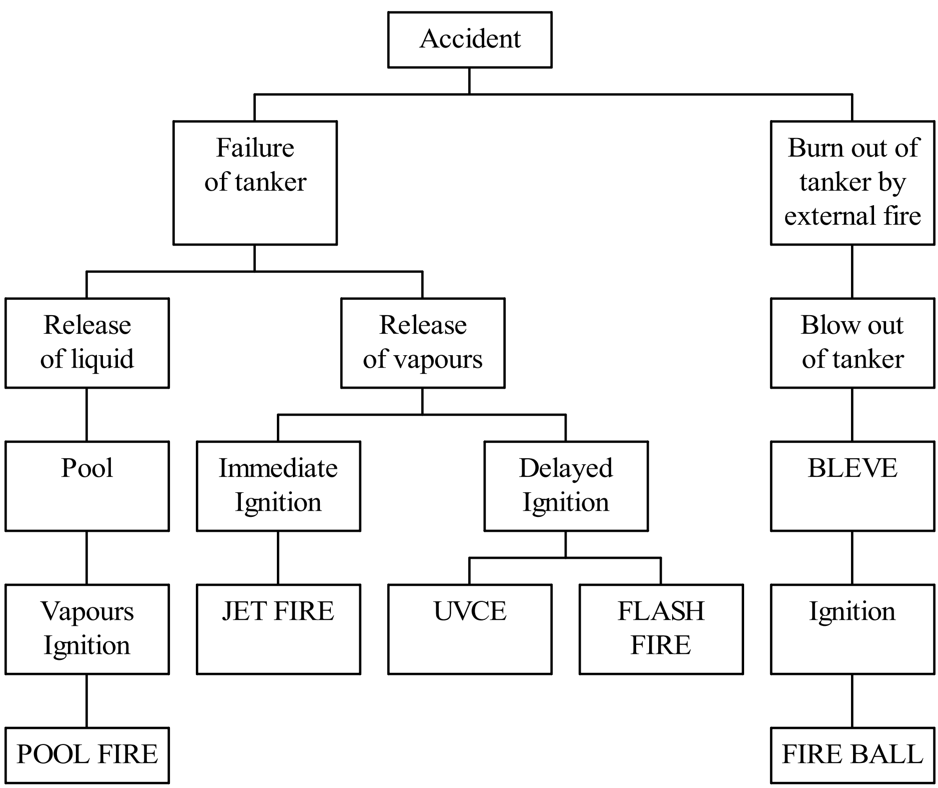

Figure 9. Event tree of truck accident

By comparing the data with the conventional classification of the environment typology, it appears that the first three stretches of A7 highway, starting from Genoa, can be classified as urban/sub-urban environment, while only the two last towards the North direction have rural characteristics.

In order to evaluate correctly the number of on-road population involved in the accident, the response and variations in the motorists density following an accident were considered.

In particular, heavy goods vehicle were assumed to occupy 20 m of lane length and other vehicle 4 m. Two classes of motorist density are to be considered: the former refers to the carriageway where the accident occurs, the latter considers the opposite carriageway, were the “ghoul effect” causes the slowing down of the traffic.

In order to evaluate the lethality area, the consequence model was applied making reference to the event tree reproduced in Figure 9.

Making reference only to flammable and explosive events, five scenarios were theoretically considered, i.e. BLEVE, unconfined vapor cloud explosion, jet-fire, flash-fire and pool fire. Dealing with these scenarios, it seemed realistic to consider that owing to the congestion of the traffic and to the low protection offered by cars and trucks to these events, all motorists in the lethal area die. Making reference to off-road population a two steps model was considered [21], total lethality within the LD_{50} hazard range; 25% lethality between the LD_{50} and $LD_{0.1}$ ranges; no lethality beyond $LD_{0.1}$ range.

We should notice that, for example dealing with LPG, some scenarios are rather unlike and limited to a small distance from the accident spot (i.e. UVCE).

Figure 10 shows the results obtained performing a dispersion analysis to determine the extent of the cloud in three different scenarios of LPG tank failure from a road accident, namely: continuous spillage from small puncture; minor tank failure, catastrophic tank rupture and instantaneous release.

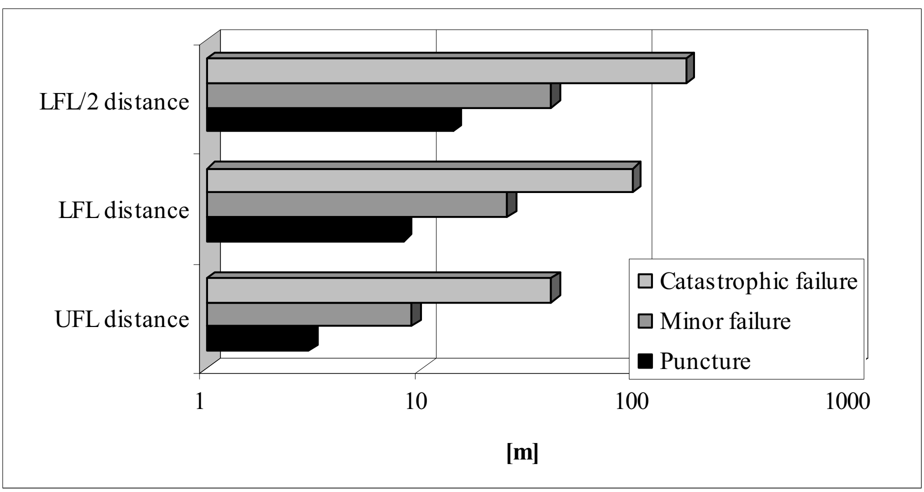

Figure 10. Calculated hazardous distances of LPG cloud, m, corresponding to Upper Flammability Limit (UFL), Lower Flammability Limit (LFL) and Half Lower Flammability Limit (LFL/2) in connection with three different tank accident scenarios.

It can be noticed that the dispersion of the gas is so fast that at a distance of nearly 100 m the concentration is below the Lower Flammability Limit (LFL), while if we consider with a more conservative approach the leading edge of the hazardous cloud corresponding to half LFL, it results that the maximum hazardous area is nearly 170 m.

On the other side, LPG is particularly exposed to the risk of serious accidents such as BLEVE (Boiling Liquid Expanding Vapour Explosion), i.e. explosion of a tank due to rapid evaporation of the liquid either arising from a depressurization wave generated by an accidental hole in the tank shell or due to heavy heat radiation load due to an external fire. As a consequence of the tank failure, the tank is flattened to the ground, giving rise to a strong blast wave, a destructive fire-ball, and in some instances to the formation of projectiles. The characteristic time duration of a BLEVE usually ranges from 10 to 30 min, in the case of full fire-engulfment, even if the time can become significantly shorter in tunnels. Obstructions and confinement are recognized as factors determining fire and explosion strength: in this sense, road tunnels must therefore be considered major risk spots.

4. Discussion

The above-described technique was adopted for the evaluation of individual risk, defined as “the frequency at which an individual may be expected to sustain a given level of harm from the realization of a specific hazard” [22]. In this way, an in-depth evidence on the distribution of the risk along the route and on the localization of high spots is performed, with good accuracy and precision. Considering the potential for transported hazardous materials to cause multiple fatalities and the likelihood of the occurrence, the well-known societal risk can be modeled with the same approach, by the frequency of exceedance curve of the number of deaths (F/N curve) due to transport (see Table 7).

As previously explained, the results of the frequency and consequence analysis were combined with population density data along each road arc. Overall, the results are similar to those reported by Milazzo et al. [23] who performed a risk analysis in an urban area, where flammable substances were prevalent in road transportation.

Table 7. Acceptability criterion of the risk

Evaluation of the risk	Criterion	Explanation
Acceptable risk	$P < \frac{10^{-5}}{N^2}$	No need for detailed studies. Check that risk maintains at this level.
Tolerability region A	$\frac{10^{-5}}{N^2} < P < \frac{10^{-4}}{N^2}$	Tolerable risk if cost of reduction would exceed the improvements gained
Tolerability region B	$\frac{10^{-4}}{N^2} < P < \frac{10^{-3}}{N^2}$	Tolerable only if risk reduction is impracticable or if its cost is grossly in disproportion to the improvement gained
Unacceptable risk	$P > \frac{10^{-3}}{N^2}$	Risk intolerable: risk cannot be justified even in extraordinary circumstances

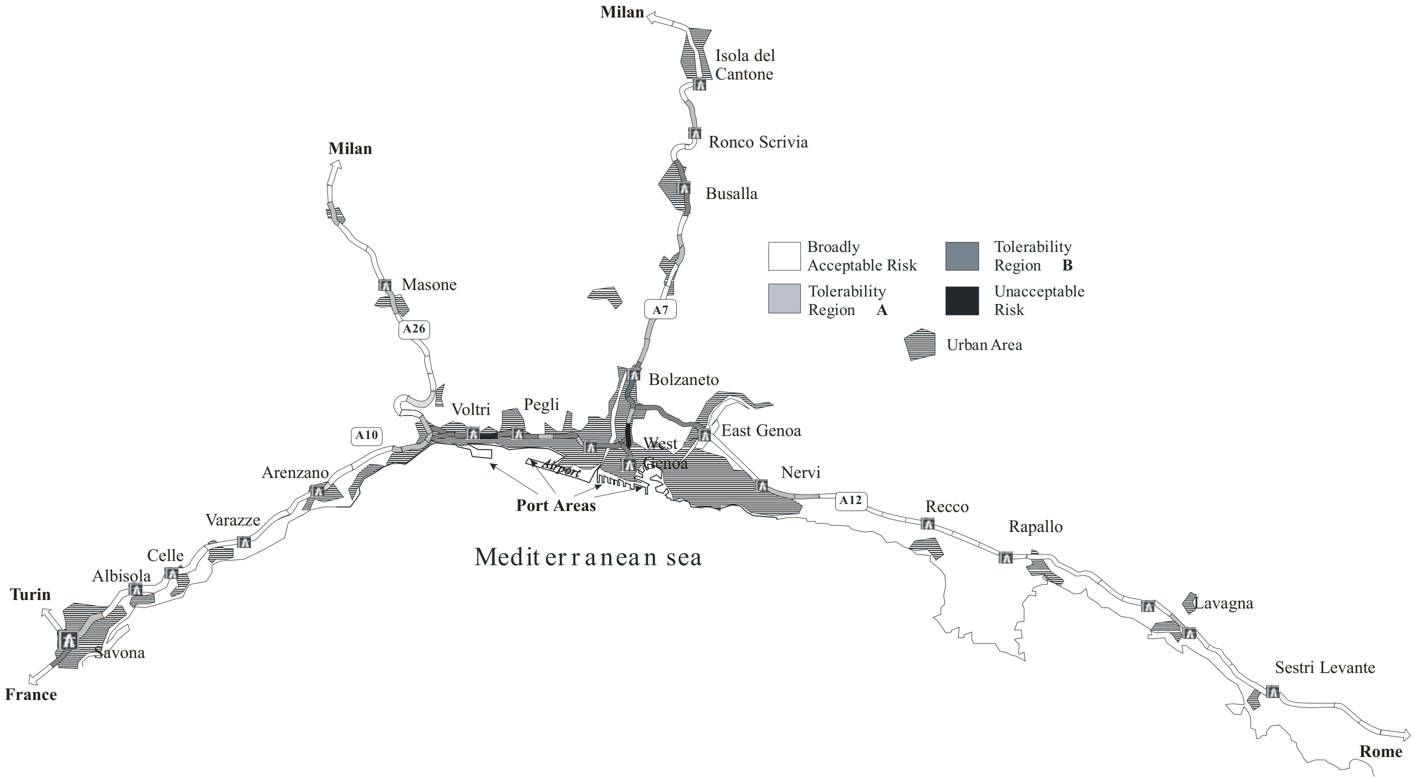

Figure 11. Risk associated with highway stretches.

They concluded that overall societal risk was not acceptable on the basis of the Dutch risk criteria and that the risk associated with the road transportation is higher for $N<20$, while the risk associated with railway transportation become dominant for $N>20$.

It was noticed that, outside the “spot arcs”, for each substance transported, the risk level mainly depends on the shipment number, rather than on the length of the route or its itinerary. The results shown in Figure 10 are to be considered carefully also owing to the fact that the stretches defined at major risk are common to different directions, namely Genoa port-North and East Riviera-North.

Risk mitigation measures can include:

- control of day time for the movement of dangerous goods through highly congested areas;
- restrictions on the transportation during bad weather;
- restrictions on the equipment to be used;
- special requirements on safety driver training ;
- enforcement of the area emergency plan.

Dealing with the last issue, the importance of the ability of the emergency response services to minimize the damage was recently highlighted by a pilot project carried out in the Netherlands, where the evaluation method of external safety risk included new criteria, additional to individual risk and societal risk, and in particular “controllability” i.e. keeping the disaster consequences limited by emergency response services [24].

This criterion is focused on the ability of the emergency response services to minimize the severity of the event and to prevent escalation of the accident.

In the context of HazMat transportation, for the emergency responders it is relevant in particular the amount released. In connection with meteorological circumstances, the release amount determines for the main effect area and the needed emergency response logistics, such as capacity to restore the remaining hazardous materials in tank units or evacuations plans [25].

In case of accident in HazMat transportation and subsequent release into the environment, it is very important to have at one's disposal information on each chemical hazardous product involved, trained and skilful personnel and suitable “prompt action vehicles”, properly equipped to be employed if the above mentioned hazardous release would happen. It is relevant for the Fire Brigades to have an indication of the release amount and probabilities, so that they can manage for routing and logistics. In order to reduce “intervention time”, the localization of “prompt action vehicles” must be founded on scientific statement taking into consideration the concept of “minimum pathway”. The problem can be solved adopting the graph theory, as explained in Fabiano et al. [26], where a linear graph is defined as a set N of objects named vertices V_i ($i = 1,\dots,n$) corresponding to a toll gate, a fire brigade station or to a storage area and a set A of arcs linking couples of vertices (V_i, V_j). In details, a graph is a couple G(N,A) where $N=[V_1,\dots,n]$ is a set of vertices and $A=[a_{i,j}=(V_i,V_j)|\ V_i, V_j \in N]$ is a class of elements called arcs. The arcs, which link vertices together, represent normal way and highway “units”, in the considered area. In order to perform an analysis of the considered graph, a scalar, defined “cost of the arc” was allotted to each arc. This scalar value corresponds to the Average Run Time (in minutes) needed to reach from a vertex the subsequent one. The problem was solved starting from the Dijkstra algorithm [27] of label setting and developing an original optimisation algorithm.

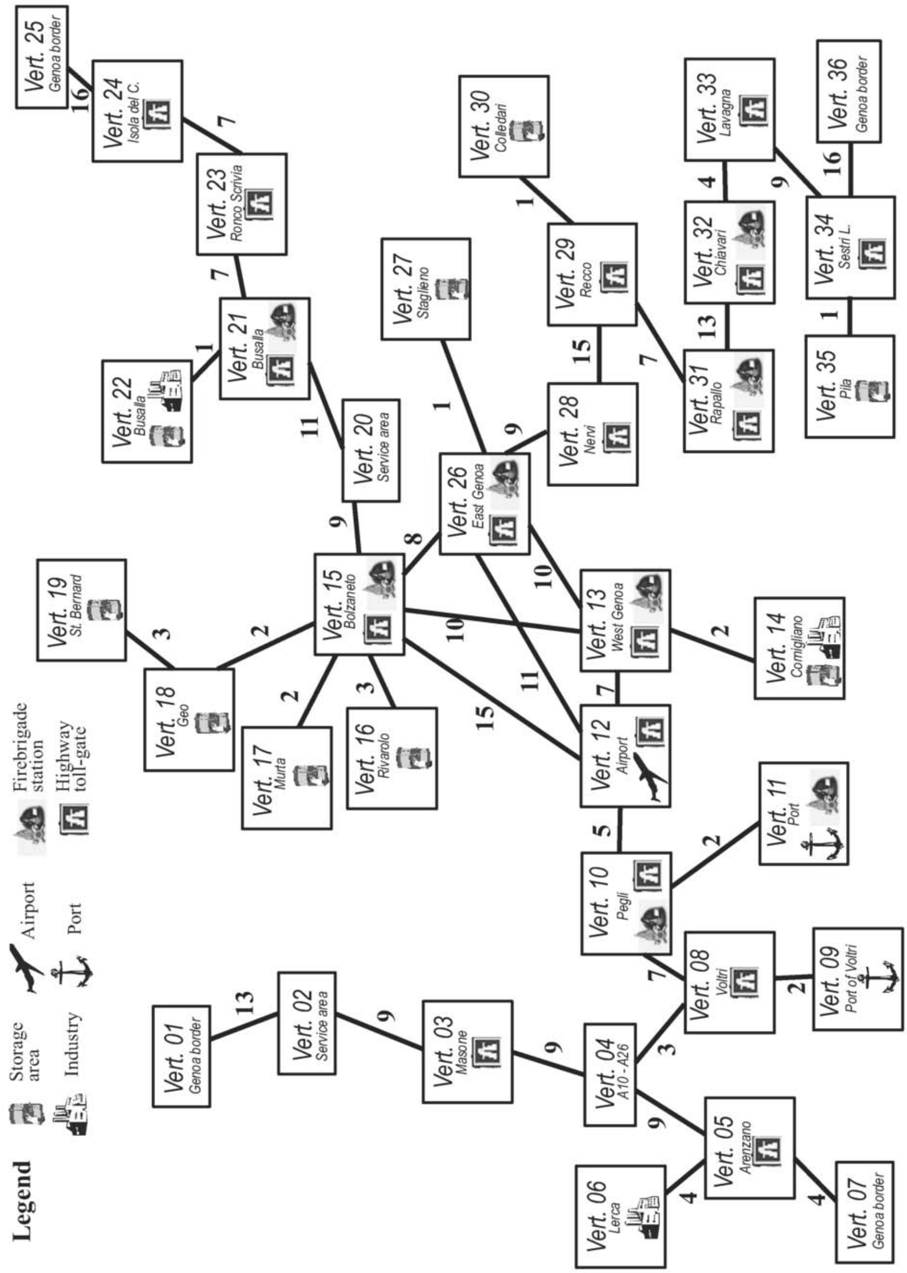

Figure 12. Example of graph model for the optimal consistency and localization of prompt-action vehicle

As shown in Figure 12, the developed graph methodology allows selecting optimal consistency and localisation in the area of “prompt action vehicles”, properly equipped, quick to move and ready for each eventuality. In this way, it is possible to obtain an unambiguous and consistent selection criterion that allows reduction of intervention time in connection with technical and economic optimisation of emergency equipment (number of vehicles corresponding, in the case-study, to three prompt action vehicles).

Fire brigades can follow several strategic lines to contain the hazardous area following an accidental release:

– by covering and containing the released volume, so to limit the dispersion (e.g. with mobile water barriers);
– by stopping the leakage (e.g. by freezing a hole in a tanker);
– by storing the HazMat volume in an additional container (e.g. pumping it over in an additional truck or drum)

Other preventive risk measures can include radio or satellite communication/positioning systems (GPS) and dealing with the wider issue of land use planning the selection of a different highway route for hazardous materials transport or even the design of a new route. In this case-study an alternative route is represented by A26 highway, from Genoa Voltri towards Alessandria. This highway actually collects the traffic from the West port of Genoa, from Multedo oil port and from the West Riviera, but being more recent and characterized by lower intrinsic risk factors, it could gather also the traffic from East and Genoa central port. However, the practical utilization of this option is made difficult by the need of crossing a long urban stretch, while the risk of the transport of hazardous substances is lower if the route followed avoids centres of population. A design solution for the risk mitigation is therefore represented by the construction of slip roads by-passing the urban road arcs of highways A7 and A10. A suggested road layout is schematically reproduced in Figure 13, even if the feasibility of this option is obviously constrained by economical and environmental impact issues. Moreover, as in several other Countries, in Liguria (Italy) the possibility of developing new infrastructures is limited by the scarcity of land availability and by more stringent environmental limitations. Two options can be considered in this context, namely transport corridors and road tunnels, both posing severe safety implications.

In fact, nowadays, in several instances, the approach followed by policy-makers is to cluster large scale infrastructures with already existing line infrastructures, known as transportation corridors. Transportation corridors are zones in which clustered lines infrastructures handle main traffic and transport flows and in which other infrastructures for human activities are concentrated (e.g. rail and highway road) [28].

From the safety viewpoint, this option should be carefully investigated, especially with reference to possible knock-on or domino effect, that dealing with transportation activity may include:

- an additional accident induced by the primary accident;
- a barrier for emergency response workers to access accident spot due to a parallel line infrastructure;
- a traffic interruption on one line, caused by HazMat accident on a parallel line.

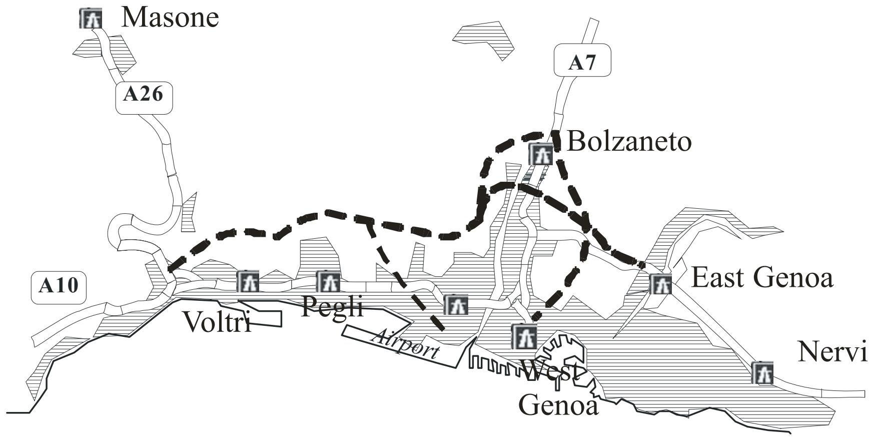

Figure 13. Schematic layout of new alternative routes, at the preliminary design stage.

In this respect, starting from FACTS database and considering transportation accidents, Rosmuller and Van Beek [29] concluded:

- that clustering seems to yield more fatalities than similar accidents of non clustered accidents;
- clustering seems to yield more fatalities and injuries than similar accidents on non-clustered accidents;
- there is no difference in terms on injuries between accidents on clustered and non-clustered line infrastructures.

A conclusion is that safety should be given special attention in situations when one intends to cluster line infrastructures.

Coming to the second considered option, the findings about road tunnel accidents, outlined in chapter 1.2, even if limited by the amount of information available, indicate clearly that the prevention of tunnel accident and the mitigation of the consequences, should an accident occurs, must be carefully considered, starting from the design stage of new road stretches. As discussed in detail in [30] in tunnel accidents, especially those involving fires, a large number of people and a lack of evacuation possibilities, can have very severe consequences. In this respect, the presence of adequate and well-designed ventilation can provide a decisive tactical advantage when tackling fires from hazardous materials, in road and rail tunnels. In fact, the possibility of fighting a tunnel fire, at relatively close range, is strictly connected to the provision of forced ventilation system enabling free access from the upstream side, allowing, as well, a safe exit way for persons involved. The key design parameter is the so-called critical ventilation velocity, i.e. the minimum speed of the longitudinal ventilation avoiding the spread of the smoke produced by fire in the upstream direction (phenomenon known as "backlayering"). The design of the ventilation system in an existing, or in a new tunnel can be conveniently performed according to the analytical model presented in detail in Palazzi et al. [30].

5. Conclusions

The risk from transporting dangerous goods by road and strategies for selecting road load/routes and for emergency plan optimization are faced in this paper. by. A methodological approach for the assessment of standard vehicle and dangerous good truck flows was applied to a pilot area, developing a site-oriented framework of general applicability. In this way a risk assessment sensitive to route specifics and population exposed is proposed and the overall uncertainties by the risk analysis can be lowered. The results presented in the paper may be further developed in various directions. The developed model, of general applicability, can represent a useful tool not only to estimate transport risk but also to define strategies for the reduction of risk (i.e. distribution and limitation of ADR road traffic, improvement of highway section, alternative routes) and emergency management.

References

[1] B.J. Thomson, Proc. of International Workshop on Safety in the Transport, Storage and Use of Hazardous Materials, NRIFD, Tokyo, Japan, 1998.

[2] J.C. Pine and B.D Marx,. Utilizing state hazardous materials transportation data in hazardous analysis, *Journal of Hazardous Materials* 54 (1997), 113-122.

[3] D. Miller-Hooks, S. Elise, Mahmassani, Least, possible time paths in stochastic, time-varying networks, *Computers & Operations Research* 25(12) (1998), 1107-1125.

[4] E. Erkut, A. Ingolfsson, Catastrophe avoidance models for hazardous materials route planning, *Transportation Science* 34(2) (2000),165–179.

[5] J. Kara, E. Erkut, V. Verter, Designing a road network for hazardous materials transportation, *Transportation Science* 38(2) (2003), 188-196.

[6] K.G. Zofgrafos, K. N. Androutsopoulos, A heuristic algorithm for solving hazardous materials distribution problems, *Eur. j. Oper. Res.* 152 (2004), 507-519.

[7] T.S. Glickman and M.A. Sontag, Tradeoffs associated with rerouting highway shipments of hazardous materials to minimize risk, *Risk Analysis* 15(1) (1995), 61-67.

[8] P. Cassini, Road transportation of dangerous goods: Quantitative risk assessment and route comparison, *Journal of Hazardous Materials*, 61 (1998), 133-138.

[9] E. Erkut, A. Ingolfsson, Transport risk models for hazardous materials: revisited. *Oper Res. Lett.* 33 (2005), 81-89.

[10] P.A. Davies, Loss Prevention Bulletin, 150 (1999), 22-23.

[11] S. Kaplan, and B.J. Garrick, On the quantitative definition of risk, *Risk Analysis*, 1 (1981), 1-11.

[12] *Guidelines for Chemical Transportation Risk Analysis*, Center for Chemical Process Safety, AIChE ed., New York, 1995.

[13] K. Lauridsen, I. Kozine, F. Markert., A. Amendola., M. Christou,., M. Fiori, Assessment of Uncertainties in Risk Analysis of Chemical Establishments, Report R-1344 (EN) Riso National Laboratory, Roskilde, Denmark.

[14] H.J. Pasman and B. Fabiano, Trends, problems and outlook in risk assessments: Are we making progress? Chemical Engineering Transactions 13, 2008, vol.1, 9-16, S.S. Buratti (ed.) AIDIC Servizi S.r.l. ed., Milano.

[15] A. Oggero, R.M. Darbra, M. Munoz, E. Planas,., J. Casal, A survey of accidents occurring during the transport of hazardous substances by road and rail. *J. Hazardous Materials* A133 (2006), 1-7.

[16] B. Fabiano, F. Currò,., D. Cazzola,., E. Palazzi, and R. Pastorino,., A study on road and tunnel fires by full-scale and laboratory experimental testing, *Chemical Engineering Transactions*, Vol. 6, Proc. ICheaP 7 pp. 551-556. (2005)

[17] B. Fabiano, E .Palazzi,, F. Currò, and R. .Pastorino, Risk assessment and decision making strategies in dangerous good transport. From an Italian case-study to a general framework, In *Loss Prevention and Safety Promotion in the Process Industries X*, vol. II, 955-966, Elsevier Science B.V., Amsterdam, The Netherlands, 2001.

[18] I.A. James, Dept. of Environment, Report DoE/RW, London, (1986), 85-175.

[19] U.S. PHMSA. 2007. Department of Transportation, Hazardous Material Information System, U.S. Gov. ed.

[20] D.W. Harwood, Russell, E.R., and Viner, J.G., National Research Council, Transportation Safety Board, Transportation Research record 1245, Washington, DC, 12, 1989.
[21] G. Purdy, Risk analysis of the transportation of dangerous goods by road and rail, *J. of Hazardous Materials* 33 (1993), 229-259.
[22] J.K. Vrijling, W. Van Hengel, R.J. Houben, Framework for risk evaluation, *J. Hazardous Materials* 43 (1995) 245.
[23] M.F. Milazzo, R. Lisi, G. Maschio, G. Antonioni, S. Bonvicini, G. Spadoni, HazMat transport through Messina town: From risk analysis suggestions for improving territorial safety, *Journal of Loss Prevention in the Process Industries* 15 (2002), 347-356.
[24] T. Wiersma, and M. Molag (2004). Development of new evaluation method for external safety risk. Loss Prevention 2004 Vol. A, pp.1163-1170. PCHE PetroChemEng Publ., Praha, Czech Republic.
[25] K.G. Zografos, G.M. Vasilakis, I.M. Giannouli,., Methodological framework for developing decision support systems (DSS) for hazardous materials emergency response operations, *Journal of Hazardous Materials* 71 (2000), 503-521.
[26] B. Fabiano, F. Currò, A..P. Reverberi, R. Pastorino, Dangerous good transportation by road: from risk analysis to emergency planning". *Journal of Loss Prevention in the Process industries,* 18(2005), 403-413.
[27] E. W. Dijkstra,., A note on two problems in connection with graphs, *Numerische Matematik* 1(1959), 269-271.
[28] C.H. Weir and P. Heng, Some comments on joint usage of Utility Corridors, 21-31 In: Joint Usage of Utility and Transportation Corridors, C.H. Klohn (eds) American Society of Civil Engineers, New York, USA, 1963.
[29] N.Rosmuller, P.C.Van Beek, Database analyses and transport corridors: parallel lines for accident research, in *16th ESReDA seminar on Safety and Reliability in Transport* (1999), 1-10.
[30] E. Palazzi, F. Currò and B. Fabiano, A study on road tunnel fires from hazmat, with emphasis on critical ventilation velocity, *Process Safety and Environmental Protection, Official Journal of the European Federation of Chemical Engineering: Part B,* 83(B5) (2005), 443-451.

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Safety in Hazardous Material Road Transportation: State of the Art and Emerging Problems

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Abstract. In the last years, numerous accidents have made to lift the level of attention related to the safety in the road transportation of hazardous materials. Also in absence of serious wounded, the dangerousness of the interventions requires very long times for the restoration of the normal road circulation causing huge damages economic and strong discomforts to the users. The hazmat transportation is disciplined for a long time by the ADR. However it only concerns passive measures related to the vehicles, to the packing and the labelling of materials, but it does not prescribe provisions to adopt during the trip. The purpose of the present job is to furnish a wide overview of the risk forecast and prevention and of emergency activation measures resorting to the employment of technological and operational systems and especially to the decision support systems tools.

Keywords. Hazardous Material Transportation, Risk Analysis, Transport Risk Prevention, Optimization of Road Routes

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1. Risk in transportation

The "Risk in Transportation" (RT) arises in relation with the displacement activities over the territory of any type of person or goods, and can reveal itself in the direct involvement of the actors of the displacement, in case of accidents or congestion, or even in the generation of effects that are external to the transportation lines, and may involve subjects that do not take part in the transportation activities. The RT as an external effect can therefore come through in an "active" and/or "passive" form [1]:

- *active risk*: shows up in association with any type of transportation activities performed on the territory, in case any danger should be generated from such activities for the safety of populations that are non directly involved in the activities themselves, for the environment and for the system itself; this is the case of the transportation of dangerous goods;
- *passive risk*: shows up in case, either due to some serious natural disaster, e.g. an earthquake, a flood, or to an accident, e.g. the collapse of buildings and/or to correlated catastrophic events, it is locally impossible or complex to perform the transportation activities, so that a limited area remains isolated and without connections with the rest of the territory or hardly accessible, with some danger for the safety and survival of the settled populations.

The methodological approach to the issue of risk management in the transportation activities of dangerous substances is based on the application of the risk analysis techniques [2]. This approach derives from the handling modalities of risk management in industrial plants and, in particular, in those presenting a relevant risk of accidents, i.e. characterized by the presence of *point sources* of risk. It shows up a few practical difficulties when extended to cover mobile risk sources along *linear* routes, such as the vehicles transporting dangerous goods on the roads (*active risk*) and even more so when it is applied to the study of events that see the transportation system as the victim of externally originated disastrous events, e.g. in case of floods, landslides, earthquakes (*passive risk*).

Quite a significant investigation of such problems was performed in the framework of research projects funded by the Department of Civil Protection through the GNDRCIE (National Group for Prevention of the Chemical-Industrial and Ecologic Risk of the National Research Council) [3]. These studies led to the development of instruments that are able to accurately perform the risk assessment for single transportation activities and to facilitate the risk management in those complex cases determined by the simultaneous occurrence of various transportation activities, e.g. those covering the same area of the territory or a specific transportation infrastructure.

As far as the methodological approach to the risk analysis is concerned, this technique, originally developed in the field of nuclear industry and later extended to the other industrial sectors, achieved an exceptional degree of maturity and can be further extended to the transportation of dangerous goods.

The most relevant applicative difficulty is the movement of road vehicles, and the simultaneous variation of a number of factors that are part of the risk assessment, by influencing the frequency of accident scenarios, the probability for them to evolve into specific final events, fires, explosions, leaching of toxic substances, etc., and the magnitude of the consequences of such events.

Among the factors involved in the risk assessment it is worth mentioning here the accident rate, the conditions of road infrastructures, the environmental conditions, from meteorology to the terrain morphology, the distribution of the resident population as well as the one moving along the itineraries, etc.

To extend the risk analysis and cover the transportation of dangerous goods, the proposed approach in the literature [4] consists of partitioning each itinerary in elementary links, assuming that all factors affecting the risk can be regarded as constant within each link. The shorter is the length of elementary links, the more detailed, and costly, is therefore the analysis; the latter will be in any case confined by the availability of local data related to the required parameters.

The approach proposed herein postulate the identification of events, i.e. phenomena that may directly or indirectly cause some damage to people, transport infrastructures, circulating vehicles, economic activities using transport services, and the environment. The above mentioned phenomena also determine a significant reduction of the reliability of the transport network.

Starting from the identification of the event it will be possible to define and modelling scenarios, which can be used to investigate the interactions between the various elements influencing the risk with the objective of studying its evolution and determining the actions aimed at mitigation of the risk itself. A scenario can be suitably adapted at the analysis through geographic information systems (GIS), which allow simulating the events and the effects of possible mitigation actions. These can be identified by assessing the network vulnerability.

The scenarios taken into account are not crystallized at the moment of the impact and the emergency, since usually even the modalities for recovering the functionality of the road network are prefigured, once the initial emergency phase is terminated.

The main difficulty remains, however, the identification of the frequency of rare events, which may occur in even very different circumstances with possible human errors assuming a decisive role. In these cases, therefore, to assess the occurrence probability of a given event it is necessary to base on subjective evaluation methods; the aggregation characterizing such procedures ha not the meaning of arbitrariness, but rather that of being “related to the know-how of the subject” [5].

The coverage of the risk associated with the transport of Dangerous Goods can be divided in two main fields: quantitative methods and qualitative methods.

Quantitative methods are equivalent to the Transportation Risk Analysis (TRA) whose origins derive from the Quantitative Risk Analysis (QRA) approach developed in the ’70 for fixed installations. The major difference between QRA and TRA can be found in the uncertainty of the localization of the accident: although for fixed stations the risk and the surrounding environmental conditions are almost known, the same does not apply for the transportation activity. In this latter case, indeed, the factors affecting the event frequency and consequences varies along the entire route. To solve this problem it is usually decided, therefore, to divide the route in various portions characterized by nearly constant values of the involved parameters.

For this reason the amount of information required for the risk management rapidly increases; the mass of data is proportional to the level of details of the analysis to be performed. In an effort to obtain some forecast of the risk associated with a single travel, even in the presence of rare events, and to be able to identify the minimum risk route the qualitative approach was developed. A number of decisional models allow the identification of best routes and mainly consist of using algorithms that were developed in the disciplinary field of Operational Research for the definition of the optimum route to connect a origin and a destination by minimizing aspects that may influence the risk in its main components i.e. the probability and the consequences. The main advantages of qualitative methods are to take into account also aspects such as the environmental impacts, that were not considered in the TRA, and especially to allow identification of the best route per each single travel in each day of the year as well as the existing meteorological conditions, instead of using the average ones per each season as employed by the TRA [6].

The main drawback of such methods is however that of being not able to define a quantitative assessment of the risk, but rather to allow just for sorting based on the risk of different alternatives. A few basic concepts of the risk analysis are recalled [7].

1.1. Security and Safety

In the common language the concept of risk is strictly connected to those of security, related to criminal acts, and safety, related to accidental events: natural disasters, catastrophes, accidents, culpable acts, etc. Security issues are dealt with by the police forces, while safety issues are dealt with by the State structures that altogether form the Civil Protection apparatus.

In technical terms a number of different definitions are commonly used to express the meaning of security, although all of them agree on stating that security must be intended as the condition of the absence of any risk, i.e. the absence of possible negative events. The concept of security is also associated with the one of reliability.

The frame of reference is the degree of security that the community believe is necessary, for a given true life or job situation, in the course of practising a given kind of activity. Total security is the asymptotic limit of the actual security. Total security can not be achieved in any human activity, whichever the resources invested to achieve it. It follows from the concept of security as the absence of risk that this must be intended as the complementary element to security.

1.2. Risk

In the common sense, the acceptation of the term *risk* recalls the possibility of suffering damages following more or less predictable circumstances. The components concurring to the definition of risk are basically two: magnitude of the negative consequences, otherwise said *damages*, occurrence frequency (or probability) of the damages.

The risk is analytically defined as a function of the estimated frequency, F, for a given suspected event, and the magnitude of the consequences, M:

$$r = f(F, M).$$

1.3. Frequency

The allocation of numerical values to the expected frequency F is far from being a simple problem. The suspected events are often the consequence of a complex series of simple circumstances: the probability of the first ones bases on a combination of probabilities of the latter ones. For determining the occurrence probability of the events that may produce damages, the knowledge of the reliability of the single components is necessary, which is not always available nor updated. The frequency is involved in the determination of the magnitude of a risk as a multiplicative factor that takes into account the number of negative events occurred in the past in similar situations.

1.4. Magnitude

As the *magnitude*, the amount of *consequences* deriving from the expected damages is intended. It is important to consider that even the magnitude is hard to evaluate.

The insurance companies allocate a monetary value to the material goods and to human lives. This is not applicable in the field of Civil Protection.

Indeed it is possible that absolutely unquantifiable damages in the eyes of the public opinion may show up, such as injuries and victims. Other damages are on the contrary quite difficult to evaluate, such as nuisances, the costs of evacuation, the interruption of production activities, the interruption of services, etc.

No one of the above mentioned damages is negligible: for a rational assessment of the magnitude it would be necessary to evaluate also delayed damages in time.

Although it is not easy to evaluate the magnitude of an accident, it is now quite consolidated to consider it as the result of combining vulnerability and exposition [8].

Vulnerability, V, is a measure of the existing link between an event and the deriving amount of damages over a given element of either the transportation system or the surrounding environment, i.e. it represents the attitude of that element to be damaged following a critical event of a given magnitude.

Exposition, E, is the quantification of the subjects that are prone to the risk and may potentially suffer some even indirect damage, for example: people, highway users, properties, travel time, economic activities.

Therefore the risk can be more precisely represented using the following expression:

$$r = f(P, V, E).$$

2. The issue of dangerous goods

Within the transport of dangerous goods, many problems that could increase the probability of accidents or exacerbate their consequences have been already circumscribed and limited by the current regulations in force [9], although a very relevant aspect exists that was not yet regulated and therefore is susceptible of regulatory, technological and organizational interventions: the actual operation of transporting dangerous loads from the originating point to the various destinations. Indeed, after a vehicle that is perfectly prepared by complying with all the existing regulatory provisions on the subject leaves the originating plant and starts its travel, its traces are lost until arrival at the final destination.

A vehicle transporting any dangerous load is subject, along its travel, to the same accident probabilities suffered by all other heavy vehicles, but furthermore it can be the reason of anomalous events occurring to the container or to dangerous load. Moreover, in case of involvement into an event originated from the exterior, the presence of the dangerous substance may considerably exacerbate the consequences of the event on people, on the environment and on infrastructures.

A survey of the accidents put in evidence, in particular, the following problems among the various possible ones that could show up in case of the involvement of a dangerous load into a serious accident [10]:

- the alarm could not be immediate,

- the activation of rescuers could be delayed by their inexperience,
- in the emergency call difficulties could arise in the communication of the localization of the accident, the characteristics of the event and, especially, the type of substance involved,
- the intervention of the rescuers could be made difficult by the scarce accessibility of the orange panels, the labels and the security cards, circumstances that could prevent the knowledge of the type of substance involved and its potential effects on the people and the environment, and the identification of the most suitable intervention modalities;

also, the following additional issues should be emphasized:

- the density of dangerous loads circulating along a road link could exceed a limit that is believed as critical;
- the above mentioned case might occur along a link of a specially critical infrastructure in terms of the accident probability or its consequences, for example a tunnel, a viaduct, a mountain winding route;
- the transit of dangerous loads may occur in specifically critical areas, for example a densely populated centre, or a sensitive territory;
- a road route may cross territories that are subject to hydro-geological disasters;
- a road route may be subject to intense traffic or congestion phenomena;
- relevant meteorological events could occur along the travel;
- the driver could have an incongruous behaviour or be subject to feel faint or drop in attention;
- the vehicle, the container and the load could be subject to faults or anomalous conditions;
- the vehicle could be stolen by evil-minded subjects.

3. Actions for risk mitigation

3.1. Present situation

In general, the possible interventions for the mitigation of risk in the transport of dangerous substances are many. Actions can be taken for improving the following elements: the marching security of vehicles, the structural strength of vehicles, trailers and containers, the security of packaging, the professionalism and reliability of the drivers, rigour in the loading and unloading operations, emergency equipment of vehicles, the planning of rescue operations. Indeed, many of the above listed interventions are already dealt with by the international regulations [9]. Scientific research can however provide further elements aimed at reducing the causes of risk as highlighted in the previous section.

The risk deriving from the various mentioned issues can be suitably mitigated by using suitably designed and planned technological equipment and organisational measures. The content of this chapter aims at providing a few hints, some of them already partially designed and tested, which could considerably improve the security conditions in transporting dangerous substances.

At present, many projects devoted to risk prevention and the rescue operation to be adopted in case of accident have been prepared and tested both in Italy and in other countries. Nearly all of them have in common the fact of resorting to telematic systems oriented to the monitoring of vehicles transporting dangerous goods on roads.

Many aspects of monitoring have already been defined and operated, especially as far as technology and software are concerned. A vast set of issues however exists that is still susceptible of design and implementation interventions with special reference to methodological and organisational interventions for the prediction and prevention of the risk, which may take advantage of the results achievable by scientific research and the desirable collaboration between research institutes and institutional bodies with responsibilities in transport security and civil protection interventions.

The possible lines of action aimed at risk mitigation should be especially oriented to the actions listed below:

- the preventive analysis of the risk associated with each single transportation activity of dangerous goods and the planning of travels, by assigning each travel to the route that minimizes the risk of accident in both its components, probability and consequences;
- the detection (or monitoring) and real time supervision of the vehicle and the transported load during the whole travel;
- the activation of suitable rescue procedures to be adopted in the event of an accident.

3.2. Architecture and features of a remote control system for risk management

As already mentioned above, a number of interventions aimed at monitoring have already been tested and can be adopted in the practice of transport systems. The Department of Civil Protection [3] and the Ministry of Transportation [11] have also developed projects that explicitly take into account even the risk prediction and prevention interventions as well as activation and support in case of emergency. These projects already defined some elements of the possible architecture of a remote control system for risk management and its expected features.

From the structural and operational point of view, a remote control system should base on the presence of three basic elements:

- Control and Coordination Centres (CCC), where prediction and prevention of the risk is performed, travels are planned, the running of transportation activities is supervised and support is provided to the management of emergencies by alerting the bodies in charge of rescue interventions;
- Peripheral Operational Centres (COP), where continuous control is exerted on the vehicle and its load during transport, assistance is provided to the drivers and communication is maintained with the CCC in order to provide them with all the necessary information;
- the vehicles transporting dangerous loads; these must be equipped with on board systems able to define their position (for example using a GPS), to detect their operational conditions and the integrity of their load, to communicate with the COP and possibly with the CCC to inform them about their status and to receive operative indications or special instructions to be comply with during their travel.

The CCC operates at the institutional level, i.e. they are managed by a government body and have the responsibility of providing the operators of the field (through the COP) with indications or instructions to prevent that a maximum risk threshold is exceeded while respecting as far as possible the economic and commercial needs of the companies involved in the transportation activities.

The COP operates at the operational level, i.e. they are typically managed by transportation companies themselves, which are in strict contacts with their own fleet of vehicles in order to know every location and operational conditions and to transmit to the drivers indications and instructions coming from the CCC. This latter configuration can be hypothesised only for medium to large size companies, who can find economical to run their own situation room for the management of the vehicles fleet. Small-size companies, the typical case being that of *owner-drivers*, can perform this task by making use of external service companies, already existing on the market, e.g. for the supply of anti-theft services.

Minimizing the risk associated with the road transport of dangerous goods can be achieved by adopting a series of actions related to the various elements defining the risk itself. In particular, these actions can be divided in three main macro areas that are differentiated from each other based on the time frame of application, either before or during the travel, and on the regularity of application of the related procedures – for

instance the management of emergencies is only activated in case of anomalies, while monitoring is performed continuously. These concepts are illustrated in the Figure 1.

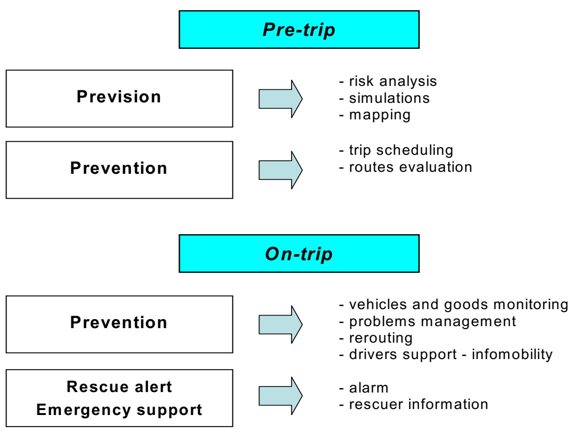

Figure 1. Features of a remote control system.

The above mentioned macro areas can be represented also according to the scheme reported in the list below, ordered according to the temporal sequencing of the events:

- risk forecast: analysis of the risk associated with the single transport of dangerous goods;
- risk prevention: definition of alternate lower risk routes, programming of travels;
- monitoring: localization of the vehicle and its load, control of the correct functioning of the vehicle, control of the status of the transported dangerous load, display of the position of the monitored vehicles on geo-referenced maps, operators’ control of the fleets;

- handling the emergencies: reception of alarm signals from the vehicle, activation of operators in charge of rescue.

3.3. Applications of the remote control of risk management

By directly implicating the operators and the transportation companies that daily circulate with their vehicles on the road network for transporting dangerous goods, a remote control system for the risk can be applied and used on condition that the operators themselves are suitably involved and equipped with the necessary instrumentation for monitoring and processing of the information exploited by the system to provide the expected results. A few indications are briefly provided below about the actions to perform in order to allow a practical implementation of the various remote control and risk mitigation functions.

3.3.1. The monitoring function

Conditions

It is necessary that transportation companies have their vehicles equipped, if not already, with suitable devices for the following functions: localization of vehicles (GPS receivers), two-way radio data transmission (GSM phone), detection of the conditions of the vehicle and the transported dangerous load; transportation companies should also indicate, telematically and per each vehicle under monitoring, the following data: vehicle plate number, type and amount of transported materials, origin and destination of the travel.

In order to provide drivers with information related to the road conditions the availability of information coming from the CCISS (Centre for the Coordination of Data about Road Security) of the Ministry of Transportation as well as information on meteorological forecasts is required.

Implementation likelihood

In order to facilitate its feasibility as much as possible, the remote control system must be prepared to induce the operators of the field to voluntarily take part in monitoring by providing them as a compensation the possibility of managing their fleet and receiving assistance in case of accidents and information about the traffic conditions.

Anticipating that the unsolicited availability of the operators will not ensure a mass participation, this could be attained through the definition of suitable regulatory actions, e.g.: the supply of monetary incentives, the granting of tax relieves, the feasibility of a discount on the insurance bonus, and the regulatory obligation (in the last resort).

Achievable benefits

The presence of transport operators connected to the remote control system would allow the public authority in charge of the realization and management of the Control and Coordination Centre to obtain the following results:

- to know in real time the number, position and behaviour of circulating vehicles;
- to be promptly informed about the onset of possible risk conditions, for example: high concentration of dangerous loads in restricted territorial areas, possibility of faults on board the vehicles, possibility of critical conditions related to the transported loads;

- to provide the transport operators with updated information about: accidents involving other vehicles, interruptions or delays along the route, formation of adverse meteorological conditions and a high risk of accidents.

3.3.2. Emergency management functions

Conditions

Further to the conditions illustrated for monitoring, it is necessary to define suitable operational procedures together with the subjects in charge of the rescue operations and the management of emergencies in case of accidents, e.g.: Fire Brigades, Traffic Police, Prefectures, etc., Transport Emergency Service (SET).

Implementation feasibility

A suitable TRAMP remote control system must be conceived and implemented to receive possible alarm signals from the vehicles, through the COP, and to undertake the consequent actions, consisting of the supply to the appropriate subjects of the following essential information for the prompt management of rescue: site and type of accident, type and amount of the transported substance, general data about the transport company and the chemical company that committed transportation, boundary conditions, e.g. the release of toxic substances, fires, exposure of people to the risk of contamination, etc.

Achievable benefits

The availability of the above mentioned information and their forwarding to the envisaged bases allows the public authority in charge to activate with proper promptness the rescue operations and to effectively exert their coordination role.

3.3.3. Risk prevention function

Conditions

Further to the conditions indicated for monitoring, it is necessary to create suitable conditions for producing companies and transportation companies to agree with the Control and Coordination Centres upon the travel conditions that may guarantee the achievement of the minimum risk conditions.

Implementation feasibility

For the implementation of the above mentioned conditions it is necessary that, following proper confrontations and agreements with the operators involved, suitable regulations are defined, possibly at the European level, to establish the modalities for performing the following actions: the transportation operators preventively communicate their transportation needs to the competent CCC, which perform the forecasting of the consequent risk, and the interested transportation operators agrees upon the conditions that may reduce the risk to a minimum, for instance: the route to follow, the starting time, and possible stops.

The programmed travel conditions could be subject to modifications during the travel following changes in either the traffic or meteorological conditions; in that case the system allow to indicate the interested driver possible alternate routes or other actions that may prevent the occurrence of accidents.

Achievable benefits

Thanks to the implementation of this level of functionality of the remote control system, the public authority in charge can achieve the maximum risk prevention possibility by defining together with the transportation operators the conditions that may reduce the accident probability to a minimum.

In the following the prediction, prevention and rescue phases in the framework of risk mitigation are described with additional details, by specifying especially the most relevant methodological aspects and the implementation modalities. Such concepts will be further illustrated by describing the feasibility study of a telematic system for the monitoring of road transport of dangerous goods tested in the Province of Lecco (the TRAMP project). Finally an overview is provided of the emerging and still open issues.

4. Risk Prevision: analysis and mapping

4.1. Indicators

The risk assessment process is decomposed into two sub-objectives corresponding to the two factors generating the risk: the probability that an event happens and its consequences. The indicators identified above must be defined in relation with their variability in time according to the following scheme [6], [12]:

- static indicators: they describe phenomena that are characterizes by slow dynamics and therefore, once quantified, they can be updated with a very low rate, for example every one or more years; demography, land use and the accident frequency can be considered as static indicators;
- dynamic indicators: they describe phenomena that may vary appreciably, like traffic flows and the meteorological conditions, and can be used in two ways depending on the operation to be performed:
  - preventive planning: the magnitude of such variable being not known, an average value is assumed as derived from historic records, for example the traffic flows during peak times or the seasonal wind speed and direction,
  - real time planning: the knowledge of the current value of the traffic flow and the meteorological conditions is required, and therefore such indicators must be updated with a high frequency, for example daily or even hourly.

Using indicators is made very difficult by their actual availability. Generally the demography and land use are available at sufficient scale and updating rate, even if they must be suitably elaborated. The accident frequency is available in the form of a rate related to the traffic volume running on some road links and can be obtained for highways and main roads, while for the other roads an average general value must be assumed. Traffic flows are usually available for some links of the highways and major roads; since their knowledge is required on all the considered road links, often they are obtained by using traffic simulation models. Meteorological conditions can be provided in real time by the operators in charge of that service.

The indicators defined in this way offer the following advantages in the definition of risk scenarios and their reciprocal comparison:

- they provide quantitative measures that may result very useful for supporting decisions;
- they allow to perform comparisons;
- they allow to measure the efficacy of actions aimed at risk mitigation;

- they allow for evaluation, integration and comparison of environmental effects that can not be measured in quantitative terms.

The analysis is structured by means of the following actions per each of the employed indices:

- verification of the possible influence of that index either on the occurrence probability of an event or on the deriving consequences;
- definition of the scenarios to be assumed for the investigation;
- provision of a judgement on the hazard associated with each of the defined scenarios;
- definition of a synthetic representation of the judgements provided.

4.2. Comparative analysis of the scenarios

Among the various methods available for comparative synthetic assessment of the scenarios, the *Multi Attribute Analysis* (MAA) is the most effective [12], [13]. Indeed this is the only correctly formulated method from the theoretical point of view, adequate to the requirements of the present application. The MAA allows us to:

- take into account the simultaneous availability of qualitative and quantitative assessment of the criteria;
- explicitly account for the conflicts without concealing them;
- include the participation in the decisional phase of the various subjects involved, with no need to pretend that this operation is objective, but rather handling its subjectivity in a transparent and repeatable way;
- operate with the successive elimination of the less effective alternatives.

The basic element of the MAA consists in building an *evaluation matrix*. This is made of as many columns as the number of risk indicators and of as many lines as the number of road links covered by the hazardous loads. Therefore each cell will contain a performance index *gi*(*k*) that provides an estimate of the risk generated on each road link with respect to the phenomena represented by each indicator.

In general, in case the quantitative assessment of any indicator should not be possible, a qualitative judgement can be formulated that may vary according to the following scale, expressed in ascending order of the hazard: very low, low, fair, high, very high.

Table 1. Structure of the evaluation matrix.

		Indicators			
Road network links		Demography	Land Use	Accident freq.	Traffic
	Link 1				
	Link 2		$g_i(k)$		
	…				
	Link n				
Measurement Units		Exp. Popul.	Risk*km^2	Accident/km	Vehic/h

Among the various operations, the provision of a judgement about the hazard associated with each scenarios is the most difficult one, indeed the modelling of a large number of elements that may be either sources of risk or representing the risk receptors is required.

4.3. Utility Functions

Once the evaluation matrix related to the considered indicators has been built, it is now necessary to aggregate the various indicators into one single synthetic indicator, useful to obtain a unique final mapping.

This result can be obtained by assigning a *utility function* u_x, to each indicator (Figure 2). The function relates the values assumed by each indicator with non-dimensional measures between two arbitrary values, generally 0 and 1. It also has the aim of normalizing the indicators into a related measurement unit, included between 0, expressing the minimum utility – i.e. the worst value, and 1, i.e. the best value.

The utility functions for the indicators here considered can not be found in the literature, and must be built based on individual values. Defining the utility function u_x for a given indicator x means transforming the indicator, expressed in physical units, into a *degree of satisfaction*.

By applying utility functions to the evaluation matrix we obtain a new matrix with lines and columns that are comparable to each other. The elements of the utility matrix do not represent the performances $gi(k)$ any more, but rather the $v_i(g_i(k))$ values in between 0 and 1.

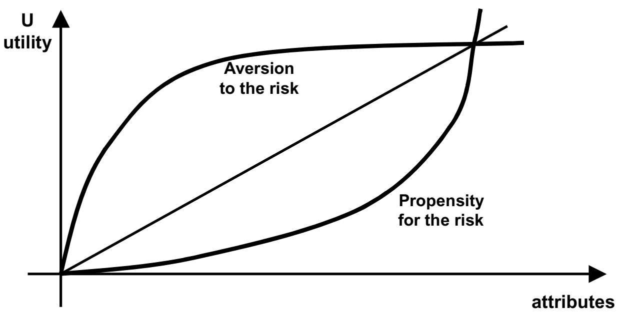

Figure 2. The convex curve representing the propensity for risk, while the concave curve the aversion to the risk, and the straight line the complete indifferent relation with the risk.

4.4. Overall Utility

After building the utility matrix, the various indicators must be aggregated into a unique value that may represent the overall performance of each road link with respect to all components of the risk taken into consideration. The overall utility *V(k)* for each link can be obtained after application of the additivity property to the relative utilities of single components of the risk, i.e. by calculating weighted sum of the relevant performances as follows:

$$V(k) = v_1(g_1(k)) \times w_1 + v_2(g_2(k)) \times w_2 + ... + v_i(g_i(k)) \times w_i \text{, where:}$$

- $V(k)$: overall performance of road link k,
- $v_1(g_1(k)$: performances with respect to single risk components i for the road link k,
- w_i : weights associated with the risk components.

The weights w_i allows assigning a relative importance to the risk indicators, i.e. a sort of contribution that each indicator provides to the assessment of the overall risk generated by a road link.

4.5. Example of the definition for some indicators

An example is provided here of the possible procedures to be adopted for quantifying two static indicators: demography and the land use [14]. Basic data can be usually obtained from statistical agencies and in territorial information systems. Many of such data are available in a geo-referenced format on cartographic layers that are suitable for the elaboration by means of a GIS support. The examples described refers to the territory of the Lombardia region of Italy.

4.5.1. Demography

Among the potential receptors of the risk, a relevant component is made of the people that are present in a given instant in time within the areas involved in the transit of hazardous loads or that may anyway be reached by toxic clouds coming from possible accidents sites. The knowledge of the number of people exposed depends on the following elements:

- distribution of the population over the territory, taking into account the urbanised areas and identifying residential, industrial and mixed areas;
- configuration of the road network run through by hazardous loads,
- type of transported substances and the possible accident scenarios, elements that help determining the exposure area of the population.

By using a GIS it is possible to obtain the intersection between the territorial band beside a road, sensitive to the release of hazardous substances, and the urbanised surface area; the product of the areas determined in this way and the associated population density provides the number of people exposed. As for the width of the sensitive band the following values are available, as proposed in the literature [4], [15]: 150+150 metres from the road axis for those events that may produce fires and explosions, 500+500 metres for those events that may produce spilling of GPL, 1500+1500 metres for those events that may produce a dispersion of toxic substances. In the described example we will make reference to the case of GPL.

Basic data that can be used to estimate the exposure of the population may come from various sources. The cartographic layers related to the urbanized areas and their administrative limits have been extracted from the Technical Map of the Lombardia Region at the scale of 1:10000. The resident population of the municipalities is related to the last general census performed in 2001 by the National Institute of Statistics (ISTAT) of Italy. Moreover, the displacements generated and attracted by the Municipalities have been taken into consideration, obtained from the Source-Destination (SD) survey performed by the Lombardia Region in 2002; similar data can be obtained from the SD matrix realised by ISTAT after the census of the year 2001. For the configuration of the road network the TeleAtlas® vector network was used.

Since the real value of the demographic density was not available per each single urbanized area, an average density was used for each municipality calculated as the product of the resident population and the overall surface of urbanized areas.

The population actually present in the urbanized areas was not assumed as constant, but rather variable in two time slots: during the night time this corresponds with good approximation to the resident population provided by ISTAT, during the day time this can be defined as the sum of the resident population in that municipality and the difference between the displacements attracted and produced by the same municipality, directed towards the other municipalities.

The displacements attracted and generated for working and studying reasons have been calculated by analysing the results of the SD survey of the Lombardia Region. In order to attribute displacements to the relevant municipality it was necessary to introduce a few hypothesis depending on the fact that the zoning included in the SD survey has a municipal, sub-municipal or over-municipal character.

The indicator's values obtained per each road link are graphically displayed in Figure 3, where the exposure of the population to the risk of hypothetical accidents involving hazardous loads circulating in Lombardia is indicated.

The analysis of the total percentage of arcs falling inside each of the five identified exposition classes allows to put in evidence that the majority of road links within the Lombardia network (77,87%) exposes a population lower than 5000 inhabitants, while for 7,5% of the links the resulting exposed population is 10000 people, see Figure 3. The number of road links that have not any influence on the populated areas because they are at least 500 metres away from a urbanised area is minimal, confirming the strong urbanization of the Lombardia Region.

Population exposed [inhabitants]	Number of links	% of links
Not exposed	1888	0,35%
<=1000	142283	26,37%
1000< >=2000	109383	20,27%
2000< >=5000	168515	31,23%
5000< >=10000	77005	14,27%
>10000	40535	7,51%
Total links	539609	

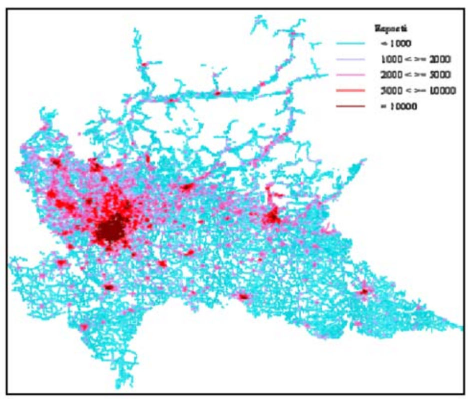

Figure 3. Number and percentage of road links per each class of exposed population and map of the exposed people in the vicinity of links in relation with the transport of GPL with a band of influence of 500 metres

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4.5.2. Land Use

The *land use* indicator is considered as representative of the exposition of the environment to the risk. The estimation process is similar to the one defined for the population: the characteristics of the territory are divided in macro-classes, according to these aggregations: Water bodies, Woods, Wood agricultural, Natural Vegetation, Meadows, Unproductive areas, Sowable ground, Urbanized areas and infrastructures., moreover a few scenarios are defined in relation to the type of substances hypothetically transported in the hazardous loads and involved in possible accidents. In this example the GPL was considered.

A few scenarios are defined later as a combination of various substances and the various land use classes and to each of them a qualitative level of judgement is assigned about the consequences deriving from an hypothetical accident. The judgements are expressed by taking into consideration the vulnerability of each land use class with respect to the interaction with the considered substances. The result of this first phase is therefore given by assigning a risk assessment to each land use class for every substance (in this example the GPL).

In order to assign each road arc with a value of the risk associated with the land use a band of 500+500 metres from the road axis is assumed. In this way each road arc is assigned the portion of the area having a given destination of use that could be involved in a possible accident occurring on the road network by relating the area of influence of the road link with a risk constant; the measure of the indicator is therefore expressed as an equivalent area for the risk.

The data used for calculating the vulnerability of the soil come from the geo-referenced layers extracted from the Technical Map of the Lombardia Region in the scale 1:10.000.

The values of the indicator obtained in this way are represented in Figure 4. The results put in evidence that nearly all the road links of the network in Lombardia affect a non urbanised area with an extension lower than 750 ha of equivalent area.

GPL equivalent Area [ha]	Number of links	%of links
No intersections	191	0,04%
<=250	25886	4,80%
250< >=500	496293	91,97%
500< >=750	15174	2,81%
750< >=1000	1558	0,29%
>1000	507	0,09%
Total links	539609	

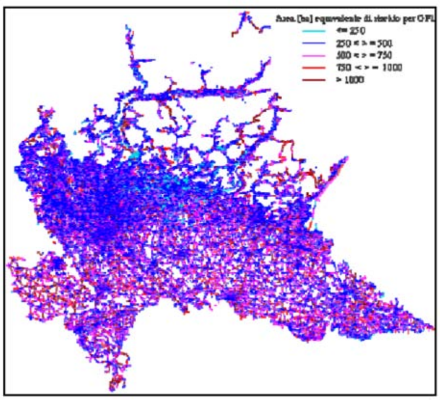

Figure 4. Number and percentage of road links per each class of equivalent area for the risk associated with the transport of GPL and map of the risk equivalent areas in the vicinity of the road arcs in relation with the transport of GPL with a band of influence of 500 meters.

4.5.3. Total Risk

Thanks to the above described results an evaluation matrix was prepared. Then the utility matrix was also derived. To perform this operation linear utility functions were used, i.e. a neutral propensity to the risk was assumed.

The utility function of the demography indicator, representing the number of people exposed to the risk, is a straight line that reports the maximum satisfaction, i.e. $u = 1$, right at the 0 value of the indicator, i.e. when no exposed population is present, and the minimum satisfaction right at 10.000 exposed people. The lowest satisfaction value is not the minimum of the possible values of that attribute, since, in the opposite case, the utility function would have altered the gap between the lowest values, reducing them to very similar figures. The choice is motivated by the analysis of the percentage of links that can affect, in case of release, a population higher than 10.000 inhabitants, as already highlighted in Figure 3.

The utility function of the land use indicator is a straight line that reaches the maximum satisfaction, u = 1, right at the 0 value of the indicator, i.e. when no interaction exists with the land use, and the minimum satisfaction at 1.000 hectares of equivalent area for that risk. Like for the population indicator, the latter does not represent the lowest value assumed by the indicator to avoid that the alternatives order could be altered. The choice is motivated by the analysis of the percentage of links that can affect, in case of release, an equivalent area of the territory larger than 1.000 hectares, as already highlighted in the Figure 5.

To obtain the total risk we assumed the same weight per each indicator, believing that all the risk components would equally contribute to the determination of the total risk.

The map produced illustrates the total risk generated by each link of the road network in the Lombardia region with respect to the demography and land use indicators in the transport of GPL.

The total risk was divided in 10 classes. Obviously a different subdivision could also be used.

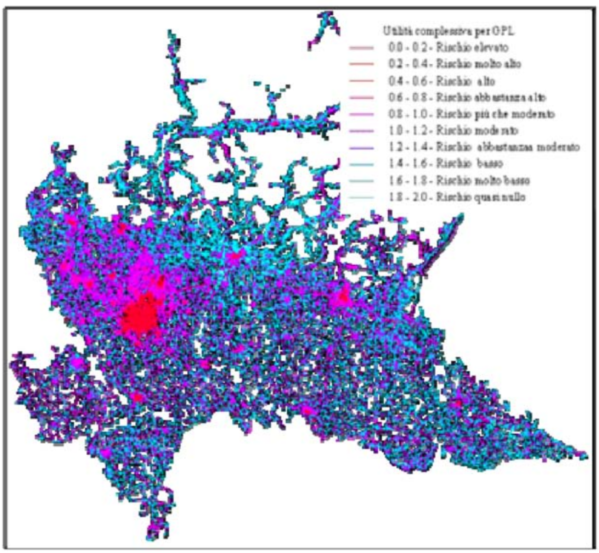

Figure 5 Map of the total risk with respect to the demography and land use indicators in the vicinity of the road arcs of the Lombardia network in relation with the transport of GPL with a band of influence of that substance of 500 metres.

5. Risk Prevention

5.1. Prevention measures on the vehicles. - On board equipments

The necessary components for the correct work of the system to be installed on board of vehicles can be so listed: sensor, communication, electronic, mechanic and wiring equipments.

In the following a review of the various components available on the market is furnished. This analysis can be useful to appraise the financial burdens that a transport company should sustain for technologically adjusting its own vehicles to the specifications of a tracking system and mitigation of the risk.

5.1.1. Sensor equipment

For monitoring the vehicle during its trip is necessary to notice two different set of parameters, related to the working of the engine, of the towing and of the mechanical parts of the whole vehicle and to the state of the container and of the transported dangerous substance.

Relatively to the first function, it is important to consider that the vehicles currently in commerce are normally equipped with an electric plant based on the so-called *CAN BUS* logic, therefore they are already predisposed for monitoring tens of parameters related with the safety of the vehicle during the moving or in the parking phase.

From this it achieves that can be considered void the costs to adjust the mechanical part of the vehicle to the monitoring function comprised from the tracking system specifications.

Anyway, for completeness, an indication of some of the essential mechanical parameters is furnished by to hold under control on vehicles that are not equipped with *CAN BUS* technology and that therefore need the installation of special sensors: put in service of the vehicle, speed, temperature of the brakes or other sensitive parts for the safety.

Besides one must take in consideration the presence of a sensor of bump to notice possible collisions or turnovers of the vehicle and therefore necessary to automatically activate a call of emergency in case of accident. This sensor, in fact, is not normally included in the standard equipment of the trucks, although are endowed with technology CAN BUS.

It finally goes considered that the greatest part of the cisterns devoted to the transport of oil products, currently in circulation, is endowed with an electronic device that notices the product quantity present and its physical conditions.

stato dei portelloni o posizione dei colli presenti nel cassone.

For monitoring the state of the transported substance, we hold opportune the measurement at least of the following parameters: pressure, in the case of gas and liquefied gas, temperature, presence of the substance externally to the vehicle, state of hatches or position of the charge in the container.

5.1.2. Electronic and Communication Equipments

The electronic and communication components of a vehicle equipped for the transport of hazardous materials essentially is concentrated on the on board unit, that must be able to pick up the signals coming from the different sensors and to send them to the plants of control. The principal components of the centralina are:

- an interface that receives the signals coming from the sensors;
- a processor of the picked data;
- a system of satellite location, for example, GPS integrated by a differential odometer that intervenes when the satellite location is not available, for example in the mountain lines and inside the galleries;

- a cell phone device, for example compatible with the GSM or UMTS networks , that allows the transmission of the signals of the sensors in the form of character strings the operation centres (COP and CCC).

The on board unit also includes an entry to receive information from the digital speed counter of the vehicle with the purpose to integrate the GPS locator with an odometer signal that increases the precision and the reliability of it.

The cell phone device consists essentially in a tool analogous to a cellular telephone and it is used for the exchange of the data and messages between the vehicle and the operation centres (CCC and COP).

The employment of the technology GPRS, that exploits the GSM cellular network, subsequently favours this communication limiting the necessary quantity of memory for the dispatch of the strings.

Recently he is spreading cellular telephone instruments of the "third generation" that use the technology UMTS (*Universal Mobile Telecommunication System*) that makes still more efficient the interchange of the data. The GPRS technology allows to develop the tracking functions to very contained costs, to condition to adequately define the dimensions and the frequency of forwarding of the messages.

The cost of an on board unit endowed with the components underlined to the beginning of this paragraph is very varying depending on the attained economy of scale, that is it curtains to decrease to increase the number of apparatuses that have to be produced.

5.1.3. Wiring and Installation

The last cost item attributable to the vehicle is constituted by the wiring of the equipments by to install and by the manpower's cost employed for this operation.

5.2. Minimum Risk Path Calculation and Trip Planning.

The trip planning is, in chronological order, the first operation that the tracking system must complete. It is finalized to appraise the characteristics of the transport and to define the conditions of every single trip in function of the characteristics of the transported commodities.

Particularly, the planning allows to quantify in advance the risk prefiguring the consequences of possible accidents and furnishes a support to determine the least risk path.

During the planning the interaction happens among the different interested actors, (manufacturing firms, clients, organizers of the transport, haulage contractors, operational centre), the characteristics of the trip are determined, and the dispatch of the trip data happens to the involved carriers and network managers, to allow the monitoring and the management of the trip with the resolution of the possible anomalies.

This function has to produce a bounded but sufficiently elevated number of paths connecting the origin with the destination of the trip.

To produce such paths is necessary to use a GIS software containing the road network update information: the sense of route of every arc, the length of the same and the time that the vehicle should presumably employ to cover it, gotten assuming different speed values for the various street types included in the network.

Different types of approach are available for the individualization, from the CCC, of minimum risk paths to be pointed out to whom performs the transport. In the paragraph 3.3 a review of the optimization methods for the planning of the trips and the generation of paths are furnished. Here we present the method that, to the moment, has furnished the most promising results. The determination of the paths should happen in two phases:

- definition of a set of alternative meaningfully dissimilar paths, so that we have a sufficiently large set of possibility to subsequently appraise;
- analysis of the paths defined in the previous phase to build an ordered list containing the paths satisfying some criterions of compatibility between the transported commodity and the crossed environment.

Likewise to how much already said regarding the mapping of the risk, after a series of comparative evaluations of the available methods, illustrated in 3.3, for the execution of the second phase of the trip planning the Multi Attributes Analysis (MAA) results suitable in comparison to the demands of this application. In fact it allows to consider the simultaneous presence of qualitative and quantitative estimation of the risk components and it allows to make meaningful the analysis also for a single trip furnishing a classification of the alternatives in order of preference. This result is not achievable instead with the classical quantitative methods of the risk analysis.

The availability of ordered alternatives allows to easily furnish a different path solution to a vehicle that had the necessity to change path during a trip, for example, because of the change of some conditions of the traffic or other remarkable phenomena, without the necessity to repeat the procedure of evaluation.

All the things stated regarding the risk mapping hold for the definition of the risk indicators associated to the trips of the dangerous loads. In the operation of definition of the least risk paths the following indicators are considered: demography, use of the ground, intrinsic incident rate of the roads, traffic, meteorological conditions, travel time.

To every alternative path found the relative index of risk is associated on the base of the data of the trip furnished from the carriers and of the information coming from the territorial GIS files, where the characteristics determining the risk indicators above listed are modelled. The final result consists in an ordered list of the alternatives classified in function of the risk index.

The employment of a multi attributes evaluation method implies to preliminarily have determined a set of alternative paths to submit to the analysis for the final choice of the most convenient path. Also the paths already habitually used or more known by the drivers are indicated by the transport company to the CCC and belong to the set of alternative paths above mentioned. In every case it is opportune do not submit to the risk evaluation paths that it would not be possible subsequently to propose to the transport companies, since anti-economic.

It appears evident that the determination of a set of paths to subsequently be used for building the sceneries that will be object of the MAA, with the purpose to detect the least risk path, constitutes one of the most delicate and critical phase of the whole analysis.

Theoretically all the possible paths connecting an origin with a destination should be considered but this exhaustive approach, besides behaving an excessive computational effort, could also comprise alternatives that it is possible to exclude in advance since clearly impracticable or anti-economic.

For these reasons, the set of alternatives have to be numerically bounded and already to guarantee in this first phase the exclusion of paths that, in comparison to the shortest or to the fastest one, involves a cost penalization greater than a certain threshold, varying also according to the degree of dangerousness of the goods: for very dangerous goods a great penalization can be accepted in name of the safety and the public interest.

How economic criterion we can use the supposed travel time, attributed on the basis of the average speed, function of the road typology and of the typical traffic conditions, and of the arc length. Insofar, the paths characterized by a cost that differ from the optimum less than a certain threshold and having the most spatial dissimilarity are detected. Therefore the method allows to detect a set of alternatives, all economically acceptable but the more possible different spatially among them. The dissimilarity of the paths reveals to be particularly useful in the problem of the rerouting of the dangerous goods, for different reasons:

- the CCC also has the role to verify, before or during the trip, any unexpected impediments as accidents or works in progress, that could limit or get inopportune to travel along a road: to know alternative paths, with risk and length slightly greater and already valued in advance, but that at that time does not introduce impediments, allows to immediately furnish alternative indications, with great efficiency advantage for the solution method of the problem;
- if different vehicles that transport incompatible materials must effect the trip among the same couple origin-destination, in very close time windows, the possibility to have different paths that maintain a certain mutual distance among the vehicles contributes to decrease the total risk associated to their trips;
- the utility of the model increases in more marked way when the vehicles are numerous: the possibility to route them on different dissimilar paths contributes to the attainment of the spatial equity of the risk, "spreading" the latter in a more wide territorial zone; in this way one contributes to lower the risk for the external receivers, that are involved by a smaller number of passages of dangerous materials
- If some adverse atmospheric phenomena make the transit dangerous in determined arcs of the path it becomes important to be able to divert the itinerary followed by a vehicle and to make it to travel sufficiently far roads from the first ones, so that to bring it to the outside of the zone interested by the event preventing an uncontrolled increase of the time and the length of the trip.

We detect in the so called Iterative Penalty Method (IPM) the method that allow to reach the two purposes of the economic efficiency and the spatial dissimilarity: it conjugates the effectiveness to the greatest simplicity of employment, as experimental campaigns have verified. It has been defined and applied within the transport of dangerous goods by Johnson et to the. in 1992 [16]; among the most interesting applications we must to quote Ruphail [17] and Erkut [18].

The formulation of the IPM is based on a sequence of iterations in which an algorithm of search of the paths of least cost is employed in a road network. The procedure requires, beginning from the second iteration, to every step to increase of a fixed percentage the impedances of the selected arcs in the least walk detected in the previous step.

This shrewdness is introduced for having available, as final result, a series of meaningfully different paths each one from the other one to satisfy the demands above underlined. As it regards the penalization procedure, the followings aspects are to hold in consideration:

- penalized unity: the penalties can be applied to the arcs or to the nodes of a path already detected in the previous iteration or to both;
- structure of the penalty: an additive penalty can be used, adding a positive value fixed to the impedance value of the arcs or a multiplicative penalty, multiplying the current impedance for a factor greater than one; it is to notice that using a multiplicative function is possible to choose to apply it to the current impedance of the arc, that can have been already penalized in precedence, and to the original impedance;
- intensity of the penalty: if a value of the penalty is chosen relatively elevated, one discourages, in great measure, the further selection of the arcs already penalized; a lower penalty, on the other hand, favours the most frequent apparition in the following paths of the arcs already penalized;

One of the advantages of the IPM is the simplicity of employment, but some negative aspects also exist not to neglect: the arbitrariness of the choices related to the type and to the formality of penalization and the possibility of computational error due to the numerical instability of determined operations.

The list of the paths calculated by the IPM algorithm is subsequently valued by mean of the MAA to order them in function of the risk associated to every of them, through a method entirely analogous to that described for the risk mapping.

5.3. Decision Support Systems

A review of the scientific literature makes evident that two main research lines exist in the framework of Decision Support Systems (DSS) for the transport of hazardous materials: the first one relates to the risk assessment models, the other to the problem of selecting high security routes and to the scheduling of vehicles on such routes. Just recently a new research line is born concerning the hazmat transport network design.

5.3.1. Risk Assessment

As for the risk assessment issue, most of the papers published on this topic suggest probabilistic models that take into account the transported material and the transport modality [19], environmental conditions [20] and the routes employed. The analysis and assessment of the risk associated with the transport activities of hazardous materials (and wastes) were performed using various models [21]. In [22] the authors critically review the various definitions of risk and suggest an axiomatic approach to modelling, by underlining that some of the definitions derived from the literature can violate even apparently reasonable axioms. In general, the risk assessment is not neutral with respect to the choice of the minimum risk route selection model [23] and in some cases the definition of the risk function and the related model simultaneously occur [24].

Among the most useful tools aimed at the risk assessment we can find Geographic Information Systems (GIS). These systems, when integrated with suitable mathematical models for simulation of the dispersion of contaminants, allow to assess the risk associated with a potential accident on each arc of the transport network (see [25], [4] and [26]), taking into account the distribution of the population and the impact of a possible release of hazardous materials on the examined geographical regions. A recent overview on this research line can be found in [27].

5.3.2. Route Selection

Assuming the transport network as a graph characterized by a number of nodes connected by arcs, the problem of determining minimum risk routes is typically reduced to the search for special minimum paths on a graph. When for a given source-destination pair various travels are necessary, a question also arise on how to equally share the risk among the population. In this case not only the total risk should be minimized, but the risk should be also distributed in the most uniform way over all parts of the region involved in the transport of toxic-harmful materials by partitioning the transport flows on various routes.

This problem was addressed following various modelling approaches. For example, Gopalan et al. [28] proposed a model where an equitable distribution of risk is ensured by partitioning in various zones the geographical region involved in the transport activities and limiting per each pair of zones the difference of the risk induced on the population in the two zones. A similar approach was proposed in [29] where, further to determine the minimum total risk routes, the equity of risk is taken into consideration by suitably limiting the risk on the population living in the vicinity of the arcs of the transport network [29].

Another method for determining the minimum total risk routes that keeps considering also the equity of the risk is based on the search for spatially dissimilar paths. Various models have been proposed, also in different contexts than the transport of hazardous materials, in order to generate spatially dissimilar paths ([30], [31], [32] and [17]). Among these models it is worth mentioning the *Iterative Penalty Method* [17], which is based on the iterative application of minimum path algorithms: at each iteration of the procedure, a penalty is assigned to every selected arc in such a way to discourage the repeated selection of the same arc and generate in this way dissimilar paths. Other two methods proposed in the past are the *Gateway Shortest Path* [32] based on the generation of minimum paths, between one source and one destination, constrained to passing through specific nodes named "gateways", and the Minimax method [31], which selects the routes starting from k given paths, and using special dissimilarity indices. More recently Akgün et al [33] proposed another method to obtain dissimilar paths based on the generation of a large number of candidate paths and on selecting a sub-set of them through the use of a p-dispersion model [32] and [35].

[36] notice that computing the risk associated to a path, the probability of incident on a given link depends on the probabilities of all links leading up to that link. Hence, the incident probabilities on links are path-dependent. Although most papers use a simplification approximating by zero the products of incident probabilities, given the small magnitude of incident probabilities (usually on the order of 10^{-6} incidents per mile), however this problem can correctly faced by mean of suitable algorithms. The first algorithm shown in [36] is a modified version of Dijkstra's node-labeling shortest path algorithm. The second one is an adaptation of a link-labeling algorithm developed for the urban transportation.

While in most part of the papers mentioned hitherto the risk is evaluated in terms of the expected consequences in case of accident, and is therefore often expressed as the product of the occurrence probability of the accident multiplied by the number of people involved, in [37] a different definition is presented in order to build routing decision models able to prevent catastrophes. Indeed, since the catastrophes are events that have a low probability of occurrence although with very strong consequences, the previous decision models are, in these extreme cases, scarcely effective. In particular, in [37] three models are presented: the first minimizes the maximum exposure of the population, the second takes into account the variance of the consequences on the various paths and finally the third one bases on an explicit disutility function. All three models can be reduced to a problem of minimum path and were tested on realistic examples.

The objectives pursued in the transport of hazardous materials do not include only the reduction of the risk, but also a limitation of the costs of transport, the minimization of the route length, etc. In this picture, approaches based on multi-objective models were proposed for identifying optimal paths from a given source to a given destination. Cox [38] proposed a multi-objective algorithm for the search of the minimum path in the transport of hazardous materials with different attributes associated with the arcs of the network, including: travel time, population density, etc. Wijerante et al. later proposed [39] a method applied to networks with stochastic attributes associated with each arc of the network. Recently, Dell'Olmo et al. [40] proposed a two phases multi-objective approach where, in the first one a set of Pareto-Optimal paths is determined, using a multi-criteria algorithm for the search of minimum paths, and in the second one a subset of spatially dissimilar paths is selected using a p-dispersion algorithm.

A minor attention was devoted instead to the study of integration of decisions about the selection of the routes and the scheduling of vehicles for the transport of toxic-harmful substances, i.e. the study of models able to simultaneously assign routes and starting times to the vehicles. This need raises from the fact that risk data are in general a function of time, especially in case of long-distance transports. The problem of combining routing and scheduling was addressed for the first time in [41] where a model was introduced that includes the starting times in such a way to minimize the delay due to temporary restrictions on parts of the transport network. The same kind of problem was later studied also in [42] where the authors developed an algorithm for multi-objective routing in time variant transport networks. A bibliographic review of this type of studies presented in the literature until 1991 can be found in [43].

5.3.3. Hazmat Transport Network Design

While most of the scientific literature on the hazardous material transportation hitherto focus on risk assessment, routing and scheduling of vehicles, only recently the researchers are taking into consideration the hazmat transport network design problem. In this problem, instead of looking for a set of minimum risk routes, we want to decide which roads have to be forbidden to the hazmat transportation, leaving the carrier free to choose its favourite route in the resulting network. The problem has been faced for the first time in [44] where a bi-level programming formulation is presented for planning such a network with the aim of minimizing the total risk for the involved population. This is a bi-level problem in that two distinct decision makers are involved: the government and transport companies.

The first decision maker can determine the roads where the transport of hazardous materials is prohibited, while the second decision maker can arbitrarily choose the path they wish to follow over the resulting transport network (*hazardous-network*). As an objective of the government, the minimization of the risk intended as the exposure of the population is here considered. Obviously it would be possible to consider other objectives such as the reduction of the total probability of accidents. The assumed objective of the transport companies is instead the minimization of the operational costs and the assurance costs.

Note that in this context the government has a dominant position since it acts as the legal authority while the transport companies must adhere to its regulations to be able to continue performing their operations. Therefore the problem of designing a transport network for hazardous materials is formulated by means of two integer linear programming problems, one embedded in the other. These problems are transformed into a single mixed non-linear integer programming problem that is later linearized, originating a linear model with binary variables that can be solved using a commercial solver.

More recently the same problem has been also faced in [45] where before a generalization of the bi-livel program model to undirected graph is presented. Moreover, since such model is often hard to be solved and can become ill-posed, a heuristic method is proposed to find a stable solution exploiting the network flow structure.

Experiments on real world data show that while the linearization of bi-livel model often fails in finding stable solutions, the heuristic algorithm finds networks having least risk value in less time. Additional experiments on random instances show that although the solution obtained are not optimal, however they are very close to be so having an average gap of 2%.

An easier version of this problem, where the road network is a tree, has been considered in [44]. This more restrictive hypothesis offers the advantage that in the road network there exists exactly one path between each origin and each destination: in such a way the second decision level is removed, since the transport companies have no alternative path. The problem is formulated through an integer program model where the objective is the minimization of the total transportation risk. Such a model can be solved on moderate size instances by means of commercial solvers. Moreover a simple construction heuristic to expand the solution of the tree design problem by adding roads links is developed always in [44]. In such a way the assumption of tree network is relaxed for yielding to the transport companies alternative paths. Although with this procedure we expect the transport costs decrease, instead the risks could increase or decrease. Therefore the heuristic algorithm adds paths incrementally, which allows local authorities to trade off risk and cost.

5.4. Telecontrol

The telecontrol macrofunction allows to observe, control and analyse each transport operation while it is carried out. It can be divided into two main functions: monitoring and management of anomalies.

5.4.1. Load tracking - Monitoring

This function allows to remotely control hazardous materials during transport by means of vehicle *tracking* and *survey* of the load integrity by analysing data transmitted by onboard devices.

A monitoring function shall also be applied to transport networks and their services in order to get constant and updated information on their conditions.

The analysis carried out while monitoring allows to check the consistency of data transmitted by several devices, to validate load conditions, to detect any deviation from the route defined during the planning phase, and to analyse the risks caused by both the proximity of a vehicle to other vehicles transporting hazardous materials and by the conditions of the area to be crossed.

5.4.2. Route control

This function allows to check that a vehicle does not make a detour exceeding a given range from the route defined during the planning phase, every time tracking data are sent. If the detour is relevant, its proximity to particularly sensitive points is also checked, as these would make the consequences of any accident even more serious due to their infrastructural or environmental characteristics.

In order to check this, data sent from vehicle monitoring shall be compared with the display of the predefined route and with the mapping of sensitive points.

Cases when a detour from the predefined route is relevant and the proximity to sensitive points is excessive are detected as anomalies, and the relating function is therefore activated.

5.4.3. Validation of vehicle and load conditions

This function allows to analyse data on load and vehicle conditions that are sent by onboard sensors, to check if they describe an anomalous and potentially dangerous situation on the vehicle, and to timely send information on the occurring anomaly to the anomaly management function. This can prevent any dangerous situations or activate rescue operations to reduce any effects on the environment and the people as quickly as possible.

Based on the information sent from vehicle monitoring, this function can detect two different types of an anomaly:

- instant survey of an accident occurred to the monitored vehicle;
- survey of anomalous conditions of the vehicle and/or load that may foreshadow an accident. For example, an accident caused by the excessive speed of a vehicle with respect to the road it is travelling on, a fire caused by the overheating of brakes, the explosion of the tank because of an increase in the pressure of the load, etc.

Sending timely information is crucial to manage emergencies, and it can often prevent an accident that is not particularly serious from turning into a disastrous event. Whenever controls point out dangerous situations, the function detects an anomaly and activates the specific function.

5.4.4. Run-time risk analysis

During a journey, safety conditions on a defined route may vary and become unsuitable. Particular events that cannot be foreseen during the planning phase may change the conditions of the road network, for example traffic congestion, accidents, hold-ups caused by landslides, adverse weather conditions, concentration of vehicles carrying hazardous materials.

The *run-time* risk analysis allows to check the practicability of a road network based on its functional and environmental conditions that were supposed during the phase of risk prevention analysis, and to verify any negative re-occurrence of significant variations that may considerably affect transport risks during the journey.

Every time tracking data are sent, the function analyses the risk caused by the proximity of the vehicle to other vehicles carrying hazardous materials, as well as the risk due to the conditions of the area to be crossed. If these controls point out a risk level exceeding a predefined threshold, the function of anomalies and alarms management will be activated.

5.4.5. Management of anomalies – Operation protocol

This function manages any anomalies and risky situations by providing, if possible, useful information to solve the problem, for example by sending messages to the driver throughout the COP (Operation Centre), by re-planning the journey, by alerting the system operator, etc. If required by the anomalous situation, it also activates the emergency management phase.

By monitoring a vehicle, it is possible to detect any anomalous situations that may lead to an emergency or point out events leading to critical circumstances.

It is difficult to choose the parameters to survey in order to achieve a sufficiently reliable control of the risks of a transport; the telecontrol of a great number of parameters considerably increases the quantity of data to manage and the cost of communication. It also increases the possibility to run into false alarms, thus slowing down a transport and uselessly alerting both the operation centre and rescuers.

It is therefore necessary to identify those elements which are worth monitoring, and to define for each of them a series of additional information to check that the message sent is no false alarm; for example, the activation of the tilting sensor will only be credible if the speed of the vehicle becomes null.

The parameters that can be telecontrolled by the control centres can be grouped into the following categories:

- telecontrol of the vehicle:
  - sudden and instant (crash) stop or tilting, respectively detectable by the activation of the accelerometer or inclinometer,
  - parameters of the journey of a vehicle: speed, temperature of brakes and other safety-relevant functions,
  - load conditions: temperature, pressure, level, possible leaks;
- interaction vehicle-territory-road network:
  - proximity to particularly sensitive points, for example tunnels or urbanized or densely populated areas,
  - proximity to other vehicles that have broken down or prove dangerous because of the hazardous materials they carry,
  - proximity to points that are considered at a high risk by the risk analysis,
  - presence of particularly intense weather conditions,
  - presence of accidents or road works,
  - situations of environmental instability in progress.

5.4.5.1. Anomalies pointed out by the telecontrol of a vehicle

The following anomalies can be surveyed on a vehicle:

- diagnostics of an emergency in progress:

  - accelerometer: it activates at every sudden and instant deceleration of the vehicle; the sensor is calibrated not to activate after braking with no following crash; to validate the state of emergency it may be useful to check whether the vehicle is actually stopped and to contact the driver; if the critical situation is validated, the vehicle shall be surveyed to draw the data necessary to manage the emergency, such as the temperature and pressure of the load, as these parameters can describe the seriousness of the emergency in progress,
  - inclinometer: the same considerations made for the activation of the accelerometer apply;
- diagnostics of events foreshadowing an emergency of a vehicle; one of the following parameters exceeds a threshold value: temperature of brakes, speed of the vehicle;
- diagnostics of events foreshadowing an emergency of a load; one of the following parameters exceeds a threshold value: temperature of the load, pressure of the load;
- transmission of anomalies by the driver: failure of elements of a vehicle which are not monitored, anomalous event of a load, dangerous travelling conditions after external events have occurred.

5.4.5.2. Alert signals surveyed by the SW at the operation centre

Anomalies that may occur on a network are surveyed by several monitoring sources activated by the CCCs (Control and Coordination Centre). This information may come from vehicles transporting hazardous loads or other sources, for example from traffic information services that are agreed with the system operator. It may also be produced by routine controls carried out by the monitoring software. Timely providing the following information proves particularly useful:

- data sent from other vehicles: a vehicle approaching another vehicle carrying hazardous materials that has broken down;
- anomalies transmitted by drivers of telecontrolled vehicles: accident limiting the use of a road link, particularly relevant weather conditions;
- anomalies surveyed by the monitoring SW: a vehicle approaching a tunnel that cannot contain it, based on the results of the risk analysis, a vehicle approaching an area that is considered at a high risk, a vehicle approaching particularly risky points, proximity of hazardous loads on the same route;
- anomalies surveyed on other information that is collected by the operation centre: a vehicle approaching road sections that are closed for road works, a vehicle approaching congested road sections, a vehicle approaching areas where adverse weather conditions are particularly intense, a vehicle approaching areas where a hydrogeological disruption is active, a vehicle approaching areas where emergency operations are in progress because of road accidents or civil protection emergencies.

5.4.6. Display of anomalies

The operator at a CCC must be immediately alerted when an anomaly occurs on a telecontrolled vehicle.

In particular, the operation protocol must provide for several operations to be performed for each anomaly. However, in order to immediately identify the emergency level to face, surveyed anomalies shall be divided into 4 different alert level that the SW displays in different colours and with increasing importance.

Furthermore, for the most serious emergencies acoustic signals shall be provided to draw the operator's attention.

	Anomaly	Additional info	
VEHICLE	Sudden deceleration	Speed	Alert 4
	Non-allowed inclination	Speed	Alert 4
	Overtemperature of brakes	Communication with the driver	Alert 3
	Failure of the tractor	Communication with the driver	Alert 3
	Anomalies transmitted by the driver	Communication with the driver	Alert 3
	Non-allowed speed	Communication with the driver	Alert 3
LOAD	Overtemperature of the load	Communication with the driver	Alert 3
	Overpressure of the load	Communication with the driver	Alert 3
NETWORK	Proximity of hazardous loads on the same route	Communication with the driver	Alert 1
	Accident limiting the use of a road link	Communication with the driver	Alert 2
	Particularly relevant weather conditions	Communication with the driver	Alert 2
	Vehicle approaching a tunnel that cannot contain it	Communication with the driver	Alert 2
	Vehicle approaching an area that is considered at a high risk	Communication with the driver	Alert 1
	Vehicle approaching particularly sensitive points	Communication with the driver	Alert 1
	Vehicle approaching road sections that are closed for road works	Communication with the driver	Alert 2
	Vehicle approaching particularly congested road sections	Communication with the driver	Alert 1
	Vehicle approaching areas where a serious hydrogeological disruption is active	Communication with the driver	Alert 2

Figure 6. List of alarm conditions where the alert levels are highlighted.

5.4.7. Emergency levels

The several anomalies can be classified from the lowest to the highest alert according to the following emergency levels.

- Level 1: it does not require any particular operation by the operator, but it draws his attention since the telecontrolled vehicle is in a particularly risky situation. For example, it is approaching a road section at a high risk or a tunnel . During this alert level the SW must increase the monitoring frequency and collect additional information with respect to a normal situation: direction of the vehicle, speed of the vehicle, pressure and temperature of the load.
- Level 2: it requires the intervention of an operator who, according to the procedures provided by the operation protocol, must suggest instructions to the driver, throughout the COP, about the behaviour to adopt. The SW must in particular carry out the same operations defined for level 1 while adding the following interventions: looking up the cartography of sensitive points, looking up the cartography of areas where the vehicle can stop, opening the processing modules to manage level 2, opening the communication modules with the COP or the vehicle.

Alert 1	Direction of the vehicle Speed of the vehicle Characteristics of the goods transported
Alert 2	Direction of the vehicle Speed of the vehicle Pressure and temperature of the load Position and characteristics of sensitive points Position and characteristics of areas available for the vehicle to stop Data sheet of the substance
Alert 3	Direction of the vehicle Speed of the vehicle Pressure and temperature of the load Position and characteristics of sensitive points Position and characteristics of areas available for the vehicle to stop Data sheet of the substance Quantity of the product that is present in the tank Characteristics of the impact area provided by the SW Position of vehicles transporting hazardous materials within a safety distance
Alert 4	Direction of the vehicle Speed of the vehicle Pressure and temperature of the load Position and characteristics of sensitive points Position and characteristics of areas available for the vehicle to stop Data sheet of the substance Quantity of the product that is present in the tank Characteristics of the impact area provided by the SW Position of vehicles transporting hazardous materials within a safety distance Communication masks provided by the operation protocol

Figure 7. Information to collect on the several alert levels.

- Level 3: it requires the intervention of an operator who, according to the procedures provided by the operation protocol and by the intervention protocol, must suggest instructions to the driver, directly or throughout the COP, about the behaviour to adopt, as well as inform rescuers about the risky situation that is occurring. According to their internal procedures, they shall therefore be able to activate the pre-alarm state and, if necessary, to send a rescue team to carry out operations that make the area around the vehicle safe. The SW must collect the information required by rescuers and transmit it according to the ways provided by the intervention protocol. In particular, besides operations provided at previous levels, it must be able to manage the following information: data sheet of the substance, quantity of the product that is present in the tank, temperature inside the tank, pressure of the substance in the tank, impact area calculated with the SW that displays it, position of vehicles transporting hazardous materials within a safety distance from the damaged vehicle[2], communication masks provided by the operation protocol.

[2] The value will be defined based on the results of the risk analysis.

	Anomaly	Required data
VEHICLE	Sudden deceleration	Signal detected by the accelerometer
	Non-allowed inclination	Signal detected by the inclinometer
	Overtemperature of brakes	Signal detected by the thermometer
	Failure of the tractor	Signal detected by the onboard diagnostics
	Anomalies transmitted by the driver	Communication with the driver
	Non-allowed speed	Signal detected by the tachometer
LOAD	Overtemperature of the load	Signal detected by the thermometer
	Overpressure of the load	Signal detected by the pressure gauge
NETWORK	Proximity of hazardous loads on the same route	Position of the vehicle Position of all monitored vehicles
	Accident limiting the use of a road link	Position of the vehicle Information from other monitored vehicles Information from the operation centre
	Particularly relevant weather conditions	Position of the vehicle Information from other monitored vehicles
	Vehicle approaching a tunnel that cannot contain it	Position of the vehicle Information from the cartographic database Results R.A. tunnels Information from the tunnels control centres
	Vehicle approaching an area that is considered at a high risk	Position of the vehicle Results of the analysis and risk mapping
	Vehicle approaching particularly sensitive points	Position of the vehicle Regional sensitive points cartography
	Vehicle approaching road sections that are closed for road works	Position of the vehicle Information from the operation centre
	Vehicle approaching particularly congested road sections	Position of the vehicle Information from the operation centre
	Vehicle approaching areas where a serious hydrogeological disruption is active	Position of the vehicle Information from the operation centre

Figure 8. Data to collect on each anomaly

- Level 4: it indicates a serious emergency. In this case the SW and the civil protection operator must provide all the information required by rescuers to minimize the impact on operators, on the people nearby and on the environment. First, the SW must alert rescuers according to the procedures provided by the operation and intervention protocols. It must provide them with the following information: ADR class and UN no. of the substance transported, safety data sheet of the substance, quantity of the product that is present in the tank, temperature inside the tank, pressure in the tank, impact area calculated with the SW that displays it. Meanwhile the SW must gather the following information that is necessary to validate the anomaly detected and to verify that it is no false alarm: speed, direction.

5.4.8. Redefinition of routes

This function is applied when safety conditions on the defined route vary and become unsuitable, for example if unexpected events change the practicability of the road network.

In these cases this function finds and suggests an alternative route starting from the current position of the vehicle, which therefore becomes the new origin of routes to define, up to the destination.

In order to speed up replanning operations, the function uses simplified versions of the IPM (*Iterative Penalty Method) and of the* AMA (*Analisi Molti Attributi, Analysis of Many Attributes*), which have already been used for similar functions during the planning phase. It then points out the sections of the road network that, for any reason, cannot temporarily be used by the vehicle. The new route is therefore communicated to the COP and then to the driver and to onboard devices.

If it is not possible to find a sufficiently safe route, the driver is required to stop in a parking area and to wait for the conditions making the risk of his transport unacceptable to cease.

6. Rescue and management of emergencies

6.1. Alarm management – Intervention protocol

In case an event is detected that requires intervention by the rescuers, the macro-function of the activation and support to the emergencies on the one hand alerts the institutions in charge while on the other hand, thanks to a detailed knowledge of the load characteristics acquired before departure, its status continuously detected during monitoring and the road conditions and transport network security, supports the competent authorities in the efficient and prompt management of rescues and protection actions, making available those information that is useful to the management of the intervention.

6.1.1. Activation of the Competent Authority

In case of emergency, i.e. the occurrence of an event that requires the intervention of rescuers, this function will activate as quickly as possible the competent authorities by providing the basic information about the event: event type, vehicle, location, time, type and amount of transported goods.

The rescuers alerting procedures should continue with transmitting the alarm to the rescuers, typically the Fire Brigades, using the following informative instruments:

- SMS sent to the mobile phone of the responsible person on duty at the operational rescue centre;
- E-mail sent to the e-mail address of the operational rescue centre;
- TeleFax sent to the number of the operational rescue centre,
- Telephone communication to the operators of the operational rescue centre.

It can be anticipated that, further to the responsible of the rescue operations, even the manager of the infrastructure and the transportation company owning the involved vehicle are informed of the event.

A prototype of the emergency activation system was tested directly with the responsible people for the rescue operations in the course of an experiment performed in 2004 in the Province of Lecco[3].

6.1.2. Information management

This function makes available to the competent authorities all useful information for the management of rescue operations that are not included in the initial activation message. The information categories provided are:

- Information about the transported product: very useful to guarantee that rescues are rapid and safe is the prompt diffusion of understandable and

[3] See the description of the TRAMP Project illustrated in section 7.

comprehensive instructions about the operations to be performed among the operators that will take action on the accident's site. This function makes available to the competent authorities the technical specifications of the product related to the dangerous goods involved in the rescue operations, which contain detailed information on the hazards connected with the dangerous material and the procedures to be adopted to handle it.

- Information about the transportation: this makes available to the competent authorities complete information about the specific transport involved in the rescue operations: type of transported materials: type and quantity of goods, type of container, etc., characteristics of the vehicle and the devices installed on board, general data about the driver and the transportation company: addresses, contact telephone numbers, etc.;
- Cartographic information: in order to efficiently manage the rescues it is necessary to know thoroughly the territory of interest. Such knowledge allows understanding the type of the evolving accident scenario, anticipating the possibility that the current accident could trigger the superposition of the effects and approximately evaluating the portion of the population that is prone to the risk. This function makes available to the competent authorities the thematic cartography of the area covered by the rescue operations. This cartography includes the information related to: population density, land use, sensitive sites (high risk industries, schools, hospital, …).
- Context related information: this function makes available to the competent authorities the information about other transports of dangerous goods that may be present in the area covered by the rescue operations, for instance the position of the vehicles and the transported goods.

6.2. Transport Emergency Service (SET)

Federchimica promotes the implementation of the Transport Emergency Service, called SET[4], which is able to intervene in case of accidents occurring during the transportation of chemical products, with 3 possible levels of intervention:

- level 1: information about the involved chemical products,
- level 2: mobilization of a qualified engineer on the accident site,
- level 3: mobilization of a company emergency unit on the accident site.

At present, the SET can be activated by calling a dedicated phone number set up at the *National Response Centre* attended 24 hours/day for 365 days/year.

The National Response Centre, situated in Porto Marghera, takes care – upon request from the public competent authorities and after consulting the SET database – of identifying a company contact point that is able to provide information about its own products (level 1) as well as, based on specific criteria connected to the nature of the involved product and to the geographical proximity to the accident site, the contact point to be called for mobilizing a qualified engineer (level 2) and/or an emergency unit (level 3). The SET must be activated upon formal request by the Regional Inspectors and/or the Province Headquarter of the Fire Brigades that is institutionally competent for the management of emergencies.

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[4] SET was created in January 1998 through an agreement between Federchimica, the Ministry of the Interior and the Department of Civil Protection and envisages the voluntary participation of the companies affiliated to Federchimica [47].

Federchimica, through the SET, makes available to the public authorities in charge and based on the knowledge available, the following elements:

- information about the nature of the transported dangerous materials;
- indications about the intervention modalities, the precautions to be adopted in case of accidents, following fires, spreading of a toxic clouds, etc., and the first aid procedures;
- indications about the protection measures to be used;
- contribution of experts and emergency units from the chemical companies that made themselves available for this kind of support;
- supply of specialist equipment for performing the interventions;
- acquisition, whenever possible, of information about the products from other ICE Response Centres in European Countries that are activated from the National Response Centre.

The companies participating in the SET framework with their own engineers and intervention units only operate as a support and upon request of the public authorities that remain therefore the sole subjects responsible of the emergency management and the interventions undertaken, with no burden nor responsibility chargeable to the companies themselves.

With the implementation of a tracking system, the experts of SET will not only communicate with the Fire Brigades, but the processing of information could be possibly envisaged by involving the CCC in the role of activating the emergency.

7. An application: the TRAMP project

7.1. Preface

The TRAMP project – Remote Hazard Control in Road Transportation of Dangerous Materials was carried out by the Polytechnic[5] of Milan in two phases. During the first phase, named *Mapping the multi-modal transportation system – Pilot project for a tracking system of dangerous loads* and developed in the years 1996-1998, [47] and [49], the problem of the transportation of dangerous materials was addressed, and after identifying the available instruments and technologies for hazard prediction and prevention the general architecture of the TRAMP system was defined, together with its organisation and functional structure. During the second phase, named *Prototype of a system for hazard prevention and control in the road transportation of dangerous substances* and developed in the years 2000-2002, [12], [50] and [51], the operational procedures have been prepared and software programmes and technological equipment have been developed that altogether constitute the prototype of the TRAMP[6] System.

The customer of this research was the National Group for Prevention of Chemical-Industrial and Ecological Hazards (GNDRCIE) of the CNR, contracted by the Department of Civil Protection [3].

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5 The structure in charge for this research at the Polytechnic of Milan is the Transport Section of the Department of Transportation and Handling Systems, replaced since 2001 by the Transportations and Mobility Laboratory, affiliated to the Research Unit DIS – Mobility System of the IN.D.A.CO. Department.

6 The scientists in charge for this research were Claudio Podestà and Pietro Mengoli during the first three years and Roberto Maja in the next three years. The Operative Unit was composed of: Elena Caprile, Giovanna Marchionni, Giovanni Rainoldi, Luca Studer, Daniele Vaghi, Giovanni Vescia.

Consistently with the philosophy that has been accompanying every step of this research, the main pursued objective was that of providing actually usable instruments, keeping low the installation and implementation costs and paying special attention to the acceptability of the various instruments by the operators involved in the transport and management of the emergencies.

The TRAMP system was tested in the field in Lecco on May, 4th 2004 by involving two vehicles made available by Daimler-Chrysler Mercedes-Benz, the Atego tarpaulin covered lorry and the Actros van, suitably equipped with the technological apparatuses developed within the project in collaboration with the Alasat company in Milan.

Testing of the TRAMP project was made possible by the cooperation among numerous subjects, involved at various rights in the activities related to the transport of dangerous materials. This had the objective of verifying the interactions that transport may determine with the natural and anthropic environment, and especially the management of the emergency interventions to be adopted in case of accident. The following institutions took part in the testing: Department of Civil Protection – General Directorate for Large Impact Events, Prefecture of Lecco, Provincial Administration of Lecco, National Research Council – National Group for Prevention of Chemical-Industrial and Ecological Hazards, Regional Base in Lecco of the Polytechnic of Milan, and the provincial bureaus of Fire Brigades, Road Police and the 118 Operational Centre.

7.2. Structural characteristics of the system

TRAMP is a complex system, composed of technological and modelling elements and organised on two levels:

- institutional, managed by the Control and Coordination Centres (CCC), with the function of predicting and preventing the hazard as well as supporting the management of the emergencies;
- operational, assigned to the Peripheral Operative Centres (COP) already existing within the transportation companies or in special service companies, with the delegation for continuous control during the transport and the assistance to the drivers.

The *Control and Coordination Centres* (CCC) represent the focal point of the system and the most innovative aspect envisaged in the TRAMP project; their role is that of performing the forecast of hazards associated with the transportation activities of dangerous materials, and to define prevention actions for possible accidents[7].

At the present state this function is performed by the Prefectures just for a few classes of dangerous materials, in particular for explosives, or in relation with some regional areas that are prone to relevant risks of accident.

The introduction of the CCC would extend the application to a larger number of dangerous materials throughout the national territory and would provide the institutions with suitable information and decisional tools for hazard prediction and prevention and the efficient management of the emergencies.

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7 What is only mentioned here in a general way, so as to avoid weighing down the coverage with useless repetitions, is dealt with in details in the Final Report 1998 [49], as for the architecture and the system's functions, and in the Final Report 2000 [12], as for the dimensioning of the CCC and the models for risk analysis.

The CCC therefore assumes a role of decision and coordination of the activities concerning the transport of dangerous materials.

A few external conditions, such as the wide spread of the road network, the number of vehicles every day operating in the transportation of dangerous materials and the huge amount of data requested for an efficient assessment of the risk associated with a given load, led us to plan the presence of various CCCs, each of them with competences over a given territorial area, and to delegate most of the functions of the CCCs to lower level centralized centres, directly connected with the vehicles: the *Peripheral Operative Centres*.

At present, *Peripheral Operative Centres* (COP) can be identified in two different, though functionally similar, subjects: the internal structures that are already part of the equipment of many large size road transportation companies and used to manage fleets, and the companies offering anti-theft services, security, remote communication, management of fleets on behalf of those road transportation companies that are not able to implement their own situation rooms[8].

Their main function is that of establishing direct contacts with the vehicles, a function that does not require any decisional responsibility and institutional authority. The COP is therefore assigned the ordinary tracking activity of vehicles, while all about the hazard prediction and prevention activities, as well as the activation of the emergencies, concerning the tasks of Civil Protection are performed by the CCC.

The functionality of the system assumes that continuous contact is maintained in real time between the CCC and the COP.

The above described structure is in line with the recent regulatory trend, at both the national and international level [9], [52], [53] and [54], where the companies are assigned an increasingly important role in the framework of security[9], and allows moving in the direction of a direct involvement of road transportation companies in the vehicles tracking operations.

The vehicle transporting the dangerous materials is the source of the risk and the most susceptive element to design interventions.

In the framework of the TRAMP System the vehicle used for transportation of dangerous loads is equipped with devices suitable for its localization and the transmission of data. Basically, the on-board equipment must include the following components [54]:

- a localisation system able to estimate, with a proper degree of precision, its geographical position;
- all sensors needed to control the status of the load by measuring some characteristic parameters: temperature, pressure, level, etc., as a function of the type of the transported material; the collected information must be sent to a proper on-board control unit suitable for recording and storing the information;

8 This is the case for companies owning a limited number of vehicles, down to the limiting case of *owner-drivers*, i.e. only made of the driver and its vehicle. The owner-drivers cover a relevant portion of the overall goods transportation in Italy and, to a lower extent, of the transportation of dangerous goods.

9 The introduction of the figure of the Responsible Person for Security (or the Consultant for Security) is emblematic in that sense. The Directive 96/35/CE [55] provides for the need for all companies operating in the field of dangerous materials, either performing the complete transportation or participating in the loading and unloading operations, to be equipped with one or more responsible people (or consultants) for security, who must keep watch on the compliance with regulations and prepare a report on the activity of the company itself, to be made available to the authorities in case of possible inspections.

- a deceleration sensor, which in case of an instantaneous reduction of the velocity, clue for a collision, stops the fuel flow and activates an alarm;
- an inclinometer, a device that allows recording possible anomalous inclinations or overturning of the vehicle;
- telecommunication devices, required for the exchange of information and messages between the vehicles and the respective COP, first of all the position and the alarms.

The control unit receiving the on-board sensor information must be able to send pre-coded alarm messages to the COP, or directly to the CCC, following the detection of anomalous values of the variables allowing to trace the status of the load or mean.

7.3. Testing

The field testing performed in Lecco on May, 4th 2004 was the fist test bench for the Project, where a few accident events that are typical of the transport of dangerous materials were addressed using computer technology tools, operational procedures and various technological components suitably created in the course of the research. The objective of the test was to verify the effectiveness of results, so as to introduce possible correction elements as possibly coming out [56].

The simulation of the emergencies allowed to verify the correct flow of information between the Control and Coordination Centre and the involved institutional subjects, Fire Brigades, Road Police, 118, and the optimization of the times of intervention, also facilitated by the information provided to the rescuers by the software running on the TRAMP Server.

The contribution of two private companies was decisive. ALASAT SpA, specialized in the development of technological systems for the management of fleets, provided the CoAla control unit installed on-board the vehicles. This allows the vehicle to communicate during the travel with the control units, COP and CCC, and was equipped with new communication protocols that can be read and displayed by the localization software, the TRAMP Server, and equipped with a basic set of sensors that allowed to manage a few types of accidents: impact and overturning.

The Daimler-Chrysler Mercedes-Benz company did not only provided the essential supply of two commercial Mercedes vehicles, Atego and Actros, but also took care of installing on these vehicles the pressure gauge, installed inside the transported load, a sensor for the opening of the hatchback and the CoAla control units, realized by Alasat for the localization of the vehicles, load control and data communication with the CCC. The Actros vehicle was equipped with the Telligent Stability Control (TSC), a device that detects and opposes the skid and derapage risk operating in a targeted way on the engine torque, on the single wheels and on the control of the braking system.

The verification of the time necessary for automatic detection of the accident events, forwarding of the alarms to the rescuers and for the prompt and targeted intervention of these latter with respect to the class of dangerous materials present on the vehicle was the most relevant element of the testing. The TRAMP System demonstrated to be able to provide a significant contribution to the institutional operators in charge of the rescue operations and the management of emergencies by plugging a gap that characterizes the current situation.

The presence of transport operators connected to the TRAMP system would allow the public authority in charge of the realization and management of the Control and Coordination Centre to achieve the following results:

- to know in real time the number, position and behaviour of the vehicles;
- to be promptly informed about the coming out of possible hazard conditions, for instance: the high concentration of dangerous loads in restricted regions, the possibility of faults on board the vehicles, the possibility of critical conditions related to the transported loads;
- to act quickly and efficiently in case of any serious accident;
- to provide the transportation operators with updated information about: accidents occurred to other vehicles, closures or delays along the route, formation of adverse meteorological conditions and a high risk of accident.

8. Conclusions and open problems

We want now to draw some conclusions about the arguments faced in the previous paragraphs and emphasize the open problems.

Although the hazmat transportation is disciplined for a long time by the ADR (European Agreement concerning the International Carriage of Dangerous Goods by Road), however it only concerns passive measures related to the vehicles but it does not prescribe provisions to adopt during the trip. Indeed, at present, as soon as a vehicle leaves the originating plant and starts its travel, its traces are lost until the arrival at the final destination. Therefore the ADR ignores that a vehicle transporting any dangerous load is subject, along its travel, to the same accident probabilities suffered by all other heavy vehicles, but furthermore it can be the reason of anomalous events occurring to the container or to dangerous load. Moreover, in case of involvement into an event originated from the exterior, the presence of the dangerous substance may considerably exacerbate the consequences of the event on people, on the environment and on infrastructures.

Therefore we need carry out interventions for the risk mitigation through suitably designed and planned technological equipment and organisational measures.

Although, many projects devoted to risk prevention and the rescue operation to be adopted in case of accident have been prepared and tested both in Italy and in other countries, however strong improvements concerning both methodological and organisational aspects for the prediction and prevention of the risk, are still possible.

In particular, the possible lines of action aimed at risk mitigation should be especially oriented to the actions listed below:

- the preventive analysis of the risk associated with each single transportation activity of dangerous goods and the planning of travels, by assigning each travel to the route that minimizes the risk of accident in both its components, probability and consequences;
- the detection (or monitoring) and real time supervision of the vehicle and the transported load during the whole travel;
- the activation of suitable rescue procedures to be adopted in the event of an accident.

From the structural and operational point of view, a tracking system should base on the presence of three basic elements:

- Control and Coordination Centres (CCC), where prediction and prevention of the risk is performed, travels are planned, the running of transportation activities is supervised and support is provided to the management of emergencies by alerting the bodies in charge of rescue interventions;

- Peripheral Operational Centres (COP), where continuous control is exerted on the vehicle and its load during transport, assistance is provided to the drivers and communication is maintained with the CCC in order to provide them with all the necessary information;
- the vehicles transporting dangerous loads; these must be equipped with on board systems able to define their position (for example using a GPS), to detect their operational conditions and the integrity of their load, to communicate with the COP and possibly with the CCC to inform them about their status and to receive operative indications or special instructions to be comply with during their travel.

Concerning to the trip planning problem the Operations Research constitutes an effective methodological tool. First it supplies risk assessment models that allow to order the path according to their dangerousness, also without quantitative estimations because of the rarity of the events considered. Moreover algorithms for solving different aspects of hazardous material transportation are developed in the Operations Research field: from the computation of Pareto-Optimal paths with respect to the risk and cost criteria, to the combined routing and scheduling problem. Finally, concerning to the applications of Operations Research to the hazardous material transportation, recently a new research line is born: the hazmat transport network design problem. This approach restricts the planning of the paths just to the more dangerous cases, leaving the carrier free to choose its favourite route in the resulting network preventing it from travelling on roads with huge risk.

According to this criterion, also defined during the development of the Tramp Project and quoted in [57] and in technical reports [49] and [51], three different levels of risk can be identified. In the low level case the carrier is free to travel the paths that it considers more convenient. In the medium level case the forbidden roads are indicated to it. In the high level case the carrier is obliged to travel according to an established path having least risk.

At present, these problems are object of study of Operations Research with the aim to detect the more suitable algorithms.

Before concluding it is important to quote a further aspect of the transport of dangerous goods that strongly increases the risk of it: the transit in the long galleries. When a dangerous load travels inside a tunnel the probability of accident it is similar to that that he finds under the other conditions, but the consequences of an accident can assume catastrophic entity, as some tragic events have recently shown.

This problem has been studied in the Tramp Project, see [58], and it has been object of particular attention in the SNSTMP Project [11] and [59].

Currently two normative provisions that concern the safety of the galleries exist. The directive UE 54/04 [55] imposes that the tunnels are submitted to the analysis of the risk to appraise its safety level so that the index of risk does not overcome a determined value of threshold. The edition 2007 of the ADR [53] defines the criteria of classification of the tunnels in five classes of risk, to every of which a determined transit restriction of dangerous loads corresponds according to the belonging ADR class. Moreover the same normative imposes that, in the cases of forbidden transit, some alternative paths with inferior risk are defined.

The elements above underlined represent a further field of application of the methods of analysis and prevention of the risk described in this work.

References

[1] P. Mengoli., R. Maja., “Rischio trasporti - Lineamenti progettuali per il controllo dei carichi pericolosi”, CNR GNDRCIE, Atti del Seminario Unità Operative, pag. E11-E21, Roma, 1998.
[2] B. Mazzarotta., “Sviluppo di Linee Guida per la valutazione del rischio nel trasporto di sostanze pericolose”, CNR GNDRCIE, Atti del Seminario Unità Operative, Roma, 1998.
[3] CNR Unità Operative linea E: Di Cave S., Donat S., Leonelli P., Maschio G., Mazzarotta B., Mengoli P., Podestà C., Spadoni G., Relazioni Semestrali sullo Stato di Avanzamento e Relazioni Finali, Dipartimento nazionale della Protezione Civile e CNR GNDRCIE - Linea E, Roma, Varie annualità.
[4] R. Bubbico, S. Di Cave, B. Mazzarotta, “Risk analysis for road and rail transport of hazardous materials: a GIS approach”, J. Loss Prev, Proc. Ind., 17(6) 483-488, 2004.
[5] B. De Finetti, “Teoria delle Probabilità”, Einaudi, Torino, 1970.
[6] R. Maja, L. Studer., G. Sala, G. Vescia, G. Marchionni et al., “Progetto TRAMP - Sviluppo e applicazione di metodi per l’analisi preventiva del rischio e l’assegnazione degli itinerari”, Convegno nazionale VGR 2002 Valutazione e gestione del rischio negli Insediamenti Civili e Industriali, Pisa, 15-17 ottobre 2002.
[7] R. Maja et al. “Vulnerabilità e gestione delle reti di trasporto in seguito a perturbazioni rilevanti”, Relazione finale annualità 2005 per il Dipartimento della Protezione Civile, Contratto del 21/12/2005, Milano, 2007.
[8] ONU, 1972
[9] “European Agreement concerning the international carriage of dangerous goods by road (ADR) and protocol of signature”, Economic Commission for Europe, Inland Transport Committee UN.
[10] R. Fanelli, R. Carrara., “Guida al trasporto di sostanze pericolose - Come prevenire e gestire le emergenze nel trasporto su strada”, Fondazione Lombardia per l’Ambiente, Milano, 1999.
[11] “Progetto SNSTMP - Sperimentazione di un sistema nazionale di sicurezza per il trasporto di merci pericolose, Convenzione tra Ministero dei Trasporti, Regione Lombardia, Politecnico di Milano, Intermode, Roma, 2005-2008.
[12] R. Maja., G. Marchionni, L. Studer, G. Vescia, “Procedure automatiche per la definizione degli itinerari a minimo rischio - Dimensionamento di massima del sistema”, Contratto di ricerca CNR Progetto TRAMP - Telecontrollo del Rischio nell’Autotrasporto di Merci Pericolose - Prototipo di un sistema per la prevenzione e il controllo del rischio nel trasporto su strada di sostanze pericolose, Relazione finale annualità 2000 per il Dipartimento della Protezione Civile, Contratto CNR 00.00612.PF37, Milano, 2002.
[13] G. De Leo, M. Gatto, E. Laniado (1998), “Fondamenti di valutazione di impatto ambientale”, Politecnico di Milano - Università di Parma, 2001
[14] G. Marchionni, G. Rainoldi, R. Maja., “Mappatura del rischio trasporti di materiale pericoloso in Regione Lombardia” Relazione interna per il Ministero delle Infrastrutture e dei Trasporti, Progetto SNSTMP - Sperimentazione di un sistema nazionale di sicurezza per il trasporto di merci pericolose, Milano, 2007
[15] P. Leonelli, G. Spadoni, “Ottimizzazione del trasporto di sostanze pericolose mediante minimizzazione del rischio indotto”, CNR GNDRCIE, Atti del Seminario Unità Operative, Roma, 1998.
[16] P.E. Johnson, D.S. Joy, D.B. Clarke, J.M. Jacobi., “HIGHWAY 3.01 - An Enhanced Highway Routing Model: Program - Description, Methodology, and Revised User’s Manual”, Oak Ridge National Laboratory, ORNL/TM-12124, Oak Ridge, TN, 1992.
[17] N.M. Ruphail. et. al., “A Dss for dynamic pre-trip route planning. Applications of advanced technologies in transportation engineering”, Proceedings of the 4th Intl. Conference 1995, 325–329.
[18] E. Erkut, V. Verter, “Incorporating insurance costs in hazardous materials routing models”, Transportation Sicence, 31(3) 227-236, 1997.
[19] Abkowitz M., Lepofsky M., Cheng P., “Selecting criteria for designating hazardous materials highway routes”, Transportation Research Recor, 1333 30–35, 1992.
[20] M.H. Patel., A.J. Horowitz, "Optimal Routing of Hazardous Materials Considering Risk of Spill", Transportation Research, A 28, pp. 119-132, 1994.
[21] B. Fabiano, F. Currò, E. Palazzi, R. Pastorino, “A framework for risk assessment and decision-making strategies in dangerous good transportation”, Journal of Hazardous Materials, 93, pp.1–15, 2002.
[22] E. Erkut, “On the Credibility of the Conditional Risk Model for Routing Hazardous Materials”, Operations Research Letters, 18 49–52, 1995.
[23] E. Erkut., V. Verter, “Modeling of transport risk for hazardous materials”, Operations Research, 46 (5), 625-642, 1998.

[24] R. Batta, S.S. Chiu, "Optimal obnoxious paths on a network: Transportation of hazardous materials", Operations Research, 36(1) 84–92, 1988.
[25] J. Zhang, J. Hodgson, E. Erkut, "Using GIS to assess the risks of hazardous materials transport in networks", EJOR, 121, pp. 316-329, 2000.
[26] S. Contini, F. Bellezza, M.D. Christou., C. Kirchsteiger, "The use of geographic information systems in major accident risk assessment and management", J. Hazardous Materials, 78, pp. 223-245, 2000.
[27] E. Erkut, S. Tjandra and V. Verter, "Hazardous Materials Transportation", Chapter 9 in Transportation, C. Barnhart and G. Laporte (editors), Handbooks in Operations Research and Management Science vol 14, Elsevier, 539-621, 2007.
[28] R. Gopalan., K.S. Kolluri, R. Batta, M.H. Karwan, "Modeling equity of risk in the transportation of hazardous materials", Operations Research, 38(6) 961-973, 1990.
[29] P. Carotenuto, S. Giordani,, S.Ricciardelli, "Finding minimum and equitable risk routes for hazmat shipments", Computers and Operstions Research, 34 1304-1327, 2007 (Available online 25 July 2005).
[30] P. Carotenuto., G. Galiano, S. Giordani, "Finding dissimilar efficient routes for hazmat shipments. Advanced OR and AI Methods in transportation".
[31] M. Kuby, X. Zhongyi, X. Xiaodong, "A minimax method for finding the k best differentiated paths", Geog. Anal., 29(4) 298–313, 1997.
[32] K. Lombard, R.L. Church., "The Gateway Shortest Path Problem: Generating Alternative Routes for a Corridor Routing Problem", Geographical Systems, vol. 1, pp. 25-45, 1993.
[33] Akgun A., Erkut E., Batta R., "On finding dissimilar path", European Journal of Operational Research, 121 232-246, 2000.
[34] E. Erkut, J . Euro, "The discrete p-dispersion problem", Oper. Res., 46(1) 48–60, 1990.
[35] E. Erkut, Y. Iksal., O. Yenicerioglu, "A comparison of p-dispersion heuristics", Comput. Oper. Res., 21(10) 1103–1113, 1994.
[36] B.Y. Kara., E. Erkut, V. Verter, "Accurate calculation of hazardous materials transport risks", Operations Research Letters 31, 285-292, 2003.
[37] E. Erkut, A. Ingolfsson, "Catastrophe Avoidance Models for Hazardous Materials Route Planning", Transportation Science, 34(2) 165-179, 2000.
[38] R.G. Cox, "Routing and scheduling of hazardous materials shipments: algorithmic approaches to managing spent nuclear fuel transport", Ph.D. dissertation, Cornell University, Ithaca, N.Y., 1984.
[39] A. Wijerante., M. Turnquist, P. Mirchandani, "Multiobjective Routing of Hazardous Material in Stochastic Networks", EJOR, 65, pp. 33-43, 1993.
[40] P. Dell'Olmo, M. Gentili., A. Scozzari, "On finding dissimilar Pareto-optimal paths", European Journal of Operational Research, 162 (1), 70-82, 2005.
[41] R.G. Cox, M.A Turnquist, "Scheduling truck shipments of hazardous materials in the presence of curfews", Transportation Research Record, 1063 21–26, 1986.
[42] L.K. Nozick, G.F. List, M.A. Turnquist, "Integrated routing and scheduling in hazardous materials transportation", Transportation Science, 31(3) 200–215, 1997.
[43] G.F. List, P.B. Mirchandani, M.A. Turnquist, K.G. Zografos, "Modeling and analysis of hazardous materials transportation: Risk analysis, routing/scheduling and facility location", Transportation Science, 25(2) 100–114, 1991.
[44] B.Y. Kara, V. Verter, "Designing a Road Network for Hazardous Materials Transportation", Transportation Science, 38(2) 188-196, 2004.
[45] Erkut E., Gzara F., "Solving the hazmat transport network design problem", Comput. Oper. Res., 35, 2234–2247, 2008.
[46] E. Erkut, O. Alp, "Designing a road network for hazardous materials shipments", Comput. Oper. Res., 34, 1389–1405, 2005.
[47] "SET - Servizio Emergenze Trasporti - Manuale Operativo", Federchimica, CEFIC, 1997.
[48] C. Podestà, R. Maja.,V. Cortese, et al., "Mappatura della rete plurimodale dei trasporti", Contratto di Ricerca CNR GNDRCIE 95.02003.PF37, Milano, 1996.
[49] P. Mengoli, R. Maja, "Progetto pilota del sistema TRAMP - Progetto di massima del sistema", Contratto di ricerca CNR Mappatura della rete plurimodale dei trasporti - Progetto pilota per il telecontrollo dei carichi pericolosi, Contratto di Ricerca CNR GNDRCIE 98.00545.PF37, Milano, 2000.
[50] R. Maja, G. Marchionni, G. Rainoldi, L. Studer, D. Vaghi, G. Vescia, "I componenti del sistema", Contratto di ricerca CNR Progetto TRAMP - Telecontrollo del Rischio nell'Autotrasporto di Merci Pericolose - Prototipo di un sistema per la prevenzione e il controllo del rischio nel trasporto su strada di sostanze pericolose, Relazione finale annualità 2001 per il Dipartimento della Protezione Civile, Contratto CNR 02.00175.PF37, Milano, 2004.
[51] R. Maja, G. Marchionni, G. Rainoldi, L. Studer, D. Vaghi, G. Vescia, "Caratteristiche, attuabilità e sperimentazione del sistema TRAMP", Contratto di ricerca CNR Progetto TRAMP - Telecontrollo del

Rischio nell'Autotrasporto di Merci Pericolose - Prototipo di un sistema per la prevenzione e il controllo del rischio nel trasporto su strada di sostanze pericolose, Relazione finale annualità 2002 per il Dipartimento della Protezione Civile, Contratto CNR 117.19/03, Milano, 2004.
[52] "Le politiche per l'innovazione tecnologica: telematica al servizio del trasporto merci pericolose, Appendice A 12.3 al capitolo 12 del Nuovo Piano Generale dei Trasporti e della Logistica - Documento tecnico, "Ministero dei Trasporti e della Navigazione - Servizio di Pianificazione e Programmazione, Roma, 2000.
[53] ECE/TRANS/WP.15/186/add.1, ADR Aggiornamento 2007.
[54] "Telematica per il traffico e il trasporto multimodale - Norma quadro - Parte II: trasporto merci", Progetto E14.C018.02, UNINFO, Commissione "Sistemi telematici per il traffico e il trasporto" (CEN TC/278, ISO TC/204), Torino, 2004.
[55] Direttiva. 96/35/CE 2/6/1996, "Designazione e qualificazione professionale dei consulenti per la sicurezza dei trasporti su strada, per ferrovia o per via navigabile".
[56] Maja R., "TRAMP Telecontrollo del Rischio nell'autotrasporto di Merci Pericolose", *La Protezione civile*, pag 132-141, Settembre 2004, Edizioni Nazionali, Milano, 2004
[57] Pivi M., Maja R., "Struttura e organizzazione del trasporto di merci pericolose nell'ottica della prevenzione del rischio", Trasporti & Trazione, N° 5/99, pag. 168-179, Milano, 1999.
[58] Maja R., Vescia G., "La sicurezza nel trasporto delle merci pericolose: coordinamento delle informazioni e prevenzione del rischio", Trasporti & Trazione, N° 4/00, 121-132, 2000.
[59] Rainoldi G., Maja R., Romanò D., Salimbeni R., "Il trasporto delle merci pericolose in galleria", Relazione interna per il Ministero delle Infrastrutture e dei Trasporti, Progetto SNSTMP - Sperimentazione di un sistema nazionale di sicurezza per il trasporto di merci pericolose, Milano, 2006.

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Part II

Risk Management and Control

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Finding Solutions to Mixed Route Strategies for Transporting Hazardous Materials

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Abstract. Uncertainty is intrinsic to decision-making. Decisions regarding the use of road networks in the transportation of hazardous materials are no exception. Commonly, cautious shipment of hazardous materials is focused on identifying a single safest route between a pair of points. Here we demonstrate that for repeated shipments, where there is complete uncertainty about link incident probabilities, the safest strategy is in general to use a mix of routes determined by the worst case scenario probabilities. Using game-theoretic approach embedded in a Defender-Attacker-Defender framework, it is shown that maximum exposure to risk can be significantly reduced by sharing shipments between routes. The approach posits predefined disruption, attack or failure scenarios and then considers how to use road network so as to minimize the maximum expected loss in the event these scenarios materialise. The properties of the optimality conditions are explored leading to the formulation of an equivalent linear programming problem. A solution algorithm suitable for use with standard traffic assignment software is presented together with a numerical example relating to the central London road network.

Keywords uncertainty; game theory; risk-averse routing, hazardous materials, defender-attacker-defender.

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Introduction

The transport of hazardous materials (hazmats) rightly attracts considerable attention due to the magnitude of the potential consequences for society as a whole, in terms of environmental pollution, economic damage, evacuations, injuries and fatalities. While the precise nature of the risk depends on the type of cargo, there is a growing literature on the generic problem of route planning for hazardous materials.

Uncertainty is a pervasive feature of decision-making, and decisions related to the use transport networks in hazmat transport are no exception. Where probabilities for events that affect the use of road networks (e.g. disruptions, failures) are known, it is possible to base decisions on expectations. However, a feature of uncertainty is that the probabilities corresponding to such events may also be unknown. This paper presents an approach to hazmat routing whereby unknown event probabilities are replaced by worst case event probabilities. Subsequently, a relaxation is formulated to allow the assumed event probabilities to lie between worst case and risk neutral.

The outcome is a set of optimal path use probabilities, with the implication that, under uncertainty, the risk-averse dispatcher should not “place all his eggs in one basket” but rather spread network usage across a number of paths so that the exposure to any given disruption scenario is minimised. It is noted that at the solution neither the worst case scenario probabilities nor the optimal path usage probabilities are in general unique. However, in the case of problem relaxation designed for neutralising the level of risk-averseness the scenario probabilities (but not necessarily the path use probabilities), are unique.

The paper alludes to a security-related defender-attacker-defender framework that originates from critical infrastructure studies, whereby the presented concept extends to planning for events with malicious intent (attacks). A solution algorithm suitable for use with standard traffic assignment software is presented together with a numerical example related to the hazmat shipment across London.

1. Literature review

A concept of risk denotes a potential negative impact that may arise from some future event. Although this term is commonly used synonymously with the probability of a known loss, in fact it relates to a state of uncertainty, in which there are possibilities involving some undesirable outcome and each of these possibilities can be measured in terms of impact and likelihood [1].

Most often, the risk associated with hazmat transport arises from the possibility of hazardous material being released and exerting negative impact on the environment and people. The generic problem of planning the route for the shipment of hazardous materials, so as to minimise these negative impacts, attracts growing attention and has been reviewed in [2] and [3]. Although dispatchers have to their disposal decision-support systems, such as HazTrans [4] and PC*HazRoute [5], it must be noted that the recommended route depends critically on the model adopted for the quantification of risk.

Research has addressed techniques of risk quantification that minimise total distance, the expected number of incidents (fatal or otherwise), the incident probability, the residential population within a given distance of a route, or some combination of these objectives. [3] discusses different ways of modelling hazmat transport risk and shows empirically that the route selected can be quite sensitive to the risk model used. Most researchers have focussed on one or both of two link attributes: the *probability of an incident* (in general, an event resulting in the release of hazardous material) and the *number of people impacted* in the event of an incident. The product of these two attributes, the expected number of people exposed to an incident, is the most popular measure (see [6]).

The incidents involving hazardous materials are rare, but with potential severe repercussions. There is often insufficient data on which to base estimates of incident probabilities on particular sections of the route, and even if it was, by the time the data would have been accumulated, the changing circumstances (e.g. improved vehicle designs, accident black spots treatment) would make the estimated probabilities obsolete and invalid. Still, the consequences of an incident are expected to be serious, and so most dispatchers, when dealing with such low probability high consequence (LPHC) events, exhibit risk aversion. This behaviour is sometimes referred to as catastrophe avoidance. The starting point of this paper is that the dispatcher is both risk-averse and does not know the link incident probabilities.

There have been several approaches proposed in literature to attend to the issue of risk aversion. In [7] the trade-off between the mean and extreme values of risk is considered when deciding between alternative routes for hazardous materials. [8] presents a related network model that directs shipments along the route that minimises the sum of the link losses, where the link loss is defined as the cost of a hazmat release on that link. Shipments continue to be routed along this path until an incident occurs.

Although the minimisation of the sum of the link losses is a reasonable proxy for “damage limitation”, it can lead to illogical routes (see [9], for some examples of this). Routes which minimise the sum of the link losses can nonetheless have an unacceptably high risk (sum of the products of the link losses and their respective probabilities) or route incident probabilities. Consequently, in [10] the sum of the link losses is minimised subject to two side constraints; the risk of an incident is required to be less than some threshold ν and the probability of an incident is required to be less than another threshold η. In [11] the authors consider various other objective functions based on minimising the expected losses given the number of trips to be made and given a threshold on the number of incidents tolerated before shipments cease. The authors of [12], where a useful review of the field up to 1997 is to be found, minimise the sum of the link losses subject to the two side constraints introduced in [8] and [10], but include only catastrophic incidents (those whose losses lie above a certain threshold) in the objective function.

The above approaches address the issue of risk aversion only indirectly. [13] presents three ways of introducing risk aversion into the routing of hazardous materials directly. The first minimises the maximum consequence along a route, the second incorporates the variance of the losses along a route into route selection, and the third minimises the expected disutility of the losses when a convex utility function is used. It is shown that all three approaches can be solved as shortest path problems by appropriately defining link length. The first method is appropriate when incident probabilities are unknown, but it leads to the recommendation of a single route only. Another way to reduce risk in hazmat transport has been pointed in [14], who indicated that the probability of an incident and the number of people impacted when an incident occurs are usually dependent on the time of day. Consequently, significant improvements in safety can be achieved by judicious choice of shipment departure time.

It is shown in this paper that a significant reduction of *exposure* can be achieved when shipments are shared across a number of routes. The presented work refers to interdiction problem originating from the critical infrastructure studies where focus is on consequence minimisation in the face of unknown incident probabilities [15]. The interdiction model is an attacker-defender (AD) model, which, as in [16], can be used as a procedure for identifying a near-optimal, budget limited defence plan to efficiently protect infrastructure. Such models lead to bi-level optimization problems in which an attacker maximizes the defender's minimum operating cost. Only heuristics are available to identify the critical infrastructure. It is therefore proposed in [16] to embed an AD model in a tri-level optimization problem called a defender-attacker-defender (DAD) model, in which the defender has limited resources to protect the system and must decide where to deploy them to minimize the damage the attacker is able to cause. AD models have a bilevel structure, whereby an attacker attempts to inflict maximum damage by supply interdiction and the defender seeks to route supplies in a way that minimises the damage inflicted by supply interdiction. This is a zero-sum game of pure strategies between an attacker and a defender.

This paper, by contrast, focuses on the mixed strategy case where the 'defender' represents a dispatcher trying to identify the safest route through the network, while the 'attacker' is a hypothetical player, who inflicts worse possible disruption to the shipments. This is equivalent to finding the worst case set of probabilities for failure, disruption or attack scenarios and using these to base decisions on network use. The method presented in this paper is built on [17], [18] and [19], while its extension on a variation on the [20] approach.

The method presented in [17] is a game between (1) a traveller, referred to as the 'router', who seeks a least-cost path between his origin and destination, and (2) a 'demon', who strives to maximize the trip cost by failing one link. The equilibrium solution to the game gives the optimal strategy for the traveller to avoid excessive costs, as well as the optimal strategy for the demon to be sure that at least a certain loss will be caused irrespective of the path selected by the traveller. Either pure or mixed strategies may be considered. In the case of pure strategies, the result is an Attacker-Defender model of the kind defined in [16]. The resulting bilevel integer programming problems are typically difficult to solve. In the formulation shown is [17], mixed strategies are allowed. As this relaxes the integer constraint, solutions are easier to find.

The expected trip-cost at equilibrium can be treated as a measure of overall network vulnerability, while the link failure probabilities indicate links that are critical for network performance. The optimal strategy for the traveller in general involves selecting a path from a set of paths having positive probability, where the set has more than one member. The solution delivers the worst link attack probabilities, on the assumption that these are what the traveller is reacting to. At the equilibrium, the expected cost is the same irrespective of which link is affected.

2. Notation:

q: vector of link failure probabilities
h: vector of route choice probabilities
TC: total cost to travel between OD pair
g_{jk}: travel cost on route k under scenario j
DC: disruption factor indicating the increased cost resulting from a failure/attack

tt_i: travel time on link i
c_{ij}: travel cost on link i under scenario j
a_{ik}: link incidence matrix (1 if link i is on path k, 0 otherwise)

3. General Risk-Averse Approach

3.1. Mathematical Formulation

In [21] and [22] link travel cost is indirectly influenced by the link status because a failed link is defined as a link with reduced capacity and hence more prone to congestion. The following formulation, however, remains in line with [17], where it was assumed that link travel cost is directly influenced by link status and is not a function of the link flow. Following [22], the game described above can be expressed as a bi-level optimisation problem, but in contrast to standard bi-level problems both problems are solved simultaneously.

In the following we assume for simplicity that scenario j implies a failure, disruption or attack on link j. This is not, however, a limitation of the method. It is possible for a single scenario to encompass multiple link failures, disruptions or attacks. If only movement between a single OD pair is considered, the bi-level problem is then to solve the following maximisation and minimisation in Eq. (1) simultaneously:

$$Max_{\mathbf{q}} Min_{\mathbf{h}} \; TC(\mathbf{q},\mathbf{h}) = \sum_j \sum_k q_j h_k g_{jk} \tag{1}$$

subject to $\sum_j q_j = 1$, $\mathbf{q} > 0$ and $\sum_k h_k = 1$, $\mathbf{h} > 0$

$$\text{with } g_{jk} = \sum_i a_{ik} c_{ij} \tag{2}$$

$$\text{where } c_{ij} = DCtt_i \text{ if link } i \text{ fails in scenario } j \text{ and } c_{ij} = tt_i \text{ otherwise} \tag{3}$$

Note the lack of the time dimension: The traveller does not proceed through the network links dynamically. However, where routes are pre-determined and not adjusted in the course of the journey, such a static approach is suitable, especially for route planning purposes.

At equilibrium the following conditions must hold:

Upper Level: $\forall$ scenarios j

$$q_j = 0 \Leftarrow \sum_k h_k g_{jk} < \max_s \sum_k h_k g_{sk}$$

$$q_j \geq 0 \Leftarrow \sum_k h_k g_{jk} = \max_s \sum_k h_k g_{sk} \tag{4}$$

Lower Level: $\forall$ paths k

$$h_k = 0 \Leftarrow \sum_j q_j g_{jk} > \min_s \sum_j q_j g_{js}$$

$$h_k \geq 0 \Leftarrow \sum_j q_j g_{jk} = \min_s \sum_j q_j g_{js} \tag{5}$$

This problem can be reformulated as a linear program as follows:

$$Min_{\mathbf{h}} \ C \tag{6}$$

subject to $\sum_k h_k g_{jk} \leq C$ and $\sum_k h_k = 1$, $\mathbf{h} > 0$

for which at the solution the dual variables are equal to **q** and *C* is equal to *TC* at the solution to the corresponding maxmin problem (see [17]).

3.2. A Solution Algorithm

While this problem may be solved very efficiently using a standard linear program solver, this approach requires the prior enumeration of all the relevant paths. The objective here was to solve the problem using standard traffic assignment software which would create the paths as the iterations progress. Standard traffic assignment software is optimised for large road networks to make use of electronic road navigation networks such as Navteq or Teleatlas, and can display the results efficiently. The software chosen for the numerical example presented later is VISUM from PTV AG.

The algorithm used to solve this bi-level problem is based on the Method of Successive Averages [23]. After the initialisation in Step 0, the lower problem (find optimal path flows) and the upper problem (find optimal link failure probabilities) are solved sequentially in each iteration *m* until convergence. The algorithm has converged when neither **q** nor **h** change significantly between iterations. Though a formal proof of convergence for the MSA is missing for this application, experience shows that the solutions obtained are nearly optimal.

Step 0:
Initialise $m = 1$ and $\mathbf{q}^0 = 1$ /*number of links*. Set path flows $\mathbf{h}^0$ to 1 for the fastest path found by VISUM (obtained in free-flow conditions) and 0 otherwise.

Step 1:
Calculate expected link usage costs for given scenario $\mathbf{q}^{m-1}$

($\sum_j \sum_k q_j^{m-1} a_{ik} g_{jk}$ for all links *i*).

Step 2:
Obtain auxiliary path probabilities $\mathbf{y}^m$ by assigning a unit OD flow to the least cost path. Note that only one path is used so only one element of $\mathbf{y}^m$ is non-zero, and that element is one.

Step 3:
Update path probabilities using the MSA:

$\mathbf{h}^{m} = \mathbf{h}^{m-1} + (\mathbf{y}^{m} - \mathbf{h}^{m-1})/m$

Step 4:
Calculate expected scenario losses for given $\mathbf{h}^{m}$

($\sum_{k} h_{k}^{m} g_{jk}$ for all scenarios j).

Step 5:
Obtain auxiliary link failure probabilities $\mathbf{z}^{m}$ by assigning 1 to the scenario with the highest expected loss, and 0 to other scenarios.

Step 6:
Update link failure probabilities by the MSA:

$\mathbf{q}^{m} = \mathbf{q}^{m-1} + (\mathbf{z}^{m} - \mathbf{q}^{m-1})/m$

Step 7:
If convergence criteria are satisfied stop, otherwise set $m{:=}m{+}1$ and return to Step 1.

This algorithm is found to converge rapidly for *TC* but not necessarily for $\mathbf{q}^{m}$ and $\mathbf{h}^{m}$ (see Figures 4 and 5). It should be noted that at the solution, *TC* is unique but not in general $\mathbf{q}^{m}$ and $\mathbf{h}^{m}$, probably accounting for the slow convergence of these parameters.

An interesting alternative algorithm has been suggested by [20]. By adding a weighted entropy term in **h** to Eq. (1), the minimization problem gains an explicit solution in the form of a logit path choice model. As the weight tends to zero the solution tends to the solution to the original problem. Substituting the logit model solution for **h** back into the augmented Eq. (1) leads to a single level convex programming problem, which may be solved efficiently by an appropriate numerical method. The solution in **h** is now unique, as the augmented Eq. (1) is strictly convex in **h**, although not in general in **q**.

[20] proposed further problem modification which ensures that the solution in **q** is also unique. The disadvantage of this approach is that at the solution all paths have a non-zero probability, whereas the linear program partitions the set of paths into those to be used, referred to collectively as a *hyperpath*, and those not to be used. It is believed that this partition will not in general be unique.

4. Neutralised Risk-Averseness

4.1. Mathematical Formulation

A number of application areas for the proposed network vulnerability analysis have been identified in the planning domain, with application to the movement of VIPs and hazardous material, e.g. [19]; [24]; [20], in addition to the design of risk-averse tours for freight distribution as in [25]. As mixed strategies are considered, the method indicates how to distribute repeated shipments across a set of paths or, in security applications, what probabilities to use when selecting a path at random.

However, in some cases basing predictions on the worst case set of scenario probabilities may be perhaps too extreme, and the wide spread of routes may be undesirable because of petrol, operational and other reasons. A variation on the [20] approach may be appropriate here, whereby Eq. (1) is augmented by a weighted entropy function in **q** to yield Eq. (7):

$$Max_{\mathbf{q}} Min_{\mathbf{h}} \; TC(\mathbf{q},\mathbf{h}) = \sum_j \sum_k q_j h_k g_{jk} - (\frac{1}{\theta}) \sum_j q_j \ln q_j \tag{7}$$

This time the maximization problem has an explicit solution for **q**, namely:

$$q_j = \frac{\exp(\theta \sum_k h_k g_{jk})}{\sum_s \exp(\theta \sum_k h_k g_{sk})} \tag{8}$$

which can be substituted back into Eq. (7) leading to an alternative convex programming problem:

$$Min_{\mathbf{h}} \; TC(\mathbf{h}) = (\frac{1}{\theta}) \ln \sum_j \exp(\theta \sum_k h_k g_{jk}) \tag{9}$$

subject to

$$\sum_k h_k = 1 \, , \; \mathbf{h} > 0$$

with $g_{jk} = \sum_i a_{ik} c_{ij}$ (2)

where $c_{ij} = DCtt_i$ if link i fails in scenario j and $c_{ij} = tt_i$ otherwise (3)

4.2. A Solution Algorithm 2

Note that the gradient of the objective function is

$$\frac{\partial TC(\mathbf{h})}{h_k} = \sum_j q_j g_{jk} \tag{10}$$

which is the expected usage cost for path k. The path with the least expected usage cost therefore defines the steepest descent direction. Eq. (9) may thus be minimised subject to the constraints on **h** by the following revised and shortened MSA algorithm:

Step 0:
Initialise $m = 1$ and $\mathbf{q}^0 = 1/$*number of links*. Set path flows $\mathbf{h}^0$ to 1 for the least non-disrupted cost path and 0 otherwise.

Step 1:
Calculate expected link usage costs for given scenario $\mathbf{q}^{m\text{-}1}$

$(\sum_j \sum_k q_j^{m-1} a_{ik} g_{jk}$ for all links i).

Step 2:
Obtain auxiliary path probabilities $\mathbf{y}^m$ by assigning a unit OD flow to the least cost path. Note that only one path is used so only one element of $\mathbf{y}^m$ is non-zero, and that element is one.

Step 3:
Update path probabilities using the MSA:

$\mathbf{h}^m = \mathbf{h}^{m\text{-}1} + (\mathbf{y}^m - \mathbf{h}^{m\text{-}1})/m$

Step 4:
Calculate $\mathbf{q}^m$ given $\mathbf{h}^m$ via Eq. (8).

Step 5:
If convergence criteria are satisfied stop, otherwise set $m{:=}m{+}1$ and return to Step 1.

This algorithm, unlike the predecessor, is not a heuristic. The solution is now unique in **q** rather than **h**, because Eq. (7) is strictly convex in **q**. The weight θ could be chosen to reflect the degree of risk aversion present in the population of drivers. When θ tends to infinity, the solution tends to that of Eq. (1). Conversely, as θ tends to 0, **q** becomes insensitive to the size of the expected loss in the event of a disruption, failure or attack, and therefore the traffic assignment is risk-neutral. This model has similarities with the approach described in [26].

5. Numerical Example

This section presents the results obtained by applying the algorithm presented in Section 3. The data available for this example comprised the entire Greater London road network including link characteristics, such as permitted speeds, capacities and number of lanes. The path choice was modelled by VISUM, macroscopic traffic assignment software, widely used for small and large-scale traffic assignment problems in addition to use for multimodal assignment problems. The software has been interfaced via the COM-interface with purpose-written Python script, in this case to obtain an assignment for the new link costs found in each iteration.

Here we show how the game was applied to determine a risk-averse routing strategy for the hazmat shipment from south to north London. The dispatcher believes there will be disruption and, to be safe, he assumes that this disruption will probably occur at a location that is worst for him. In other words, he considers a worst case set of link disruption (link failure, link attack) probabilities.

The part of the network considered comprises three river crossings: (1) Blackwall Tunnel, (2) Rotherhithe Tunnel and (3) Tower Bridge. Figure 1 shows the location of these river crossings and the shortest path for this OD pair obtained in free-flow conditions (light grey) together with the critical link in case of single path routing (dark grey). A low disruption cost factor (*DC* = 2) was chosen in this example, meaning that the disruption would cause the cost of the disrupted link to double. Given such a disruption, the total cost of traveling this route would be 847 units, as indicated in Figure 1.

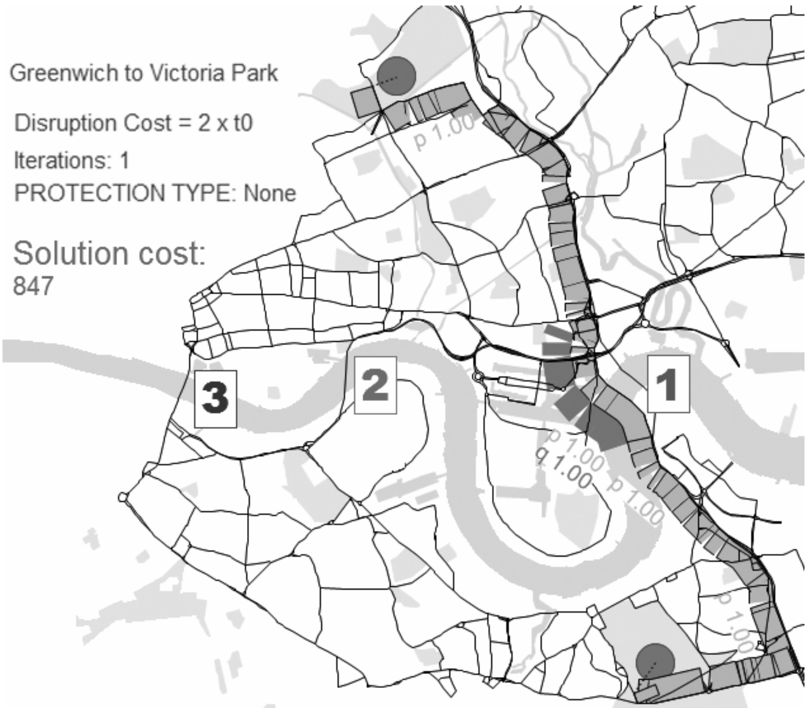

Figure 1. Shortest path from Greenwich to Victoria Park

By contrast, Figure 2 shows the results at equilibrium obtained after 500 iterations. In this case the risk-averse dispatcher considers not only the direct route but also allows for the option of re-routing via the nearby Rotherhithe Tunnel. This route would be taken with a probability of 46%, whereas the route including the Blackwall Tunnel would be used with a probability of 54%. The inclusion of the second route leads to a decrease in the expected cost to 825 units. The scenario shown in Figure 2 might correspond to the case where one takes into account only the possibility of minor disruption.

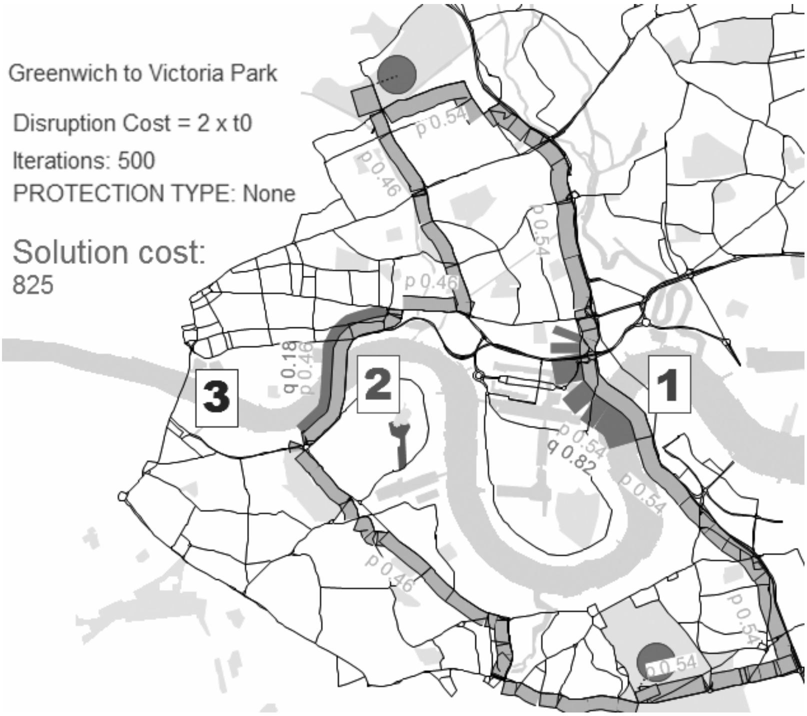

Figure 2. Equilibrium solution (low disruption cost)

Figure 3 shows the equilibrium solution for the case where *DC*=1,000,000. Such a high value was chosen in order to demonstrate that the solution obtained depends on the severity of the potential disruption. The scenario with a very high disruption cost might be used to plan for the scenario where there is a risk of a life-threatening incident or a terrorist attack.

In the scenario with a high disruption cost, in addition to the two routes shown in Figure 2, a third route via Tower Bridge is added, involving an even longer detour. This route is preferred (h_k = 62%) for two reasons. Firstly, the cost of disruption, being proportional to link travel time (see Eq. 3), is lower for shorter links, hence the shorter bridge will be favoured. Secondly, the longer travel time with the detour via Tower Bridge is still relatively low compared to the disruption cost.

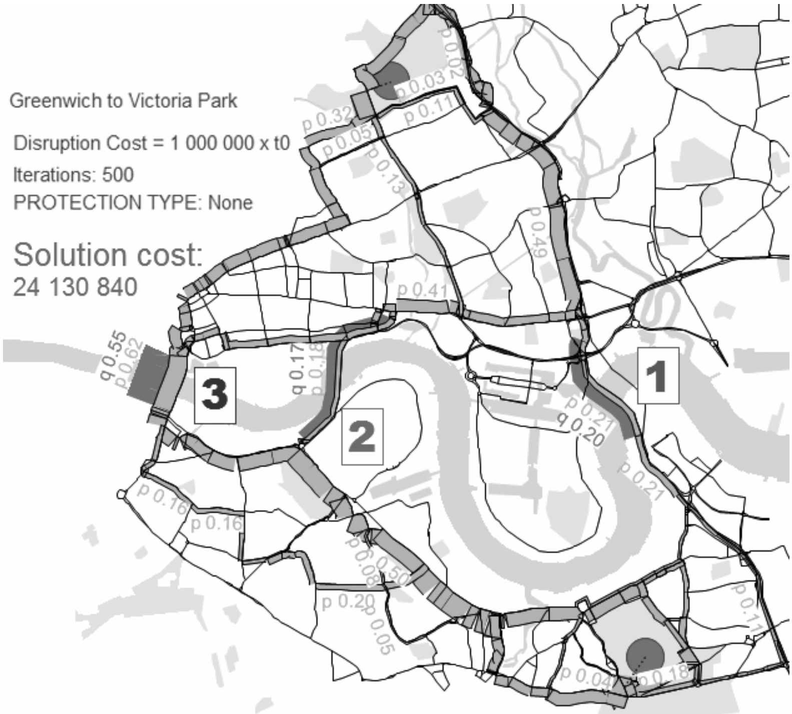

Figure 3. Equilibrium solution considering very high disruption cost

The above analysis shows that anticipating heavily disruptive incidents, the risk-averse shipper should consider a wider spread of routes. Additional analysis with different DC values showed that for DC < 2 multiple paths do not need to be considered. Table 1 below summarises the results obtained in each case and illustrates that the optimal routing strategy is a cost-effective measure to distribute the risk.

Table 1 Solution cost *TC* in the considered scenarios

Routes Used	Minor Disruption DC=2		Major Disruption DC=1,000,000	
	Does not Happen	**Does Happen**	**Does not Happen**	**Does Happen**
Single	727	847	727	120 mln
Optimal	753	825	1,102	24 mln
	Required Investment	Possible Benefit	Required Investment	Possible Benefit
	26	22	375	96 mln

Figure 4 shows the convergence of the MSA for the solution cost TC and for the link-use probabilities of the three river crossings. As mentioned before, the solution cost *TC* converges rapidly and is unique at the solution. Although multiple equilibria of link use and link failure probabilities are mathematically possible, existence of several equilibria is unlikely given the size and the non-symmetric structure of the network.

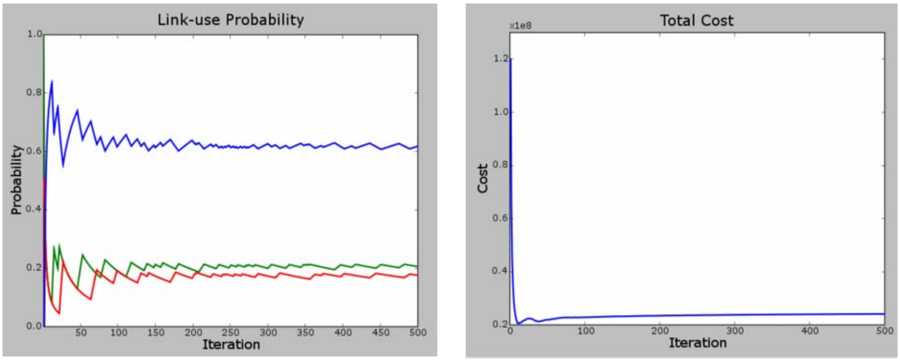

Figure 4. Convergence of the solution algorithm

6. Protection of a Critical Asset

The solution of the game indicated that river crossings are critical links, which if attacked, would impose the greatest detours. The analysis with a very high disruption cost pointed out that Tower Bridge should be used in most cases from Greenwich Park to Victoria Park. This evokes a question about what the optimal routing strategy would be if additional security measures were available to assure protection of a chosen asset (e.g. a bridge) from a potential attack. This has been modeled by excluding a link from the set of attack scenarios.

Should Tower Bridge be protected, the frequency of choosing a path across this bridge increases from 0.62 to 0.86 (see Figure 5). The shortest path leading through the Blackwall Tunnel should be used sometimes, despite the fact that it is indicated as a potential attack target. The route via Tower Bridge is still not regarded as fully safe, as the attacker would now focus on some other links that lie on routes using this bridge. The Rotherhithe Tunnel should not be used anymore, because the shorter detour (compared to traveling via Tower Bridge) is not enough to compensate for the perceived risk associated with traversing this tunnel. When Tower Bridge is protected, the critical locations become links located closer to the origin and destination, rather than river crossings.

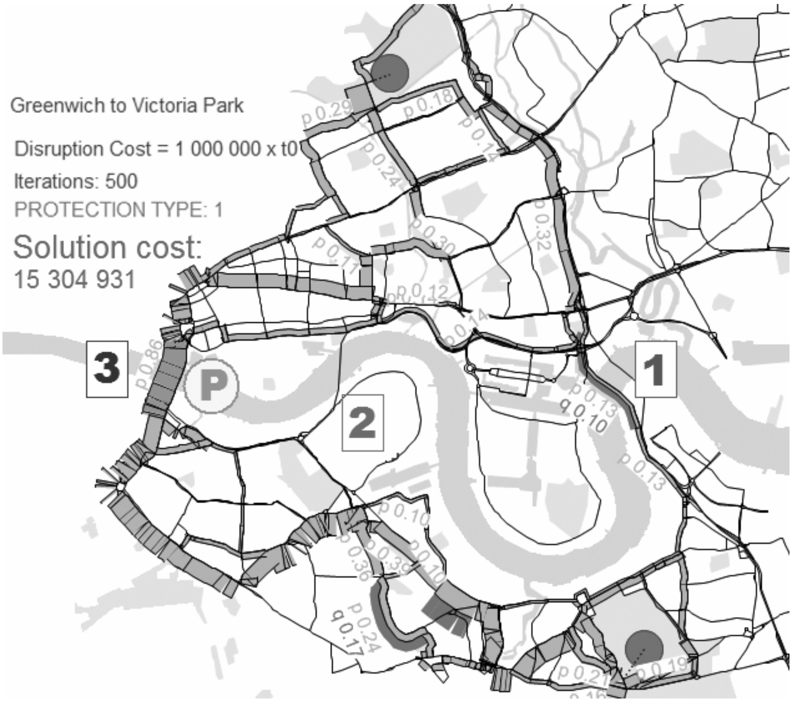

Figure 5. Equilibrium solution considering infrastructure protection

7. Conclusions

This paper presents an approach to decision-making under uncertainty in the context of hazmat transport and addresses the problem of risk-averse routing in the context of low probability, high consequence incidents. Where probabilities of predefined disruption, failure or attack scenarios are not known, it is suggested that worst case probabilities, or probabilities that lie between worst case and risk neutral may be used. This presents a significant extension to recent work presented in [20], which has the beneficial side-effect of uniquely defining the scenario probabilities.

When travel costs are small in relation to the potential losses, a multi-routing strategy is in general optimal to spread risk and thereby reduce the maximum exposure to an incident. However, when travel costs increase in importance, the size of routes included in the hyperpath can be limited by neutralising risk-averseness. The algorithms, as presented, employ the Method of Successive Averages in conjunction with standard traffic assignment software and electronic road navigation network, and hence may be applied to large road networks.

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References

[1] D.E. Bell, H. Raiffa,, A. Tversky (1988) Decision Making: Descriptive, Normative, and Prescriptive Interactions, Cambridge University Press.
[2] G. List, P. Mirchandi,, M. Turnquist, and K. Zofrafos (1991) A modelling and analysis for hazardous materials transportation: Risk analysis, routing-scheduling and facility location, Transportation Science, 25(2), 100-114
[3] E. Erkut, and V. Verter (1998) Modelling of transport risk for hazardous materials, Opns. Res., 46, 625-642
[4] M. Abkowitz, M. Lepofsky, and P. Cheng (1992) Selecting criteria for designating hazardous materials highway routes, Transp. Res. Rec., 1333, 30-35
[5] ALK Associates (1994) ALK's PC*HazRoute (Version 2.0), ALK Associates, Princeton, NJ
[6] US Department of Transportation (1994) Guidelines for applying criteria to designate routes for transporting hazardous materials, Report No. FHWA-SA-94-083, Federal Highway Administration, Washington DC
[7] T.S. Glickman (1983) Rerouting railroad shipments of hazardous materials to avoid populated areas, Accid. Anal. Prevent., 15, 329-335
[8] R.A. Sivakumar,, R. Batta, and M.H. Karwan (1993) A network-based model for transporting extremely hazardous materials, Oper. Res. Lett., 13, 85-93
[9] E. Erkut, (1995), On the credibility of the conditional risk model for routing hazardous materials, Oper. Res. Lett., 18, 49-52
[10] R.A. Sivakumar,, R. Batta, and M.H. Karwan (1995) A multiple route conditional risk model for transporting hazardous materials, INFO, 33, 20-33
[11] H. Jin, , R. Batta, and M.H. Karwan, (1996) On the analysis of two new models for transporting hazardous materials, Oper. Res. 44(5), 710-723
[12] H.D. Sherali, L.D. Brizendine, , T.S. Glickman, and S. Subramanian (1997) Low-probability high-consequence considerations in routing hazardous material shipments. Transportation Science, 31(3), 237-251
[13] E. Erkut, and A. Ingolfsson (2000) Catastrophe avoidance models for hazardous materials route planning. Transportation Science, Vol 34, 165-179
[14] K.L. Nozick, G.F. List, and M. Turnquist, (1997) Integrated routing and scheduling in hazardous materials transportation, Transportation Science, 31(3), 200-215
[15] R.L. Church, and M.P. Scaparra (2005) Protecting Critical Assets: The r-interdiction median problem with fortification. Working paper 79, Kent Business School, Canterbury, UK.
[16] G. Brown, , M. Carlyle, J. Salmerón and R.K. Wood (2006) Defending Critical Infrastructure. Interfaces, 36(6), 530-544.
[17] M.G.H. Bell (2000) A game theory approach to measuring the performance reliability of transport networks. Transportation Research B, 34B, 533-546.
[18] M.G.H. Bell (2003) The use of game theory to measure the vulnerability of stochastic networks. IEEE Transactions on reliability, 52(1), 63-68.
[19] U. Kanturska, M.G.H. Bell, J.D. Schmoecker and A. Fonzone (2007) Improving reliability through multi-path routing: An application of game theory to VIP protection. Proceedings, 3rd International Symposium on Transport Network Reliability (INSTR), Delft, Holland.
[20] T. Nagae, and T. Akamatsu (2007) An efficient algorithm for a maximin routing model for hazardous materials. Proceedings, 3rd International Symposium on Transport Network Reliability (INSTR), Delft, Holland.
[21] M.G.H. Bell, and C. Cassir (2002) Risk-averse user equilibrium traffic assignment: an application of game theory. Transportation Research B, 36, 671 – 681.
[22] C. Cassir, , M.G.H. Bell, and J-D Schmöcker (2003) A normative assessment of transport network reliability based on game theory. In Bell, M. G. H. and Y. Iida (Eds.) The network reliability of transport. Pergamon, Oxford, UK.
[23] Y. Sheffi (1985). Urban transportation networks: Equilibrium analysis with mathematical programming methods. Prentice-Hall, Englewoods Cliffs, New-Jersey.
[24] M.G.H Bell (2006) Mixed route strategies for the risk-averse shipment of hazardous materials. Networks and Spatial Economics, 6, 253–265.
[25] M.G.H Bell (2004) Games, heuristics, and risk averseness in vehicle routing problems. J. Urban Plan. Dev., 130(1), 37–41.
[26] M.G.H Bell (1999) Measuring network reliability: A game theoretic approach Journal of Advanced Transportation, 33(2), 135-146.

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The Trade-offs in Rail-Truck Intermodal Transportation of Hazardous Materials: an Illustrative Case Study

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Abstract. Intermodal transportation has sustained a promising growth rate over the past two decades and continues to be one of the rapidly growing segments of the transportation industry. Intermodal transportation is increasingly being used to move hazardous materials, and most of the studies underline the irreversible nature of this trend. In this paper, we make a first attempt to develop an understanding of the risk-cost-time trade-offs that underlie decisions pertaining to dangerous goods shipments via a rail-truck intermodal transportation system. A realistic case study that focuses on transportation of both dangerous goods and regular freight among one 100 shipper-receiver pairs in Canada is developed, and an intelligent enumeration algorithm to solve the problem is presented.

Keywords. intermodal transportation, dangerous goods, population exposure risk, enumeration technique, trade-offs.

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Introduction

Rail-truck intermodal transportation (IM) combines accessibility advantage of road networks with scale economies associated with railroads in moving shipments. The main attractiveness of IM for shippers is its reliability in terms of on-time delivery as well as the significant reduction in delivery times in comparison with traditional trains. Perhaps due to these competitive advantages, IM has experienced an impressive growth over the past two decades, and continues to be one of the rapidly expanding segments of the transportation industry. Furthermore, intermodal shipments constitute the fastest growing activity for railroad companies and they are slated to overtake coal as the largest source of revenue [1]. The phenomenal growth of intermodal transportation has been attributed to the competitive pressures on global supply chains [2], the increasing demand for new service patterns driven by ocean carriers [3], as well as the globalization of industry ([4], [5]).

IM is increasingly being used for hazardous materials (hazmats) shipments that are potentially harmful for human health and the environment. For example, the Bureau of Transportation Statistics estimated that in 1997 over six million tons of hazmats were shipped across the U.S. intermodal transportation system [6], while the equivalent number for 2002 is over eighteen million tons. Even this 200% increase, within five years, is qualified as an underestimate by the 2002 Commodity Flow Survey [7]. With regards to the future, the U.S. Chemical Manufacturers Association estimates that the total volume of hazmats shipped by 2020 will be 5.1 billion tons, which according to the U.S. Department of Transportation [8] will be increasingly carried via intermodal transportation channels. The proportion of dangerous goods moved by IM in Europe is higher than that moved in North America. A study conducted by the International Road Transport Union, Geneva, states that more than 20% of all rail/road combined transport contain dangerous goods [9].

Despite the increasing significance of IM in carrying hazmats, [10] identified – through a comprehensive review of the literature on hazmat logistics – that IM is an area that has not been studied in this domain. In this paper, we make a first attempt to develop a solid understanding of the trade-offs that underlie the decisions pertaining to dangerous goods shipments via IM. To this end, we build a realistic case study that focuses on transportation of hazmats across Canada (i.e., from Quebec to British Columbia) among one hundred shipper-receiver pairs via IM network of Canadian Pacific Rail Company (CPR). In an effort to replicate the IM network of CPR, there is a single pair of intermodal rail terminals (IMRT) in the illustrative case study –located at Montreal and Vancouver, and hence the arising problem lends itself to solution via an intelligent enumeration algorithm. Our contribution is a detailed analysis of the risk-cost trade-offs, driven by the element of *time* as explained in the next two sections, that define this unstudied problem rather than the development of a solution algorithm for the most general case.

Traditionally, hazmat transport risk is defined as the *expected* undesirable consequence of the shipment, i.e., the probability of a release incident multiplied by its consequence. This risk measure is also called the "technical risk" since it requires a detailed assessment of accident probabilities across the shipment route as well as the number of fatalities, injuries and evacuations that would be caused by an accident. Such a detailed analysis although cumbersome is possible for road networks, but is prohibitive for railroads since not only the likelihood of the entire train involving in an accident but also the number and precise locations of the damaged railcars (and their interaction) are relevant. Because of the difficulties associated with deriving detailed accident probability estimates for railroad shipments, we resort to a more aggregate risk measure in this paper: *population exposure*. We represent transport risk as the total number of people exposed to the possibility of an undesirable consequence due to the shipment. For example, according to [11], 800m around a fire that involves a chlorine tank, railcar or tank-truck must be isolated and evacuated, and hence people within this predefined threshold distance are exposed to the risk of evacuation. The fixed bandwidth approach has originally been suggested and used by [12] and [13]. In contrast to the traditional risk measure, population exposure constitutes a "worst case" approach to transport risk, and hence is particularly suitable for assessing risk as perceived by public as well as for estimating the required emergency response capability.

In this paper, we focus on hazmats that become airborne in the event of an accidental release (such as chlorine, propane and ammonia) since they can travel long distances due to wind and expose large areas to health and environmental risks. Spatial distribution of toxic concentration level is estimated using Gaussian plume model (GPM), and at any given distance the maximum concentration is observed at the downwind locations. We use the immediately dangerous to life and health (IDLH) concentrate levels of the hazmat being shipped in determining the threshold distances for fatality and injuries (NIOSH, www.cdc.gov./niosh).

In estimating the population exposure, we adopt the worst-case approach by assuming least favorable weather conditions and focusing on maximum concentrate levels. Also, our population exposure estimates are based on the derailment and rupture of all railcars with hazardous cargo, which constitutes a real possibility (FRA, http://safetydata.fra.dot.gov). A recent Canadian incident involving multiple railcars was in April 2006 in Charette - Quebec, when 14 railcars, including seven containing dangerous goods, were derailed resulting in ecological damage and loss of lading [14]. Less conservative exposure scenarios can be easily incorporated in the parameter settings of the risk assessment methodology as shown in [15].

Excellent reviews of the academic literature on intermodal transportation can be found in [16], [17], and [18]. Here, we focus on the studies pertaining to IM and provide an overview. A detailed description of IM systems will be provided in the next Section. In brief, IM involves inbound drayage of the intermodal container unit via truck to the origin IMRT, transfer of the container onto the intermodal railcar, rail-haul between the IMRT pair, transfer of the container onto the truck at the destination IMRT, and finally, outbound drayage to the receiver via truck. According to [19] and [20], trucking constitutes the weakest links of the intermodal chain, and is viewed as an opportunity for significant service improvement and cost reductions. The planning and decision-making regarding rail-haul can be strategic, tactical or operational in nature. The papers with strategic orientation typically focus on network and service design, freight terminal location, and equipment design ([21-30]). The prevailing studies adopting an intermediate time horizon are on train scheduling and container routing [31], intermodal container routing [32], planning operations for an intermodal rail-truck service [33], minimum cost intermodal routings [34] and on bundling operations ([35-37]). The work of [38] is operational in nature. To the best of our knowledge, there is no refereed publication involving intermodal transportation of hazmats. In their recent and comprehensive review of hazmat logistics, [10] confirm our observation. This paper aims at filling this important gap in the literature.

The remainder of the paper is organized as follows: Section 1 describes a rail-truck intermodal transportation system pertinent to this study. Section 2 provides the problem statement and highlights our assumptions. Section 3 develops an instance of the problem in Canada, which is used in the following sections as an illustrative case. Section 4 describes an evaluative framework, whereas the underlying trade-offs in IM transportation of hazmats are analyzed in Section 5 -within the context of the case. We conclude the paper by outlining future research directions in Section 6.

1. A Time-Based IM System

Intermodal trains, unlike the traditional freight trains, operate on a *fixed-schedule*, and are usually quite punctual [33], therefore such trains often operate non-stop between a pair of IMRTs, although infrequent stops and transfer of railcars among trains are also possible. The need to match the intermodal unit with the type of flat railcar and the shipment with the type of train service it will travel on differentiates intermodal trains from traditional rail services which have been the subject of much modeling in the last two decades (see [39], [40]).

Figure 1 depicts a time-based IM network with a single pair of IMRTs, wherein the latter is representative of the sparse railroad network in North America. The nodes in the network represent shipper, receiver and IMRT facilities, whereas arcs represent routing alternatives for trucks and intermodal trains. The tractor-trailer pools ('*A*' and '*B*' in figure 1) are usually maintained in the vicinity of the IMRT, and an empty unit is dispatched when requested by the shipper. Of course, railroad companies offer different plans, whereby the intermodal unit (also referred to as container in this paper) can belong to the shipper or the railroad company. For example, Canadian Pacific Railroad (CPR) offers six different plans in Canada: ramp-to-ramp; door-to-ramp; ramp-to-door; door-to-door; and the last two plans with container belonging to the shipper [41].

Using the notation in Figure 1, receiver *(l)* will place an order with shipper *(i)* specifying the quantity of goods (hazardous and non-hazardous) required and the time (D_l) by which they should be delivered. Shipper *(i),* on receiving the order information at time (t_i), immediately requests intermodal units based on the shipment order (and type) from the nearest IMRT. On receiving the request, the IMRT will dispatch the specified containers from the pool, which starts *inbound drayage*. Shipper *(i)* expends time (p_i) preparing and loading the order onto the trucks, which is then brought to the IMRT for the rail-haul. The arrival at the IMRT completes the inbound drayage part of IM, which has taken time (t_{IN}).

It is important to note that the departure time (D_s) of the intermodal trains is fixed, and hence the loading time at the IMRT (p_j) together with the inbound drayage time should be less than the cut-off time for loading. It is reasonable to assume that shippers know about these critical times and are willing to make adjustments in order to meet demand by the specified time (D_l). At the origin IMRT, the routing of rail-haul is determined. Given the sparse railroad network and even sparser IMRT network in North America, often there is a single preferred routing to each destination but there will be time-of-departure options. It should be noted that intermodal train services are differentiated based on speed, route, intermediate stops, etc. For example, in figure 1 there are two train routes between the IMRT pair and each route has different types of intermodal train services operating on it. Intermodal train service s, with travel time (t_s), brings the shipments to the destination IMRT, where following an unloading process that takes *(p_k)* units of time, shipments embark on the last of the three legs viz., *outbound drayage*, so that containers are delivered to receiver *(l)* within the stipulated delivery time *(D_l)*.

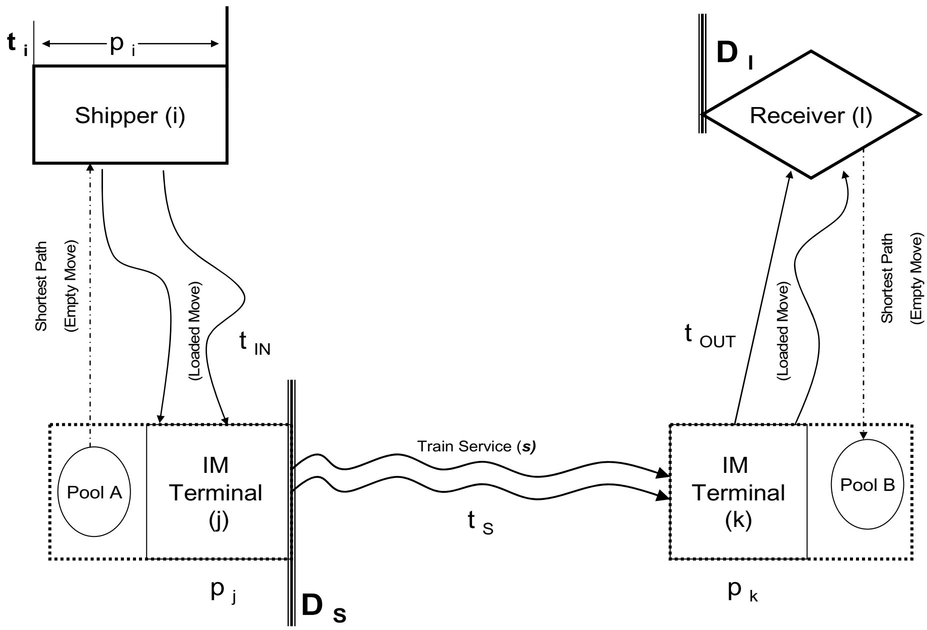

Figure 1. A Time-Based IM Network

As is evident from the description of figure 1, stipulated delivery time (D_l), is the underpinning of IM operations, wherein delivery reliability is brought about by aligning the preceding stages of the intermodal chain.

2. Problem Definition

As noted earlier, the rail-haul of IM operates on *fixed-schedule* and hence is more punctual than a traditional freight train. Such punctuality, associated with the transportation mode responsible for moving shipments over long distance in an IM system, implies reliable delivery that is possible only if the intermodal trains do not wait for traffic accumulation and hence charge more to ensure this service. On the other hand since the receivers are willing to pay more, they can specify a delivery date when placing orders. Given the aforementioned, an IM system can be modeled as a *just-in-time* movement of traffic, both hazardous and non-hazardous, in an intermodal chain while ensuring that the delivery at receiver *(l)* takes place by the specified time *(D_l)*. Using the notations developed in figure 1, we need to ensure shipment delivery from each shipper to each receiver while the following constraints are being adhered.

$$t_{IN} + p_j + t_s + p_k + t_{OUT} \le D_l - t_i \tag{1}$$

$$t_{IN} + p_j \leq D_s \tag{2}$$

It is important to note that an intermodal chain, formed by the three links – inbound drayage, rail-haul, and outbound drayage – is feasible only if the total time needed to complete the set of link activities is less than the time specified by the receiver. It should be noted that (D_l), the specified time also called the *lead-time*, plays a major role in the construction of feasible intermodal chains. We assume that intermodal trains of same service class (speed) on the same route arrive at the destination IMRT around the same time. Therefore, if the maximum train length is exceeded, then the containers that belong to a shipment can be split between such trains.

In here, our objective is to understand the trade-offs that underlie the decisions pertaining to dangerous goods shipments via IM, which is also the contribution of this paper. It should be noted that unlike the conventional *cost-risk* analysis, our trade-off analysis also takes into consideration one an additional dimension, viz. *time*. Hence we are trading risk and cost attributes off each other, while taking into consideration the aspect of *delivery-time* (also called lead-time).

3. An Illustrative Case Study

It should be evident from the literature overview provided in the first section that this paper constitutes the first step towards the development of an analytical framework for decision making in a *delivery-time* based IM environment. This development requires a solid understanding of the trade-offs underlying the problem, which we aim to articulate in this paper. To this end, we develop and analyze a realistic problem instance based on intermodal shipments across Canada by Canadian Pacific Railroad (CPR) - one of the two major railroad companies. The realistic problem instance is developed using publicly available data at the company's web site (www.cpr.ca), which is complemented by a detailed interview with one of its staff in charge of intermodal transportation [41]. Information pertaining to the existing railroad and road networks, location of the Montreal and Vancouver IMRTs as well as the population zones is represented via a geographical information system (GIS) model (ArcView, www.esri.com). The case data outlined in this section constitutes the basis of our analyses in the remainder of this paper.

In Canada, the westbound traffic volume via IM is significantly larger than that of the eastbound traffic [41]. Therefore, the case focuses on rail-truck intermodal shipments from Quebec to British Columbia that contain hazardous as well as regular freight. Although the IM infrastructure and population data used in this problem instance are accurate, we had to resort to hypothetical data pertaining to shipment orders because demand data is confidential. The randomly generated demand between origin-destination pairs range from 5 to 23 containers, while the number of containers with hazardous cargo vary from 2 to 11. A total of 1,036 container (also referred to as intermodal-units) shipments are to be planned among 100 origin-destination pairs, where each shipment needs to be made within the delivery time stipulated in the order (respective D_l at each receiver). Clearly, the analyses procedures presented in sections 5 and 6 are not dependent on these demand figures. The door-to-door service plan of CPR, using their equipment, is adopted in this paper.

We assume that there are ten shippers in Quebec, distributed around Montreal, and each has received *delivery-time* based orders (for hazmat and non-hazmat goods) from ten customers in British Columbia. The ten shippers are at *Repentigny, Boucherville, Saint Hubert, Brossard, Chateauguay; Beaconsfield, Kirkland, Saint-Eustache, Sainte-Therese,* and *Laval* (see Figure 2). CPR's IMRT in *Lachine* municipality, on the Island of Montreal, is the only intermodal terminal available to these ten shippers. Furthermore, we assume that these shipments are directed to the Delta Port in *Vancouver*, British Columbia (see Figure 3). The ten customers are at: *Kelowna, Kamloops, Burnaby, Surrey, Richmond, Haney, Coquitlam, Forest Hills, Prince George,* and *Prince Rupert* (for the six receivers closest to Vancouver, see Figure 4). We assume that the truck driver stays on-site during loading and unloading at the shipper and receiver locations.

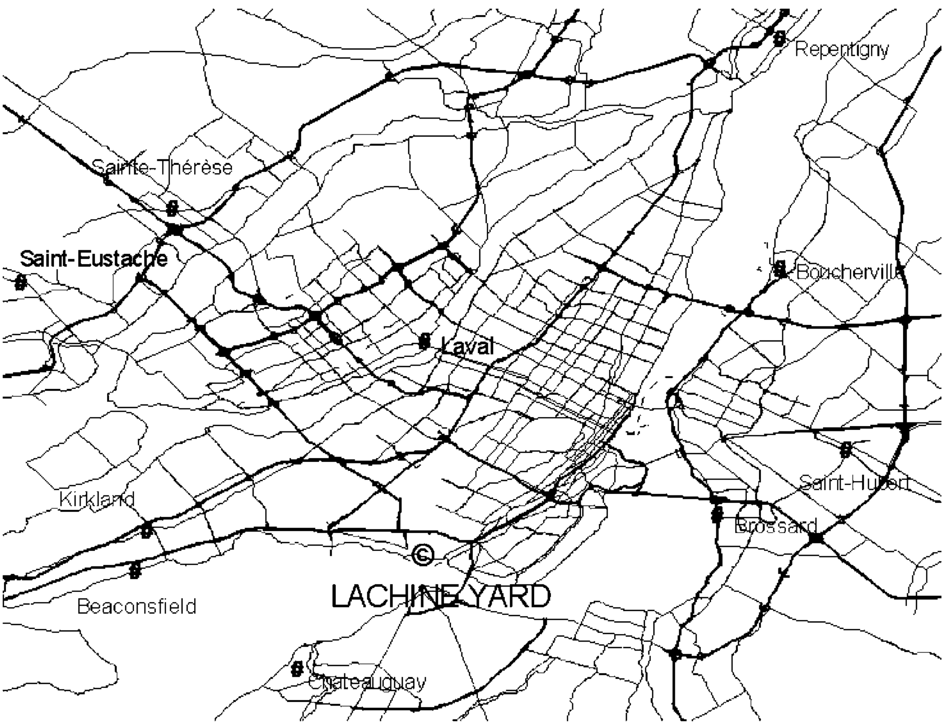

Figure 2. The Shippers and Lachine Intermodal Yard

Each shipper is linked to Lachine IMRT through the road network. The thicker links in Figure 2 represent the expressways, whereas the thinner links depicts roads of other types. Among the multiplicity of available routes, it is natural for a truck driver to take the shortest path between the shipper and the IMRT as long as the cargo not hazardous.

Figure 3 depicts the two intermodal train routes between Lachine yard and Delta Port. Since the intermodal infrastructure is sparse in North America it is not plausible to have a large number of intermodal routes between an IMRT pair. We refer to the route passing through Edmonton (and bypassing Calgary) as the *North* route and the one passing through Calgary as the *South* route. On both routes there are two types of intermodal train services: a *regular* service (R-IM) with a stop at Edmonton and Calgary respectively, to pick-up and drop-off traffic; and a *premium* service (P-IM) that is non-stop and faster but more expensive. Finally to ensure reliable delivery by aligning different links of the intermodal chain, we assume that all the parties strive for a *just-in-time* system and hence the waiting times prior to loading, unloading and transshipment activities along the IM chain are negligible.

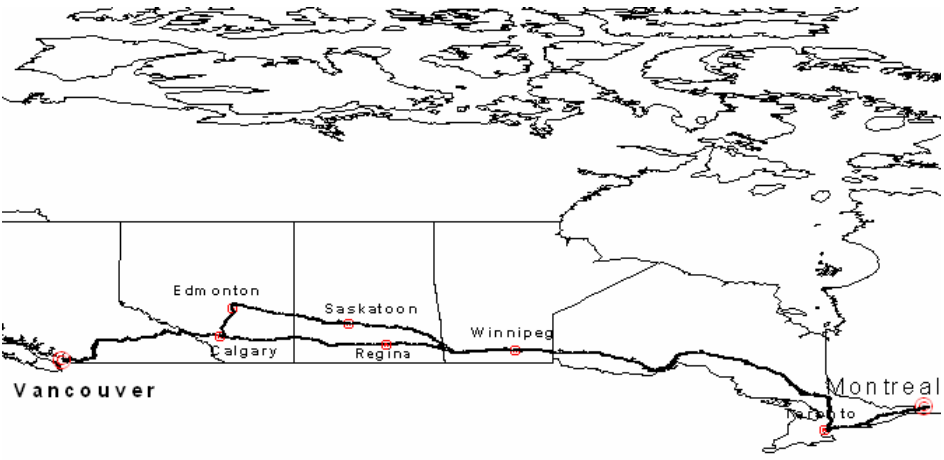

Figure 3. Intermodal Train Routes between Montreal and Vancouver

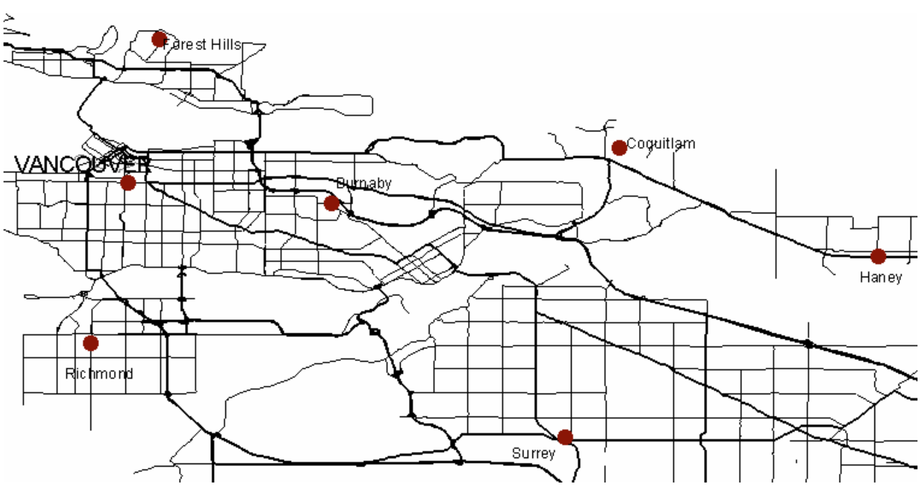

Figure 4. The Receivers and Delta Port Intermodal Yard

The final components of the case data are the specified *delivery-time* and the *order-receipt- time*, which using the notations introduced in figure 1 are (D_l) at receiver l and (t_i) at shipper i respectively. For illustrative purposes, we assume that the receivers at *Kelowna* and *Kamloops* want to receive their orders within 5 days (120 hrs) from the time an order has been placed. Receivers in and around Vancouver (*Burnaby, Surrey, Richmond, Haney, Forest Hills* and *Coquitlam*) have specified 4.5 days (108 hours) as the deadline. The two furthest points, *Prince George* and *Prince Rupert*, have specified 6 days for delivery.

Based on the case data outlined in this section, we will analyze routing options in a delivery-time based IM environment by experimenting with the total cost and population exposure of hazmats attributes. In the next section an intelligent enumeration scheme, which takes advantage of the presence of a single IMRT pair in this case, is presented. This will be followed by a section that highlights the nature of the trade-offs among the cost, risk and time attributes of intermodal shipments of dangerous goods.

4. The Assessment of an Intermodal Shipment

In this section we present a scheme to assess an intermodal shipment that involves hazmats. Our approach is based on the three links of an intermodal chain viz., inbound drayage, rail-haul and outbound drayage, a shipment has to traverse to get to its destination. Since the origin and destination of the rail-haul are pre-specified, the assessment problem is amenable to solution by an enumeration-based procedure. Although, we have conducted the complete evaluation for the 1,036 containers, grouped into 100 shipments, for the sake of brevity we will analyze (present) the *Repentigny-Kelowna* shipment to understand the decisions underlying intermodal shipments in a delivery-time based IM environment. We make the following assumptions during assessment: *First*, the request for empty containers is generated immediately on receiving an order from the customer. *Second*, the shippers are aware of the departure times of the intermodal trains and resulting time by which shipments should be ready in order to make to a particular intermodal train. *Third*, a just-in-time approach is being incorporated whereby relevant activities are performed as soon as a container reaches the concerned location, and hence there is no waiting. *Fourth*, there is sufficient capacity and enough equipment at each stage of the intermodal chain, which implies no congestion.

Table 1. Per container Inbound Drayage to Repentigny

Paths	1	2	3	4
Time(hrs.)	2.08	2.28	2.12	3.00
Distance (kms.)	83	91	85	120
Cost ($)	254	264	256	300
Population Exposure (people)	2959	2787	2557	1266

In Table 1, information pertaining to four of the paths between *Repentigny* and origin IMRT yard (in Lachine) are presented. Path 1 indicates using the shortest path for both segments of inbound drayage. Path 2 through Path 4, imply taking the shortest path to the shipper, and then a different one to get back to the IMRT. Each path has four attributes: *time, distance, cost* and *risk*. In general, in Canada trucks can travel at a maximum speed of 50 km/hr in the city, but due to lights and traffic an average speed of 40 km/hr is assumed in this case study, and hence the travel time on the first path will be 2.1 hrs. Normally drayage is charged in terms of the amount of time the crew (driver-truck) is engaged, and at a very conservative estimate of $50/hr, the crew-cost-fuel for the transportation part of inbound drayage is $104. Furthermore it is estimated that it will take approximately two hours to load a container at the shippers' site ($p_{\text{Repentigny}}$) and an hour to unload it at the yard (p_{Lachine}), for a combined crew cost of $150. Hence a container using Path 1 can be moved to the IM yard for $254, and similarly for other paths.

As indicated in the first section, we prefer using *population exposure* as the indicator of hazmat transport and handling risk, which we calculated using the Gaussian Plume Model (GPM)- based procedure developed in [15] and adopted in [42]. Note that the traditional fixed bandwidth approach of [12] and [13] is suitable for the drayage segments of IM, since it assumes a standard hazmat volume being shipped, i.e., full-truck load. During the rail-haul of IM, however, the number and location of containers with hazardous cargo vary considerably among trains, and consequently it is important to define the boundary of exposure zone as a function of the volume of hazmat being shipped. GPM is a commonly used model for estimating the level of toxic material concentration as a function of the distance to the release source, release rate, wind speed and direction as well as the elevation factors. If the concentration level at a point exceeds the IDLH specified for the hazmat being shipped, then this point is considered exposed. [15] extended the GPM to multiple release source incidents so as to incorporate this differentiating feature of the trains and showed that the toxicity level increases much faster in the vicinity of the train as the number of railcars with hazardous cargo is increased.

At Repentigny, 1,557 people will be exposed due to the handling of a single container with hazardous cargo, and 53 such containers originating at this location will expose 82,521 people. Although the population exposure risk, at the shipper's location, cannot be reduced without reneging or defaulting on the orders, it is possible to implement a prudent routing approach that can reduce network risk. Path 1, the shortest of the four paths, is the riskiest since it goes through downtown Montreal and exposes more than twice the number of people than Path 4, which is the longest but bypasses downtown Montreal.

Unfortunately for our instance a conventional risk-cost trade-off analysis will not suffice, since the element of *"delivery-time"* has to be incorporated. It should be noted that the available time to deliver the shipments and feasible intermodal chain generation is limited by the following two hard constraints, namely departure times of the schedule-based trains (D_s) and delivery time specified by the receiver (D_l). It is clear from Table 1 that 1,700 fewer people would be exposed for every hazardous container traveling from this shipper to the origin IMRT if the stakeholders are willing to spend an additional $46. As this reduction in risk is being brought about by taking Path 4, the longest amongst the four paths, this also means that the shipment would have to be ready an hour earlier in order to make it to the same intermodal train. For the 53 hazmat containers demanded from this shipper, a staggering population exposure reduction of 89,729 people can be brought about if the interested parties are willing to spend $2,348 more than what they would be if the shortest path was taken to the IMRT. Generally speaking it can be surmised that the increased cost and/or lower risk is acceptable only if the specified *time* element for the next link in the chain is not violated. For this instance, each of the four paths in Table 1 is feasible if the shipments are readied at appropriate times so as to be able to make the designated intermodal train.

On reaching the IMRT, cost will incur and risk will accrue due to the additional handling operations. While [25] estimated $140 to be the cost of a lift at the *IM* yard we have assumed a rate of $150 to reflect current conditions. All the containers, including the 538 hazmat ones, will go through the single origin IMRT, in Lachine, thereby exposing 837,666 people.

Now for the next link of the intermodal chain i.e., rail-haul, we first focus on the *North* route viz. through Edmonton. This route was measured at 2,920 miles in ArcView GIS. Average train speed, calculated using public information, of CPR in 2004 was 28.5 miles per hour, which was rounded up to 30 miles per hour for *R-IM* and the estimate for *P-IM* was 40 miles per hour. *R-IM* train will need a yard-to-yard time of 103 hours, including 6 hours for traffic swaps in Edmonton. On the other hand *P-IM* train, being both non-stop and faster, will cover the same distance in 73 hours.

Table 2. Total Time (in Days) for shipments from Repentigny on the North Route

Regular Intermodal Train Service: 97 hours.																				
INBOUND Drayage	Path 1					Path 2					Path 3					Path 4				
OUTBOUND Drayage	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
Kelowna	5.03	4.93	4.93	4.94	4.94	5.04	4.94	4.94	4.94	4.95	5.03	4.94	4.94	4.94	4.94	5.07	4.97	4.97	4.97	4.98
Kamloops	4.96	4.92	4.93	4.93	4.92	4.96	4.93	4.94	4.94	4.93	4.96	4.92	4.93	4.93	4.93	4.99	4.96	4.97	4.97	4.96
Burnaby	4.64	4.64	4.64	4.65		4.65	4.65	4.65	4.66		4.64	4.64	4.64	4.65		4.68	4.68	4.68	4.69	
Surrey	4.66	4.67	4.68	4.66	4.66	4.67	4.68	4.69	4.67	4.67	4.66	4.67	4.68	4.66	4.66	4.70	4.71	4.72	4.70	4.70
Richmond	4.64	4.64	4.65	4.64		4.65	4.65	4.66	4.65		4.64	4.64	4.65	4.64		4.68	4.68	4.69	4.68	
Haney	4.66	4.66	4.66			4.67	4.67	4.67			4.67	4.66	4.66			4.70	4.70	4.70		
Coquitlam	4.65	4.65	4.66			4.66	4.66	4.67			4.65	4.66	4.66			4.69	4.69	4.70		
Forest Hills	4.64	4.65	4.65			4.65	4.66	4.66			4.64	4.65	4.65			4.68	4.69	4.69		
Prince George	5.18	5.39	5.39	5.39	5.39	5.19	5.40	5.40	5.40	5.40	5.18	5.39	5.40	5.39	5.39	5.22	5.43	5.43	5.43	5.43
Prince Rupert	5.70	5.77	5.77	5.90	5.90	5.71	5.78	5.78	5.91	5.91	5.70	5.78	5.78	5.90	5.90	5.74	5.81	5.81	5.94	5.94
Premium Intermodal Train Service: 73 hours.																				
INBOUND Drayage	Path 1					Path 2					Path 3					Path 4				
OUTBOUND Drayage	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
Kelowna	4.03					4.04					4.03					4.07				
Kamloops																				
Burnaby	3.64	3.64	3.64	3.65		3.65	3.65	3.65	3.66		3.64	3.64	3.64	3.65		3.68	3.68	3.68	3.69	
Surrey	3.66	3.67	3.68	3.66	3.66	3.67	3.68	3.69	3.67	3.67	3.66	3.67	3.68	3.66	3.66	3.70	3.71	3.72	3.70	3.70
Richmond	3.64	3.64	3.65	3.64		3.65	3.65	3.66	3.65		3.64	3.64	3.65	3.64		3.68	3.68	3.69	3.68	
Haney	3.66	3.66	3.66			3.67	3.67	3.67			3.67	3.66	3.66			3.70	3.70	3.70		
Coquitlam	3.65	3.65	3.66			3.66	3.66	3.67			3.65	3.66	3.66			3.69	3.69	3.70		
Forest Hills	3.64	3.65	3.65			3.65	3.66	3.66			3.64	3.65	3.65			3.68	3.69	3.69		
Prince George																				
Prince Rupert																				

Table 2 provides the total time elapsed (in number of days) since the release of order, which is listed under the two types of train services. Each value is determined by calculating the amount of time a shipment will take to move from the one to other end of an intermodal chain, and therefore is equivalent to the sum of travel times on the different arcs and activity times at the different nodes forming the chain. Please note that infeasible combinations have been shaded for expository convenience. A case in point is the value 5.03 days for the first customer. It simply means that, for this shipper-receiver combination, path 1 for inbound drayage, *R-IM* service and path 1 for outbound drayage is infeasible since the *delivery-time* is 5 days from the order-receipt date.

It should be noted that, for the given problem instance any infeasible route can be made feasible either by moving traffic between the IMRTs at a faster pace or by relaxing the delivery-time constraint. It is easy to implement the former if faster intermodal trains are available between the IMRTs in question. On the other hand relaxing *delivery-time* constraint will translate into loss of revenue in one form or the other, and hence it is reasonable to conclude that any shipper would want to avoid late deliveries as long as the faster trains do not eat away the profit (margin).

P-IM is faster and hence all shipments would arrive at their destinations before the cut-off time if transported on it, but given that it is more expensive it may only be used to meet demand of customers in the greater Vancouver area (i.e., the six infeasible locations in table 2). The element of *time* is quite interesting in this instance, since the advantage is realized in the next link of the intermodal chain. By spending more money and moving shipments at a faster pace between the IMRTs we are saving time, which could be used to take longer but less risky route for outbound drayage. In [19] the authors estimated $0.70/mile as IM rail-haul cost, but in our case study it has been estimated as $0.875/mile. Furthermore in the absence of any public information to quantify premium service a crude rule of thumb, namely the speed ratio between the two types of train services of 1.33, was used to yield $1.164/mile as the rate for premium service. The risk stemming from these services depends on the makeup of trains, and will be analyzed in the next section.

The third link of the intermodal chain i.e., outbound drayage, will trigger the reverse of the operations performed on the first link. It should be noted from Tables 2 and 3 that the driver will take any path except Path 1 for outbound drayage to the first receiver at *Kelowna.* This is because this path is not just the longest but also infeasible when used in conjunction with *R-IM*, but as explained the said infeasibility can be overcome by taking the more expensive *P-IM*. On reaching the receiver's location, the containers (trailers) are unloaded and the driver returns the truck to the pool.

Table 3. Per Container Outbound Drayage to Kelowna

Paths	1	2	3	4	5
Time(hrs.)	21.30	18.38	18.35	18.40	18.50
Distance (kms.)	852	735	734	736	740
Cost ($)	1215	1068	1068	1070	1075
Population Exposure (people)	37	87	86	88	89

It is evident from table 3 that although Path 1 is the most expensive but is also the safest amongst the five paths. The other four paths, while being very similar to each other from both cost and risk standpoint, expose roughly 2.5 times more people than if Path 1 is used to move the hazardous cargo. By spending an extra $149 per container 49 fewer people per container will be exposed by taking Path 3. Finally, roughly 1,700 more people will be exposed at the receiver's site, due to the handling of the hazardous containers from all ten shippers.

5. Analysis of the Trade-offs

In this section, we will analyze the *delivery-time* based cost-risk trade-offs for intermodal shipments. Since the population exposure at the stationary locations (shippers', receivers' and the two IMRTs) are fixed, we will focus on mitigating transport risk via routing decisions at each leg of the intermodal journey. It should be noted that the two time-based constraints that define feasibility, and cannot be violated, are the departure time of the intermodal trains and the delivery-time for shipments. Figure 5 depicts the process of IM as well as the associated timeline between a shipper-receiver pair. The durations denoted by "flexible time" represents those activities for which a cost-risk trade-off can be made without violating time-feasibility. More specifically, any transport activity in a flexible time window can be expedited (e.g., the use of *P-IM* rather than *R-IM*) to allow for more time for the following (or preceding) transport activity, which will enable the use of a path with less population exposure. The discussion, in the subsections to follow, explains this time-feasibility based interaction between cost and risk in IM of hazmats in the context of the case data provided in section 4.

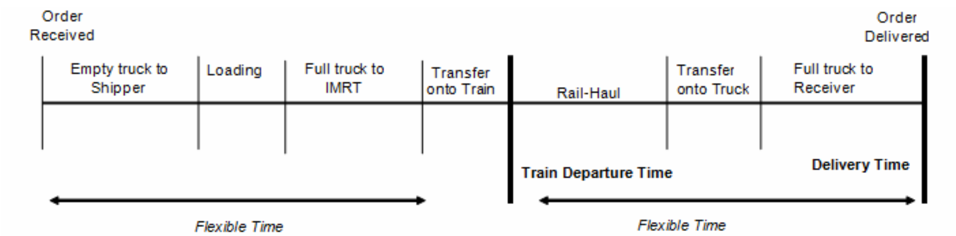

Figure 5. The Receivers and Delta Port Intermodal Yard

5.1. Inbound Drayage

As discussed in the previous section (Table 1), the driver will take Path 1 to move shipments to the origin IMRT. The judiciousness of this approach is validated if non-hazardous containers are being moved since this is the cheapest path. But a pure cost-based approach is not reasonable when hazardous cargo is involved since we note from the same table that the shortest paths are not necessarily the least risky as they pass through dense population centers. On the other hand, for our problem instance, we noticed that the longest paths to six of the ten shippers (*Saint Hubert, Chateauguay, Beaconsfield, Kirkland, Saint Eustache* and *Sainte Therese*) are also the riskiest. Hence it is reasonable to conclude that cost and risk may or may not be in conflict with each other, and using either cost or risk as the decision criterion may yield suboptimal results. Since we are interested in carrying out a *delivery-time* driven trade-off analysis where both risk and cost could be used, we will implement a *weighted* shortest path strategy. It is important to note that in an effort to nullify the dominance of cost or risk, our analysis makes use of calibration to adjust the magnitudes of risk and cost numbers. Of course such an analysis is being conducted based on the understanding that the two primary stakeholders, namely regulatory agencies and IM parties, can arrive at mutually agreeable weights for the two attributes of interest.

Because the 'departure time of intermodal trains' is the critical event inbound drayage is concerned about, it is logical to assume that all related activities would be aligned to ensure that the concerned shipments make the specific train. For example, we were able to infer from Table 1 that it is possible to move hazardous cargo on Path 4, at approximately half the risk per container, and still make the same intermodal train if the shipments could be readied an hour earlier than if they were to move on Path 1.

Table 4. Inbound Drayage

Repentigny				
Measures / Paths	**1**	**2**	**3**	**4**
First	*3213*	*3051*	*2813*	*1566*
Second	*5700*	*5636*	*5319*	*4503*
Third	*3692*	*3549*	*3296*	*2132*

Beaconsfield					
Measures / Paths	**1**	**2**	**3**	**4**	**5**
First	*1309*	*1097*	*1105*	*1545*	*1592*
Second	*3458*	*3772*	*3729*	*4336*	*4412*
Third	*1723*	*1613*	*1611*	*2083*	*2135*

Table 4 focuses on the shippers at *Repentigny* and *Beaconsfield* in presenting the impact of different weighting/calibration schemes that incorporate cost and risk in a single attribute. Under the first measurement scheme, both cost and risk have equal importance and hence receive unit weight which results in a straightforward summation of cost and risk numbers. The population exposure numbers for the Island of Montreal was significantly larger than the cost numbers, and hence for the next two measurement schemes the latter is calibrated with the former as follows.

Let Cp denote the cost and R_p denote the risk of path p, for all paths between a shipper and the IMRT. If $\overline{C}_{\max} = \max_p C_p$ and $\overline{R}_{\max} = \max_p R_p$ then the calibration factor $\overline{C}_p = \frac{\overline{R}_{\max}}{\overline{C}_{\max}}$ is multiplied with cost and the result is added to path risk to generate the second measure. Similarly, if $\tilde{C}_{\min} = \min_p C_p$ and $\tilde{R}_{\min} = \min_p R_p$ then the calibration factor $\tilde{C} = \frac{\tilde{R}_{\min}}{\tilde{C}_{\min}}$ is used to generate the third measure. Calibration factors for the two measures are 10.79 and 2.89, respectively. It is clear from Table 4 that for the shipper at *Repentigny*, the best choice using any of the three schemes is to use Path 4 for hazardous shipments. But as delineated earlier, this is possible only if the shipments are readied an hour earlier. On the other hand the decision for the shipper at *Beanconsfield* is not so straightforward and one that warrants additional weight analysis based on stakeholder preferences. It is interesting to note that none of the routes chosen from the analysis above for the two shippers would have been identified by a pure cost-based approach. Through a complete evaluation for all the ten shippers, we found out that such a coincidence exists only for the shipper at *Saint Therese*.

5.2. *Rail-Haul*

We recollect, from Table 2 and discussion in Section 5, that path-combinations involving *R-IM* was infeasible for receivers at *Burnaby, Surrey, Richmond, Haney, Coquitlam and Forest Hills*. Out of the 1036 containers to be moved west, 612 destined to these six centers would be moved on *P-IM* at the rate of $3,399, while the remaining 424 will take *R-IM* at a cost of $2,555 each.

219 of the 424 containers to be moved by *R-IM* have hazardous cargo, while *P-IM* will move 612 containers including 319 with hazardous content. Although the length of the train can be varied, it is assumed that 120 containers (with no stacking) bound for the destination IMRT can be accommodated on *R-IM*, while the rest are made available to Edmonton traffic. The development of a risk assessment methodology and problem insights gained in [15], which were then applied to a realistic size railroad network in [42] underlined the importance of train makeup plan in the determination of population exposure risk.

The train can be formed using a heuristic. For illustration purposes we present three different plans and then argue for, what, we deem to be best. Under the first plan, one could use a heuristic whereby the entire shipment from a particular shipper is assigned to only one train. *First* plan in Table 5 exhibits train make up based on such a heuristic. Consignment splitting is permitted under the *second* makeup plan. In here split entails division of traffic, from a shipper to a receiver, on more than one train of the same service class (speed) and traveling on the same route so that they arrive at the destination IMRT around the same time. Such an approach is also reasonable from the perspective of yard handling as it saves the additional assembling effort at the destination IMRT is shipments are traveling on different routes or service classes. Under the *third* plan a train is formed based on the nature of cargo. This makeup plan is motivated by the insights offered by [15], wherein it was showed that the non-linearity associated with aggregate toxic concentrate curves yields economies of risk when transporting multiple railcars (containers) with hazardous cargo. That is, moving a certain amount of hazardous cargo with fewer trains, each carrying more volume, entails less population exposure than the use of more trains, each carrying less volume. Such a prudent train makeup plan is possible by separating hazardous cargo from non-hazardous cargo, and by forming *hazmat unit-trains*. Unit-trains carry same type of cargo between two yards without any intermediate handling. Such a train makeup plan when applied to the four *R-IM* trains will result in two *hazmat unit-trains* and two regular freight trains.

Table 5 depicts the three train makeup plans for the four *R-IM* used to meet the demand of the receivers outside the Greater Vancouver area. Under the first two plans, four mixed (hazardous and non-hazardous cargo) trains are used to move the shipments, while in the third plan hazardous and non-hazardous cargo are traveling on separate trains. In each of the three plans, population exposure is computed using the methodology developed in [15]. Under the *first* plan 1,242,218 people were exposed while 1,236,541 people were exposed under the *second* plan. The two hazmat unit-trains together expose 1,058,775 people, which mean that population exposure from the rail-haul can be reduced by at least 177,766 (or 14.38%) for the given demand level by implementing the third plan.

Table 5. Three Representative train assignments

R-IM				
Train Makeup Plan	**Train Type**	**Length**	**Number of hazmat containers**	**Population Exposure**
First:	*Mixed*	*119*	*59*	*333,386*
	Mixed	*118*	*65*	*341,993*
	Mixed	*100*	*45*	*281,699*
	Mixed	*87*	*50*	*285,140*
Second:	*Mixed*	*120*	*59*	*333,386*
	Mixed	*120*	*68*	*343,960*
	Mixed	*120*	*56*	*319,530*
	Mixed	*64*	*36*	*239,665*
Third:	*Hazmat*	*99*	*99*	*522,044*
	Hazmat	*120*	*120*	*536,731*
	Non-Hazmat	*104*		
	Non-Hazmat	*101*		

Now 612 containers need to be moved by *P-IM* including 319 with hazardous cargo and once again any assignment heuristic can be used to load these trains. For brevity we just present the exposure numbers resulting from implementing the *third* plan for *P-IM*. A total of five (two hazmat, one mixed and two non-hazmat) trains would be needed to move the shipments thereby exposing a total of 1,393,377 people. Hence the cost and risk numbers for the rail-haul are $3,163,508 and 2,452,152 people respectively.

It is important to note that one of the two ways to carry out a "*delivery-time*" based risk-cost tradeoff analysis for the rail-haul terminates with train formation based on the third makeup plan, which is possible since similar train services have same arrival time at the destination IMRT. Given the aforementioned, it makes sense to try and reduce risk since the cost under each of three plans is the same. The second lever for tradeoff is the train speed. For example, if shipments moving on *R-IM* are placed on *P-IM* then there is more time for outbound drayage which can now involve longer but less risky routes, which is evaluated next.

5.3. *Outbound Drayage*

At the destination IMRT, the containers are transferred to the waiting trucks to start outbound drayage. We recollect from Table 2, that if *R-IM* is used to move shipments between the IMRTs, then Path 1 to *Kelowna* is infeasible. While it is evident from Table 3 that Path 1 is the longest path, it is also clear that the population exposure risk on this path is less than half that of the other four paths. Before we conduct a "delivery-time" based tradeoff analysis, we would like to develop weighted shortest paths for outbound drayage as for inbound drayage.

In Table 6 two of the three paths to *Kelowna* match the shortest path in Table 3, although each exposes 2.5 times more people than Path 1. As indicated earlier Path 1 can be taken only if *P-IM* is used to move shipments between the IMRTs, while the other four paths can be taken irrespective of the train service. For this receiver two of the three recommendations are in line with a cost minimization objective while the third is consistent with risk minimization objective, and just as before appropriate weights for the two objectives have to be decided by the stakeholders. On the other there is no contradiction for shipments to *Burnaby*, since both cost and risk minimization objectives are realized by taking Path 1.

Table 6. Outbound Drayage

Kelowna					
Measures / Paths	**1**	**2**	**3**	**4**	**5**
First	*1102*	*1005*	*1004*	*1008*	*1014*
Second	*1219*	*1280*	*1275*	*1285*	*1295*
Third	*1140*	*1095*	*1093*	*1099*	*1106*

Burnaby				
Measures / Paths	**1**	**2**	**3**	**4**
First	*480*	*567*	*535*	*670*
Second	*1888*	*2232*	*2106*	*2639*
Third	*941*	*1112*	*1050*	*1315*

"Delivery time" based tradeoff analysis can be conducted by focusing on just the hazardous containers destined to *Kelowna*. *P-IM* can move all the hazardous containers to the destination IMRT in about 4.2 days, thereby leaving more time for outbound drayage and hence to take the longest but the least risky path. Now Path 1 becomes feasible and population exposure risk can be reduced by 57% by spending an extra $147 per container, and the total risk stemming from shipments to *Kelowna* can be reduced by roughly 2,600 people at a cost of $8,000 more. The 53 containers with hazardous cargo destined for *Kelowna* can be accommodated on the mixed *P-IM* thereby leading to the creation of a third hazmat unit-train, while the 13 non-hazardous cargo containers can be moved from the erstwhile mixed train to the two non-hazmat trains.

Due to the aforementioned transfer, 53 slots would open on hazmat unit-train of *R-IM* service class which will eliminate the need to form and run the fourth train, but the 46 containers with hazardous cargo will result in the creation of a mixed train. Normally such an assignment, from *R-IM* to *P-IM*, could be an expensive proposition to the intermodal operator, but then it eliminates the need to run a fourth train. A shipper is only concerned about the safe and timely delivery of the shipments, and hence should not have any problem with this transfer. It is also true that shippers have no say in the assignments/loading of intermodal trains, which is the exclusive domain of the yard master.

5.4. Southern Route

"Delivery time" based tradeoff analysis brings forth another interesting dimension, i.e., the presence of alternate rail-haul routes between the IMRT pair. In an effort to evaluate the impact of this dimension, we introduce another route between Montreal and Vancouver called the *South route* (Figure 3). This route also has two types of trains on it, which go through Calgary and depart from Lachine yard two hours later than the one through Edmonton. The length of the South route as measured in *ArcView GIS* is 2,713 miles, a full 207 miles shorter than the *North route*. *R-IM* will cover the yard to yard distance in 96 hours including the 6 hour for container swap at Calgary, while *P-IM* in 68 hours. It is interesting to note that given the original delivery times and the time it takes to traverse on this route, all intermodal combinations involving *R-IM* are feasible and hence there is no need to use the faster train service. This option is useful since now shipments from *Repentigny* can take Path 4, the least risky but the longest path, and still make to the *R-IM* going on the *South* route without preparing them an hour early than when traversing on the *North* route.

It is important to note that all the shipments may not travel on *South* route, since the intermodal operator is likely to split traffic between the two routes depending on the need for consolidation and the nature of demand. Normally a shipper will approach an intermodal (railroad) operator with the delivery date and service type preferences, and based on the delivery date the *IM* operator will quote a price and the time of delivery. According to [33], as soon as a container leaves a shipper's location, almost simultaneously information regarding the destination and content (if hazardous) of the shipment is generated. So in essence a route plan has been prepared for the shipment, without the knowledge of the shipper, even before the shipment reaches the IMRT. The terminal to terminal routes of these intermodal trains are fixed, and could safely be assumed to be the shortest. In other words, an intermodal operator knows that if an *R-IM* on *South* route can enable meeting demands on time, then there is very little motivation to use *R-IM* on *North* route. But the operator could route traffic over the longer North route if there is a less-than-train load traffic for Edmonton and something needs to be moved from Edmonton to Vancouver. Of course only the shipments with enough buffer time would be consolidated with the Edmonton traffic and dispatched on *North* route.

It is reasonable to assume that the intermodal operator will not quote two different costs for the *R-IM* on two routes, since shorter route will always be preferred by the shippers. Hence, irrespective of the routes, the intermodal operator will quote only two rates, one for regular and the other for *premium* service. Although the sparse railroad network in Canada precludes having multiple routes between an IMRT pair, it is safe to expect that price quotes would be based on the longest route. The *South* route provides shippers with the option to be able to make deliveries before the specified time by using *R-IM*. Now, all 1,036 containers will be moved by *R-IM* to the destination IMRT at a cost of $ 2,646,980, which is $ 516,600 lower when *North* route was being used to move shipments. The cost savings indicated above is possible only when both the cost structures and the routes are transparent to each and every player in the system, which is never the case and hence one should not read too much into the cost savings.

The introduction of the *South* route necessitates re-determination of population exposure risk. Four hazmat unit-trains, one mixed train, and four regular freight trains would be needed to move all the 1.036 containers on the South route. Each hazmat unit-train will carry 120 hazardous containers thereby exposing 557,683 people each, while the mixed train with 58 hazardous containers will expose 338,749 people. The population exposure on the South route is 2,569,481 people, while 2,452,152 people were exposed on the North route. It appears that the route through Calgary passes through denser population centers than the route through Edmonton and bypassing Calgary.

Based on the above numbers the intermodal operator can save a total of $516,600 by taking the *South* route, but now 117,329 more persons are being exposed on the rail-haul. The increase in the risk here needs to be traded-off against the increased time for both inbound and outbound drayage, which can reduce the magnitude of network risk.

For example, all the 53 containers from the shipper at *Repentigny* could travel on Path 4, which would reduce the inbound drayage risk by 89,729 people. Similar numbers can be computed for the other nine shippers. For outbound drayage, Path 1, the erstwhile infeasible but the least risky path to the receiver at *Kelowna* becomes feasible if used in conjunction with R-IM on south route. Again, similar numbers can be computed for the other nine receivers.

To sum up, "delivery-time" dictates the paths and train service to be taken in order to meet demand. If the specified-time allows flexibility, a longer but less risky route can be taken for drayage purposes. In general, risk reduction is possible only when all the intermodal parties are concerned about safety and not driven just by the desire to minimize cost.

6. Conclusion

This work was motivated by the need to develop a solid understating of the trade-offs in IM, which combine the advantages of rail and truck transportation of hazmats. A realistic case study was used to illustrate an intelligent enumeration technique to solve a 100 supply-demand pair problem, where the risk-cost tradeoff analysis was driven by "delivery-time" and its variants. It is possible to reduce population exposure risk by spending more money and/or readying the shipments at an earlier time in the event of inbound drayage, and by taking the faster service for the rail-haul in order to enable the outbound drayage to take the best possible risk-cost weighted path to the receiver's site. In addition, population exposure stemming from intermodal trains can be reduced by implementing a train make-up scheme striving for hazmat unit-trains. In general, risk reduction is possible only when all the intermodal parties are concerned about safety and not driven just by the desire to minimize cost.

Our immediate future research direction is the development of a mathematical formulation and a solution procedure for the general case of the problem studied in this paper, which involves multiple IMRT pairs. Other directions for future research include, studying congestion in the IM system by relaxing the just-in-time assumption; comparing the performance of intermodal transportation with rail and road shipments from a risk-cost perspective; and investigating the assignment of intermodal units to flat railcars and make-up of intermodal train services when hazardous cargo is involved. Perhaps more importantly analyzing the suitability of the assessment scheme proposed in this paper to other forms of intermodal transportation constitutes a fruitful avenue.

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References

[1] Logistics Management 2004. Intermodal posts record gains in 2003. Logistics Management 43, 2, 15.

[2] J. S. Szyliowicz, 2003. Decision-making, intermodal transportation, and sustainable mobility: towards a new paradigm. UNESCO 2003. Published by Blackwell Publishing Ltd.

[3] B.A. Stone, 1997. Profitability and Risk. Containerization International 30, 11, 83-85.

[4] S. Stone, 1999. Intermodal at global watershed point. Purchasing 126, 8, 103.

[5] D. Rondinelli, and M. Berry, 2000. Multimodal Transportation, Logistics, and the Environment: Managing Interactions in a Global Economy. European Management Journal 18, 4, 398-410.

[6] U.S. Department of Transportation., 2000a. 1997 Economic Census: Transportation and Commodity Flow Survey. April.

[7] U.S. Department of Transportation, 2004. 2002 Economic Census: Transportation and Commodity Flow Survey. December.

[8] U.S. Department of Transportation., 2000b. Departmentwide Program Evaluation of the Hazardous Materials Transportation Programs Final Report. March..

[9] Rasmussen, Sören., 2005. Bureau International des Containers et du Transport Intermodal (B.I.C.): Security Issues on Logistics of the Intermodal Transportation Chain.

[10] E. Erkut,. S. Tijandra, V. Verter, 2007. Hazardous Materials Transportation. Chapter 9 in C. Barnhart and G. Laporte (editors), Handbooks in Operations Research and Management Science vol 14, Elsevier, pp. 539-621.

[11] North American Emergency Response Guidebook, 2000. Prepared by Transport Canada, U.S. Department of Transportation and the Secretariat of Communications and Transportation of Mexico.

[12] R. Batta and S.S. Chiu,.1988. Optimal obnoxious paths on a network: transportation of hazardous materials. Operations Research 36, 1, 84-92.

[13] C. ReVelle, J. Cohon and D. Shobrys, 1991. Simultaneous siting and routing in the disposal of hazardous wastes. Transportation Science 25, 2, 138-145.

[14] Transport Canada., 2007. Transport Dangerous Goods – Newsletter. Spring.

[15] M. Verma and V. Verter, 2007. Railroad Transportation of Dangerous Goods: Population Exposure to Airborne Toxins. Computers and Operations Research 34, 1287-1303.

[16] C. Macharis and Y.M. Bontekoning, 2004. Opportunities for OR in intermodal freight transport research: A review. European Journal of Operational Research 153, 400-416.

[17] Y. M. Bontekoning, C. Macharis and J. J. Trip, 2004. Is a new applied transporation research field emerging? –A review of intermodal rail-truck freight transport literature. Transportation Research 38A, 1-34.

[18] T.G. Crainic and K.H. Kim, 2007. Intermodal Transportation. in G. Laporte and C. Barnhart (eds.). Handbooks in Operations Research and Management Science, Vol 14, Elsevier

[19] E.K. Morlok and L.N Spasovic,. 1995. Approaches for Improving Drayage in Rail-Truck Intermodal Service. Proceedings of The 1995 Pacific Rim Transportation Conference, Seattle, WA, USA. July 30-August 2.

[20] T. B. Gooley, 2001. Local Connections. Logistics Management and Distribution Report 40, 1, 65.

[21] H.L. Richardson, 2002. Rail service on the right track-finally. Transportation and Distribution 43, 2, 50-54.

[22] B. W. Wiegmans, E. Masurel and P. Nijkamp, 1999. Intermodal Freight Terminals: An Analysis of the Terminal Market. Transportation Planning and Technology 23, 2, 105-128.

[23] H. Priemus, 1999. On Modes, Nodes and Networks: Technological and Spatial Conditions for a Breakthrough Towards Multimodal Terminals and Networks of Freight Transport in Europe. Transportation Planning and Technology 23, 2, 83-103.

[24] Y. M. Bontekoning, 2000, The Importance of New-Generation Freight Terminals for Intermodal Transport. Journal of Advanced Transportation 34, 3, 391-413.

[25] J. E. Barton, C. L. Selness, R. J. Anderson, D. L. Lindberg,. N. S. J. Foster, 1999. Developing a Proposal for a Multi-User Intermodal Freight Terminal as a Public-Private Partnership. Transportation Research Record 1659, 145-151.

[26] P. Arnold, D. Peeters, and I. Thomas, 2004. Modeling a rail/road intermodal transportation system. Transportation Research 40E, 3, 225-270.

[27] A Ballis, and J. Golias, 2004. Towards the improvement of a combined transport chain performance. European Journal of Operational Research 152, 420-436.

[28] F. Southworth and B.E. Peterson, 2000. Intermodal and international freight network modeling. Transportation Research 8C, 147-166.

[29] A. E. Rizzoli, N. Fornara and L. M. Gambardella, 2002. A simulation tool for combined rail/road transport in intermodal terminals. Mathematics and Computers in Simulation 59, 2, 57-71.

[30] P.T. Evers, 1994. The occurrence of statistical economies of scale in intermodal transportation. Transportation Journal 33, 4, 51-63.
[31] A.M. Newman, C.A. Yano, 2000. Scheduling Direct and Indirect Trains and Containers in an Intermodal Setting. Transportation Science 34, 3, 256-270.
[32] J.H. Bookbinder, N.S. Fox, 1998. Intermodal Routing of Canada – Mexico Shipments Under NAFTA. Transportation Research 34E, 4, 289-303.
[33] L.K. Nozick and E.K Morlok, 1997. A Model for Medium-Term Operations Planning in an Intermodal Rail-Truck Service. Transportation Research 31A, 2, 91-107.
[34] C. Barnhartand, H. D. Ratliff, 1993. Modeling Intermodal Routing. Journal of Business Logistics 14, 1, 205-223.
[35] J.J. Trip and Y. Bontekoning, 2002. Integration of small freight flows in the intermodal transport system. Journal of Transport Geography 10, 221-229.
[36] B. Jourquin, M. Beutheand, C.L. Demille, 1999. Freight Bundling Network Models: Methodology and Application. Transportation Planning and Technology 23, 2, 157-177.
[37] M. Janic, A.Reggiani and P. Nijkamp, 1999. Sustainability of the European Freight Transport System: Evaluation of Innovative Bundling Networks. Transportation Planning and Technology 23, 2, 129-156.
[38] W.B. Powell and T.A. Carvalho, 1998 . Real-Time Optimization of Containers and Flatcars for Intermodal Operations. Transportation Science 32, 2, 110- 126.
[39] A.A. Assad, 1980. Modeling of Rail Networks: Toward a Routing / Makeup Model. Transportation Research 14B, 101-114.
[40] J-F. Cordeau, P. Toth, D. Vigo, 1998. A Survey of Optimization Models for Train Routing and Scheduling. Transportation Science 32, 4, 384-404.
[41] V. Calluri, 2004. Personal Communication.
[42] M. Verma, V. Verter, M. Gendreau, 2008. A Tactical Planning Model for the Railroad Transportation of Mixed Freight. Transportation Science, under review.

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Modeling a Real Time Mobile Information System for HazMat Telegeomonitoring

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Abstract. In this paper, we propose a real time mobile information system architecture for hazardous materials telegeomonitoring. We illustrate the integration of various software components and we give an object oriented model for overall system with real time considerations. The component-based development is also introduced with a framework of mobile object modeling on transportation network. In addition, a significant component giving multicriteria fuzzy routing is incorporated into a spatial decision support system (SDSS). Its allows analyses of risks and evaluation of routing strategies that minimize the transportation risk. Integrating the SDSS within our proposed system increases its performance and viability. A prototype system of HazMat transportation for Mohammedia city has been developed.

Keywords. Hazardous materials, SDSS, mobile object, LBS, Telegeomonitoring, Location Based Services.

Introduction

Hazardous materials (HazMat) are essential to our everyday lives as they are used for agriculture, medical applications, manufacturing, mining, chemicals and other industrial processes. Thousand of tons of petroleum, toxic, chemical, corrosive, flammable and radioactive materials are transported every day. However, these substances may pose a threat to public safety or the environment during transportation due to their physical, chemical, or nuclear properties. By considering this vulnerability, it is necessary to carry out research project to develop information system dealing with the management of risks and the routing of the hazardous materials transportation [34].

In fact, during the last years wireless communications have experienced a spectacular growth. Most of the population is already familiarized with the use of devices like mobile phones and Personal Digital Assistants (PDAs), etc. This factor and others point out the great business opportunity which is those services that can be used by a great mass of customers through a mobile phone. Location Based Services (LBS) refers to the wireless services provided that the subscriber is based on his current location. The position can be known by getting it from mobile phone network, or from

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another positioning service, such as the Global Positioning System (GPS). The location-based system is complex and requires the seamless integration of many different technology components into a single system. The core technology for any LBS solutions is GIS system, which performs important functions such as determining street addresses, look up landmarks, calculate optimal routes and render custom map. Moreover, the integration of geospatial information and mobile computing is driven by market demands and technologies. This system creates a new channel of business practice, and thousands of potential applications and services can be developed. Hence, it is exploring a new era of mobile geographic information services [18] [24].

The location based services can be classified under the umbrella of telegeomonitoring, which can be defined as a new discipline characterized by positioning systems, cartography, the exchange of information between different sites and real time spatial decision making [29]. Telegeomonitoring system development combines two heterogeneous technologies: the geographical information systems (GIS) and telecommunications technology [4].

In this paper, we describe mobile information system architecture with real time consideration for hazardous materials transportation and environmental monitoring. We illustrate the integration of the various components software and we propose a real time object oriented model of this system. For object modeling we use for object modeling UML 2.0 [39-40] and RT-UML [39] that has recently appeared to facilitate object development with real-time modeling notation and to represent real-time tasks with UML.

On other hand, since the modeling and the management of a mobile object are fundamental in this type of system to furnish the requested services, we provide a mobile object data model for representing and querying mobile objects especially those with point geometry moving on a transport network. This data model constitutes a framework that is employed notably in the component based modeling introduced in this paper.

Furthermore, we discuss also the development of spatial decision support system (SDSS) for hazardous materials transportation routing and monitoring. The design of The SDSS was the result of project led by Boulmakoul and his team [4] [6]. The SDSS which is based initially on the technologies of both geographical information system (GIS) and decision support system has been extended by the integration of GPS and handled by fuzzy routing algorithms in fuzzy graphs that capture the concept of risk.

The rest of the paper is organized as follows: Section 1 presents an overview of UML 2.0 and RT-UML. Section 2 proposes a generic architecture of real time mobile information system for HazMat telegeomonitoring. Section 3 gives the object oriented model of the proposed system with real time considerations. Section 4 presents a data model of mobile object on transportation network. Section 5 introduces the components based modeling of our system and section explains the HazMat database creation process. Section 7 discusses an open architecture with the use of web services technology. Section 8 concerns the SDSS for hazardous materials transportation routing and monitoring. In section 9, a prototype system of HazMat transportation of Mohammedia city is described.

1. UML 2.0 and RT-UML Specification

UML 2.0 represents a major revision to the Object Management Group's Unified Modeling Language (UML), for which the previous current version was UML v1.5. It is composed of two specifications: Infrastructure and Superstructure specifications. The first defines the foundational language constructs required for UML 2.0. The Superstructure specification that uses the architectural foundation provided by the Infrastructure specification, defines the user level constructs required for UML 2.0 [39-40].

The major improvements to UML 2.0 include the Support for component based development via composite structures and integration of action semantics with behavioral constructs [27]. In addition, UML 2.0 presents some features that support real time aspects [3]: concurrency modeling, timing constraints, etc. UML 2.0 introduces new diagram called timing diagram to allow reasoning about time and visualize conditions or state change over time [20].

The RT-UML specification is the UML profile for real time modelling, formally called schedulability, performance and time (UML-SPT) [38]. It has been adopted by the Object Management Group (OMG). This increased the interest in the use of the object oriented technology and UML in particular to model and build real time systems. This profile is designed to add standard real-time extensions to UML in order to facilitate development with real-time modeling notation. This profile allows the construction of predictable UML models and it focuses notably on key system properties such as timeliness, performance, and schedulability. RT-UML is a framework to model quality of service, resource, time and concurrency concepts. Actually, it provides the user (modeler) with a set of stereotypes and tagged values in order to annotate the UML model. Quantitative analysis (schedulability and

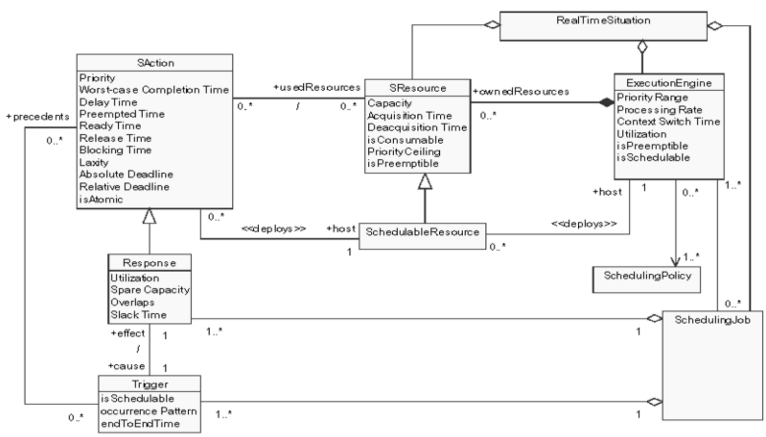

Figure 1. Core schedulability model from [38]

performance analysis) can then be applied to these (predictive) UML models.

The structure of the profile is modularized to allow users to only choose the elements that they need. The profile defines a basic framework which is a set of sub-profiles that represent the general resource modeling framework. This framework is divided into three packages:

- Resource modeling for the basic concepts of quality of service and resource
- Concurrency modeling for concurrency modeling
- Time modeling for time and time-related mechanisms modeling

Derived from the basic framework, there is a sub-profile used for schedulability analysis of systems. This model is more interesting for real-time systems where the question of when a response to an event occurs is very important for the correct behavior of the system. The schedulability sub-profile focuses on how to annotate the model in ways that allow a wide variety of schedulability techniques to be applied. Figure 1 depicts the metamodel defined in RT-UML for the main concepts involved in the schedulability analysis: the execution engine, threads (task or process), shared resources, external events and the response of the system to the external events. To representing these concepts in UML, a set of stereotypes and their associated tagged values is defined in schedulability sub-profile. The figure 2 presents a sample of stereotypes. The application of these stereotypes will be illustrated in our real time object oriented model in section 6. The ability to undertake quantitative analysis at early phases of the development process is important to reduce the cost.

Table 1. SPT common stereotypes for schedulability analysis

Stereotype	Real-time Concept	UML Model Element
«SAsituation»	Real-time situation	Collaboration, Sequence diagrams
«SAtrigger»	Event	Message, Stimilus
«SAresponse»	Response	Method, Action
«SAaction»	Action	Method, Stimilus, Action
«SAschedRes»	Task, Thread	Instance, Object, Node
«SAresource»	Resource	Instance, Class, Node
«SAengine»	CPU, Processor	Object, Class, Node

2. Architecture

The architecture of the proposed system for location based services is depicted in Figure 2. It is complex and requires the seamless integration of many disparate technologies in one system. A global positioning system (GPS) receiver will be needed in order to determine the current position of the mobile object (i.e. client truck) and also to send periodic updates of the mobile user's position to the location server. This system permits mobile users in real time to access information related to location, such as HazMat and risk data, or the fuzzy shortest path to get a specific destination. The mobile user can define criteria to satisfy in the research of the path in the network. The real time information about for instance traffic data can also be retrieved.

Figure 2 shows the main components of the considered architecture:

- *Mobile Object (MO)*: represents moving object like truck with embedded device equipped with a location detection mechanism such as GPS. Periodically it sends its coordinate to location system.

- *Service Provider (SP)*: coordinates between different components of this system to provide anywhere, anytime real-time data, map or other services to the mobile object related to its spatial position. It can use web services [37] that permit to interact with any type of mobile devices to furnish the desired services. The web services can communicate and coordinate with other web services developed with different technologies.
- *Location Server*: in order to determinate any mobile object positions, the database servers storing the user's location will be generally distributed among cellular architecture network [41]. We can use in our system a simple architecture in which a Location Server is connected to whole local database servers related to a number of cells. These moving object databases have to deal with the moving objects and all kind of spatio-temporal queries [22]. The location server (Index Server) holds for every object its local database server.
- *GIS Server*: it has a suite of tools to perform spatial operations which include geocoding, reverse geocoding, routing and several other services. It needs to access GIS Content database to perform its functions. It can also access via Internet network other GIS servers and GIS databases.
- *HazMat Data*: this server permit to retrieve hazardous material description stored in the HazMat multimedia database, which is designed to be user-friendly and to allow remote access. The HazMat information concerns the product identification, the nature of the danger, the physical and chemical properties, the risk and security instructions, etc.
- *Risk Data*: this entity provides risk information on the three main targets: population, environment and economy.
- *Emergency services:* in case of emergency, this component allows to take a

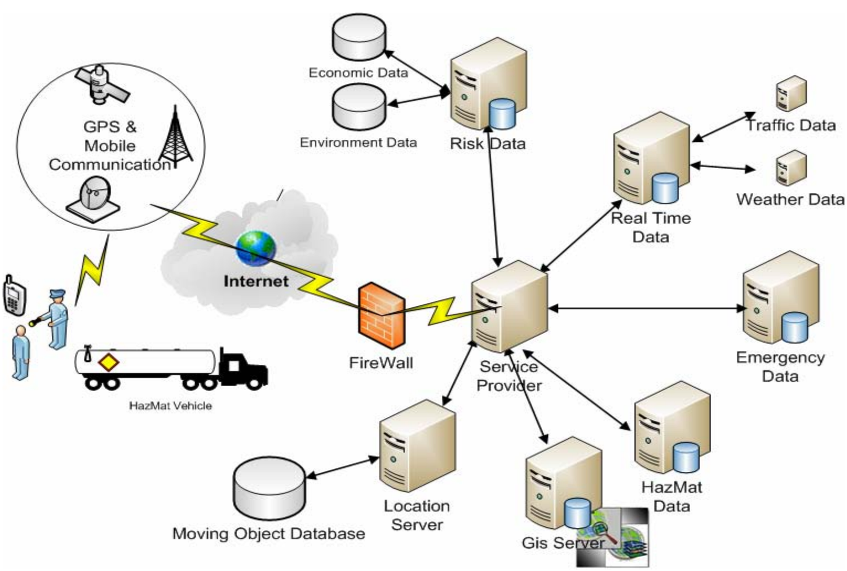

Figure 2. Architecture of overall system

number of decisions. It permits to estimate the radius of the impacted area with soft and hard consequences, give the optimum deployment of the emergency response units and minimize the evacuation time on the impacted area by reducing the traffic assignment.

- *RealTimeData*: represents an entity that is accessed concurrently and receives real-time data from different data sources concerning for instance traffic or weather data. It analyses up to date information and stores the processed data in RTData Storage database. The Service Provider may interact with this server to retrieve real-time data.

3. A Real Time Object Oriented Model of Overall System

In this figure 3, we propose an object oriented model with UML 2.0 following, as possible as, the definition found in the open GIS specification [36]. Figure 3 shows a communication diagram that emphasizes the structural organization of the objects that exchange messages.

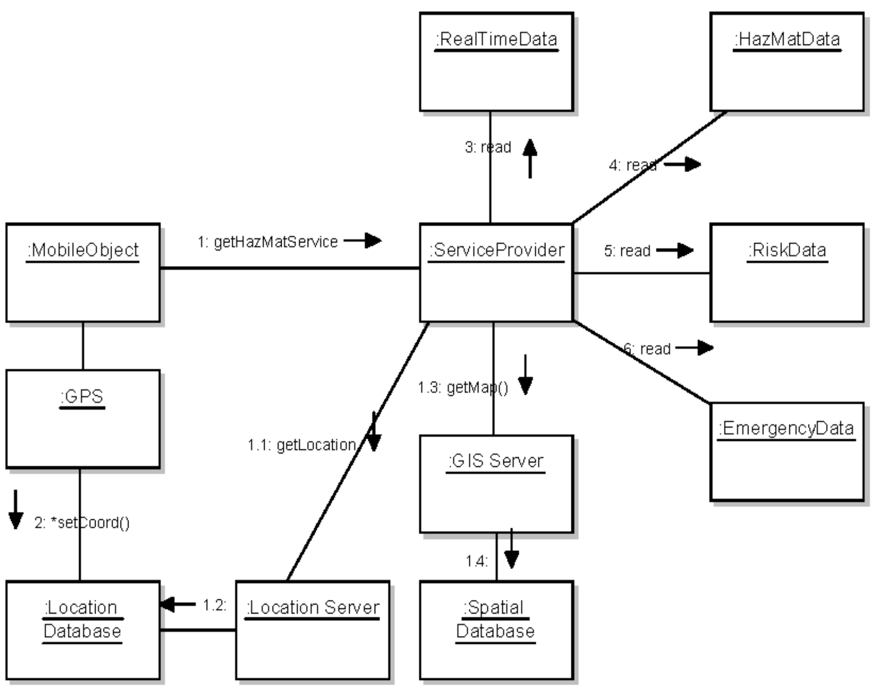

Figure 3. Communication diagram of the proposed system

The following steps describe the interaction between components in the system. These sequences of events take place to provide requested service and improve mobile application:

- The Mobile Object requests via wireless network real-time desired services from the Server Provider.
- After identification of the subscriber and the requested service, the SP parses, evaluates and interprets this spatio-temporal request and call different components in order to provide mobile geographic services to mobile client. The SP formats the request data to Location Server to have positions of whole mobile objects that are mentioned in the MO request.
- The Location Server validates Service Provider's identity and request format. Then, it retrieves the relevant positioning data from the moving object databases. It constructs a message which consists of the positioning data and other supporting elements such as GMT and local time. It sends it to the SP.
- The SP parses this message to get positioning data. Then, it opens a connection to GIS Server to send a map request or request searching some spatial objects in whose influence areas the MO is found.
- The GIS Server sends its response to the SP.
- Since the SP has now information about the MO, other mobile objects and spatial objects, it can interact with RealTimeData, EmergencyData, HazMatData or RiskData object to retrieve the appropriate information.
- Finally, the SP sends its response to the Mobile Object describing the service.
- Mobile device application installed on mobile terminal permits to parsing the response receiving from the SP. For instance, it allows subscriber to view the processed map with services and plotted position, and interact with other functions.

On other hand, we can annotate the communication diagram with several stereotypes from the schedulability sub-profile [10] to represent real time considerations of different scenarios inside our system. For example, *ServiceProvider*, *HazMatData*, *EmergencyData*, *RiskData* and *TrafficDataGatherer* classes in Figure 4 are associated with *« SAschedRes »* stereotype. Instances of the classes that are associated with this stereotype execute concurrently in the application context. The execution flow of « SAschedRes » stereotype is identified as a scenario which is started after an activation message stereotyped with *« SAtrigger »*. During this execution, many actions stereotyped by *« SAaction »* with a specified priority *(SAaction.SApriority)* may be executed in response, for instance, to a method call. The *RTduration* tag indicates the total duration of action.

The basic structure of the class scenario is characterized by the *« SAresponse »* stereotype and executes periodically after a periodic event of the trigger associated to the tag *RTat= ('periodic',300,'ms')*. In addition, the *RealTimeData* class stereotyped with *« SAresource »* is a protected resource that is accessed concurrently using mutual exclusion mechanisms. The *SAcapacity= 1* means that one element can simultaneously access to an instance of this class. The *SAaccessControl* tag defines the access control policy.

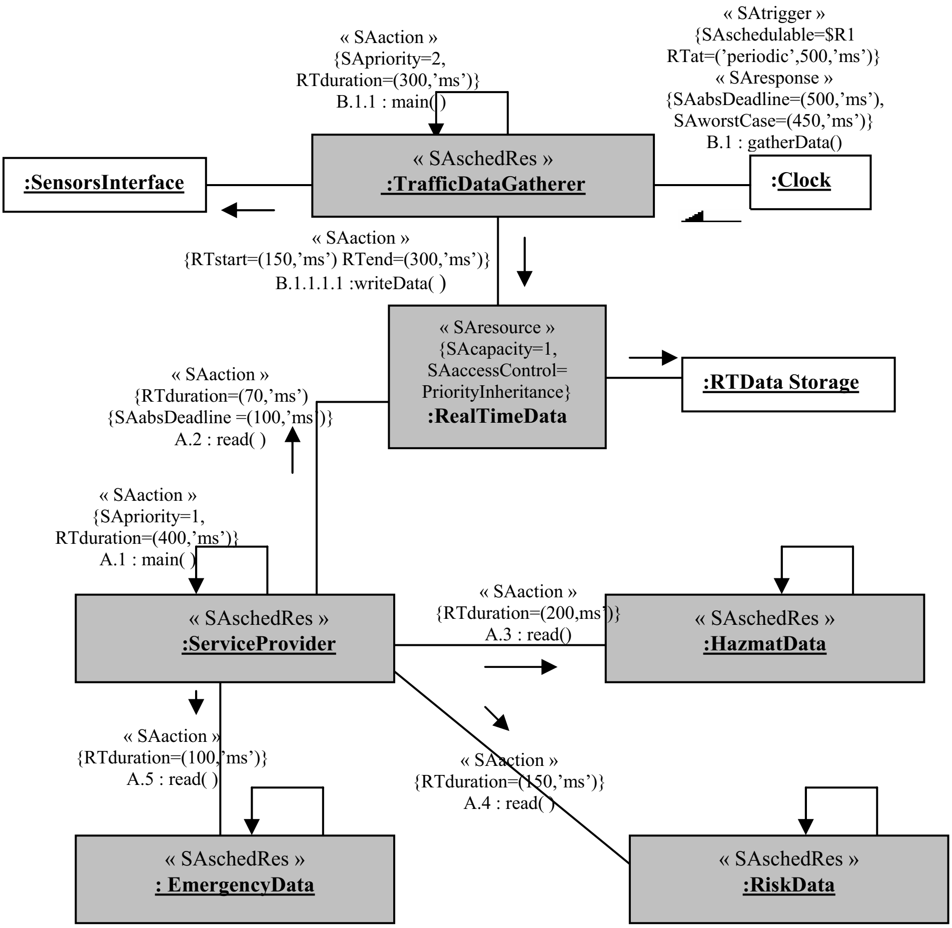

Figure 4. Communication diagram annotated with RT-UML Stereotypes

4. Mobile Object Data Model

In this section, we present a data model of mobile objects moving on the transportation network. The model is represented by spatio-temporal classes with mobility aspects. This is arisen from our work on mobile object modeling and location based services [8-9]. The LBS are concerned by the mobile point objects, i.e. objects with zero extent that change their location continuously over a predefined network infrastructure. Thus, our emphasis is put on the modeling the mobile point object and its relationships with the main classes which represent the multimodal transportation network.

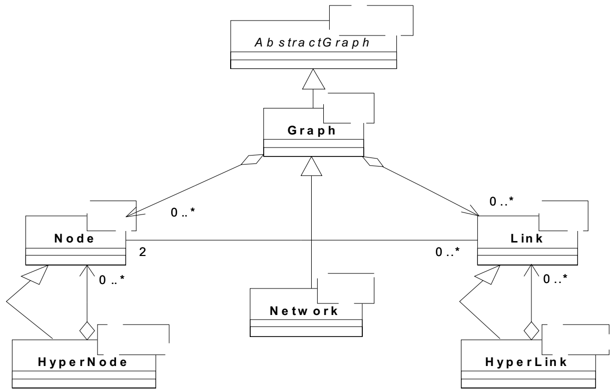

Figure 5. Class diagram of transportation network

The multimodal transportation network is modeled as an oriented graph, whose fundamental elements are nodes and links. The transmodel defined the two entities (*point* and *link*) at the core of the network model [47]. For topological aspect, we prefer to use the concept of a node instead of a point. We shall start our spatial network model by focusing very sharply on the definitions and semantics of these two entity types and the relationships between them. A *node* (for generic topology) is the smallest identified location in space. It can play many different roles in the transportation network (node is not just a location in space). A *link* is the unique oriented path which connects two nodes. We can also introduce hypernodes and hyperlinks entities in this modal. A *hypernode* is a node composed of one or more nodes, i.e., a node is a station for a single transportation mode and an hypernode is an intermodal station, that is a place where people can enter or leave the transportation network or change their mode of transport. A link is an unidirectional path. A *hyperlink* is a link connecting two hypernodes, and it is composed of one or more links [4].

Figure 5 gives a logical view of spatial networks. The node, the link and the relationships between them are considered as a generic structural pattern which specifies many concrete structures in a transport network.

To represent transportation network in mobile object data model, The *PhysicalNetwork* class is added. It represents a road network or a rail network, in which the transport services are supposed to run. The basic entities of the physical network are *TransportLink* and *TransportNode* that inherits respectively link and node classes of the generic model. The road network represents all carriageways available for vehicles (cars, buses, etc.) and into which the mode lines can be inserted. Two entities: *RoadLink* (carriageway available for cars, buses …) and *RoadNode* (connection between road segments) are basic elements of the road network. In similarity, the description of the rail network is meant to be a model of the track network along which vehicles (or trains) can physically proceed. It is modeled by two entities *RailLink* (track along which metro or train can physically proceed) and *RailNode* (located at switches).

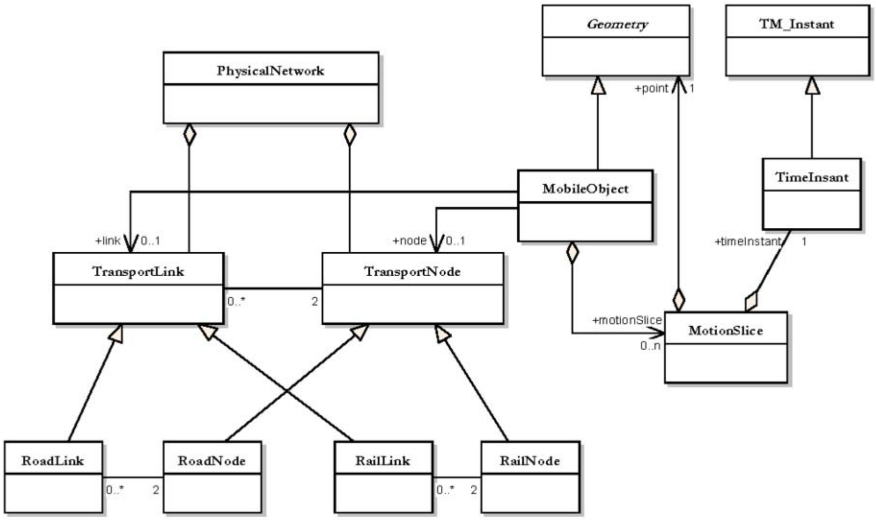

Figure 6. Mobile object data model

On other hand, the data model of the mobile object depicted in Figure 6 appropriately extends the Simple Features model of open geospatial consortium (OGC), which defines abstract *Geometry* class, and its hierarchy of the specialized geometric classes (*Point*, *LineString*, *Polygon*, etc.) [35]. The time dimension of a mobile object is defined in accordance with ISO TC 211 Temporal Schema (*TM_Instant*, *TM_Period*, etc.) [23]. The *MobilePoint* class provides modeling mobile point objects that move continuously over a predefined network infrastructure. Since it inherits the OGC Geometry class, this class and its specialized classes can be treated in the same way as any other geometric object. The *MobilePoint* defines predicates and operations for the management and querying mobile objects with the respect to the OGC and ISO 211 specifications. Our approach is based on the comprehensive framework of the data types, the rich algebra defined in Güting et al. [22] and the works related to location data models and query languages [46][48]. In addition, the model describes relationships between *MobilePoint* class and the main classes of the transportation network, such as *TransportLink* that is the way where the mobile object can move. The *MotionSlice* class provides the representation of the complete motion of the mobile object. An instance of this class, aggregated by the *MobilePoint* class represents the registered location of the mobile geometry.

5. Modeling with UML 2.0 Components

We will use the concepts of components in UML 2.0 [2][44]. With regard to UML 1.x, this concept has been modified by addressing now system structures. It is from the main improvements in UML2 which supports the component based development via

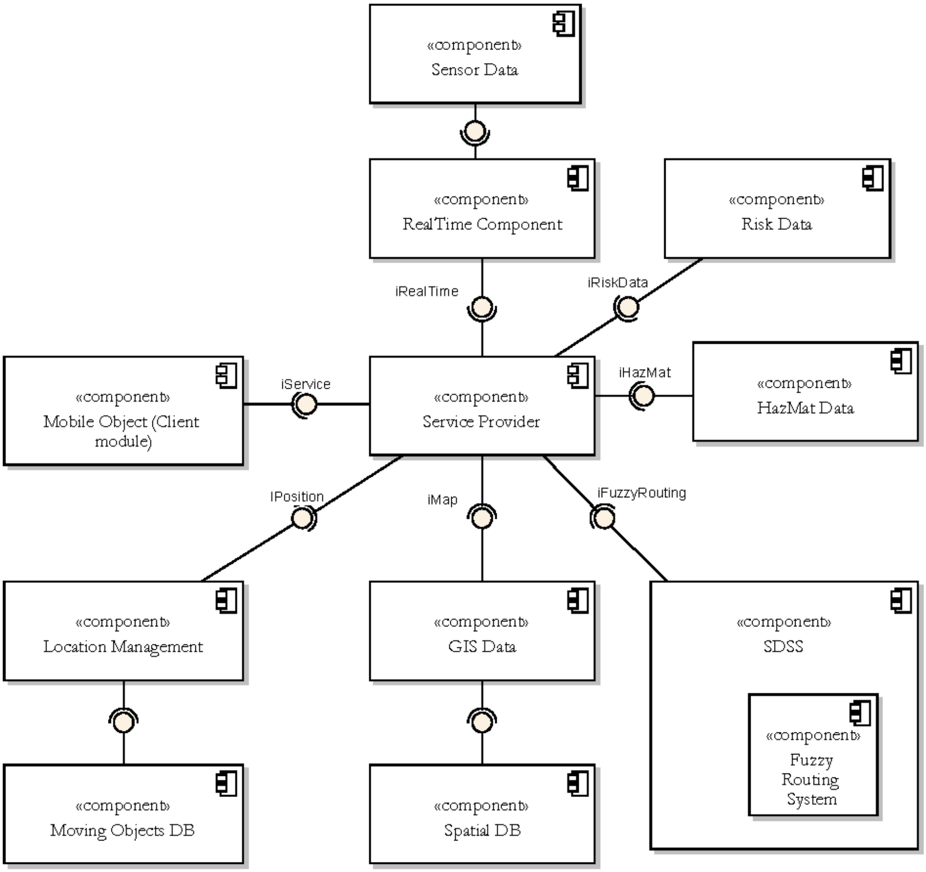

Figure 7. Compositional structure of overall system

composite structures.

A component is a modular unit with well-defined interfaces. The interfaces of a component are classified as provided interfaces and required interfaces. Provided interfaces have defined a formal contract of services that the component provides to other components while required interfaces have defined the services that it requires from other components in its environment to operate properly. In UML 2, a component can have two different views, external view and internal view: The external view is also known as a "black-box" view in which it exhibits only the publicly visible properties and operations which are encapsulated in the provided and required interfaces. The wiring between components is specified by dependencies or connectors between component interfaces. The internal view is a sort of "white-box" view which shows the component internals that realize the functionality of the component.

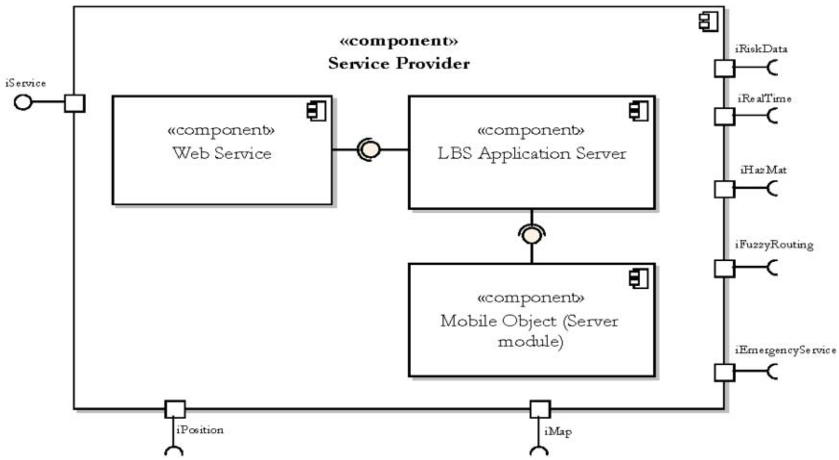

Figure 8. Internal view of Service Provider

The structure diagram in Figure 7 shows the composite structure of components. The wiring between components is represented by assembly connectors between provided and required interfaces. This component-based structure aims to hierarchically decompose the complex system into smaller sub-systems and then connect these sub-systems together. We can reuse any part of the modeling system in many other contexts. In this component based modeling, based on the data model of mobile object, we make up two components relative to mobile object: a module in the server side and another for the client. The component of the client has some additional classifiers (classes or components) and interfaces with purpose to deal with the location capture and to calculate the uncertainty. These issues are discussed in [50].

Moreover, the SDSS component plays an important role. It represents a decision-making unit that permits risk analysis performed by the simulation of scenarios. At this level the decision system uses fuzzy routing algorithms in fuzzy graphs that capture the concept of risk. It provides simulations by analyzing the accidental scenario impact on the tree main targets: population, environment and economy. The section 6 gives more details on the SDSS component.

Focusing the Service Provider in Figure 7, we see its external view in the middle of the figure. The internal view of design for this component is depicted in Figure 8 that shows how some Service Provider parts are connected to each other.

6. Web Services Based Open Architecture

The previous solution offering internet access through architecture based on browser client and web server to get specific services presents some limitations:

1. the data accessibility which depends on different mobile user's devices

2. the interoperability issues of various distributed and heterogeneous systems
3. the need for remote and mobile control access

Recently, the web services concept is rapidly rising as a new solution to solve the integration problem among heterogeneous application systems. It is a kind of standardized software technology that can integrate and share various computer programs [19][33]. It has an advantage of flexibility by perfectly defining standard specifications for mutually sharable data among distributed systems. The web services represent the convergence between the service-oriented architecture (SOA) [17] and the web. SOA has evolved over the last years to support high performance, scalability, reliability, and availability. However, traditional SOA are tightly coupled with specific protocols. The web services architecture takes all the best features of the SOA and combines it with the web. It supports universal communication using loosely coupled connections. The web services support web-based access, easy integration into a neutral platform, and service reusability [16][19]. It is based on standard XML (extensible Markup Language) language and accessible across many protocols such HTTP, SMTP, etc [32][53].

The main standards of the web service architecture are composed of XML, UDDI (Universal Discovery Description and Integration), WSDL (Web Services Description Language), and SOAP (Simple Object Access Protocol). The SOAP is a communication protocol based on XML that enables users to mutually communicate their services under distributed environment. The purpose of UDDI is to build a distributed global registry that could be accessed through web environment. The WSDL as a kind of language that defines usages of web services is used in order to describe the interface name, argument and return value of serviceable programs [45][49].

The web services technology has been adopted in this context. The main advantage is to offer an open architecture for any type of client in a simple way. The mobile client can access the same hazmat information independently from its platform, language, and above all device.

A number of web services are defined:

1. a group that handles the hazmat data
2. a group that permits access to the real time information i.e. traffic and weather information
3. a group implementing the access to the risk data
4. a group that permits to get the fuzzy shortest path to get a specific destination.

In fact, our Server Provider is a set of components and particular servers. To offer the desired services to the different mobile users, an open architecture based on web services and n-tiers model are considered. Any mobile devices that can support SOAP protocol can request the HazMat services and communicate with the server provider. The figure 9 shows the web services based open architecture adopted to deliver the SOAP services. In the presentation level, the heterogeneous mobile devices interact with web services like SMS, WAP, J2ME or Windows CE clients. In particular, Java 2 Micro Edition (J2ME) is a platform for developing applications for mobile devices. The J2ME technology consists of a set of core Java APIs and virtual machine for tailored runtime environments for resource-constrained devices [26].

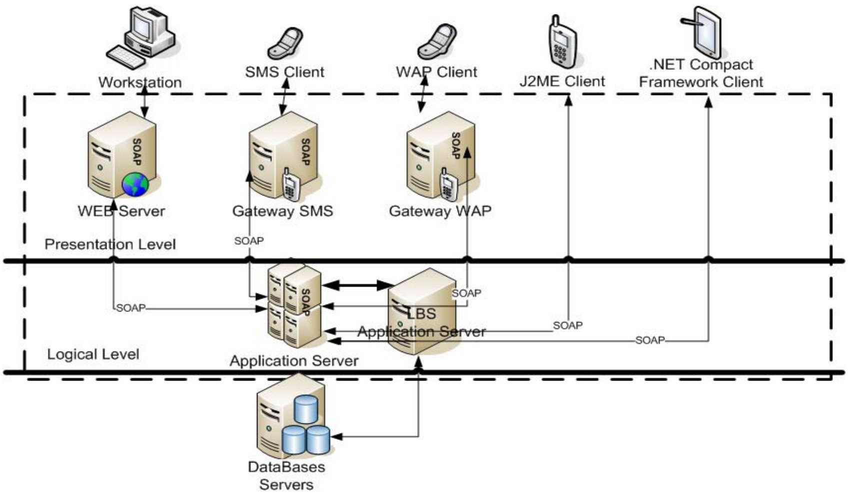

Figure 9. Web services open architecture

The different mobile clients can access a number of services via the same web services and application server. The logical level is responsible for all processing operations and coordination between of distributed components of overall information system. In our Server Provider is a set of components and particular servers. The windows CE mobile devices support the .Net compact framework that enables the development of XML web services applications on mobile devices such as personal digital assistants (PDAs) and mobile phones.

7. HazMat Database Creation Process

For this work, we study the European Agreement concerning the International Carriage of Dangerous Goods by Road (ADR) [1]. We analyze the structure of this document and then we extract from it the information concerning the hazardous materials to give a HazMat data model and to create the hazmat database.

The class diagram of the Figure 10, gives a high level object describing the hazardous material. This general model can be exploited by other hazardous materials transportation system such as RAIL transport (RID) and Arial transport (IATA OACI). This diagram contains the fundamental classes for Hazardous materials transportation. The main class of this model is the *HazMat* class that represents the dangerous substance or article that characterized by different properties: id, name, description, etc. this class has an association with *Agreement, Vehicle* and *Driver* classes. The

Agreement class represents the agreement applying for hazardous materials transportation mode. The *Vehicle* class contains the information and properties about the vehicle that transports the dangerous goods, and the *Driver* **c**lass represents the information about the driver. In addition, the class that contains the number of the class, whose heading covers the dangerous substance or article, is named *Class.* The tank class is an abstract class that contains the standard characters of tank.

Furthermore, the Figure 11 presents the different steps to create the HazMat Database. In this process, the ADR Reader is a component taken in input the tables A and B of part 3 from ADR document. The table A concerns dangerous good list and the table B contains alphabetic index of substances and articles of ADR. The ADR Reader subdivide the table A in tow excel part to know the even pages and odd pages. The HAZMAT DB CREATOR component take excels files and analyze them. After validation, it creates the database schema using JDBC/ADO drivers in a specified database server.

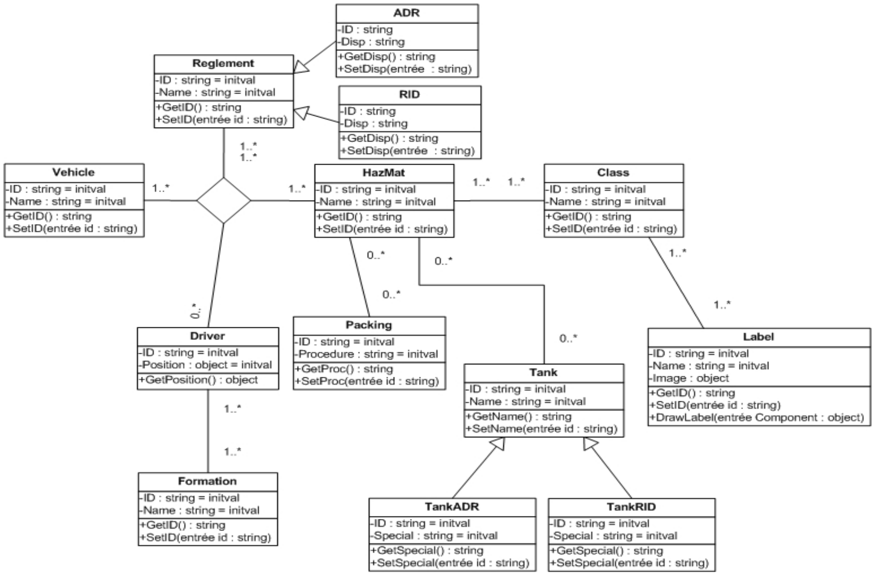

Figure 10. Class diagram of hazardous materials

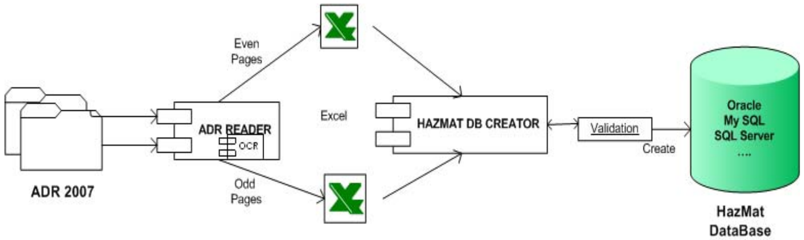

Figure 11. HazMat database creation process

8. Incorporating Multicriteria Fuzzy Routing Within Spatial Decision Support System Component

This section describes a spatial decision support system (SDSS) arisen from the project involving Boulmakoul and his team [4-7] aiming at developing the SDSS for hazardous materials transportation routing and monitoring.
This SDSS that includes components implementing the multi-criteria fuzzy shortest path algorithms is incorporated in the proposed real time mobile information system to ensure the management of the fuzzy dynamic routing of hazardous materials.

8.1. Fuzzy Risk Modeling

In the case of accident of hazardous materials transportation, impacts can reach considerable dimensions: environment, infrastructure, economy, etc.
A good monitoring system for HazMat transportation on a network must integrate procedures of prevention of potential risks related to the transportation of hazardous materials. This risk depends on the type of the transported product and all the targets which can be touched according to the considered dimensions. The American Department of Transport guide, published by the Federal Highway Administration [14] gives procedures for calculation of risk per route segment. These calculations are essential for routing algorithms that identify minimum risk routes, where risk is established as being the product of the probability of having an accident by the consequences in term of cost, which can be expressed on the route segment in question and on its vicinity:
Risk = accident probability × accident consequences.
Two remarks are to be formulated relatively to this procedure of calculation of risk. They underline the limits of calculation of risk according to this classical and probabilistic method:

1- The above calculations suppose the existence of probabilities of occurrence of accidents on a route sections. However information is often insufficient to allow this calculation. In certain cases, the absence of data results in taking null probabilities, by considering that the sections in question are invulnerable.
2- It may be very difficult to give a precise evaluation of an accident consequence in term of cost. For example, how can one quantify, with high accuracy, the cost component of an environmental impact?

Since those data can't be precisely known, we have presented a fuzzy approach, which use fuzzy data, to model the risk on route sections. Our approach, which is based on some basic concepts of Multi-criteria Analysis (MA) and Fuzzy Set theories, is designed to avoid the aforementioned drawbacks. It will use everyday words for rating and translate theses linguistic terms into fuzzy sets for subsequent calculations. Furthermore this fuzzification of risk will allow the use of the results concerning path problems in fuzzy graphs, described in section 5.

8.2. Risk Modeling Using Fuzzy Set Theory

Our approach models the concept of accident risk on each arc of the transportation network by taking account of the vulnerability of the arc in question and of the cost generated in the event of accident on this arc with respect to the various impacts considered. Examples of such impacts are given in the next section.

In our approach, the concept of vulnerability of an arc replaces and generalizes that of the probability of having an accident on an arc in the traditional method. It is evaluated by holding account not only of accidents data on a given arc (such data are not always available) but of more general information concerning the arc in question and its vicinity with respect to a given impact. The cost of the consequences generated in the event of accident on an arc is estimated in components relating to the considered impacts. Our method is thus to be more general than the traditional method since it makes it possible to hold account of more factors for the risk modeling. Moreover the introduction of all these parameters will be done in such a manner which will simplifies the complexity of the probability calculation in the classical method since the level of vulnerability and the eventual accident cost on an arc with respect to a given impact are taken as being fuzzy quantities.

These fuzzy quantities are obtained by asking the actors (experts and decision makers) in the management system of the involved network to assign, with a degree of plausibility, qualitative evaluations to theses various parameters. Thus, the complexity of probability calculations will be replaced by a human judgment which allows integrating into our model the experience of the transportation network actors. On each arc the risk by impact is then taken as being the product of the vulnerability and the cost components evaluated for the considered impact. The overall force of risk on each arc is calculated by the application of an adequate fuzzy aggregation operator on the previous fuzzy parameters corresponding to the various impacts taken into account. The approach that we propose for risk modeling on each arc of a transportation network can be seen to consist of the following major components:

- Impacts selection,
- Quantifying the vulnerability and the cost of an arc with respect to each impact,
- Evaluating risk of an arc relatively to a given impact,
- Impacts weighting,
- Aggregating the risk fuzzy components, corresponding to all the impacts on an arc, to calculate the overall force of risk on an arc.

8.2.1. Impacts Selection

Numerous impacts can be proposed to account for modeling accident risk on arcs of a transportation network. Theses impacts can be classified into categories according to the dimensions considered. Table 2, shows examples of such dimensions and impacts.

Table 2. Risk components

Environnemental components	*Population*
	Protected areas
	Hydrography and Hydrology
	Land Use
Infrastructure components	*Road network*
	Traffic conditions
Economic components	*Transport costs, Factories*

8.2.2. Quantifying the Vulnerability /Cost of an Arc With Respect to Each Impact

After having fixed the various impacts to be considered in the modeling of accident risk on arcs, the next step is to rate the vulnerability and the cost of an arc with respect to each of theses impacts. In real life transportation network theses rating data can't be precise. A decision maker may encounter difficulty in quantifying what should be the consequence in term of cost on an arc for the environmental impact population for example. Thus, theses rating data are subjective and depend on the decision makers judgments. Different rating systems may be used. They are based on fuzzy sets, fuzzy numbers [31] [42] [54], or linguistic terms. Each linguistic term can be represented by the approximate reasoning of fuzzy set theory. Several standard conversion scales are proposed in [11] [13] to systematically convert linguistic terms to their corresponding fuzzy numbers for eventual fuzzy arithmetic operations. In theses referenced works, the authors consider trapezoidal fuzzy numbers to capture the vagueness of those linguistic assessments since they are easy to use and easy to interpret.

In here, we propose the linguistic scale S = {very low, low, medium, high, very high} to account for ambiguities involved in the evaluation of the vulnerability and the cost of an arc with respect to each of the considered impacts.

8.2.3. Evaluating the Risk of an Arc with Respect to a Given Impact

We note I = $\{imp_1, imp_2, \ldots, imp_n\}$ the set of the considered impacts. For each arc *u* of the graph structure modeling the transportation network, let us denote:

- $\varphi_1(u, imp_i)$, the fuzzy quantity obtained as described in section above and which represents the vulnerability assessment for arc *u* with respect to impact *i*.

- $\varphi_2(u, imp_i)$, the fuzzy quantity representing the cost evaluation for arc *u* with respect to impact *i*.

We define the degree of risk relating to an impact of I for an arc *u* as a fuzzy quantity noted φ_3 (u, imp_i), and calculated on the basis of the fuzzy quantities φ_1 (u, imp_i), and $\varphi_2(u, imp_i)$, according to the following formula:

- $\varphi_3(u, imp_i) = \varphi_1(u, imp_i) \otimes \varphi_2(u, imp_i)$ for i = 1,...n. Where $\otimes$ is the fuzzy multiplication [14].

8.2.4. Impacts Weighting

For various reasons, on a given arc the decision maker can consider that an impact is more or less important than the others. We call weight this measurement of the relative importance of the impacts such as it is seen by the decision maker. We note w_i the weight to be given to impact *i*. A number of methods for determining criteria weights in Multi-criteria Analysis have been developed. Some good comparison and review studies concerning the relevant criteria weighting techniques developed especially for MA models based on Multi-Attribute value theory and outranking methods can be found in [12], [15-16]. In this work, we propose to compute weights of the different impacts by Analytical Hierarchy Process AHP [43], a popular method for solving MA analysis problems involving qualitative data. AHP starts by arranging criteria and alternatives of the problem in a hierarchical structure. A reciprocal pairwise comparison matrix is then constructed at each node of the hierarchy to reflect decision maker preferences of criteria and alternatives. The weights are derived by applying an eigenvector method on some of theses comparison matrices. For more details concerning this method we refer to works given in [16-18].

8.2.5. Aggregating the Risk Fuzzy Components

After having evaluated in the previous paragraph, ($\varphi_3(u, imp_1)$, …, $\varphi_3(u, imp_n)$), the risk components on an arc with respect to each of the n impacts of I, and, in the parameters w_i ($i \in I$), the relative importance of theses impacts. This section will present how to integrate theses fuzzy and crisp quantities to determine the overall force of risk on an arc. There are many methods to aggregate decision maker fuzzy assessments. A broad classification of such methods which are the frequently cited can be found in [51]. As we face here a problem of weighted aggregation, our proposition is based on Yager's work on weighted median aggregation [51]. To include the weights in the aggregation procedure, for each arc *u* we transform the quantities $\varphi_3(u, imp_i)$ into $\hat{\varphi}_3(u, imp_i)$ using the following transformation function g based on the probabilistic t-norm as follows (see figure 12):

- $\hat{\varphi}_3(u, imp_i) = g(w_i, \varphi_3(u, imp_i))$

Then we apply the max aggregation to obtain the overall force of risk on arc *u*.

As discussed by Yager *For the max aggregation operator : Since it is the large values that play the most important role in the aggregation we desire to transform the low importance elements into small values and thus have them not play a significant role in the max aggregation*. The transformation function g could be any t-norm for max aggregation.

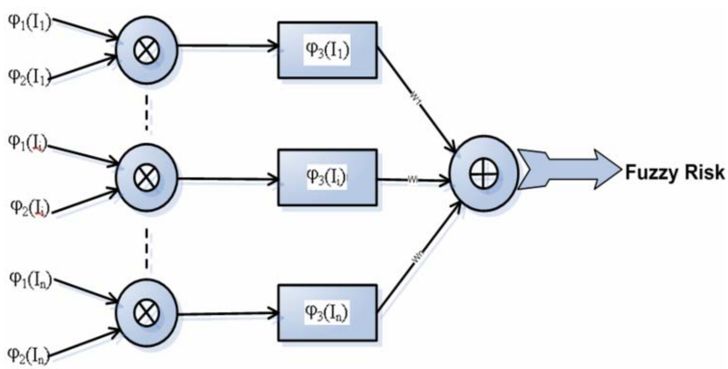

Figure 12. Calculation process of fuzzy risk

8.3. Fuzzy Routing

The Fuzzy shortest path-finding problem from a specified source node to the other nodes appears in several applications. In transportation systems area, their corresponding networks use fuzzy information on the arcs, assumed to represent transportation time or economic cost than traffic flow, etc. This information is soft and would be well presented by fuzzy numbers or fuzzy set based on fuzzy set theory [ ] [ ]. The first works developed to solve the problem of the fuzzy shortest path have been initiated for the first time by Dubois and Prade [15]. Nevertheless, if the research of the shortest path length in a fuzzy graph is feasible, generally this path doesn't correspond to a real path in the considered fuzzy graph. This exception is explained by the particular behavior of the generalized min and max operators for the fuzzy numbers.

Dubois and Prade [8] comment the solution of the classical fuzzy shortest path problem through the use of extended sum, and extended *min* and *max*. To solve the problem Floyd's algorithm and Ford's algorithm are applied. Unfortunately, this approach, even though it can determine the length of a fuzzy shortest path, it cannot find a fuzzy path which corresponds to this length in the fuzzy graph. This failure is a consequence of the classical operators extension *min* and *max*, according to the extension principle. From that principle, the extended *min* or *max* of several fuzzy numbers may not be one of those numbers.

Some approaches based on the concept of α-cut [ ] [11] [13] and other models based on the parametric orders [ ] or relation order [ ], did permit to reuse the classic methods in various fuzzy graphs applications on operations research field.

With regard to the based methods on parametric or relation orders, a work proposed by Furulawa [] uses a modified Dijkstra's algorithm for valued fuzzy graphs, where valuations of the arcs are L-Fuzzy numbers. An other algorithm has been proposed by Okada [ ] for the valued fuzzy graphs with L-R fuzzy numbers. The proposed algorithm defines a relation order between L-R fuzzy numbers. It is based on the multiple labeling method to obtain all nondominated paths. The multiple labeling can be considered as a generalization of Dijkstra's algorithm [ ].

A formulation of the fuzzy shortest path problem not doing reference to the concept α-cut or parametric orders, has been proposed by Klein [25]. Klein's algorithm is based on multi-criteria dynamic programming, and can find a path or paths for a level of membership set by a decision maker. This algorithm, however, assumes that the valued fuzzy graphs are acyclic graphs. To apply the Klein's algorithm for other graphs, Klein proposed a transformation for these graphs according to the following remark owed to Lawler [30]: *each graph that has no cycles of negative weight can easily be converted to a directed acyclic graph*. Nevertheless the transformation procedure is NP-Hard. Hence for the computational aspects, the Klein's algorithm is restricted to acyclic graphs.

The approach that we proposed consists in defining an algebraic structure for the problem of operator's traversal in fuzzy graph. The principal contribution of our approach is to build structures of path algebra [21][30] adequate to solve the problem of graph traversal in a fuzzy graph without negative circuits.

Concerning the selection of the routing with lesser risks, the decision system applies algorithms and algebraic structures developed in [5]. The urban transportation system is represented by a fuzzy risk graph that captures both the urban traffic network and the concept of accident risk. The main contribution of this part of the project is the construction of adequate and new structures of dioïds to solve the path retrieval problem by means of a fuzzy graph, and to make it available for the resolution of other problems.

A first structure has been proposed to solve the problem of the *k*-best fuzzy shortest paths. This structure generalizes existent results. A second algebraic structure has been established to enumerate all the fuzzy shortest paths. Concerning the general

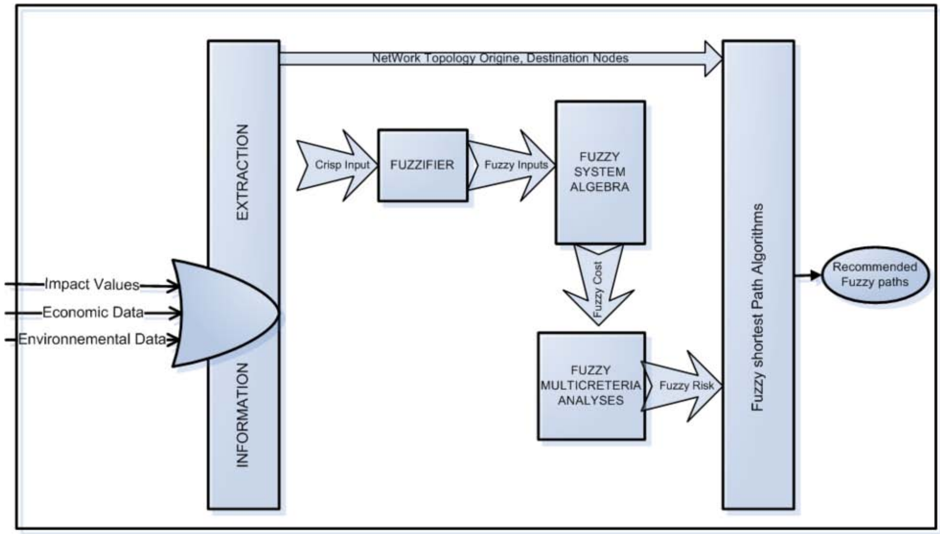

Figure 13. Fuzzy dynamic routing

routing algorithm, our choice is not restrictive. Indeed, the development of the component software of graph traversal operators in a fuzzy graph is based on the Dijkstra and A* algorithms. This component is integrated in the spatial decision support system (see figure 13).

Furthermore, the SDSS includes the multi-criteria fuzzy routing components. We have used mainly the object-oriented-programming methodologies. We use the C++ programming language for the implementation of concepts. Frequently, basic Abstract Data Types are implemented in the Standard Template Library (STL). STL is assumed to become a part of the C++ standard library and therefore it is an ideal basis when writing portable programs. Unfortunately, STL has no support for graphs Abstract Data Type. We decided to implement a fuzzy graph library based on STL. The built library contains the classes needed to work with fuzzy graphs, nodes and edges and some basic fuzzy path-finding algorithms: Klein's algorithm, Dijkstra's algorithm for parametric and relation orders, Generalized Gauss-Seidel's algorithm with the corresponding path algebra for the K-best shortest path problem.

9. Prototype System

In this section, we present a prototype of real time mobile information system for hazardous materials transportation. Our pilot site is the city and region of Mohammedia (Morocco), because it presents an intensive chemical industry activity. The economic life of the region is linked, partly, to its geographical position: proximity of the economic capital Casablanca, maritime facade, oil and chemistry industries installed to the edge of Atlantic Ocean of the region of Mohammedia. Industrial installations receive and dispatch many harmful matters that present, in case of accidents, risks for people and environment.

The Server side employs the Microsoft visual C++.Net based on Microsoft .Net Framework 1.1 and MapObjects software (Version 2.2) as a mapping and GIS components. The MapObjects is employed to create applications that include dynamic live maps and GIS capabilities (e.g. spatial and attribute querying, geocoding, etc…). The ArcSDE technology permits to act as the database access engine to spatial data, its associated attributes, and metadata stored within an object-relational database management system.

To integrate the spatial data in our system, we use the shape data for storing the geographical objects such as point, line, polygon, etc. The MapObjects integrates the APIs for storing and getting the desired information from shape data. Our model integrates a multiple layers such as Accidents layer, population layer, network layer and others.

The Figure 14 gives a global view of application developed on server side. The blue Triangles in the application interface present the layer of the occupation of population and the red triangles represent the layer that contains the accident locations. This application permits to provide the multicriteria fuzzy routing of hazardous materials transportation by selecting the origin and destination nodes. In background the algorithm to solve K-best fuzzy shortest path problem are applied, the algorithm collects the different information concerning accident and population from accident and population layers. These parameters are "fuzzified" and then a shortest path is depicted in the map of Figure 14. The application can also simulates scenarios of the tracking the hazardous materials transportation from origin to destination node.

For mobile client, a mobile application has been developed. It can connect to web service to get a desired service. We have employed Windows CE mobile device that

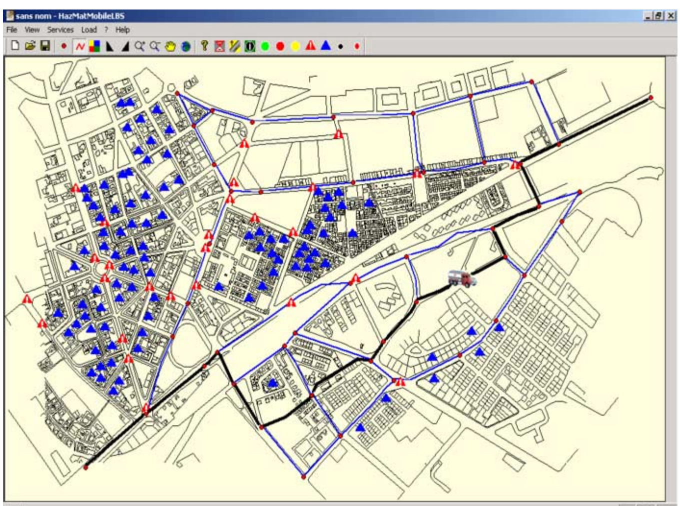

Figure 14. Global view of HazMat application on server side

supports the .Net compact framework. The PC Pocket snapshots of Figure 15 present an example of HazMat services from LBS Application Server to a tow client. The first snapshot presents the mobile client interface with various functionalities to get services about dangerous good, and the last snapshots gives the emergency response guide that can be received in case of incident.

Figure 15. Screenshots of HazMat mobile application

Conclusion

The main goal of this paper is to define architecture of the real time mobile information for hazardous materials routing and monitoring. An object oriented model is proposed with real time considerations using UML 2.0 and RT-UML specification. In addition, the proposed component based modeling permits to identify the role of each component, data need, information flow and harmonize functions performed by these components. A data model of mobile object is also discussed to improve location based services and mobile applications. The web services are proposed to have an open architecture for various mobile devices with different technologies.

The performance of the proposed system is significantly increased by incorporating the spatial decision support system that analyses the hazardous materials risk and provide routing strategies that minimize the transportation risk. A prototype of HazMat transportation for city of Mohammedia has been developed with various risk data. Obviously, as illustrate in this work, this type of system by their complexity and particularity implies specific and different development. A number of reflections must be made to provide satisfactory HazMat services: improvement of communication aspects, real time and scedulability validation, etc.

References

[1] ADR, European Agreement Concerning the International Carriage of Dangerous Goods by Road. ECE/TRANS/185 (Vol.1), 1 January 2007

[2] M. Björkander, C. Kobryn, Architecting systems with UML 2.0. *IEEE Software*, pp. 57-61, 2003

[3] A. Boulmakoul and A. E. Bouziri. Processus logiciels pour les systèmes temps réel embarqués : RT-UML, RdP & logiques des défauts. *Systèmes Electroniques Informatiques & Traitement de l'Information (SEITI'07)*, FSTM, Mohammedia, 25-26 Janvier 2007, pp. 216-224

[4] A. Boulmakoul, Fuzzy graphs modeling for HazMat telegeomonitoring, European Journal of Operational Research, Volume 175, Issue 3, 16 December 2006, Pages 1514-1525.

[5] A. Boulmakoul, Generalized path-finding algorithms on semirings and the fuzzy shortest path problem, *Journal of Computational and Applied Mathematics*, *Volume 162, Issue 1*, *1 January 2004*, *Pages 263-272.*

[6] A. Boulmakoul, R. Laurini, K. Zeitouni, Spatial Monitoring and Routing System for the Transportation of Hazardous Materials, In "Environmental Information Systems in Industry and Public Administration", Claus Rautenstrauch and Susanne Patig Editors, IDEA Group Publishing, pp. 227-236, 2001.

[7] A. Boulmakoul, Fuzzy graphs modelling for HazMat telegeomonitoring. *European journal of operational research*, (175), pp. 1514-1525, 2006.

[8] A. E. Bouziri., A. Boulmakoul and R. Laurini. Mobile object and real time information system modeling for urban environment. *The 26th International Symposium of Urban Data Management (UDMS'07), published by Taylor & Francis*, Stuttgart, Germany, 10-12 October 2007.

[9] A.E. Bouziri, A. Boulmakoul, M. Chala and H. Mouncif. Modeling and querying mobile object on transportation network for mobile applications. *In the Proceedings of the Fifth IEEE International Symposium on* Signal Processing and Information Technology, 2005 *(ISSPIT'05*), Athens, Greece, 18-21 December. 2005, pp. 317-321.

[10] A. E. Bouziri, A. Boulmakoul, A, Applying RT-UML and RTSJ specifications for mobile tourist information system. *SITA'04*, Rabat, Morocco, 2004.

[11] S. Chanas, M. Delgado, J.L. Verdegay and M.A. Vila, Fuzzy optimal flow on imprecise structures, *European Journal of Operational Research* 83 (1995) 568-580.

[12] S. Chen, C. Hwang, Fuzzy Multiple Attribute Decision Making - Methods and Applications. *Springer-Verlag*, (1992) New York.

[13] D. Delgado, J.L. Verdegay and M.A. Vila, On valuation and optimisation problems in fuzzy graphs: a general approach and some particular cases, *ORSA Journal on Computing*, vol. 2, n°1, 1990, 75-83.

[14] DOT, Guidelines for Applying Criteria to Designate routes for Transportation Hazardous Materials», *Report No. DOT/RSPA/OHMT-89-02*, Federal Hwy. Admin., Washington, D.C, (1989).

[15] D. Dubois and H. Prade, Algorithmes de plus courts chemins pour traiter des données floues, RAIRO/operation research, vol. 2, n°2, mai 1978, 213-227.

[16] D. Dubois and H. Prade, Fuzzy sets and systems, *Academic Press*, New York 1980.

[17] T. Erl , SOA Principles of Service Design. PRENTICE HALL, 2007

[18] O. Farias, J. Ribeiro, C. Oliveira, An object oriented model for dynamic geographic information systems and location based services. *In Proceedings of 6th AGILE Conference on Geographic Information Science*, Lyon, 2003.

[19] J.H. Gailey, Understanding Web Services Specifications and the WSE. Microsoft Press, 2004

[20] A. Gherbi and F. Khendek, UML Profiles for Real Time Systems and their Applications, in Journal of Object Technology, vol. 5, no. 4, May-June 2006, pp. 149-169

[21] M. Gondran and M. Minoux, Linear algebra in dioïds: a survey of recent results, *Annals of Discrete Mathematics*, vol. 19, pp 147-164, 1984.

[22] R. H. Güting, A foundation for representing and querying moving objects. *Geoinformatica*, ACM Transactions on Databases Systems, Vol. 25, No. 1, pp. 1-42, 2000.

[23] ISO/ TC211. 2000. Geographic Information / Geomatics: ISO 19108- Temporal Schema

[24] A. Jagoe, A. *Mobile location services- the definitive guide*. Prentice Hall PTR. 2002.

[25] C. M. Klein, Fuzzy shortest paths, *Fuzzy Sets and Systems* 39 (1991) 27-41.

[26] J. Knudsen, *Wireless Java Developing with J2ME*, Second Edition, Apress, 2003

[27] C. Kobryn and E. Samuelsson. Driving Architectures with UML 2.0, A Telelogic white paper, 2003.

[28] R. Laurini, R., Thomson, D. Fundamentals of Spatial Information Systems, APIC Series, Academic Press, 1992.

[29] R. Laurini, An introduction to TeleGeoMonitoring: problems and potentialities. GIS Innovations, edited by Atkinson & Martin, Taylor and Francis 1999, pp. 11-26.

[30] E. Lawler, Combinatorial optimisation; *networks and matroids*, Holt, Reinehart and Winston, New York 1976.
[31] G. S. Liang, M. Wang, A fuzzy multi-criteria decision-making method for facility site selection. *Int. J. Proc. Res*., Vol. 29, No II, 2313-2390 (1991).
[32] McGovern J., S. Tyagi, M. Stevens and S. Matthew .Java Web Services Architecture. Morgan Kaufmann Publishers, 2003
[33] Nantz B. and L. Moroney . Expert Web Services Security in the .NET Platform. Apress, 2005
[34] Office of Hazardous Materials Safety U.S. Department of Transportation, Hazardous materials shipments. Washington DC, Oct 1998, www.hazmat.dot.gov
[35] OGC, OpenGIS Simple Feature Specification for SQL. document 99-049, 1999.
[36] OGC, OpenGIS Location Services (OpenLS^{TM}): Part 1-5 Core Services". OGC 03-006r, 2003.
[37] OGC, Open GIS Web Services Architecture (WSA). OGC 03-025, version 0.3, 2003.
[38] OMG, UML profile for schedulability, performance and time. formal/05-01-02, version 1.1, 2005.
[39] OMG Unified Modeling Language: Infrastructure. formal/05-07-05, version 2.0, 2006.
[40] OMG,Unified Modeling Language: superstructure. formal/05-07-04, version 2.0, 2005.
[41] E. Pitoura, G. Samaras, Locating objects in mobile computing. *Knowledge and Data Engineering*, Vol 13, no.4, pp. 571-592, 2001.
[42] B. Roy, Multicriteria Methodology for Decision Aiding. *Kluwer Academic Publishers*, Dordrecht, the Netherlands 1996.
[43] T. Saaty, the Analytic Hierarchy Process. *McGraw-Hill*, New York (1980).
[44] D. Servat, H. Dubois, S. Gérard, Le concept de composant dans UML2. Rapport interne IRCCyN RI2005_1, CNRS, 2005.
[45] I. Singh, *Designing web services with The J2EE 1.4 platform JAX-RPC, SOAP, and XML technologies*. Addison Wesley, 2004.
[46] D. Stojanovic, S. Djordjevic-Karan, Modeling and querying mobile objects in location based services. *Facta Universitatis Journal*, Series Mathematics and Informatics, NIS, Serbia, 2003.
[47] RATP, Transmodel in UML. Projet SITP2. Système d'information Transport Public (france), 2003
[48] M. Vazirgiannis, O. Wolfson, A spatio-temporal model and language for moving objects on road networks. *In Proceedings of 7th SSTD*, USA, pp. 20-35, 2001.
[49] S. Weerawarana, F. Curbera, Web Services Platform Architecture. Prentice Hall PTR, 2005
[50] O. Wolfson, Cost and imprecision in modeling the position of moving objects. *In Proceedings of the Fourteenth International Conference on Data Engineering (ICDE)*, 1998
[51] R. Yager, On weighted median Aggregation, *Int. J. Uncertainty, Fuzziness and Knowledge-Based Systems* 2, 101-113 (1994).
[52] C. H. Yeh, R. J. Willis, H. Deng, H. Pan, Task oriented weighting in multi-criteria analysis. *European Journal of Operational Research* 119, 130-146 (1999).
[53] L. J. Zhang, Modern Technologies in Web Services Research. IGI Publishing, 2007
[54] H. J. Zimmermann, Fuzzy Set Theory and Its Applications, third edition. *Kluwer Academic Publishers*, Boston, MA 1996.

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Sustainable Distribution of Petrol Products to Service Stations Based on Demand Forecast, Inventory and Transportation Costs

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Abstract. The distribution of petrol products to service stations is generally based on the receipt of orders by the service stations and on the daily optimisation of the deliveries by tank trucks. Recently, the technologic possibility to monitor remotely the level of the underground storage tanks in the service stations allows a new formulation of the problem, planning deliveries on the current level of the inventory rather than on orders. An original formulation of the problem is proposed joining in the objective function of the related mathematical programming formulation both the inventory and the routing costs. In the case study the proposed formulation is applied to evaluate the improvements of the performance of the distribution of petrol products by tank trucks when the central depot can receive in real-time the levels of the underground storage tanks. The results shows that the proposed approach would have allowed a reduction in the number of deliveries and in the overall amount of kilometres necessary for the deliveries themselves. The consequences are the decreasing both of the delivery costs and of the risk - for the people, their properties and the environment in the territory affected by this transportation.

Keywords. Inventory, routing, optimization, decision support systems, risk, hazard, mathematical programming, hazardous material transport, dangerous goods.

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Introduction

Hazardous material (hazmat) transportation on roads represents a relevant risk for the people, their properties and the environment. On the other hand, hazmat transportation on roads is often necessary for many current industrial and anthropogenic activities and finding lower risk alternatives will be a hard task also in the next decade. This is the case in the delivery of petrol products to service stations. This delivery is generally performed using tank trucks travelling from a regional central depot to one or more service stations with average distances of one hundred kilometres for each trip. These deliveries, which daily cover the road infrastructures of urbanised areas all over the world, currently represent a wide fraction of the hazmat transportation on road: in Europe, the category 'Flammable liquids', in fact, constitutes the clear majority (59 %) of the dangerous goods carried on roads [1].

Sustainability in roads hazmat transportation has often been addressed as the requirement to include integrated risk analysis as well as prevention measures in the distribution planning activities of a transportation company. The nature of the risk associated with hazmat transportation may depend on several components and, in the literature, different approaches have been explored to tackle the problem. The growing literature focuses the attention on the generic problem of risk based routing in hazmat transport. Several researchers have focused on the generation of routes which minimize the distance covered by truck and the risk of damages caused by accidents [2], or which minimize the potential population exposed if an accident occurs on the road over several routes [3], or some combination of these objectives. In [4] the authors discuss different ways of modelling hazmat transportation proposing the restriction of hazmat transportation on certain links in the network while [5] applied the most classical approach to define risk, that is, the product between the probability that an incident occurs on an arc and the estimated consequence on the population living in the proximity of the considered area.

In this work, a different approach to the sustainable transportation of hazmat products on road is proposed, with the specific goal to decrease the frequency of the deliveries of petrol products to service stations (SST). These deliveries require the daily management of fleets of tank trucks transporting petrol products from central depots to the SSTs, to feed the related underground storage tanks (USTs).

Nowadays, the information requested for the planning of petrol product distribution to SSTs is gradually moving from the receipt of daily orders subjectively defined by each SST retailer to the automatic acquisition of the levels of the SST inventories, given in the current case study by the UST levels. The former method is generally based on an off-line daily planning system, which supports the computation of the optimal routing of the tank trucks in order to satisfy customer orders. Specifically, each day an optimal routing plan is defined according to the set of orders that has been received the day before and with reference to the geographic locations of the demand sites. In this case, the transportation system is completely driven by orders and managed according to the statement and the solution of a "conventional" capacitated vehicle routing problem (VRP) [6]. Actually, petrol companies need to control the whole inventory/distribution phases to manage and to improve the process performance from a cost/benefit standpoint. For instance, one of the current trends is the introduction of systems that automatically measure the level of the UST(s), and transmit these data by telematics technologies ([7], [8]) to a centralized decision maker. At the same time, in order to minimize the human factor effects on the orders, new

SSTs are more and more installed as “unmanned SSTs”, which are completely automatic SSTs with a minimum human intervention. In addition, another trend of petrol companies is to maintain the property of the product also when it is stored in the USTs of the SSTs.

Evidently, the introduction of the above mentioned technological and management innovations affects the decisions concerning the distribution process. The acquisition in real time of the data relevant to the inventory levels of the SSTs implies the necessity of considering the planning of the distribution problem within a framework wider than the conventional VRP, in which inventory dynamics and costs are to be taken jointly into account. In addition, the statement of the decisional problem may be heavily influenced by the availability of reliable forecasts of the product demand by customers at the various SSTs.

Although the above discussed trends about the petrol product distribution are recognizable in different countries and petrol companies all over the world, there are, in fact, specific features that characterized the various countries at the recent time. For instance, in Italy, the petrol product distribution is generally dependent just on the SST retailers, who are the decision makers of the inventory and refilling policy. In this case, the SST manager is the subject who controls the inventory of his/her UST and sends an order to be refilled to the central depot. Since the fuel orders generally require an immediate payment on delivery, the SST managers ask for their refilling service when lack of product in the UST occurs, and on the basis of their current cash availability. In fact, the SST manager has to balance the interest of minimizing inventory costs due to capital permanent assets, limiting the amount of product stocked into the tanks for long periods, and the possibility to tackle a stock out and a consequently loss-selling and costumers’ dissatisfaction. On the other hand, on the receipt of daily orders, the petrol company has to solve an optimal VRP [6], with no control on the UST levels and on the quantity of product to be delivered, apart from imposing some constraints such as, for example, a minimum order quantity of 1000 litres for each order. In UK, a large number of SST are already automated and, in this case, the petrol company may decide the time and the amounts of product for each refilling service according to historical data about consumption and, in some case, receiving inventory data from either automated or manual monitoring tools at the SST site. Despite of this, an optimization methodology to support decisions of transportation of petrol products to SSTs based on the prediction of the demand, on the monitoring of the inventory level and on the available transportation facilities, has not been defined yet in an integrated formulation.

The starting point of the proposed approach is the quite obvious remark that decreasing the frequency of the deliveries may represent both a significant risk reduction of an accident (see for example, one of the many hazmat transportation risk definition) and, at the same time, a significant economic cost reduction for the transportation company. Specifically, it is shown that shifting the generation of orders of petrol products from the service station personnel to an automatic order generator - based on demand forecast, inventory and transportation costs - can effectively decrease the frequency of the deliveries. In more general terms, this work aims to join the economic sustainability aspects - as they may be argued by the decision maker (DM) of a transportation company - with the risk based sustainability aspects as they may be argued by the DM of territorial local authorities.

From this perspective, the problem formulation includes two main issues: transportation and inventory. The petrol company must tackle an integrated Inventory/Routing Problem (IRP). A wealth of literature has addressed the IRP and a brief survey is given in section 1. After this survey, in section 2, the description of the common procedure based on daily order (Day by Day Order, DDO) is described. In section 3, an innovative Centralized Integrated IRP (CI-IRP) approach for the definition of the optimal distribution of petrol products to SST, based on demand prediction, real-time inventory data acquisition, and transportation routing optimization is described. In section 4, the DDO and the CI-IRP approaches are compared in a real-case study, with some considerations as to the sustainability of the deliveries in economic and risk management terms. In the conclusion section, some discussion and some aspects to be further developed are presented.

1. Inventory Routing Problems

IRP models, in general, consider a scenario where a number of customers have to be supplied from one or more warehouses. The decisional problem involves two aspects: the first one is to decide the replenishment policy of the retails spread on a given territory and the second one concerns fleet scheduling and routing to distribute products to satisfy each customers' demand so that the total cost of inventory and distribution is minimized.

Two different versions of the IRP are generally presented in the literature: Retailer Managed Inventory (RMI) [9] in which the customers control their inventories and send delivery orders, and Vendor Managed Inventory (VMI) ([9], [10]) in which a centralized decision maker controls the inventories of its customers, decides the quantity and the time for deliveries, the routing of the vehicle fleet, and controls the inventory dynamics both at the depot and at the retail sites.

The major approaches to the IRP presented in the literature deal with a sequence of short-term problems referring, for example, to day-by-day planning ([11], [12], [13]). In [11] the authors use a nonlinear-programming formulation to take vehicle-assignment, routing, and inventory-replenishment decisions for a single day. They introduce a heuristic model based on the decomposition of the problem into two sub-problems. The first one solves an inventory management problem which optimizes the inventory costs, whereas the second one is a travelling salesman problem (TSP) for each vehicle, whose objective is to optimize the transportation costs.

Later, the short-term problems were expanded to several days ([14], [15], [16], [17]). The approach by [18] embeds a two-phase solution in a rolling horizon framework. In the first phase, an integer programming model is developed to determine the customers that ought to be refilled and the size of the delivery is decided. In the second phase, given the quantity to deliver to each customer on each day of the planning period, they determine sets of delivery routes for each day, solving a sequence of VRPs with time windows for each of the vehicles available.

The authors in [16], [19] and [20] consider a particular version of IRP introducing "satellite" facilities. These kinds of facility are depots dispersed in the service area where vehicles can be reloaded and customer deliveries can be continued without the necessity that the vehicle return to the central supplier. In [21], [22] and [23], the IRP over an infinite horizon has been studied. Anily and Federgruen [21], [22] consider the objective of minimizing the long run average transportation and inventory costs and the application of a class of heuristic policies called partitioning policies. In particular they introduce the Fixed Partitioning Policy (FPP), in which a collection of regions, containing a set of customers, is created according to rules about the dimension or shape of the territory considered.

In [24], the authors present an IRP formulation whose objective is to minimize the cost over an infinite time horizon applying a FPP: the retails are clustered according to their demand rate and then each set is served at the same time. In their study they compare the FPP and the Zero Inventory Ordering (ZIO) policy, in which a retail must be served if and only if its inventory is zero. Gallego and Simchi-Levi [25] introduce a model for the split demand case called “direct delivery”. In this case, each retail is served with a separate and individual route so that this policy represents the best solution only if costumers demands are significantly close to the maximum vehicle capacity.

As described above, the IRP has been studied using various approaches, with different time horizons, by many researchers. It is obvious that solving an IRP over a long term planning horizon improves the quality and the efficiency of the solution. However, increasing the length of the time horizon, may increase the uncertainty in the evaluation of some parameters characterizing the problem (for example, the future demand). In fact, customers’ demands and requirements might not be considered as deterministic data but as stochastic parameters. In [26], [10], [27] and [28] the IRP within a stochastic framework has been considered. [29] analyze a specific case of IRP for a week planning period according to deterministic and stochastic demand. In particular, they study the IRP comparing two different approaches: the decentralized case in which retails manage their own inventories, and the centralized case, in which the distribution company is the only decision maker for all inventories and the distribution processes. The centralized case is analyzed also in [10], [9] and [30]. In [10], the authors propose an approximate method for the centralized case, in the direct delivery model, while in [30] the authors study and compare two different policies: the “order-up-to level” policy, in which the retails are served to reach their possible maximum inventory level, and “the fill-fill-dump” policy in which the last retail scheduled in each tour is served with the residual product into the tank of the of vehicle. The computational results show that the “order-up-to-level” policy is more expensive for the supplier than the second option, in which the reduction of average transportation cost is sensible.

As it appears from the analysis of the literature quoted above, the major part of methods presented in the literature to solve IRP problems is based on decomposition approaches, aiming at determining the best inventory policy and then solving the distribution problem.

In this work, an original VMI Centralized Integrated IRP (CI-IRP) approach is presented, in which the overall problem is solved taking into account the inventory data and the prediction of the demand at the different retails, as well as the transportation costs associated with the links of the network. The retailer is assumed to have just the task to send periodically (e.g., at the beginning of each day) information about its current inventory level. Each day the vendor (i.e., the centralized decision maker) receives the information about the inventory levels from the retailers and, also taking into account the prediction of the demand at each retailer, jointly defines, over a suitable time horizon (generally, one week), the set of deliveries (for each day) and the routing of the vehicles, evaluating both inventory and transportation costs. Thus, the originality of the proposed CI-IRP approach stands as a true integration of inventory and routing issues within the same decisional framework.

After a brief description of the Retailer Management Inventory (RMI) Day by Day Order (DDO) approach that is currently adopted in many countries (section 2), the VMI CI-IRP approach is formalized in section 3. To simplify the formulation, both the approaches are presented with reference to one petrol company with one depot, distributing one petrol product to a set of SSTs geographically spread over the territory, where each SST is provided with one UST level related to the quantity of product stored in the inventory.

2. The RMI day by day order approach

In a typical RMI approach, see Figure 1, each SST retailer monitors his/her own UST level and, when he/she evaluates that it is time to refill the UST, an order for the needed quantity of product is sent to the vendor. This information joint to the location (e.g. the address) of the SST is stored in a database of the vendor in order to feed a VRP ([6], [31]) solving procedure.

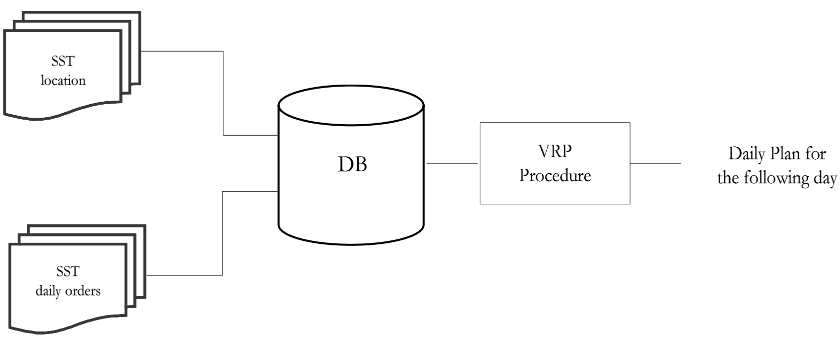

Figure 1. Information flow in the Day by Day Order (DDO) approach to plan distribution on one day planning horizon.

Actually, the time of the order emission and the quantity specified in the order generally depend on many factors: the current level, since a stock-out implies an economical loss and, on the other hand, the inventory capacity is limited; the availability of money, if the SST retailer must buy the product; the ability of the SST retailer to predict the future demand of the product; the unpredictable subjective behavior of the SST retailer etc…

New orders are then processed by the planning department of the petrol company, which, according to the quantity requested, the location of the SSTs and the time windows for the delivery, decides how many vehicles to use, computing for them the best routes. This planning is usually performed on a day-by-day temporal horizon, for example collecting orders until the evening, and, at night, processing the information in order to obtain optimal routes for day after. Then, the planning is modeled and solved as a VRP, having the objective to minimize either the total time spent or the total distance covered by the vehicles delivering the product.

In the DDO approach, the petrol company knows the SST locations and the requested quantities of product as specified in the orders. On the other hand, the petrol company does not know (and does not need to know) the inventory levels of the SSTs, it is not responsible for the emission and for the sizing of the orders, and it is not affected by the inventory costs at the SSTs.

However, the DDO approach has some disadvantages. The DDO approach makes no use of information about the system state, that is, each day's orders are dealt independently of previous or future orders by the same SST or by other SST in the neighborhood, so that optimization can not be performed over a horizon wider than one day. In addition, generally for economical reasons, the SST managers send their orders when the product in their USTs reaches a minimum threshold level, hence, the petrol company, to avoid stock-out at the SSTs, must serve them in a restricted time window and provide large product quantities. "Bull whip" effects with peaks of orders in the same day due to a greedy day-by-day management may take place, and, in general, the distribution of the product to the various SSTs is likely not to be uniform over the days of the week, thus, probably, resulting in either an over sizing of the tank truck fleet or the dissatisfaction of some orders. In addition, under an integrated supply chain management perspective, the UST levels, that are an effective indicator of the demand in each SST, are completely disconnected from the overall production model.

3. An integrated centralized inventory routing approach based on demand prediction and periodic inventory data acquisition

In the proposed CI-IRP approach, a centralized decision maker deals with both inventory and distribution management. The inventory and distribution costs are both charged to the petrol company, which decides the time and the amount of the deliveries and still owns the product also when it is stored in the SST USTs. In fact, the decision whether to transport or not a certain quantity of product to a SST completely depends on the petrol company. The petrol company is the only decision maker (DM) of the CI-IRP, knowing at any discrete time interval the system state, mainly represented by the UST level at each of the SSTs, that is supposed to be measurable and remotely retrievable. It can be assumed that each SST, which is provided with real-time sensors, can monitor the level of product in the related UST and periodically sends this information, for example at the beginning of each day, to the DM which is responsible for the daily deliveries of fuel to the SSTs. With respect to the DDO approach where orders are to be promptly fulfilled, the DM can plan distribution on a wider temporal horizon, for example a week, optimising the costs both of the UST inventories and of the transportation (Figure 2). In addition, according to the historical data on the consumed product, the DM can estimate the future demand for each SST to be served.

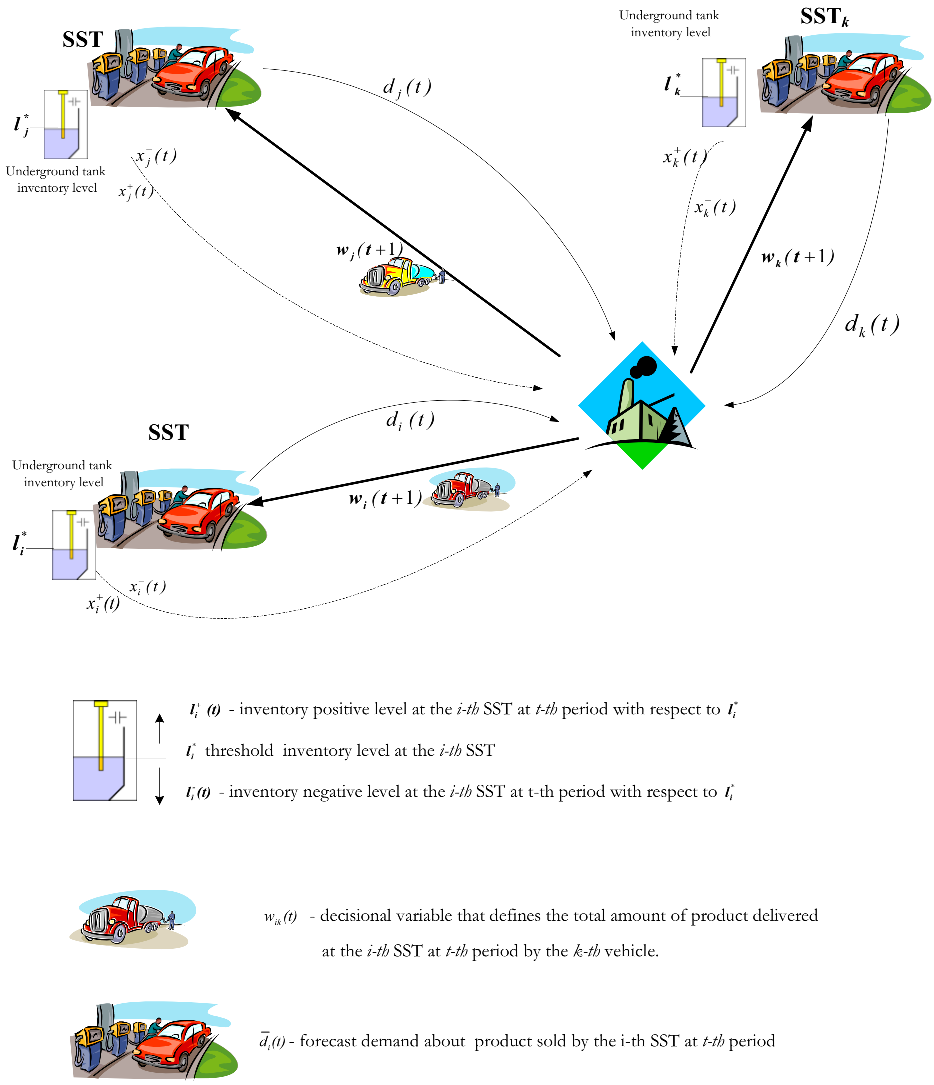

Figure 2. Information flow in the CI-IRP approach to plan product transportation

The CI-IRP approach is formulated in the following subsections.

3.1. The model

The inventory state of the *i-th* UST (i = 1..N) is defined by the variable which represents the value of the level monitored at the beginning of day t (t=0..T-1, where t=0 represents the current day). For each UST, a (desired) reference level l_i^* is defined according to some criteria (established by the SST retailers or by the petrol company). The definition of this level must take into account that a full inventory generally yields high holding costs, whereas an empty inventory may give risk to an economic loss due to stock-out. Generally, within the time horizon of the CI-IRP problem (say, a week), the i-th reference level $l_i^* \in \left[0, C_i^{max}\right]$ can be considered as constant, where $C_i^{\max}$ is the capacity of the i-th UST. For example, the reference level may be defined as sufficient to satisfy the maximum foreseen demand for one day also in case of no fuel delivery or, as an extreme choice, as zero in the case for example of the adoption of a ZIO policy.

In addition, for each day t, formally in the time interval (t, t+1) t=0,1,..,T-1, and for each SST, a forecast of the product demand $d_i(t)$ is supposed to be available. The forecasted demand $d_i(t)$ plays an important role in the statement of the CI-IRP, and its correct estimation can be a very hard task. For example, it can depend on several factors, such as the current season or the geographical position of the SST, and might be also identified taking into account the historical database of sold product. For the sake of simplicity and assuming that the optimization horizon corresponds to a week, it is supposed that a reliable estimation of $d_i(t)$, which is the demand in the future interval, may be obtained by taking exactly the quantity of product sold in the same day of the last week, so that

$$d_i(t) = sold_i(t - T) \qquad t = 0....T\text{ - }1 \tag{1}$$

where $sold_i(t)$ is the known quantity of product sold at day t in the i-th SST which can be stored in a historical database. In summary, the DM knows the following information about each controlled SST (Figure 3):

- static characteristics: UST capacity $C_i^{\max}$ and the related reference threshold l_i^* ; geographic coordinates (or address) of the SST;
- dynamic characteristics that are sent from the SST to the DM, that are:
    - forecasted information, given by the prediction of the demand $d_i(t)$ as resulting by equation (1) or more complex prediction models; this information can be also centrally determined by the DM, but, usually, the SST retailer can have a better awareness of the real future demand;
    - the current UST level in each SST, $x_i(t)$ which for modelling purposes is defined with respect to the threshold inventory level l_i^* as $x_i^+(t)$ (Positive Inventory Level) and $x_i^-(t)$ (Negative Inventory Level).

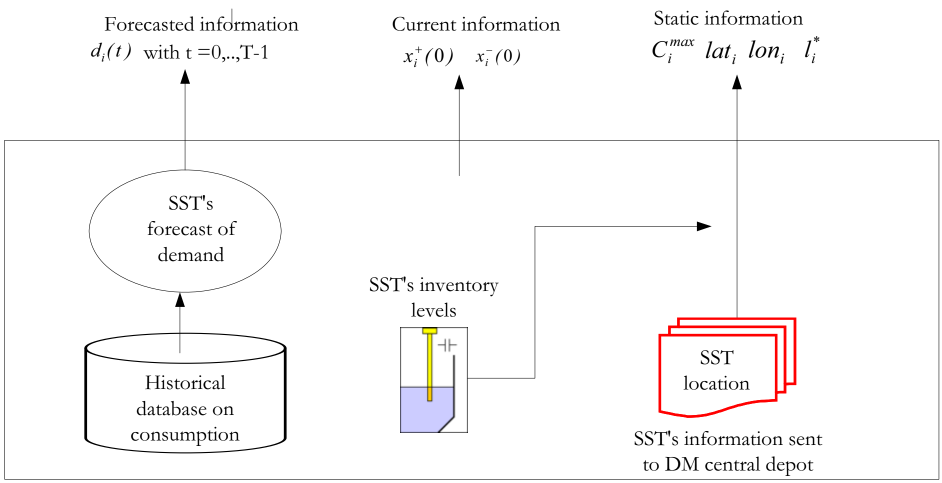

Figure 3. SST's information sent to DM central depot.

The DM's goal is to find the most favourable solution to deliver fuel to the SST, minimizing the total cost for transportation and inventory management incurred over the optimization horizon (T = 7 days). The CI-IRP solutions, supporting the DM to achieve his/her goal, are defined both by the variable $w_{ik}(t)$, that is the total amount of product delivered at the i-th SST within the t-th day by the k-th vehicle, and by the related optimal routing to be followed for the deliveries.

More specifically, the following simplifying assumptions are made. The DM can manage a single distribution depot equipped with a given fleet of tank-trucks all with the same capacity, distributing one fuel product to a set of SSTs spread over the territory and whose locations are known. Each SST is equipped with just one UST. The transportation to the SSTs $1,\dots,N$ are made by a fleet of K capacitated homogeneous vehicles, indexed $1\dots K$, each one with a loading capacity whose route starts from the petrol company unique depot at the beginning of each day. It is assumed that the DM central depot has always a sufficient supply of product that can cover all customers' demands throughout the optimization horizon. In addition the inventory costs of the central depot are not taken into account in the problem statement.

In the statement of the CI-IRP, the following notations are used:

- $t = 1..T$ days of the planning horizon
- $i = 0..N$ numbers of service stations, indexed from 1 to N, while index 0 is related to the central depot
- $k=1..K$ number of the vehicles, indexed 1 to K.

The parameters, all supposed to be known, are:

- $depot\_lon$ abscissa of the depot in a Euclidean space
- $depot\_lat$ ordinate of the depot in a Euclidean space
- lon_i abscissa of the i-th SST in a Euclidean space
- lat_i ordinate of the i-th SST in a Euclidean space
- l^* threshold inventory level of the i-th SST

- $d_i(t)$ forecasted demand of product of the i-th SST at day t
- cap_k capacity of the k-th vehicle
- C_i^{max} capacity of the UST of the i-th SST
- L^{max} maximum length that a vehicle can perform in one daily tour

The decisional variables of the problem are

- $w_{ik}(t)$ the total amount of product delivered at the *i*-th SST within the *t*-th day by the *k*-th vehicle.

Related dependent decision variables requested by the problem formulations are:

- $q_{ik}(t)$ decisional binary variable that assumes value 1 if the *i*-th SST at *t*-th period is served by the *k*-th vehicle and value 0 otherwise.

Besides, other variables involved in the problem statement are:

- $x_i^+(t)$ Positive Inventory Level (PIL), with respect to l_i^* , for UST *i*-th at time *t*
- $x_i^-(t)$ Negative Inventory Level (NIL), with respect to l_i^* , for UST *i*-th at time *t*
- $N_k(t)$ number of SSTs that the vehicle *k*-th serves in the *t*-th day
- $L_k(t)$ length of the tour for the *k*-th vehicle in the *t*-th period to serve $N_k(t)$ SST
- $C_k(t)$ transportation cost for the *k*-th vehicle in the *t*-th period

The objective of the optimization problem is to perform the following minimization:

$$min\left\{\sum_{t=1}^{T}\sum_{i=1}^{N}[\alpha_i x_i^+(t)+\beta_i x_i^-(t)]+\sum_{t=1}^{T}\sum_{k=1}^{K}C_k(t)+\gamma\sum_{t=1}^{T}\sum_{i=1}^{N}\sum_{k=1}^{K}q_{ik}(t)\right\} \quad (2)$$

This first term, that is $\sum_{t=1}^{T}\sum_{i=1}^{N}[\alpha_i x_i^+(t)+\beta_i x_i^-(t)]$ represents the total inventory cost in all the SSTs for the whole planning horizon. The inventory cost at time t for the i-th SST results from a sum of positive and negative inventory values, weighted by two positive parameters α_i and β_i [€/liter]. The parameter α corresponds to the economic loss due to the unnecessary storage of a unit of product, while β is related to the unitary economic loss due to unsatisfied demand.

The second term, $\sum_{t=1}^{T}\sum_{k=1}^{K} C_k(t)$, represents the total transportation cost associated to the whole fleet of vehicles.

The third term, $\gamma\sum_{t=1}^{T}\sum_{i=1}^{N}\sum_{k=1}^{K} q_{ik}(t)$, represents the costs deriving from the tank truck stops in the SSTs. The parameter γ represents the unitary cost for one stop, and it is related to the cost for the labour time spent to feed the UST, the risk associated with this operation and other issues.

The minimization in (2) has to be carried out taking into account a set of constraints. The first subset of constraints arises from the representation of the dynamics of each UST level, namely

$$[x_i^+(t+1) - x_i^-(t+1)] = x_i^+(t) - x_i^-(t) + \sum_{k=1}^{K} w_{ik}(t) - d_i(t) \qquad \begin{matrix} t = 0,..T-1 \\ i = 1,..N \end{matrix} \qquad (3)$$

$$x_i^+(t) \geq 0 \qquad \begin{matrix} t = 0,..T-1 \\ i = 1,..N \end{matrix} \qquad (4)$$

$$x_i^-(t) \geq 0 \qquad \begin{matrix} t = 0,..T-1 \\ i = 1,..N \end{matrix} \qquad (5)$$

The equation (3) are the balance state equations of the product in the various USTs, with the conditions given by (4) and (5). Note that structure of the objective function to be minimized implies that the following condition holds

$$x_i^+(t) \cdot x_i^-(t) = 0 \qquad \begin{matrix} t = 0,..T-1 \\ i = 1,..N \end{matrix} \qquad \text{(5-bis)}$$

without the necessity of imposing a specific constraint.

Another subset of constraints is related to the fact that whenever a certain quantity of product is delivered at time t by tank-truck k at the day t (that is $w_{ik}(t) > 0$) , a delivery has been performed (that is $q_{ik}(t) = 1$). This can be expressed as follows

$$w_{ik}(t) \text{ - } M\ q_{ik}(t) \leq 0 \qquad \begin{matrix} t = 0,..T-1 \\ i = 1,..N \\ k = 1...K \end{matrix} \qquad (6)$$

Note that the reverse implication, that is $w_{ik}(t) = 0 \Rightarrow q_{ik}(t) = 0$ although not imposed by (6), is ensured by the structure of the cost function to be minimized.

Another subset of constraints, one for each day and for each tank truck, imposes that the total amount of product delivered by each vehicle must not exceed its capacity, that is

$$\sum_{i=1}^{N} w_{ik}(t) \leq cap_k \qquad t = 0,..T-1 \quad k = 1...K \tag{7}$$

A further subset of constraints has to be introduced in order to express the distance $L_k(t)$ to be covered, in the day *t*, by the *k*-th truck to serve the number of SSTs that are determined through the solution of the overall problem. Conceptually, the distance is a function of the binary variables $q_{ik}(t)$ and the geographical positions of the various SST. As a matter of fact, each value $L_k(t)$ should be computed by formulating and solving a TSP, which is known to be a NP-hard problem. Better to say, the solution of a number of TSPs is implicitly required for the solution of the inventory/routing problem. Formally, this dependence is represented here as a set of constraints

$$L_k(t) = F(q_{ik}(t), lon_i, lat_i, i = 1,.., N) \qquad t = 0,..T-1 \quad k = 1...K \tag{8}$$

In the next subsection, a heuristic procedure, introduced by [32], will be used to provide an approximate expression of the function in (8).

Other constraints state that the overall distance, covered by a vehicle within one day must not exceed a given upper bound, that is

$$L_k(t) \leq L_{max} \qquad t = 0,..T-1 \quad k = 1...K \tag{9}$$

The daily transportation cost $C_k(t)$ per tank-truck can be so defined as the total tour length expressed by (8), weighted by a constant factor *G* [€/km] that represents the unit length cost and takes into account the driver's salary, the fuel consumption and maintenance truck cost. Thus the cost $C_k(t)$ can be written as

$$C_k(t) = G\, L_k(t) \qquad t = 0,..T-1 \quad k = 1...K \tag{10}$$

Finally, the overall delivery at each SST each day must not overfill the USTs, that is

$$\sum_{k=1}^{K} w_{ik}(t) + x_i^+(t) + l_i^* \leq C_i^{max} \qquad t = 0,..T-1 \quad i = 1...N \tag{11}$$

Once the DM has optimised the overall transportation plan for all the week, a specific transportation plan has to be defined for all the vehicles, for example through the solution of a TSP, for each day and each vehicle. In this way the product delivery schedule for each tank-truck is determined, and the interested SST can be informed also communicating the quantities of product to be delivered.

3.2. The estimated length of the tour to serve a fixed number of SSTs

As outlined in the previous subsection, a quick method to determine an estimate of the optimal tour length of a vehicle, given a certain number of nodes (SSTs) to be touched, is required, in order to take into account the transportation costs in the statement and the solution of the CI-IRP, without introducing the necessity of embedding into such problem a number of TSPs to be simultaneous solved.

In particular, Daganzo in [33] considers different strategies to partition a given area into zones for distribution of goods, from a depot to many demand points. In another work [34], Daganzo proposes an approximate relationship to evaluate the overall distance covered in the optimal solution of a TSP, given the shape of a zone where the demand points are placed. The two papers propose two methods that can be used to evaluate the optimum length tour only in connection with square-grid networks in which distance is given by Euclidean or L-grid metric. Depending on the topological aspect, [35] take into account the VRP minimizing the delivery costs on a ring-radial network. In this case, the service area is considered as a sequence of concentric rings which have the depot in the centre. The number of service region, represented by a wedge-shape sector obtaining by the partitioning of concentric rings, is equal to the number of available tank-truck for deliveries.

In a more recent paper, [32] develop an approximation of the expected costs of the detour-to-depot in a load-capacitated vehicle routing system in which customers, located in a service region, are served with a fleet of vehicles whose number is fixed across operating periods. They analyse a single period, single depot constrained VRP in which load size and customers' location are known before planning operations. In particular, they show that, if an optimal sizing of the zones with an homogenous partition is possible, the expected total distance of the detour-to-depot can be given by a simple formula.

The method used in the present paper, as regards the expression of the functional dependence in (8) is based on this heuristic rule, which states that the optimal tour length can be approximately evaluated as

$$L_k(t) = 2\,radius_k(t) + R_k(t)\sqrt{\left(\frac{2\Delta_k(t)}{3}\right)} \qquad \begin{array}{l} t = 0,..T-1 \\ k = 1...K \end{array} \qquad \text{(8-bis)}$$

where

- $radius_k(t)$ is the distance between the depot and the centre of the rectangular area where the demand points to be served by each *k*-th vehicle are located;
- $R_k(t)$ is the area of the sector associated to be visited by the *k*-th vehicle;
- $\Delta_k(t)$ is the density of customers on the considered region (customers/area).

According to the approximation introduced by [32], the sectors considered are almost rectangular and so the areas are computed as the product of length and width for the smallest rectangle which contains the SSTs to be served by each vehicle and *radius* is the distance between the depot and the centre of the rectangular service region where customers are located. Then, to approximately compute the length of each vehicle tour, in addition to constraints (8-bis), additional constraints have to be introduced. Such constraints allows the evaluation of the area and of the densities of the regions where the SSTs are located. They can be expressed as:

$$lonmax_k(t) \geq \left(q_{ik}(t)\ lon_i\right) \qquad \begin{array}{l} t = 0,..T-1 \\ i = 1,..N \\ k = 1,..K \end{array} \tag{12}$$

$$latmax_k(t) \geq \left(q_{ik}(t)\ lat_i\right) \qquad \begin{array}{l} t = 0,..T-1 \\ i = 1,..N \\ k = 1,..K \end{array} \tag{13}$$

$$lonmin_k(t) \leq M\left(1 - q_{ik}(t)\right) + \left(q_{ik}(t)\ lon_i\right) \qquad \begin{array}{l} t = 0,..T-1 \\ i = 1,..N \\ k = 1,..K \end{array} \tag{14}$$

$$latmin_k(t) \leq M\left(1 - q_{ik}(t)\right) + \left(q_{ik}(t)\ lat_i\right) \qquad \begin{array}{l} t = 0,..T-1 \\ i = 1,..N \\ k = 1,..K \end{array} \tag{15}$$

$$length_k(t) = lonmax_k(t) - lonmin_k(t) \qquad \begin{array}{l} t = 0,..T-1 \\ k = 1,..K \end{array} \tag{16}$$

$$width_k(t) = latmax_k(t) - latmin_k(t) \qquad \begin{array}{l} t = 0,..T-1 \\ k = 1,..K \end{array} \tag{17}$$

$$R_k(t) = width_k(t)\ length_k(t) \qquad \begin{array}{l} t = 0,..T-1 \\ k = 1,..K \end{array} \tag{18}$$

$$N_k(t) = \sum_{i=1}^{N} q_{ik}(t) \qquad \begin{array}{l} t = 0,..T-1 \\ k = 1,..K \end{array} \tag{19}$$

$$\Delta_k(t) = N_k(t)/R_k(t) \qquad \begin{array}{l} t = 0,..T-1 \\ k = 1,..K \end{array} \tag{20}$$

Through the equation from (12) to (17), the length and the width of the rectangular region to be served by the *k-th* vehicle in the *t*-th period are evaluated. Equation (18) provides the area $R_k(t)$ of each virtual rectangle associated to each tank truck tour. Equation (19) computes the number $N_k(t)$ of the SSTs that the vehicle *k*-th must visit and serve in the *t*-th period. Finally equation (20) gives the density of SSTs in each service region. Note that the application of equation (8-bis) requires to calculate the radius $radius_k(t)$, which, at instant *t*, represents the distance between the depot and the centre of the rectangular service region associated to the *k-th* vehicle tour. In the present application, the following equation to identify the coordinates of the centre of the service region associated to each vehicle are introduced.

$$centrelon_k(t) = \frac{lonmax_k(t) + lon\,min_k(t)}{2} \tag{21}$$

$$centrelat_k(t) = \frac{latmax_k(t) + lat\,min_k(t)}{2} \tag{22}$$

According to these values and to the location of the single depot, whose coordinates are well known, the radius is simply computed as

$$radius_k(t) = \sqrt{\left(depot\_lon - centrelon_k(t)\right)^2 + \left(depot\_lat - centrelan_k(t)\right)^2} \tag{23}$$

Thus, the set of constraints (8-bis), (12)-(23) replace the constraint (8) in the formulation of the CI-IRP described in the previous section.

3.3. Application of the model according to a rolling horizon framework

The periodic and continuous (e.g. daily) acquisition of the UST levels allows to enhance the distribution planning, computing each day a new distribution plan following the decision model described in the previous subsections, according to a rolling horizon framework [20], as described below.

In the distribution of petrol products, a discrete model horizon $t = 0,\ldots,T\text{-}1$, days, with T=7 is assumed. In other words, on the current day (e.g. t=0), the decision model can plan the distribution for all the days of the week to come. The effectiveness of the distribution plan is obviously affected by the precision of the forecasted demand $d_i(t)$ in the following days, as well as by other factor such as an actual delivery occurred according to the defined planning. However, it is possible to decrease the impact of the uncertainty in forecast of future demand, re-computing each day a weekly plan taking into account the real data related to actual demand and deliveries. In other words, each day, the optimization model is repeatedly solved over moving time windows of one week. For one week planning horizon, the decision model identifies customers which should be visited and the amount of product to deliver during each day. In this way, customer's visits and deliveries are scheduled but only the first day of the week, the delivery is performed following the scheduled planning. The planning for the days to come might be readjusted in each following day. The results presented in the next section have obtained using a rolling horizon framework on a time windows of one week (i.e. T=7).

4. Case Study and Results

The effectiveness of the CI-IRP approach has been evaluated on the basis of some real-case studies, also with respect to DDO transportation planning currently adopted by one of the major Italian companies within the transportation of petrol products. An exemplifying case study is reported hereinafter.

The case study concerns the delivery of one petrol product (gasoline) from one depot placed in Priolo, in Sicily (Italy), to eleven SSTs located in Catania district during a planning period of seven days (T= 7 days). The main characteristics of the SSTs (maximum capacity, threshold level, coordinates) are shown in Table 1.

Table 1. Main characteristics of the SSTs in the case study

SST ID	UST capacity	Threshold level l^* (litres)	Longitude	Latitude
0	∞	-	15,1823	37,1558
1	7000	2000	15,0607	37,5099
2	30000	20000	15,0983	37,5114
3	5000	1000	15,0932	37,5281
4	15000	10000	15,0908	37,5233
5	15000	10000	15,0826	37,4886
6	10000	6000	14,9769	37,5872
7	10000	5000	15,0535	37,5434
8	10000	5000	15,091	37,5399
9	20000	15000	15,0651	37,5529
10	10000	5000	15,0694	37,517
11	20000	12000	15,1155	37,5333

The fleet is made by just two vehicles each one of capacity of 39 kliters. Two different approaches in petrol product distribution planning are compared: the RMI DDO approach and the proposed VMI CI-IRP approach supported by demand forecast and real time inventory acquisition data.

In the DDO approach, that is the current approach adopted by the distribution company of the case study, the transportation planning is defined according to the receipt of orders to be satisfied, solving then a VRP according to the Christofides *et al.*'s algorithm [6]. The solution that is obtained is optimal as regards transportation costs, while there is no optimisation of the inventory level, whose control is demanded to the subjective evaluation of each single SST retailer. The data used by this method are coming from historical real data stored in the information system of the distribution company as regards real product ordered by each considered SST and transportationed by the company. Specifically, these data are referred to the first week of July 2005.

Table 2 reports the performances of this transportation planning system as regards some indicators related both to transportation and to the inventory. The total distance covered in one week by the two tank trucks is 1322 km. This corresponds to transportation cost of 2247 €, supposing a unitary cost of 1.7 € per km. The overall delivered product is 334 kliters. As regards the inventory costs, these are evaluated with reference to the positive and negative inventory levels defined for each day of the considered week. The negative inventory cost is computed taking into account that an inventory level under the threshold value may give rise a stock out. In this work, for the sake of simplicity, the unitary negative inventory cost has been supposed to be the same for all the SST and equal to the approximate value of a litre of petrol sold (specifically, in (2) β= 1 €/liter). On the other hand, the positive inventory level implies a locking up of capital, and it may be measured as the budget invested to buy the quantity of product corresponding to the quantity $x_i^+(t)$ of fuel, multiplied for an interest rate applied for each day (specifically, in (2) α = 0.0025€/liter). The overall number of stops to feed the UST in the SST are 44, for an overall cost of 2200 € (specifically, in (2), it has been fixed γ = 50 € for each stop).

The CI-IRP approach shows better performances (see Table 2).

Table 2. Performance evaluation of the DDO approach versus the CI-IRP approach.

Performance indicators	DDO approach (real case study)	CI-IRP approach
Total distance covered in one week (km)	1322	1206
Transportation Costs (€)	2247	2049
Total delivered product (kliters)	334	338
Number of feeding stops	44	16
Costs of stops	2200	800
Cumulative 6 days PIL (klitres)	276	285
Cumulative 6 days NIL (klitres)	222	123
Total Inventory Costs (€)	223	124
Total inventory/transportation/ stop costs (€)	4670	2973

Obviously, since inventory costs are evaluated in the objective function while in the DDO they are not, CI-IRP has better performances as regards the total inventory costs (625 € versus 935 € of the DDO approach). As regards transportation costs, these are also better in the CI-IRP approach (2049 € versus 2247 € of the DDO approach). A better performance on transportation costs is not so obvious since in the DDO approach transportation costs are also optimized, moreover on their own; but in the DDO approach, deliveries are ordered by SST retailers while in the CI-IRP deliveries are driven by the inventory and can be planned on more days. Transportation costs will be discussed in more detail in the conclusion section. Also the number of stops is lower (16, for an overall cost of 800 €). Finally, the overall costs - resulting from inventory, transportation and stop costs – are 4670 € in the DDO approach versus 2973 € in the CI-IRP approach. Figure 4 shows the value of SST inventory costs during the week as computed by the proposed CI-IRP approach, and the real-data following a planning procedure as described by the DDO. It is worthwhile to remind that the data obtained by the CI-IRP approach have been computed according to a rolling horizon framework, that is, by solving seven optimization problems.

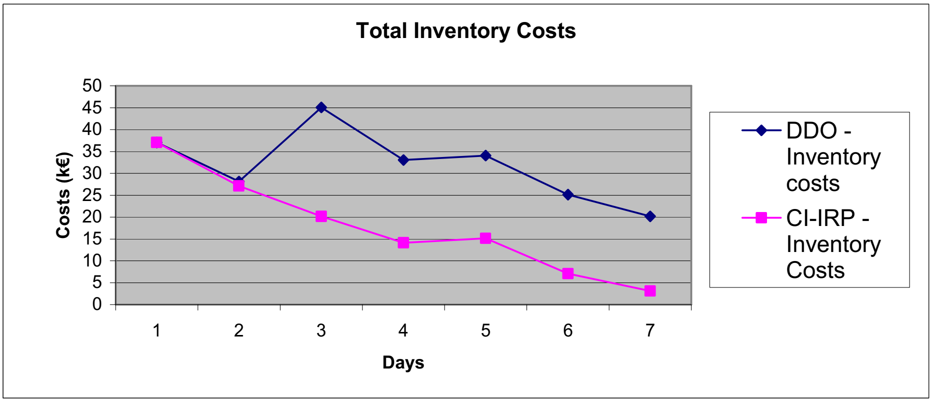

Figure 4. Total (including all the eleven SST) Inventory Cost computed for each day of the week.

From Figure 4, the improvement induced by CI-IRP model application is evident: in the seventh day, the CI-IRP method generates a saving of about 15 k€. In Figure 5, the distances covered by the trucks to serve the scheduled SST in each day of the week are displayed. Also in this case, it is useful to remind that the data has been obtained according to a rolling horizon framework.

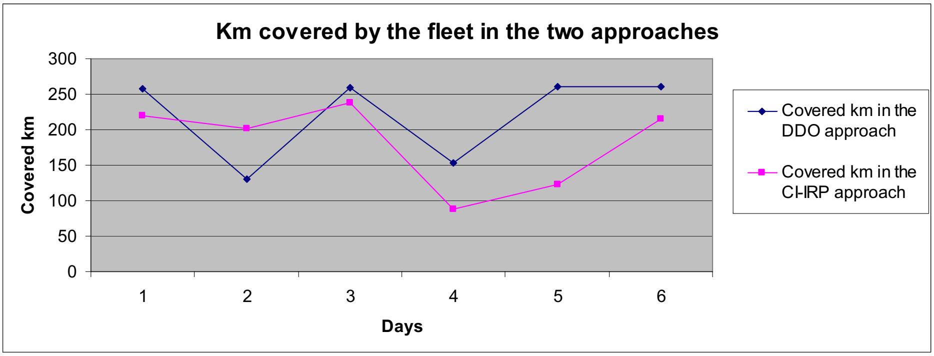

Figure 5. Total distances covered by the fleet in each day of the week to serve the scheduled SSTs in the two approaches.

The results for the seventh day (Sunday) has been omitted since in the territory of the case study, deliveries are not allowed on Sunday. Figure 5 shows that the CI-IRP approach, as regards the number of covered kilometres, has better performances than the DDO approach, which are more evident at the end of the week. During the whole week about 116 km are saved by the CI-IRP approach.

These results have an important consequences as regards both economic and risk-based aspects.

As regards economic aspects, it should be evaluated the trade-off between the reduction of costs due to saving kilometres in the deliveries, and the costs necessary to implement and maintain the technologies requested for real-time UST level acquisition. The fix costs to acquire the requested technology are 650 euro for each underground tank. Their use and maintenance costs, including the data traffic, are about 500-600 euros per SST per year. With reference to the case study, the overall costs would have been of 7200 euro and 6600 euros per year. The saving might be estimated as 80.000 per year. The implementation of the IRP approach appears to be sustainable from an economic viewpoint, since revenues are expected just after the first years.

As regards risk based aspects, the benefits seems even more relevant taking into account the decreasing number of stops requested in the service stations (which is one of the most dangerous moment of the delivery and that in the results of the case study has been reduced of the 64 %) as well as the decreased number of kilometres requested for the deliveries. Taking into account just this latter aspect, due to the definitions of dangerous goods transportation risk ([36], [37]), in the case study a decrease of 9% of risk would have been obtained (that is correspondent to the decrease of kilometres).

5. Conclusions

The optimisation model for fuel distribution, with prediction of the demand and real-time data acquisition of the inventory, guarantees an improvement in the inventory management quality at the central depot and at SST prioritizing urgent orders and stock out. The coordination of two most important components of the logistic value chain, inventory management and product transportation, through the integration of the Daganzo's approximation for the tour distance to minimize transportation costs, represents a first approach to evaluate the advantages to use real time inventory control in the logistic process.

The results, also taking into account other computations that have been omitted in this work for the sake of brevity, seem to confirm an improvement in performance as regards many aspects. This is due to many factors, the most important of which is the use of a planning horizon greater than one day, and the fact that orders are implicitly driven by the inventory rather then explicitly and subjectively driven by the SST vendor. It should be also quite evident that the prediction of the demand that is requested for the application of the rolling horizon framework can be hardly applied to enhance the DDO approach with a time window greater than one day, since, in this case, the prediction of the orders is more complex to be achieved due to the individual behaviour of the SST retailer.

The current formulation can represent a valuable help for DMs to compute quantitatively the economic value of the information of UST levels, so that it is possible to assess whether it is worthwhile to invest on remote sensing of the UST levels or not. From the case study, as well as from others omitted here, this investment seems to be worthwhile.

As regards risk based sustainability of this dangerous goods transport, the benefits seems even more relevant. The practical application of these methods in the real world transportation would require the adoption of specific operational tools in the transportation companies to define optimal risk based routes, control methods either on the road infrastructure or in specific centres of civil protection departments to assess this risk by the real-time monitoring and control of the different hazmat trucks on a territory. In addition, the overall hazmat routing on a territory should be supported by adequate regulations to verify the adoption of a risk based routing policy in the transportation company. As a matter of fact, despite several research projects on technologies and methodologies to track hazmat vehicles and the adoption of new important international regulations (such as ADR2005), the effective decision on the routing of the hazmat vehicle is not still declared (and known by public authorities) and it is often a subjective decision of the driver himself. This is the case of tank trucks transporting petrol products. In addition, under a myopic view, the adoption of risk based routing strategies may be taken into account as an unnecessary cost by the transportation company (for example, as regards the necessary equipment requested to track the hazmat vehicle, or due to the fact that a risk based optimal route might be quite different from the shortest path requested for the delivery), also derived by the fact that hazmat accidents falls in the category of low frequency high consequence events [38]. In addition, at regional and national level, public authorities are more oriented towards long term shifting of hazmat transportation from road to other transportation modes, a solution that is economically impracticable in the delivery of petrol product to service stations. That is why the path towards a hazmat transportation which is sustainable from a risk based routing viewpoint is still far to be achieved in practice.

From a risk based sustainability, the proposed approach achieves the goal to decrease the frequency of the deliveries, which quite obviously may also represent a significant risk reduction of an accident. In more general terms, this work may also represent the way to join the economic sustainability aspects of the petrol product deliveries - as they may be argued by a transportation company DM - with the risk based sustainability aspects as they may be argued by the DM of a territorial local authority.

Acknowledgements

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References

[1] EUROSTAT 2002 available at www. http://epp.eurostat.ec.europa.eu

[2] P. Serafini, 2006. Dynamic programming and minimum risk paths. European Journal of Operational Research. Vol. 175, pp. 224-237.

[3] G.H. Michael Bell, 2007, Mixed routing strategies for hazardous material: decision-making under complete uncertaintly International Journal of Sustainable Transportation, vol. 1, pp. 133-142.

[4] E. Erkut V. Verter 1998 Modelling of transport risk for hazardous materials. Opns Res 46:625–642

[5] P. Carotenuto S. Giordani S. and Ricciardelli Finding minimum and equitable risk routes for hazmat shipments Computers & Operations Research, Volume 34, Issue 5, May 2007, Pages 1304-1327

[6] N. Christofides A. Mingozzi P. and Toth P., “The vehicle routing problem.” in Combinatorial Optimization N. Christofides, A. Mingozzi, P. Toth, and C. Sandi, Wiley, Chichester UK, 1979, pp. 315-338.
[7] R. Lindau K. Lumsden, “The use of automatic data capture systems in inventory management”, International Journal of Production Economics, vol. 59, pp. 159 -167, 1999.
[8] A.C. Yao J.G. Carlson “The impact of real-time data communication on inventory management”, International Journal of Production Economics, vol. 59, pp. 213-219, 1999.
[9] L. Bertazzi, G. Paletta M. Speranza, “Deterministic Order-Up-To level policies in an inventory routing problem”, Transportation Science, vol. 36, no.1, pp. 119-132, 2002.
[10] A. Kleywegt V. Nori, M. Savelsbergh “The stochastic inventory routing problem with direct deliveries”, Transportation Science, vol. 36, pp. 94-118, 2002.
[11] A. Federgruen, P. Zipkin “A combined vehicle routing and inventory allocation problem,” Operations Research, vol. 32, no. 5, pp. 1019-1036, 1984.
[12] B. Golden, A. Assad, R. Dahl “Analysis of a large scale vehicle routing problem with an inventory component,” Large Scale Systems, vol. 7, no. 2-3, pp. 181–190, 1984.
[13] T. Chien, A. Balakrishnan, R. Wong “An integrated inventory allocation and vehicle routing problem,” Transportation Science, vol. 23, no. 2, pp. 67–76, 1989.
[14] M. Fisher, A. Greenfield, R. Jaikumar, P. Kedia “Real-time scheduling of a bulk delivery fleet: Practical application of lagrangean relaxation,” The Wharton School, University of Pennsylvania, Department of Decision Sciences, Tech. Rep., October 1982.
[15] W. Bell, L. Dalberto, M. Fisher, A. Greenfield, R. Jaikumar, P. Kedia, R. Mack, and P. Prutzman, “Improving the distribution of industrial gases with an on-line computerized routing and scheduling optimizer,” Interfaces, vol. 13, no. 6, pp. 4–23, 1983.
[16] M. Dror, M. Ball, and B. Golden “A Computational Comparison of Algorithms for the Inventory Routing Problem”, Annals of Operations Research, vol. 4, pp. 3-23, 1985.
[17] P. Trudeau and M. Dror “Stochastic Inventory Routing: Route Design with Stockouts and Route Failures”, Transportation Science, vol. 26, pp. 171-184, 1992.
[18] A. Campbell, L. Clarke and M. Savelsbergh, “Inventory routing in practice,” in The Vehicle Routing Problem, P. Toth and D. Vigo, SIAM Monographs on Discrete Mathematics and Applications, 2002, pp. 309–330.
[19] J. Bard, L. Huang, P. Jaillet and M. Dror “A decomposition approach to the inventory routing problem with satellite facilities,” Transportation Science, vol. 32, pp. 189–203, 1998.
[20] P. Jaillet, J. Bard, L. Huang and M. Dror “Delivery cost approximations for inventory routing problems in a rolling horizon framework”, Transportation Science, vol. 3, pp. 292–300, 2002.
[21] S. Anily, A. Federgruen, “One warehouse multiple retailer systems with vehicle routing costs,” Management Science, vol. 36, no. 1, pp. 92-114, 1990.
[22] S. Anily, A. Federgruen “Rejoinder to ‘one warehouse multiple retailer systems with vehicle routing costs’,” Management Science, vol. 37, no. 11, pp. 1497-1499, 1991.
[23] R.I. Webb, C.R. Larson “Period and Phase of Customer Replenishment: A New Approach to the Strategic Inventory/Routing Problem”, European Journal of Operational Research , vol. 85, pp.132-148, 1995.
[24] L. Chan, A. Federgruen and D. Simchi-Levi, “Probabilistic analyses and practical algorithms for inventory-routing models,” Operations Research, vol. 46, no.1, pp. 96–106, 1998.
[25] G. Gallego and D. Simchi-Levi, “On the effectiveness of direct shipping strategy for the one-warehouse multi-retailer r-systems,” Management Science, vol. 36, no. 2, pp. 240–243, 1990.
[26] A. Minkoff, “A markov decision model and decomposition heuristic for dynamic vehicle dispatching,” Operations Research, vol. 41, pp. 77–90, 1993.
[27] D. Adelman, “A price-directed approach to stochastic inventory/routing,” Operations Research, vol. 52, no. 4, pp. 499–514, 2004.
[28] M.I. Reiman, Rubio R. and Wein L.M., "Heavy traffic analysis of the dynamic stochastic inventory-routing problem", Transportation Science, vol. 33, pp. 361-380, 1999.
[29] R. Ribeiro, H.R.D. Lourenco “Inventory –routing model for a multi-period problem with stochastic and deterministic demand”, UPF Economics and Business Working Paper, vol. 725, 2003.
[30] L. Bertazzi, G. Paletta and M.G. Speranza, “Minimizing the Total Cost in an Integrated Vendor–Managed Inventory System”, Journal of Heuristics, vol. 11, no. 5-6, pp. 393-419, 2005.
[31] A. Lim, F. Wang “Multi-Depot Vehicle Routing Problem: A One-Stage Approach”, IEEE Trans. on Automation Science and Engineering , vol. 2, no. 4, pp. 397-402, 2005.
[32] A.L. Erera and C.F. Daganzo “A Dynamic Scheme for Stochastic Vehicle Routing,” submitted to. Transportation Research Part B: Methodological, 2006.
[33] C.F. Daganzo, "The distance traveled to visit N points with a maximum of C stops per vehicle: An analytic model and an application", Transportation Science , vol. 18, no. 4, pp. 331-350, 1984a.

[34] C.F. Daganzo, "The Length of Tours in Zones of Different Shapes", Transportation Research B, vol. 18, no. 2, pp. 135-146, 1984b.
[35] G.F. Newell and C.F. Daganzo , "Design of multiple vehicle delivery tours--I: A ring-radial network", Transportation Research B vol. 20B, no. 5, pp. 345-364, 1986.
[36] P. Button Nancy, M. Reilly Park Uncertainty in incident rates for trucks carrying dangerous goods, Accident Analysis and Prevention 32 (2000) 797–804
[37] P. Leonelli, S. Bonvicini, G. Spadoni, New detailed numerical procedures for calculating risk measures in hazardous materials transportation, J. Loss Prev. 12 (6) (1999) 507–515.
[38] G.H. Michael Bell, Mixed Route Strategies for the Risk-Averse Shipment of Hazardous Materials, Netw Spat Econ (2006) 6: 253–265.

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A GIS-Based Multi-Objective Travel Planner for Hazardous Material Transport in the Urban Area of Milan*

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Abstract. What differentiates hazardous material (hazmat) shipments from the transport of other materials is the risk associated with an accidental release of the material. The paper concerns the problem of routing and scheduling hazmat in urban and suburban road networks. This problem involves conflicting objectives among interested parties: the shipping company, the client, the vehicle driver, the environment agency of the area, the population. In presence of conflicting interests, the use of a decision support system (DSS) is recommended. The paper outlines an ongoing work to develop a DSS based on a Geographical Information System (GIS) for hazmat transport in the city of Milan. We use a probabilistic risk assessment model, which takes into account, as route selection parameters, the probability of accidents and the consequences of an accident for each road segment. The model considers population, vulnerable facilities (schools, hospitals, …), territorial infrastructures (e.g. railways, electric lines), natural elements (water bodies, green areas, …), critical areas (e.g. areas which may be a target for a terrorist attack). An hazmat multi-objective route planner has been developed in Python language using ESRI ArcGIS to perform spatial analyses and to optimize the procedure. The planner, which is in a prototype phase, has been tested on Niguarda, an area of the city of Milan characterized by the presence of an important hospital.

Keywords. Hazardous material transport, multi-objective routing, geographic information system, decision support systems.

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Introduction

There are many schemes for the classification of hazardous material (hazmat), formulated in various countries and for different scopes. The United Nations Organization categorizes hazmats in nine categories [1], with some subcategories, and specifying packaging requirements for some of them (see Table 1).

Quantitative risk analysis techniques were first developed with the purpose of assessing the risk in nuclear processes, and then widely applied to process industry [2]. Transport risk analysis derives from such techniques, but is far less used [3]. There are two approaches to the analysis of hazmat movements [4]:

- macro or aggregate studies, which focus on aggregate statistics of hazmat movements to calculate the frequency of incidents, and to measure the total exposure of the population to hazmat movements [e.g. [5];
- micro studies, which evaluate specific hazmat shipments or proposed regulatory changes. In contrast with the previous approach, the micro approach is intended for decision-making, and has been chosen for the case study described in this paper.

What differentiates hazardous materials shipments from the transport of other materials is the risk associated with an accidental release of hazardous materials. The danger associated with hazmat shipments may differ significantly depending on the situations. The degree of harm is not exclusively a function of the physical properties of the hazmat, but also of the amount that is released and, especially, of the circumstances (location, wind, etc.) [5]. Moreover, the danger of terrorist attacks has increased the concerns regarding the secure transport of hazardous materials [6].

Table 1. 2007 ADR Classification of hazardous materials [1]

Class	Hazardous material
1	Explosive substances and articles
2	Gases
3	Flammable liquids
4.1	Flammable solids, self-reactive substances and solid desensitized explosives
4.2	Substances liable to spontaneous combustion
4.3	Substances that, in contact with water, produce flammable gases
5.1	Oxidizing substances
5.2	Organic peroxides
6.1	Toxic substances
6.2	Infectious substances
7	Radioactive material
8	Corrosive substances
9	Miscellaneous of dangerous substances

Usually, in a freight transport problem, travel time is minimized in order to satisfy the time-windows requirements of the client. However, in the case of hazmat transport, minimizing travel time can put a large population at risk: dense-populated areas should be avoided by using slower and less direct roads [7, 8]. On the other hand, sparse-populated areas in Italy are often environmentally vulnerable (e.g. because of the presence of natural parks or agricultural fields). Moreover, a truck driver would like to avoid the less safe roads for his/her own safety. This problem therefore involves conflicting objectives among interested parties: the shipping company, the client, the vehicle driver, the environment agency of the area, the population. In presence of conflicting interests, the improvement of one objective typically conflicts with the improvement of other objectives, and automatic technical search for the optimum becomes meaningless. In these situations, the use of a decision support system (DSS) is recommended [9, 10].

The present work concerns a particular problem: hazmat transport in urban areas. According to the Italian law, the local public administration of a city is responsible for the control and management of hazmat transport. We outline an ongoing work to develop a DSS based on a Geographical Information System (GIS) for hazmat transport in the city of Milan. The GIS-DSS is designed to perform a fast risk analysis for hazmat road and rail transport, during all the necessary steps (from the initial route selection to risk assessment and dynamic route guidance). Both single and multiple shipments can be considered and also support to emergency planning can be achieved. So far, the GIS-DSS is in a prototype phase and only one element has been implemented. The paper focuses mainly on this element: an hazmat multi-objective route planner, which has been developed within a commercial GIS and has been tested on Niguarda, an area of the city of Milan characterized by the presence of an important hospital.

The paper is organized as follows. In Section 1, an overview on the philosophy and the structure of the proposed GIS-DSS is presented. In Section 2, the mathematical model to calculate the risk associated to hazmat transport is described in detail. In Section 3, the multi-objective problem of hazmat routing is discussed. Section 4 explains the implementation of the DSS within the GIS. Section 5 concludes the paper with a summary of the main properties of the proposed planner and with indications of the future challenges.

1. Philosophy and structure of the DSS

Possible goals and elements of a DSS for routing and scheduling of hazmat transport are described for instance in [11] and [12]. The DSS that we are implementing can be used by the public authority and by the single vehicle drivers, respectively, for:

- public decision-making;
- vehicle guidance.

In the following subsections, the two perspectives will be explained more in detail.

1.1. Public decision-making

There are some aspects of the problem that have to be taken into account when implementing a DSS related with hazmat transport:

- goal of the system;
- tracking technology.

As regards the goal of the system, we can identify two situations: the public authority is interested just in tracking the vehicles, or it is also interested in planning the hazmat shipment. The latter implies that the public authority decides a set of possible paths that the driver is allowed to take and/or a set of time-slots of the day (or days of the week) when the driver is allowed to enter certain areas.

Vehicle tracking can be implemented using two technology types:

- fixed infrastructures (e.g. gates with cameras that use automated plate number recognition);
- on-board devices.

Combining in different ways such aspects, different DSSs may be implemented based on the type of problem, on budget and legislative constraints, and on political choices.

According to the Italian law, the local public administration of a city is responsible for the control and management of hazmat transport. For the Municipality of Milan, we are implementing a GIS-based DSS that will assist not only in tracking the vehicles, but also in planning the paths and the day time-slots of each shipment. Note that the objectives and the issues of this problem could be different from those related with hazmat transport in regional areas. The Municipality of Milan decided to use a tracking technology based on gates with cameras that use automated plate number recognition (see Figure 1), because it does not have the power (either legislative or operative) to force all the trucks to have an on-board device. Moreover, some of the gates are already used for the management of *Ecopass*, a road pricing system for the center of the city.

Figure 1. One of the gates equipped with cameras that the Municipality of Milan uses for automated vehicle plate number recognition.

In addition to risk assessment and selection of the safest routes, the objective of the DSS is to schedule hazmat shipments, especially when there are many at the same time in the network. To integrate routing and scheduling decisions, the DDS has a two-stage structure (Figure 2) [13]. In the first stage, a set of alternative routes with a good combination of travel time and risk is generated for each hazmat shipment request. In a second stage, a departure time and a route, among those generated in the first stage, are assigned to each request. For example, given two materials A and B that are particularly dangerous when combined together, an hazmat shipment schedule should avoid two vehicles transporting A and B at the same time in the same area.

So far, the GIS-DSS is in a prototype phase and only the *route planner* module has been implemented.

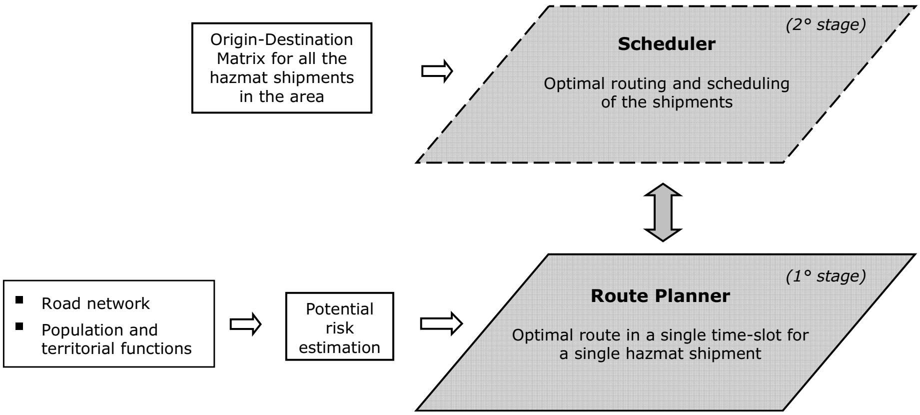

Figure 2. The two stage GIS-DSS structure. In the first stage (*Route Planner*), a set of alternative routes with a good combination of travel time and risk is generated for each hazmat shipment request. In a second stage (*Scheduler*), a departure time and a route, among those generated in the first stage, are assigned to each hazmat shipment request.

1.2. Vehicle guidance

As regards the vehicle driver, the first scope of the system is the *a priori* route and scheduling guidance, as explained as follows. The driver has to provide the system with the following information about the hazmat shipment: origin, destination, preferred time-slot and day, material, plate number and type of the vehicle. The system estimates the risks and travel time associated with the possible paths and time-slots, and proposes the "best-compromise" solution (or a set of solutions, among which the driver has to choose one). In Section 3, the meaning of "best-compromise" will be explained. The driver will have to follow the instructions, otherwise he/she will be spotted by the municipality tracking system and will be fined.

In addition to assisting the driver in selecting an optimal route, the system should also support dynamic route guidance. Dynamic route guidance is defined as the proposition of routing instructions that are automatically modified in response to changes in traffic and roadway conditions. Until recently, route guidance systems represented a non-significant part of the intelligent transport systems market. With the expansion of the Internet and the growing popularity of in-vehicle electronics, route guidance systems are experiencing an explosive growth [14]. A combination of new technologies, including GPS and wireless communications, make it possible to use real-time information. A range of dynamic information can potentially be incorporated, such as near real-time traffic information, roadworks, actual travel speeds, weather conditions. For a review of routing and scheduling models for hazmat transportation see [15] and [16]. For a review of real-time routing models see [17].

2. The risk assessment model

Let $G = (N, A)$ be a directed graph representing the transport network, with N and A being, respectively, the set of nodes and the set of directed links of the network. Each link $h \in A$ corresponds to a road segment of the network, and each node $i \in N$ corresponds to a road intersection. Some link attributes (e.g. speed, traffic density, …) are assumed to be a function of the time-slot f of the day.

We consider the following risks associated with the transport of a hazmat m during time-slot f:

- $R^{pop}(h,f,m)$ risk on population (e.g. residents, workers);
- $R^{inf}(h,m)$ risk on territorial infrastructures (e.g. railways, electric lines);
- $R^{nat}(h,m)$ risk on natural elements (e.g. water bodies, green areas, …);
- $R^{cri}(h,f,m)$ risk on critical areas (e.g. areas which may be a target for a terrorist attack).

In the model we identified, R^{pop} and R^{cri} are function of time-slot f, because the spatial distribution of the population and the safety of the critical areas are time-dependent. R^{inf} and R^{nat} are not function of time-slot f for the specific infrastructures and natural elements we considered in the study. Of course, adding to the model a possible time-dependency for R^{inf} *and* R^{nat} would be immediate.

2.1. Estimation of the risk on population

The population is modelled identifying a set Y of points, where we can assume the population is concentrated. The more points are identified, the better the distribution of the population is modelled. To each point $y \in Y$ we associate $pop_{y,f}$, the number of people present in the area represented by y at time-slot f. The quantity $pop_{y,f}$ may represent:

- the population living in the area;
- employees working in the area;
- people present in facilities (schools, stores, …);
- people crossing the area (identified by the traffic flows).

The variable $pop_{y,f}$ is clearly time-dependent, and is a function of the trips to and from the considered area. Figure 3 depicts an exemplification.

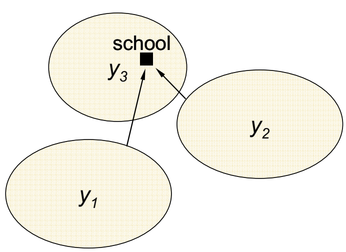

Figure 3. An exemplification of the dependence of $pop_{y,f}$ on time-slot f. The presence of a school increases the population of y_3 during a particular time-slot, because some people from y_1 and y_2 reach the school.

For the estimation of the risk on the population, we used a method derived by [18]. An incident on a link may affect not only the people who live in that link, but also persons living and working in areas that are close to the incident. The entity of the effect of the incident decreases with the spatial distance from the point where the incident occurs. To model the risk appropriately, we consider the risk of a hazmat transport on a unit-length segment of the network. Given that each street link *h* is partitioned into a sequence of unit-length segments, the risk $\sigma_{x,y}^{pop}$ associated to the hazmat travelling on a segment *x* for the population living in the proximity of point *y* is calculated as in Eq. (1).

$$\sigma_{x,y}^{pop} = p_x^{inc} \cdot pop_{y,f} \cdot e^{-\varphi \cdot [L(x,y)]^{\eta}} \tag{1}$$

where:

- p_x^{inc} is the probability per unit-length of an accident occurring on x;
- $pop_{y,f} \cdot e^{-\varphi \cdot [L(x,y)]^{\eta}}$ is the estimated damage on population popy,f.

The damage decreases exponentially with a power of the Euclidean distance *L(x,y)* between the centers of segment *x* and point *y*, where φ and η depend on the hazardous material *m* under consideration. Figure 4 shows qualitatively the shape of the damage function and, hence, the size of the impacted zone.

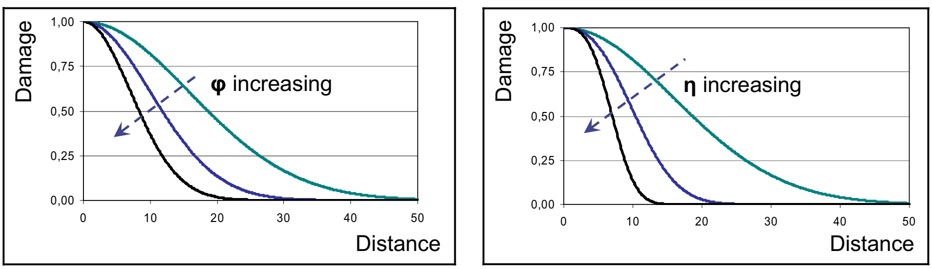

Figure 4. Shape of the damage function varying the φ (on the left) and η (on the right) parameters.

The risk on the population $R^{pop}(h,f,m)$ is calculated as sum of the contributes of all the unit-length segments of link *h* on all the points of the set *Y*, as in Eq. (2). Figure 5 depicts a graphical exemplification of the calculation.

$$R^{pop}(h,f,m) = \sum_{x \in h} \sum_{y \in Y} \sigma_{x,y}^{pop} \tag{2}$$

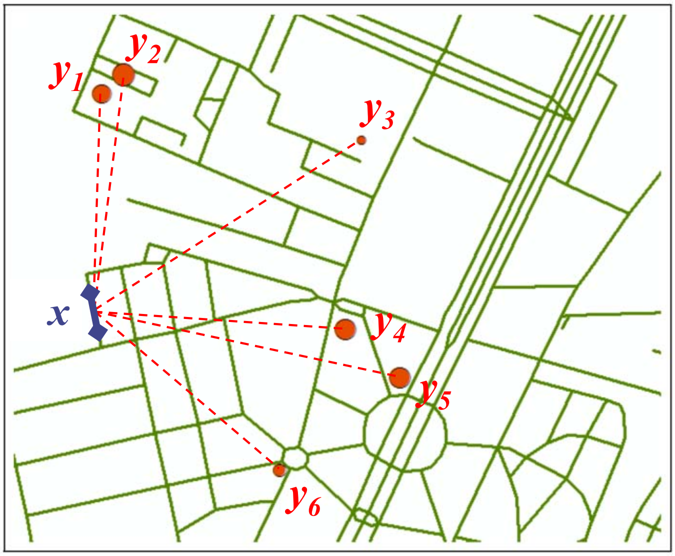

Figure 5. Exemplification of the process of summing the potential damage of an accident occurring in the unit-length segment x on the points y_1, y_2, y_3, y_4, y_5, y_6, identified by a circle whose area is proportional to the population. The dotted lines represent the Euclidean distances between x and a generic point y.

2.2. Estimation of the risk on territorial infrastructures

For the estimation of the risk on a set S of territorial infrastructures, we use a simpler method.

The risk $\sigma_{x,s}^{\inf}$ associated to the hazmat travelling on a unit-length segment x for infrastructure s $\in S$ is calculated as in Eq. (3).

$$\sigma_{x,s}^{\inf} = p_x^{inc} \cdot \pi_s \cdot \varsigma_{m,s} \cdot \delta_{x,s} \tag{3}$$

where:

- p_x^{inc} is the probability per unit-length of an accident occurring on x;
- π_s is a weight given to the infrastructure s (e.g. based on its value);
- $\varsigma_{m,s}$ is an interaction parameter that quantifies the vulnerability of infrastructure s in respect to material m;
- $\delta_{x,s}$ is the damage function adopted in the neighbourhood approach proposed in [19], where $\delta_{x,s}$ is equal to 1 if L(x,s) is less than a threshold distance, 0 otherwise. Figure 6 shows an example of estimation of the damage function.

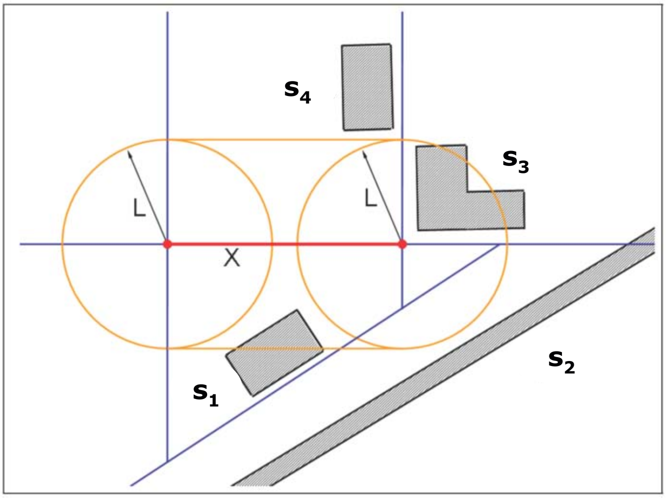

Figure 6. Examples of estimation of the damage function with a threshold distance equal to L. The damage function on a unit-length segment x is equal to 1 for infrastructures s_1 and s_3, while is equal to 0 for infrastructures s_2 and s_4.

The risk $R^{inf}(h,m)$ is calculated as sum of the contributes of all the unit-length segments of link h on all infrastructures included in set S, as indicated in Eq. (4).

$$R^{\inf}(h,m) = \sum_{x \in h} \sum_{s \in S} \sigma_{x,s}^{\inf} \tag{4}$$

2.3. Estimation of the risk on natural elements

For the estimation of the risk on a set P of natural elements, we use a method similar to the method described in the previous section.

The risk $\sigma_{x,p}^{nat}$ associated to the hazmat travelling on a unit-length segment x for natural element $p \in P$ is calculated as in Eq. (5).

$$\sigma_{x,p}^{nat} = p_x^{inc} \cdot \pi_p \cdot \varsigma_{m,p} \cdot \delta_{x,p} \tag{5}$$

where:

- p_x^{inc} is the probability per unit-length of an accident occurring on x;
- π_p is a weight given to natural element p (e.g. based on its biodiversity value);
- $\varsigma_{m,p}$ is an interaction parameter that quantifies the vulnerability of natural element p in respect to material m;
- $\delta_{x,p}$ is a damage function, where $\delta_{x,p}$ is equal to 1 if L(x,p) is less than a threshold distance, 0 otherwise.

The risk $R^{nat}(h,m)$ is calculated as sum of the contributes of all the unit-length segments of link h on all natural elements included in set P, as indicated in Eq. (6).

$$R^{nat}(h,m) = \sum_{x \in h} \sum_{p \in P} \sigma^{nat}_{x,p} \tag{6}$$

2.4. Estimation of the risk on critical areas

For the estimation of the risk on a set Q of territorial infrastructures, we use a method similar to the method described in Section 2.2.

The risk $\sigma^{cri}_{x,q}$ associated to the hazmat travelling on a unit-length segment x for critical area $q \in Q$ is calculated as Eq. (7).

$$\sigma^{cri}_{x,q} = p^{inc}_{x} \cdot \pi_q \cdot \varsigma_{m,q} \cdot \delta_{x,q} \tag{7}$$

where:

- p^{inc}_{x} is the probability per unit-length of an accident occurring on x;
- π_q is a weight given to critical area q (e.g. based on its strategic importance);
- $\varsigma_{m,q}$ is an interaction parameter that quantifies the vulnerability of critical area q in respect to material m;
- $\delta_{x,q}$ is a damage function, where $\delta_{x,q}$ is equal to 1 if L(x,q) is less than a threshold distance, 0 otherwise.

The risk $R^{cri}(h,f,m)$ is calculated as sum of the contributes of all the unit-length segments of link h on all critical areas included in set Q, as indicated in Eq. (8).

$$R^{cri}(h,f,m) = \sum_{x \in h} \sum_{q \in Q} \sigma^{cri}_{x,q} \tag{8}$$

3. The route selection model: a multi-objective problem

Given an origin o ∈ N, a destination d ∈ N, and an hazardous material m, the problem we consider is to find the path (route) from o to d that minimizes the total cost induced by travelling on this path. The total cost is a function of five attributes: travel time, risk on population, risk on territorial infrastructures, risk on natural elements and risk on critical areas. Therefore, this is a multi-objective problem.

Many techniques have been proposed for solving multi-objective vehicle routing and scheduling problems. Jozefowiez et al. [20] divides them into three general categories:

- *Scalar methods.* These methods use mathematical transformations, like weighted linear aggregation. They have some disadvantages, like the difficulty of eliciting the weights and the fact that they may not be able to find all the

Pareto optimal solutions. However, these techniques are quite simple to implement and can be used with any of the single-objective heuristics described in literature.

- *Pareto methods.* These methods apply the notion of Pareto dominance to evaluate a solution or to compare solutions. This concept is frequently used within evolutionary algorithms, and is becoming more popular [21].
- *Non-scalar and non-Pareto algorithms.* These methods, which often consider the different objectives separately, are based on genetic algorithms (e.g. vector evaluated genetic algorithm), lexicographic strategies, ant colony mechanisms, or specific heuristics.

So far, we implemented a simple scalar method. Due to the wide variation of measurement scales, each type of link attribute (travel time and risk on population, territorial infrastructures, natural elements, and critical areas) is normalized using linear functions.

Note that the level of traffic congestion affects link travel time and is affected by the time of day. Therefore, link travel time is one of the time-dependent link attributes.

The total cost *C(h,f,m)* on a link *h* in a time-slot *f* for the transport of a material *m* is calculated as a weighted sum of the attributes, as in Eq. (9)

$$\begin{aligned} C(h,f,m) &= \alpha \cdot \widetilde{T}(h,f) + \beta \cdot \widetilde{R}^{pop}(h,f,m) + \gamma \cdot \widetilde{R}^{\inf}(h,m) + \cdots \\ &\ldots + \vartheta \cdot \widetilde{R}^{nat}(h,m) + \varepsilon \cdot \widetilde{R}^{cri}(h,f,m) \end{aligned} \quad (9)$$

where:

- $\widetilde{T}(h,f)$ is the normalized link travel time;
- $\widetilde{R}^{pop}$, $\widetilde{R}^{\inf}$, $\widetilde{R}^{nat}$, $\widetilde{R}^{cri}$ are the normalized link risks associated, respectively, to population, territorial infrastructures, natural elements, and critical areas;
- α, β, γ, θ and ε are the relative weights to combine the link attributes into a single cost.

Once the total cost attribute is calculated for each link of the network, a simple Dijkstra algorithm is used to calculate the minimal cost path and the corresponding route is selected. By varying the relative weights α, β, γ, θ and ε, different routes can be created. Starting from the values chosen by the decision maker, weights can be slightly varied in order to measure the sensitivity on route selection and the robustness of the found solution [22].

The principal problem is related with the elicitation of the weights. For the decision-maker, the weights' estimation is a difficult task, because not all the attribute values have a physical meaning. Moreover, even if the decision-maker is able to determine the weights, there would be a problem associated with the automatism of the normalization. Because the maximum value may be different from situation to situation, the corresponding normalization will have a different meaning. So, the decision-maker cannot choose the weights once for all, but he/she should adapt the weights to every situation.

The method described above has been already implemented. So far, we are developing a different method where the focus is not on the single links, but on the possible paths. This method considers the following steps:

- definition of a set of paths from the origin to destination. This concerns the problem of finding dissimilar Pareto-optimal paths [23, 24];

- interactive editing of generated and displayed paths: the analyst may wish to create a detour around a sensitive location, or to remove some links from the network and have a new path generated;
- association to the paths of a "satisfaction" using utility functions;
- comparison of the paths using a multi-criteria decision method [25];
- selection of the "best compromise" solution.

As already stated, this problem involves conflicting objectives among the interested parties. In presence of conflicting interests, the improvement of one objective typically conflicts with the improvement of another one, and automatic technical search for the optimum is assumed to be meaningless. The philosophy here is to give all the necessary information to the decision maker, and to eliminate successively all the alternatives that are inferior because they are Pareto-dominated or too conflicting, or because they have critical impacts on a particular attribute. The final decision will be political, but the underlying procedure can be made rational and transparent [10]. By an iterative process of displaying paths, using different solution methods and creating detours, a compromise path can be developed [12].

4. Implementation of the GIS-DSS

4.1. Why using a GIS

A GIS is a computer application designed for the capture, storage, manipulation, analysis and display of geographic information. Geographic location is the basis for the ability of GIS to map, to measure distances, and to tie different kinds of information together because they refer to the same place [26]. An accurate DSS requires detailed territorial information, which can be efficiently managed using GIS applications. A DSS based on the GIS approach may be a comprehensive risk management tool [3].

4.2. The network data model

The GIS-DSS we are developing requires specific data structures to represent the complexities of road networks and to perform routing and scheduling algorithms [27]. The heart of any GIS is its *data model*, which is an abstract representation of some real-world situation used to organize data in a database. Data models typically consist of three major elements. The first is a set of data objects or entity types that form the basic building blocks for the database. The second element is a set of general integrity rules. The last element includes operators that can be applied to entities in the database [28].

Current GIS data models typically represent a network as a collection of arcs (links) with nodes created at the arc intersections [27]. We used the geo-relational model, which is the most widely used logical data model for networks [28 Miller]. This model separates spatial and attribute data into different data models. A logical spatial data model (the vector data model) maintains the geometry and the associated topological information, while the associated attribute information is held in relational database management system (RDBMS) tables. This solution is neither elegant nor robust, but it is effective, because it takes advantages of the RDBMS features to store and manipulate attribute information [25].

We developed also a *navigable data model*, which, as regards the routing guidance system, includes the following features [28, 29]:

- the data model unambiguously translates coordinate-based locations into street addresses, and vice versa. That is, the vehicle position has to snapped on a network link when its estimated location is outside the road network (e.g. if the position is estimated with a GPS);
- the data model has the capability to represent the transportation network in detail sufficient to perform routing and risk estimation algorithms.

4.3. The implementation for Niguarda

The Municipality of Milan provided a set of databases on road network, population, schools, main companies and main interest points. Most of the data were already geographically referenced. For some of them, we had only the addresses names or an ambiguous indication of the building block location. So, we had to geo-reference such data and to find the correspondent street link. Most of the addresses were automatically geo-referenced, since they could be easily associated to the correspondent road network database records. Otherwise, we had to manually identify the street coordinates, using satellite images.

The model has been implemented using ESRI ArcGIS 8.1. In ArcGIS, it is possible to manage data and to obtain *views* (for instance layers) in two ways:

- visual management using the graphical interface of ArcMap (high-level representation);
- direct data management using the SQL language (low-level representation).

The creation of new layers or tables may be implemented in an automatic way using the module ModelBuilder (see Figure 7 for an example of the interface), which links several ArcGIS tools together. Using parameters as input/output of the tools, we created a set of tools in Python using the geo-processing libraries. Each tool works in synergy with the others, generating reference tables, database tables and setting configuration parameters. Python is a general-purpose, high-level programming language. Python's core syntax and semantics are minimalist, while the standard library is large and comprehensive. Python supports multiple programming paradigms, and features a fully dynamic type system and automatic memory management [30].

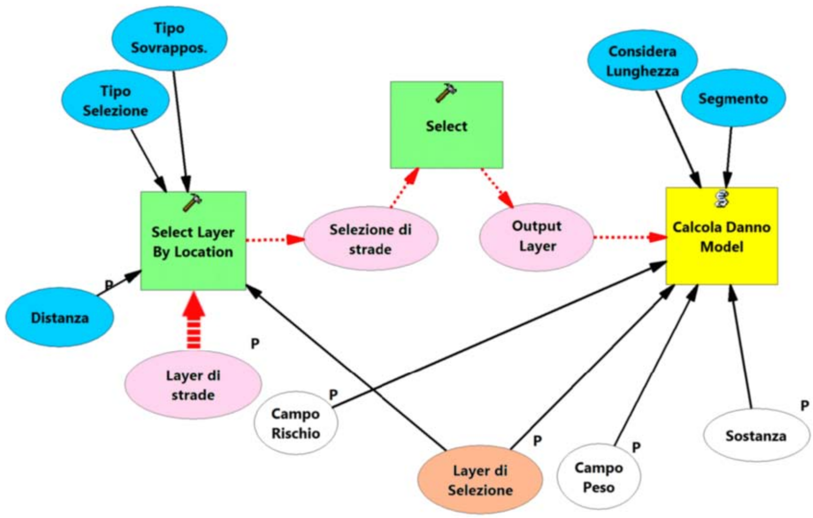

Figure 7. Example of an implementation of a GIS view using the ModelBuilder module. The two squares with the hammer symbol (on the left) represent built-in ArcGIS tools; the ellipses represent tool parameters or input/output layers; the remaining square (on the right) represent a Python script to calculate the potential damage of an accident.

As an example, we describe briefly the implementation of the estimation of the risk on infrastructures. As stated in Eq. (4), the theoretical model imply the calculation of the damage function $\delta_{x,s}$ on a infrastructure s for each unit-length segment x. Implementing to the letter this model, however, would be highly inefficient. Therefore, we made the most of the GIS features using the Spatial Analysis tools. Around the infrastructure s, a buffer is created, whose range is the threshold distance to calculate $\delta_{x,s}$. Then, the streets within the buffer are selected (see Figure 8). An accident in one of these streets may involve a potential damage for infrastructure s.

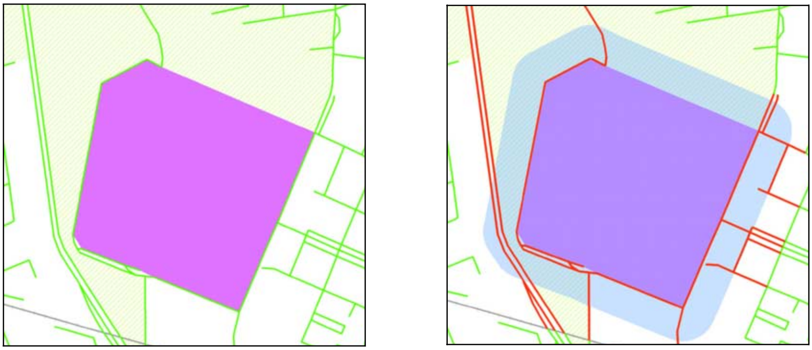

Figure 8. On the left, the road network and an infrastructure s (represented by the polygon in the center). On the right, the buffer around the infrastructure and the selected streets are graphically enhanced.

This procedure has been automated using ModelBuilder (see Figure 9): the built-in tool "Select Layer by Location" has been linked to the tool "Calculate Field". This procedure is applied to the road network using a simple interface window, which allows the user to input the parameter necessary for the calculation; that is, the interaction parameter that quantifies the vulnerability of infrastructure *s* in respect to material *m* and the threshold distance for the damage function (see Figure 10).

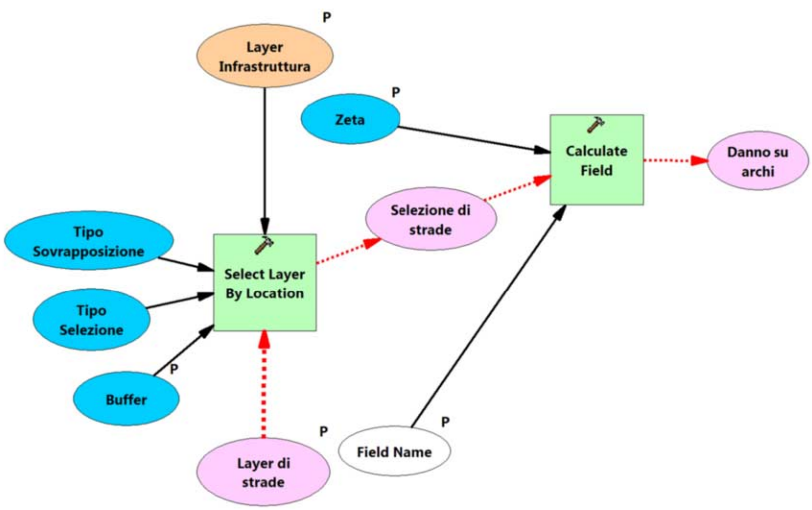

Figure 9. The interface of ModelBuilder for the definition of the procedure for the estimation of the risk on the infrastructures. The built-in tool "Select Layer by Location" (square on the left) has been linked to the tool "Calculate Field" (square on the right), in order to assign a value to the link attribute "Risk on the infrastructures".

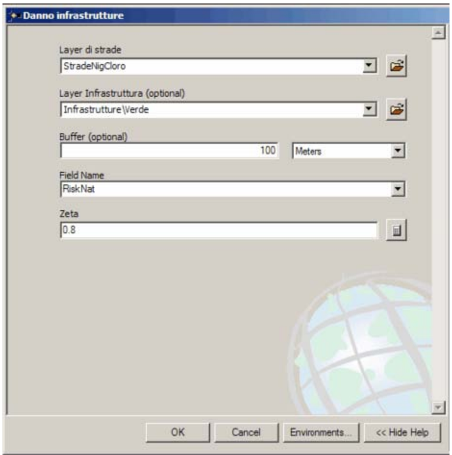

Figure 10. The interface window for the estimation of the risk on infrastructures. Besides the file paths for the layers, note the fields where the user can input the threshold distance for the damage function (third field from above) and the interaction parameter that quantifies the vulnerability of infrastructure *s* in respect to material *m* (last field).

The result of the toolbox is a geo-referenced map of the cost, where a cost *C(h,f,m)* is assigned to each link $h \in A$. Once the cost attribute is assigned to each link of the network, a simple Dijkstra method is used to calculate the minimal cost path and the corresponding path is selected on the GIS application.

As regards the case study, the Municipality chose as test site the Niguarda area, characterized by the presence of one of the largest hospitals in Milan. The Niguarda hospital is built on a 322.000 m^2 site and hosts more than 9000 people every day, including employees, patients, relatives, suppliers, etc. Moreover, the hospital buildings, located in the northern part of Milan, are protected by the Ministry of Fine Arts, because of their artistic and architectural importance.

At the book's publication date, the Municipality has been testing the DSS in the Niguarda area, calibrating the model parameters and identifying the link attribute weights. Figure 11 and 12 depict two examples of, respectively, path at minimum time and path at minimum cost in the Niguarda area.

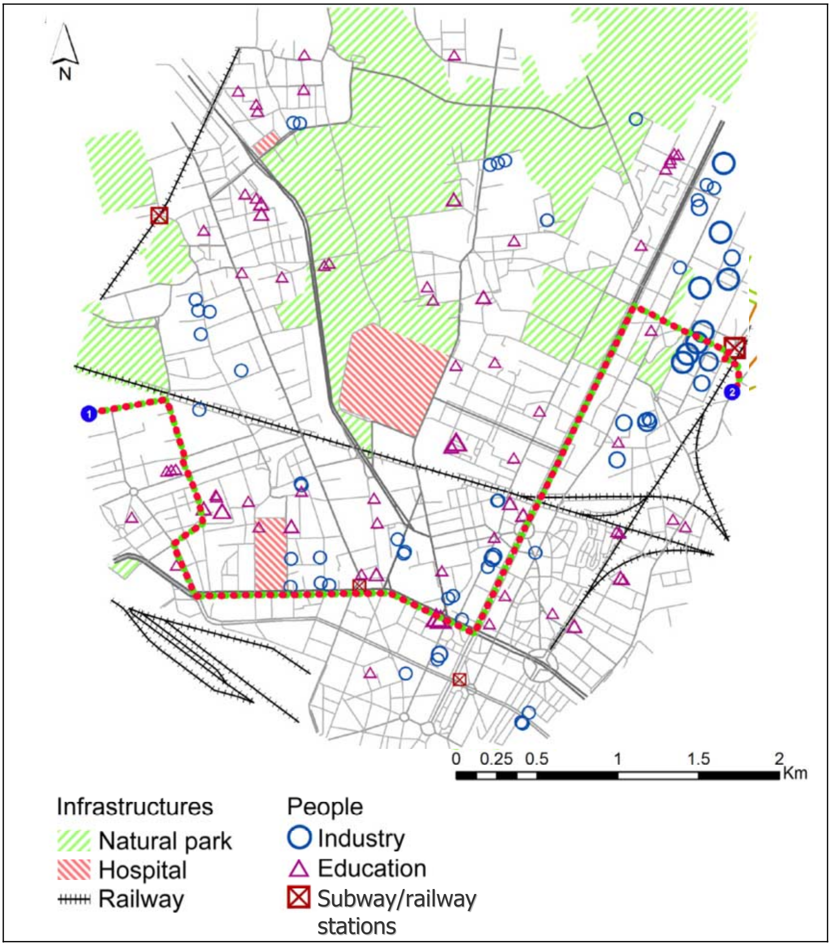

Figure 11. The Niguarda area. The figure shows an example of path at minimum time (dotted line).

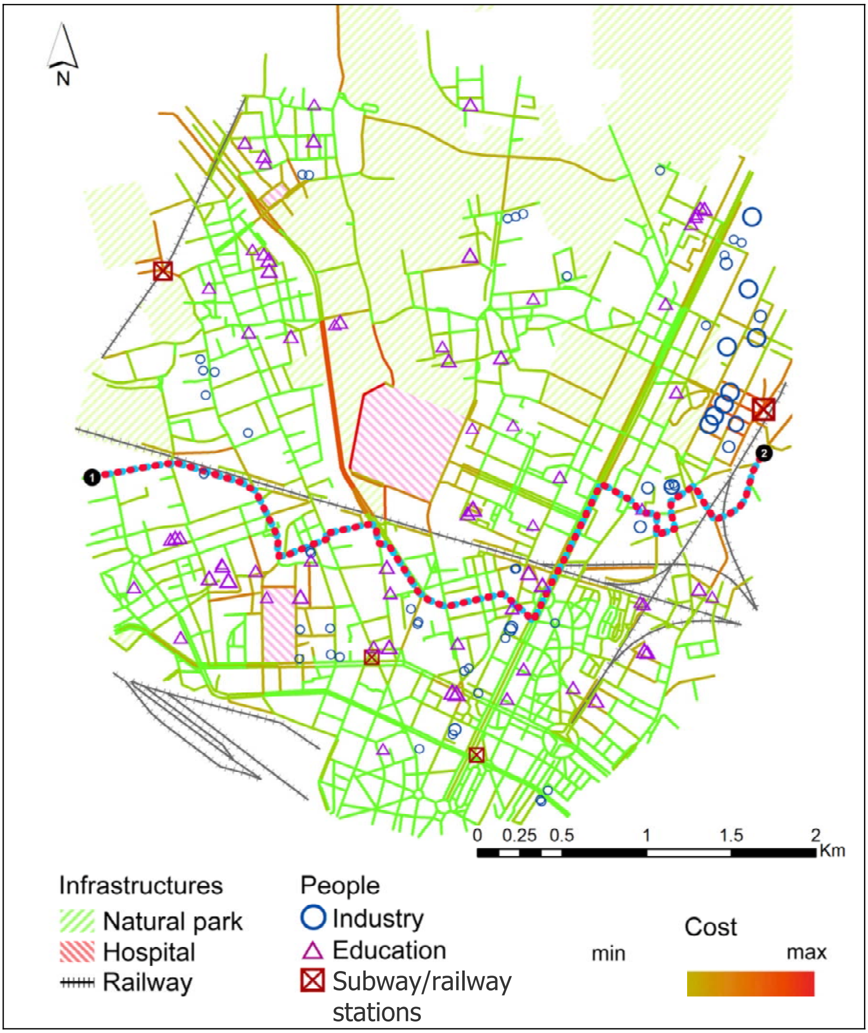

Figure 12. The result of the toolbox developed in ArcGIS is a map where a cost is calculated for each link as a function of travel time and risk. The figure shows an example of path at minimum cost (dotted line), which avoids population and infrastructures.

5. Conclusions and future challenges

The paper presents an ongoing work to develop a DSS for the multi-objective problem of routing and scheduling hazmat in the city of Milan. We used a probabilistic risk assessment model, which takes into account, as route selection parameters, the probability of accidents and the consequences of an accident for each road segment. The model considers population, territorial infrastructures, natural elements, and critical areas. The planner has been developed within a GIS and has been tested on a road network in Niguarda, an area of the city of Milan.

So far, the GIS-DSS is in a prototype phase and only one element has been implemented. We are working on the implementation of the second element of the DSS and of the second multi-criteria approach described in Section 3. As regards the case study, the Municipality has been testing the DSS in the Niguarda area, calibrating the model parameters, and identifying the link attribute weights.

The complete DSS will allow risk assessment not only for road transport, but also for rail transport and for intermodal shipments, and will permit to efficiently investigate in an interactive way possible benefits deriving from changes of paths, time-slots, etc. The idea is to develop a comprehensive risk management tool. The benefits of such an approach are not limited to the possibility of associating the risk estimation to the links, but include the possibility of visualizing the impact areas for the incident scenarios directly on the map of the zone, as well as the possibility of viewing, selecting or changing the routes or parts of them. Moreover, by combining the information on the area (population, weather, etc.) and the characteristics of shipped hazardous material, the system will also be able to support real-time emergency management, should a road or rail accident take place. Moreover, the fastest route from emergency centers (fire and police stations, hospitals, etc.) to the accident location can be also determined.

Besides the implementation of the DSS for the Municipality of Milan, more work needs to be done, both in the fields of theoretical and applied research.

A first issue concerns the availability of reliable and real-time data. Dynamic route guidance systems offer the potential to provide significant benefits to both individual drivers and the overall transportation system [14]. The realization of this potential requires a fully integrated infrastructure system that includes comprehensive surveillance of roadway conditions and coordinated dissemination of this information through travel information systems (see for instances [31]). This will require the establishment of a close partnership between the public and private sectors, as well as improving the mapping accuracy. Moreover, it also requires the development of new analytical tools for the traffic congestion forecast. This process will be helped by the fact that wireless Internet is becoming increasingly popular among drivers and many handheld and in-vehicle products for localization and navigation are becoming available to the general public.

Another issue concerns the equity of decision-making. Whenever several hazmat shipments occur in a certain area, the DSS should not only minimize the travel time and the risk, but also distribute the risk uniformly over different zones of the area. This issue is well defined in [32], where a measure of a collective risk is determined with explicit reference to equity.

The risk perception is an important aspect to be taken into consideration [4]. We can technically measure the probabilities and objective risks associated with an event such as a hazmat accident, but the DSS has to represent also the subjective preferences of the decision makers and stakeholders. Should we assume people are risk-neutral or willing to accept higher/lower degrees of risk? The theory provides that people “favour risk aversion in the domain of gains and risk seeking in the domain of losses” [33], but how does this apply to the hazmat transport problem?

The last issue involves the concept of risk communication [4, 34], which is strongly related with the previous issue. Public fears, even if unjustified, there may be an opposition to hazmat transport. Risk communication has the important role of informing the public of the best estimates of the actual risks involved. This would improve the level of debate and facilitate better decisions.

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References

[1] United Nations Economic Commission for Europe, European Agreement concerning the international carriage of Dangerous goods by Road (ADR), 2007.

[2] Center for Chemical Process Safety, *Guidelines for chemical process quantitative risk analysis.* AIChE, New York, 2000.

[3] R. Bubbico, S. Di Cave, B. Mazzarotta., Risk analysis for road and rail transport of hazardous materials: a GIS approach. *Journal of Loss Prevention in the Process Industries,* 17, 483–488, 2004.

[4] W.G. Waters, Transportation of hazardous goods and materials. In: D.A. Hensher, K.J. Button (Eds.), *Handbook of transport and the environment*. Elsevier, Amsterdam, 2003.

[5] S. Dennis, Estimating risk costs per unit of exposure for hazardous materials transported by rail. *The Logistics and Transportation Review*, 32 (4), 351-75, 1996.

[6] M.A Field, Highway Security and Terrorism. *Review of Policy Research*, 21 (3) 317-328, 2004.

[7] E. Erkut, J. Zhang, J. Hodgson, Using GIS to assess the risks of hazardous materials transport in networks. *European Journal of Operational Research*, 121, 316-329, 2000.

[8] B. Huang, C.R. Long, Y.S. Liew, GIS-AHP Model for HAZMAT Routing with Security Considerations. Proceeding of the IEEE 6th International Conference on Intelligent Transportation Systems. Shanghai, China, October 2003.

[9] G. Guariso, H.. Werthner, *Environmental Decision Support Systems.* Ellis Horwood-Wiley, New York, 1989.

[10] A. Colorni, E. Laniado, S. Muratori, Decision support systems for environmental impact assessment of transport infrastructures. *Transportation Research Part D,* 4 (1), 1-11, 1999.

[11] M.H. Baaj, S.A. Ashur, M. Chaparrofarina, K.D. Pijawka., Design of routing networks using geographic information systems: applications to solid and hazardous waste transportation planning. *Transportation Research Record,* 1497, 140-144, 1990.

[12] W.C Frank, J Thill, R Batta, Spatial decision support system for hazardous material truck routing. *Transportation Research Part C,* 8, 337-359, 2000.

[13] P. Carotenuto, S Giordani, S Ricciardelli, S Rismondo, A tabu search approach for scheduling hazmat shipments. *Computers & Operations Research*, 34, 1328–1350, 2007.

[14] D. Nelson, P.J. Tarnoff, Route guidance systems. In: K.J. Button, D.A. Hensher (Eds.), *Handbook of transport systems and traffic control*. Pergamon, Amsterdam, 2001.

[15] G.F. .List, P.B. Mirchandani, M.A. Turnquist, K.G. Zografos. Modeling and analysis for hazardous materials transportation: risk analysis, routing/scheduling and facility location. *Transportation Science,* 25, 100-114, 1991.

[16] E. Erkut, S Tjandra, V Verter, Hazardous materials transportation. In: Barnhart, C., Laporte, G. (Eds.), *Handbooks in Operations Research & Management Science: Transportation*, vol. 14, 2006.

[17] G. Ghiani, F. Guerriero, G.Laporte, R Musmanno, Real-time vehicle routing: solution concepts, algorithms and parallel computing strategies. *European Journal of Operational Research*, 151 (1), 1-11, 2003.

[18] P. Carotenuto, S. Giordani, S. Ricciardelli, Finding minimum and equitable risk routes for hazmat shipments. *Computers & Operations Research*, 34, 1304–1327, 2007.

[19] R. Batta, S.S. Chiu, Optimal obnoxious paths on a network: transportation of hazardous materials. *Operations Research,* 36, 84–92, 1988.

[20] N. Jozefowiez, F Semet, E Talbi, Multi-objective vehicle routing problems. *European Journal of Operational Research,* 189, 293–309, 2008.

[21] K. Deb, *Multi-objective Optimization using Evolutionary Algorithms*. Chichester, Wiley, 2001.

[22] D. Rios Insua, S. French, A framework for sensitivity analysis in discrete multi-objective decision-making. *European Journal of Operational Research,* 54, 176-190, 1991.

[23] A Scozzari, P. Dell'Olmo, M.Gentili, On finding dissimilar pareto-optimal paths. *European Journal of Operational Research*, 162 (1), 70-82, 2005.

[24] Y. Dadkar, D. Jones, L. Nozick, Identifying geographically diverse routes for the transportation of hazardous materials. *Transportation Research Part E,* 44, 333–349, 2008.
[25] J. Figueira, S. Greco, M. Ehrgott, *Multiple Criteria Decision Analysis: State of the Art Surveys.* Springer Verlag, Boston, Dordrecht, London, 2005.
[26] P.A. Longley, M.F. Goodchild, D.J. Maguire, D.W. Rhind, *Geographic Information Systems and Science*, 2nd Edition. Chichester, Wiley, 2005.
[27] M.M. Fischer, GIS and network analysis. In: D.A. Hensher, K.J. Button, K.E. Haynes, P. Stopher (Eds.), *Handbook of transport geography and spatial systems*. Elsevier, Amsterdam, 2004.
[28] H.J. Miller, S.L. Shaw, *Geographic Information Systems for Transportation. Principles and Applications*. Oxford University Press, Oxford, 2001.
[29] C. Dane, C. Rizos., *Positioning Systems in Intelligent Transportation Systems*. Artech House, Boston, 1998.
[30] G. van Rossum, F.L. Drake, *The Python Language Reference Manual*. Network Theory, Bristol, 2006.
[31] D. Ciccarelli, A. Colorni, A. Luè, D. Rossi, An Integrated Information and Management System for Traditional and Demand-Responsive Mobility Services in the City of Milan, Italy. Proceedings of the 85th TRB Annual Meeting. Washington, D.C., January 2006.
[32] R.L. Keeney, Equity and public risk. *Operations Research,* 28, 527–34, 1980.
[33] D. Kahneman, A. Tversky., Prospect Theory: an analysis of decision under risk. *Econometrica*, 47 (2) 263-292, 1979.
[34] A. Tversky, D Kahneman, The Framing of Decisions and the Psychology of Choice. *Science*, vol 221, 4481, 453-458, 1981.

Part III

Applications

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Risk Assessment for Coupled Critical Infrastructures

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Abstract. We provide an overview for policy-makers and opinion leaders of the physical structure and of the governance structures and processes for electricity, gas and water supply, transport and systems for general information and communication services. We also summarize their vulnerabilities and the main drivers of these vulnerabilities, as well as possible political and institutional shortcomings. Based on our findings, we outline a number of technical, management and organizational strategies and policy options that may help to reduce the probability of disruption to these systems and consequent interruptions to the vital services they supply. We offer, additionally, some suggestions for areas in which further study may be needed before definitive policy recommendations can be made.

Keywords. Gas and oil supply, transport, information infrastructures, risk governance

Introduction

We need a set of systems that supply energy and information. In at least limited ways, these systems have always been dependent on each other. Recent decades have witnessed a much greater and tighter integration and interdependence between them – effectively the creation of a 'system of systems' which has no single owner or operator. While this has often yielded improved service and convenience and promoted greater efficiency, it has also led to increased social vulnerabilities in the face of accidental or intentional disruption. Today, a disruption or malfunction often has much greater impacts than was typically the case in the past, and can also propagate to other systems, resulting in further additional disruptions.

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In this paper we will focus on risk assessment for next infrastructures: the electric power network; gas and water supply systems; transport; and, general information and communication services particularly as provided by the Internet as well as ICT as used to monitor and control other infrastructures.

These infrastructures are highly complex and interconnected, challenging our abilities and willingness to assess and understand their vulnerabilities and to take appropriate actions to reduce these vulnerabilities.

Typically, these actions involve increased costs, which must be paid for through increased service prices or from other sources such as government subsidy. The systems are all subject to increased stress, to different degrees, and are also dependent on the different market environments and operational contexts. All of these factors raise questions concerning conflicting objectives and the adequacy of risk governance.

Therefore further efforts are needed to understand these complex issues, to share that understanding with decision makers and the public, and to increase cooperation among the parties responsible for risk management of these systems. These parties include the system owners and operators, and governmental departments, agencies and regulators at levels extending from local to regional, national, and international.

1. Critical infrastructures characteristics

Much is being written about critical infrastructures at the present time [see, for example, the US Patriot Act 2001] but just what is meant by this term? Different authors adopt slightly different meanings, with a recent EU communication document [1] listing many examples.

A more academic explanation of the term is given [IRGC 2006] as: critical infrastructures are a network of large-scale, man-made systems (set of hard and soft structures) that function collaboratively and synergistically to produce a continuous flow of essential goods and services and are, finally, essential for economic development and social well-being.

1.1. Risk-Shaping Factors

The infrastructures are coupled or interconnected to different degrees and finally must be regarded as a ’system of systems‘. Their operating strategies and end-user behaviors are subject to significant contextual changes and an increasing number of risk-shaping factors (Table 1).

Table 1. Risk-shaping factors

Market organisation (e.g. competition, oligopoly, monopoly, hybrids)
−Transition from one market system to another and the speed of transition
−Control structure (unbundling, ownership patterns, legally operational rules)
−Investment incentives and financial risks (maintenance and new facilities)
−Business principles (redundancy versus cost of service trade-off, profit max)
−Price and price regulation as paradigms: how price of service is based on cost
−Behavioral issues (e.g. of corporate and political leaders, service end-users)
Government policy-making (e.g. renewable, nuclear)
Legislation / regulation (responsibilities, institutional complexity, differences within integrated networks, e.g. between EU and non-EU Member States)
Technology-related
−Potential for storage; inherent inertia
−Localised versus pan-state and multi-state vulnerabilities
−Customised versus off-the-shelf systems
−Susceptibility to failures / accidents
−Speed of developments / innovations
Infrastructure-related
−Degree of ‘criticality’, potential for choice
−Technical design and operating principles (e.g. N-1 criterion, maintenance)
−Space extension and exposure
Degree of interconnectedness, complexity
−Interdependences within single infrastructures
−Interdependences across infrastructures and regions
Availability of resources
−Shortage, depletion of scarce resources
−Contamination or degradation of supply
Natural conditions (weather) and hazards
Context of risk and threats, openness of society
−Attractiveness for, and vulnerability to, malicious attacks (cyber, terrorism)
−Public acceptance and risk awareness
−Strategic issues

1.2. Assessment Matrix

Focusing on society as a whole at a higher level, the criticality of the system can be described [EC 2004] in terms of scope (extent of geographic area affected), magnitude (degree of impact or loss) and effects of time.

Based on the summary of each infrastructure given in [1-14], Fig. 1 provides a template (assessment matrix) for an initial assessment of the characteristics of the infrastructures.

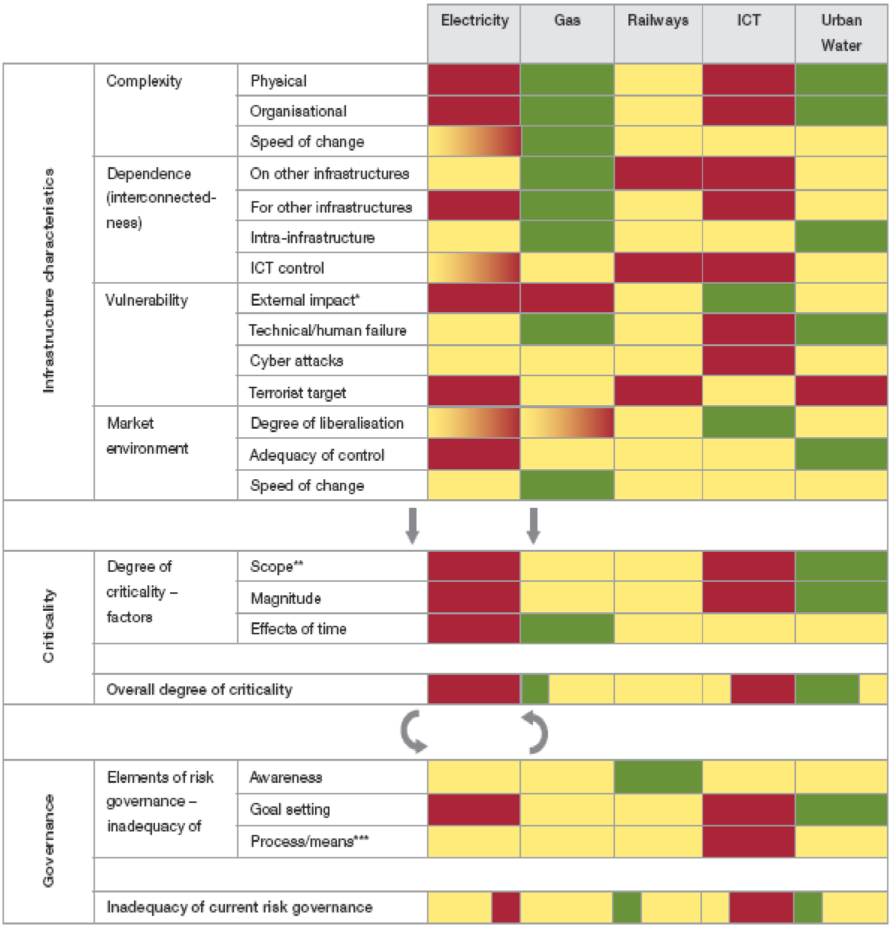

Figure 1. Assessment matrix for critical infrastructures. Colors are used for an initial judgment: red (darkest grey) corresponds to high, green (medium grey) to low, yellow (lightest grey) to in-between; transitions from one color to another indicate changes/trends

It addresses certain of the different dependencies between the infrastructures. For example, transport relies on continuous electricity supply and ICT support, so these cells are marked red. The importance of electricity to other infrastructures and the associated dependencies are more moderate and thus are marked yellow.

This assessment matrix may provide initial guidance (in the absence of more detailed assessment and analysis) on where to put emphasis on risk governance strategies and how to tailor the measures that are outlined, below.

2. Risk governance strategies

Risk governance in the context of critical infrastructures includes the totality of players, rules, conventions, processes, and mechanisms concerned with how relevant risk information is collected, analysed and communicated and management decisions are taken.

Strategies to reduce the probability of disruption to services provided by infrastructures, as well as the social vulnerabilities associated with them, should encompass technical, management, and organisational measures. Adequate strategies must consider the different characteristics of the various infrastructures such as their complexity, dependencies and interconnectedness, as well as such important contextual factors as the market environment (Fig. 2).

2.1. Step by Step

Infrastructures can be vulnerable to a variety of events including failures of system components, human errors, natural hazards such as extreme weather conditions or earthquakes, and malicious attacks. Critical infrastructures are vulnerable to a variety of disruptions.

The first step in guarding against such events is an adequate assessment of the range of possible accidental and intentional disruption scenarios as well as of possible weaknesses, including 'bottlenecks'.

Having analysed the events that might give rise to system failure, the next step is to perform contingency and failure analysis appropriate to meeting pre-agreed societal needs and objectives (e.g. appropriate levels of security; balanced degree of redundancy; alignment of the criteria for automatic protective devices with those needs; etc.).

However, in many important areas, there is as yet no agreement on such needs and objectives, especially in an international context. Simple safety criteria (N-1, N-2) and failure consequence methods are widely used in assessing and in shaping the design of many infrastructures. In many of today's complex systems, more sophisticated approaches are needed.

In the creating or modifying of such rules, consideration must be given to balancing conflicting social objectives. Market mechanisms may play a role in this process, but we believe that much of the need is for improved and more explicit political objectives and enabling frameworks, especially at the international level.

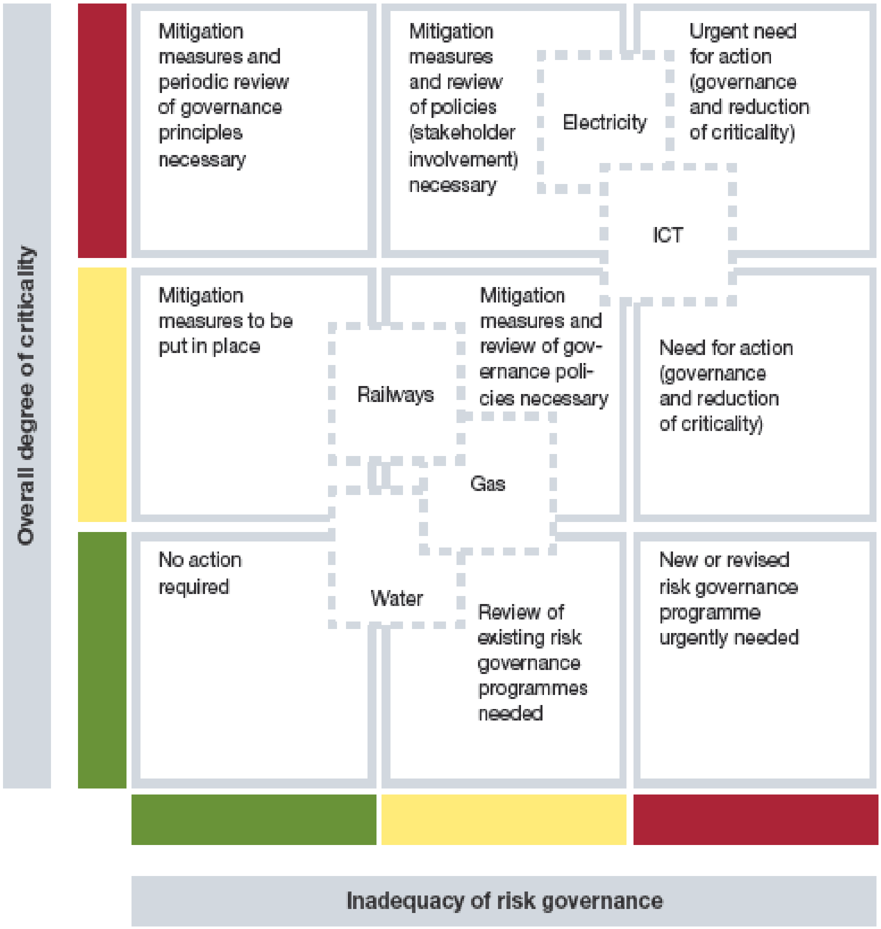

Figure 2. Inadequacy of risk governance

Of course, rules alone are not sufficient. System operators must also know what is happening so that they can take informed actions. This means that, for safe and reliable system operation, one must have real-time situational awareness and emergency preparedness along with adequate system-wide scope based on improved instrumentation and communications. The need is perhaps greatest in the case of electric power and transport. However, in a world in which terrorism is a growing threat, improvements are also needed in a number of other settings, such as urban water distribution systems, gas and oil supply.

2.2. *Identification and Prediction*

Before one can address the risks posed by potential common-cause or causal failures, they must first be identified. That is often not easy to do and requires careful and extended data collection and analysis informed by real-world experience. One solution is to add independence, redundancy or spatial separation, but these can also add unintended complications.

The performance of large complex interconnected systems is not easy to predict. In some cases, such as the electric power system and many ICT systems, the complexity can be so great that complete analysis is simply not possible. Nevertheless, more comprehensive and holistic approaches need to be undertaken and, for many areas, more sophisticated methods developed.

ICT systems present a range of challenges for all of the infrastructures. Many key systems for situational awareness and control are still highly vulnerable to accidental or intentional disruption or spoofing. Such systems should not make use of, or be interconnected to, the public Internet, which is inherently insecure and will remain so for the foreseeable future. However, at present, a number of such systems are connected to the Internet and are thus vulnerable to accidental disruption or intentional cyber attack. Further investigation and actions to reduce such vulnerabilities are urgently needed. Adequate physical system maintenance and support are also vitally important.

A number of critical infrastructures suffer from the fact that they have grown in a rather unplanned and unstructured way, sometimes without basic changes in operation and control. Often, decentralised control areas are maintained while the system has expanded spatially, hence requiring better coordination and data exchange. Coherent expansion planning and associated capacity expansion is critically important if these systems are to evolve in ways that are consistent with the interests and needs of all affected parties.

However, such systematic planning can run counter to market competition objectives and privatisation. Gradually, strategies are being evolved to reconcile these tensions but, in the case of several infrastructure systems, much additional attention is needed.

2.3. New technologies

New technology, such as more capable SCADA systems, can sometimes play an important role in relieving previous technical or institutional constraints, as well as providing new functionality. But this may also introduce new vulnerabilities.

Even the best-designed systems will fail occasionally. When this happens, operators may never have experienced such circumstances before and may not know how to react. Several actions can reduce the risks in such circumstances:

- Designs that support ‘graceful’ degradation of capabilities (‘island solutions’ in power systems’ control and grid structure and reduced bandwidth and traffic priority in ICT, to give two examples)
- Demand management, including priority setting
- The incorporation of rapid-acting, cooperating, distributed autonomous computer control agents
- Careful contingency preparation, including operator training conducted in realistic simulators.

Attention should also be directed at enabling critical social services to continue to operate in the face of primary system failure. Thus, for example, if the natural gas system fails or is degraded, storage of fuel near the gas turbine may be needed to assure that the pumps can continue to run in the event that both the electrical grid and the natural gas systems are unavailable.

Similarly, if traffic lights are converted to low power Light Emitting Diodes (LEDs) and backed up with solid state controls and trickle-charged batteries, traffic can continue to flow, even when the power goes out.

Since occasional service outages are unavoidable in a world with storms, floods, earthquakes, and terrorism, it is important that system operators maintain equipment and prepare effective plans for the rapid restoration of services. This deceptively simple observation carries some very profound implications in terms of stockpiling critical components and sharing resources among different system operators, as well as training and preparing work crews.

2.4. Standards

We suggest a number of strategies to promote the growth of effective system design standards without resorting to inflexible government regulation. These suggestions include:

- Best professional practice
- Certification
- Acquisition specification
- Legal frameworks
- Tort and liability
- Insurance
- Taxes or fees on uncertified systems.

The combined effects of such actions could prove far reaching and widespread adoption of best professional practice and certification standards should, over time, help to create a culture in which system designers routinely think about issues of anonymity and security as they develop systems.

One way to assure continuity of the services that critical infrastructures provide is to find ways to allow, or perhaps even promote, multiple service routes and providers. This is most easily achieved in telecommunications. It is also possible in electric power through the use of distributed controls, distributed generation, micro-grids, and intelligent distribution system management. But what is possible is not always allowed.

Some critical infrastructure systems (or elements of them) are owned and operated by private parties, some by local or national governments. There is no single owner of coupled infrastructures. Clearly, governance options differ in these two cases. Yet, even if in private ownership, if the system is truly critical, other parties who depend upon the services it provides (end-users) must be given a role in developing the policies and practices that govern its operation and in overseeing their effective implementation. Classical decision-making and risk management processes should be revisited and, where necessary, supplemented or even replaced by more participative governance strategies.

Information technology is evolving so rapidly that in many cases mandatory standards can be counter-productive, seriously impeding innovation or otherwise causing problems. While a few basic rules, such as no use of the Internet for system-critical control functions, make sense, in general a more flexible approach will be more appropriate.

Finally, research can often create new options which can better meet and balance private and social interests. While R&D investments in ICT are substantial (8-10% of sales), too few are focused on addressing issues of security and reliability. In electric power R&D investments are much too low to meet societal needs (<0.5% of sales). The industry has not had a strong research tradition and restructuring has complicated matters, focusing many players on short-term bottom line issues and creating a 'free rider' problem.

Unless R&D investments are mandated for all players as a 'cost of doing business' it is difficult to see how this situation can be expected to change. This could be done by specifying that some proportion of value added (e.g. 1%) must be invested in R&D. Firms that do not want to bother to manage such research could be required to support a government R&D programmer.

3. Towards an integrative approach

This initial study examined critical infrastructures, issues of interdependencies between them, and a number of socio-economic, contextual and physical factors which impact on them. We acknowledge that there are other important infrastructures that have not been considered.

We followed an infrastructure-by-infrastructure approach. Further study, involving a region-by-region approach that looks across several infrastructures simultaneously, could provide additional insights, especially if it is expanded to more regions and explores the influence of different cultures, regulatory environments and legal frameworks.

We focused mainly on reducing social vulnerabilities by increasing the reliability and robustness of the systems. There is a need for additional work which focuses on identifying social vulnerabilities and developing strategies to maintain critical services when the main infrastructures on which they depend fail or malfunction.

There is a need to develop and refine appropriate risk and vulnerability assessment methods. This should facilitate more effective assessment of the relative criticality of different infrastructures and related services.

This study gave some consideration to the duration of disruptions, although the principal focus has been on short-term impacts. Some of our conclusions could be different if, for example, we looked at long-term impacts – a long-term loss of water supply would certainly have enormous criticality.

Future studies should give greater consideration both to more extended disruptions and delayed effects arising from initial disruption, which may persist even after the original service has been restored, and to input supply issues, particularly the security of their supply.

Although we addressed a broad spectrum of threats including natural events, human failures and malicious attacks, more work needs to be done on:

- Natural disasters of large spatial extent and duration such as strong earthquakes, hurricanes, ice storms and floods
- Occurrence of multiple failures or attacks on a system, or simultaneous attacks on several systems, which may amplify total impacts
- Strikes and other labour actions
- Epidemics, pandemics, mass evacuation, etc.
- Longer-term developments such as migration or the impacts of climate change.

We have not emphasised the importance of stable social and political conditions, although their importance has been clearly demonstrated by instances of political sabotage and destabilising activities affecting key industries and infrastructures. Besides direct consequences such as loss of production, the unavailability of ICT support may seriously worsen the situation. More investigations are needed to better understand such complex situations and to propose clear, adequate governance strategies.

References

[1] Critical Infrastructure Protection in the fight against terrorism, EU Document COM(2004) 702 final, 2004.

[2] [EC 2005a] The future of ICT for power systems: emerging security challenges, report on the workshop held in Brussels, 3-4 February 2005

[3] [EC 2005b] Green Paper on a European Programme for Critical Infrastructure Protection, COM (2005) 576 final, Brussels, 17.11.2005

[4] [EC 2006] Green Paper, A European Strategy for Sustainable, Competitive and Secure Energy, COM (2006) 105 final, Brussels, 8.3.2006

[5] [Gheorghe 2006] A.V. Gheorghe, M. Masera, M. Weijnen, L. de Vries, Critical Infrastructure at Risk, Securing the European Electric Power System, Springer, 2006

[6] IRGC White Paper No. 1, Risk Governance – Towards an Integrative Approach, Geneva, 2005

[7] IRGC White Paper No. 3, Managing and Reducing Social Vulnerabilities from Coupled Critical Infrastructures, Geneva, 2006

[8] D. Kirschen, Why do we get blackouts? Presentation given at the EC Workshop on The Future of ICT for Power Systems: Emerging Security Challenges, February 2005, Brussels

[9] J. Moteff, C. Copeland and J. Fischer, Critical Infrastructure: What Makes an Infrastructure Critical? Report for Congress, Order Code RL31556, Congressional Research Service – The Library of Congress, January 2003

[10] NATO Energy Security Forum, February 24, 2006, Prague, Westby, J., CEO Global Cyber Risk LLC, Cyber Security, 2006

[11] OECD Futures Project on Global Infrastructure Needs: Prospects and Implications for Public and Private Actors, Second Meeting of the Steering Group, Discussion Paper, December 2005

[12] D. Shea, Critical Infrastructure: Control Systems and the Terrorist Threat, Report for Congress, Order Code RL31534, Congressional Research Service – The Library of Congress, 2003

[13] Uniting and Strengthening America by Providing Appropriate Tools Required to Intercept and Obstruct Terrorism (US PATRIOT ACT), Act of 2001

[14] Toward a Universal Order of Cyberspace: Managing Threats from Cybercrime to Cyberwar, Document WSIS-03/GENEVA/CONTR/6-E, World Federation of Scientists, Permanent Monitoring Panel on Information Security, August 2003

Advanced Technologies and Methodologies for Risk Management in the Global Transport of Dangerous Goods
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The Ukrainian Response System for Event of Accidents in Radioactive Material Transportation

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Abstract. Transportation of radioactive materials takes on international character today: many countries those producing electric power at NPPs, need foreign sources of materials and service to support the fuel cycle. Ukraine is a party of multilateral international agreements related to cooperation in movement of nuclear materials. These agreements set forth the main principles of cooperation in radioactive material transportation and civil liability for nuclear damage that can be caused to the environment in transportation, procedure for mitigation of accident consequences, etc. Accident prevention at transportation of radioactive materials is of prime importance since this process is the most vulnerable from the terroristic threat standpoint.

Keywords. transport, radioactive material, emergency preparedness.

Introduction

In the public sector of economy production and use of radioactive material (RAM) involves, inevitably, their transport. The transport of radioactive materials is in constant development due to their increasing use in various sectors of national economies (medicine, industry and research, alongside the transport of fresh or spent fuel). Though, the transport of radioactive materials associated with electricity production represents only a small percentage of the total number of transports of radioactive material it in considered being an important element of the nuclear fuel cycle. Transportation of radioactive materials takes on international character today: many countries those producing electric power at NPPs, need foreign sources of materials and service to support the fuel cycle. Ukraine is a party of multilateral international agreements related to cooperation in movement of nuclear materials. These agreements set forth the main principles of cooperation in radioactive material transportation and state provisions regarding escort of special cargoes, their physical protection and security, civil liability

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for nuclear damage that can be caused to the environment in transportation, procedure for mitigation of accident consequences, notification on transportation, etc. These agreements also identify international documents whose provisions shall be fulfilled in radioactive material transportation. Accident prevention at transportation of radioactive materials is of prime importance since this process is the most vulnerable from the terroristic threat standpoint.

As rule, to transport radioactive materials motor, rail and water transport is used. Air transportations restricted. When using transport, radioactive materials are containerized. The great majority of these shipments consist of RAM for medical, scientific and industrial applications.

1. Background information

At present, according to the inventory of radioactive waste, there are about 5 thousand institutions using ionizing radiation sources, approximately 3000 plants and enterprises that use radioactive materials in Ukraine. There are 15 power units with water-cooled water-moderated reactors in operation at four nuclear power plants in Ukraine: WWER type reactors (2- WWER- 440/213, 2- WWER-1000/302 and WWER-1000/308, 11 WWER-1000/320).

All spent nuclear fuel (SNF) from WWER- 440 is reprocessed at FSUE “Mayak”, RT-1 facility in Russia. In doing this:

- certified packagings are used,
- special railcars and special vessels for transportation of packages are used;
- the transportation is organized by special trains under special conditions of transportation;
- permanent control of transportation is performed

Three power units of Chernobyl NPP are under preparing for decommissioning. They all are potential sources of radioactive waste.

There are several nuclear facilities related to the nuclear fuel cycle in the Ukraine: uranium mining and milling facilities, research reactors in Kiyv and Sevastopol, low- and intermediate level waste disposal facilities Ukrainian State corporation “RADON” (USC "RADON).

Specialised management of radioactive waste resulted from utilisation of ionising radiation sources (SIR’s) in national economy is undertaken by the USC "RADON”, which is subordinated to the Ministry of Emergencies and consists of 6 State Interregional Special Enterprise (SISE): Dnipropetrovsk, Donetsk, Kyiv, L’viv, Odesa and Kharkiv, State Special Enterprise (SSE) “Complex” and SSE “Tekhnocentre”. A service area consisting of several regions of Ukraine is assigned to each SISE. Each SISE is equipped with specialised transport vehicles and process facilities.

Transportation and storage of radioactive waste and disused SIR’s is performed by SISE of the USC “RADON”, which have licenses issued by the SNRCU for such activity while the requirements of the federal norms and rules in the field of use of atomic energy are observed. Active work for the disposal of high-level SIR’s, including radioisotope thermoelectric generators (RTG’s), is performed within the frames of international cooperation, including that with IAEA. The transport packaging complete sets (UKT) are intended for storage and transportation of different type radionuclide sources of ionizing radiations.

The safety of transport of radioactive materials is based on the strict application of a large set of binding and non binding rules: organizational, operational and technical requirements of the applicable binding regulations together with the internal rules decided by companies under the control of authorities.

2. International Regulations on the Transport of Radioactive Material

IAEA is responsible for elaboration and support of radioactive waste safe transport regulations. Its regulating documents constitute the basis for national regulations of many states – UNO members. In some cases they become obligatory through the regulations of the sectoral (including transport) authorities juridically connected with them. The regulation basis contains international agreements which include, in particular, international regulation of road transportation of hazardous goods (ADR) which regulate motor transport in Europe as well as the regional agreements [1].

The International Atomic Energy Agency published its first set of regulations for the safe transport of radioactive materials in 1961. These regulations applied to all modes of transport both nationally and internationally. The Regulations provide a regulatory framework for all categories of radioactive materials and for all modes of transport (road, rail, air, inland waterways and sea). The Regulations are subject to a continuous review and revision process to keep the Regulations in line with the latest scientific and technological developments. Until 1969, the regulations had been signed by almost all international organizations working in radioactive waste shipment and became the foundation for working out national legislation in this field. In 1996 the document "Radioactive Waste Safe Transport Norms" was published and signed by over 60 states [2]. In 2000 the document was revised. And in 2002 explanatory background materials were published. The existing suite of legally binding and non-binding international regulatory instruments and regulations governing the safety and security of radioactive material shipments by all modes of transport comprises essentially:

- the IAEA Regulations for the Safe Transport of Radioactive Material,
- the Modal Regulations of the regional and international transport organisations,
- a range of EU Directives, Regulations and Recommendations, and
- a variety of international Conventions, Codes and Agreements.

The IAEA Transport Regulations establish safety standards that provide an acceptable level of control of the radiation, criticality and thermal hazards to persons, property and the environment that are associated with the transport of RAM and utilise the safety principles set forth in the International Basic Safety Standards and Fundamentals. These Transport Regulations are supplemented by a hierarchy, of Safety Guides and Advisory Material, developed and published by the IAEA. The hierarchy of Safety Guides including:

- "Advisory Material for the IAEA Regulations for the Safe Transport of Radioactive Material", IAEA Safety Standards Series No.TS-G-1.1 [3];
- "Planning and Preparing for Emergency Response to Transport Accidents Involving Radioactive Material", IAEA Safety Standards Series No. TS-G-1.2 [4];
- "Quality Assurance for the Safe Transport of Radioactive Material", IAEA Safety Standards Series No. TS-G-1.3 [5].

The fundamental aspect of radioactive waste transport regulations is safety. Besides framing the regulations, it is necessary to provide international transport safety. Safe, effective and reliable transport of materials requires clear regulations, coordination and similarity of interpretation and application of international rules all over the world. Stability and predictability allow avoiding confusion in the transport chain and any hint at difference in use of the regulations in various jurisdictions (concerning local conditions) and concentrating the resources on providing safety and conformity with these transport regulations.

IAEA requires from the organizations taking part in radioactive waste shipment application of the radiation protection programme aimed at control of radiation dose for the personnel and population during transportation. In many cases the nuclear and radioactive materials are containerized and the transport companies have a system of radiation protection measures.

Though there are some transport organizations for which radioactive material transport is only a small part of their business. Usually, they are motor, air and overseas transport and cargo handling companies. European companies working in radioactive waste transport area established some international organizations for experience exchange in this field:

- World Nuclear Transport Institute (WNTI) [6] – to act for organizations in various fields of industry taking part in radioactive waste transport and also the organizations working in the area of accident prevention and reliability control during transportation of SNF;
- International Association for hazardous loads and containers – to improve the quality and safety of containerized hazardous waste transport, which guarantee effective and reliable cargo delivery and their compliance with international norms and requirements.

The European Agreement on international road transport of hazardous loads, which contains standard requirements for shipment by different transport facilities, is in force since 1971.

The specialised regional and international organisations involved in regulating the regional and worldwide transport of hazardous material including radioactive substances have fully incorporated the recommended safety standards and provisions embodied in the IAEA Transport Regulations into their mode-specific regulations, that is ADR [1], RID [7], ICAO Technical Instructions [8].

The international conventions, codes and agreements broaden significantly the international safety and security regime concerning the management of radioactive materials. They also promote the implementation and application of international safety standards in the field of civil nuclear liability, physical protection, early notification and mutual emergency assistance and safeguards control of nuclear material.

3. Ukrainian National Legislation Regulatory

The rail transport of goods in Ukraine and in some other countries Europe is subject to the provisions of the Regulations concerning the International Carriage of Dangerous Goods by Rail (RID). The dangerous goods covered by the RID are classified in accordance with the UNO system, and the IAEA Regulations have been adopted to apply to the rail transport of radioactive material. RID consists of three basic parts:

- Part I: General requirements which contain the structure of the regulations, definitions and a list of units of measurements;
- Part II: Special requirements for the various classes. In RID dangerous substances and articles are categorised according to type of hazard into nine main classes, the numbering of which follows that of the UN Recommendations. As regards radioactive material, RID like the other modes has fully adopted the provisions of the IAEA Transport Regulations; and
- Part III: Appendices providing details of technical requirements for testing and approval of tanks, receptacles and equipment and other matters.

Ukraine as a Member State of the IAEA has implemented national regulations for a safe transport of RAM in accordance with the Agency's recommendations as well as other international specialized organizations. General safety requirements at all stages of spent fuel management are established by the Laws of Ukraine "On Nuclear Energy Utilisation and Radiation Safety" [9] and "On Permissive Activities in the Field of Nuclear Power Utilisation" [10].

The Law of Ukraine "On Permissive Activities in the Field of Nuclear Energy Utilisation", sets the legal and organisational principles of the licensing activity to transportation of radioactive material into their mode-specific regulations:

- Safety Guides: «Safety Regulations for Storage and Transportation of Nuclear Fuel at Nuclear Power Facilities» (PNAE G-14-029-91) [11];
- NP 306.6.124-2006. Rules and nuclear and radiation safety at transportation of radioactive materials (Ukrainian acronym - PBPRM-2006) [12]

These rules comply with the document titled "Regulations for the Safe Transport of Radioactive Material" [13]. These Rules establish standards of safety that assure admissible level of control over radiation hazards as well as those related to criticality and heat release for personnel, property and environments at transportation of radioactive materials. These Rules apply the principles set forth in publication "Radiation protection and safe handling radiation sources and in publication "International basic standards of safety for protection against ionizing radiations and safety of radiation sources [14, 15].

International transport of radioactive materials is carried out in accordance with the Regulations on safe radioactive material transport of IAEA and other international organizations in the presence of permissions of the State export control service and Ministry of Environmental Safety.

SNF transboundary movement is undertaken when:

- SNF of Ukraine's NPPs is transported to Russian reprocessing plants,
- SNF of Eastern European States is subject to transit movement through the territory of Ukraine to Russian Federation.

Transportation through the territory of Ukraine is performed exclusively by rail irrespective of the route and agreement to transit nuclear material transportation from the territory of Eastern European States [16]:

- Agreement between the Government of Ukraine, the Government of Hungarian Republic and the Government of Russian Federation on cooperation in the field of nuclear fuel transportation between Hungarian Republic and Russian Federation through the territory of Ukraine dated 29 December 1992.
- Agreement between the Government of Ukraine, the Government of Russian Federation and the Government of Slovak Republic on cooperation in the field

of nuclear material transportation between Slovak Republic and Russian Federation through the territory of Ukraine dated 18 October 1993.

- Agreement between the Cabinet of Ministers of Ukraine, the Government of Russian Federation, the Government of Slovak Republic and the Government of Czech Republic on cooperation in the field of nuclear material transportation between Russian Federation and Czech Republic through the territory of Ukraine and Slovak Republic dated 14 March 1998.
- Agreement between the Cabinet of Ministers of Ukraine, the Government of Bulgarian Republic, the Government of Moldova Republic and the Government of Russian Federation on cooperation in the field of nuclear material transportation between Bulgarian Republic and Russian Federation through the territory of Ukraine and Moldova Republic dated 28 November 1997.
- Law of Ukraine No. 47-V "On Ratification of Agreement between the Government of the Republic of Bulgaria, the Government of the Russian Federation and the Cabinet of Ministers of Ukraine on Transportation of Nuclear Materials between the Russian Federation and the Republic of Bulgaria via the Territory of Ukraine" dated 27 July 2006.
- Agreement between the Government of Ukraine and Government of Russian Federation on cooperation in the field of nuclear material transportation dated 12 April 1996.

Transportation of packages with spent fuel from Czech, Hungarian, Slovak and Ukrainian nuclear power plants is performed by rail by through train. Transportation of packages with spent fuel from Bulgarian NPP is performed by water transport and by rail as this NPP is located on the Danube and has no local railway. To transport packages from Kozloduy NPP along the Danube the non-self-propelled barge "Nautilus" is used, and the reloading of the packages to the railway is performed in river ports of Reni (Republic of Moldova) and Izmail (Ukraine).

All transportations are performed in full compliance with the international legal norms as well as the national legislation of Bulgaria, Ukraine and Russia.

Having approved the law of Ukraine "On accedence to the European agreement on international road transport of hazardous loads", Ukraine assumed liability regulated by this agreement.

4. Tranportation of Radioactive Waste and Nuclear Materials

The transport of radioactive materials is a very important problem considering the potential risks and radiological consequences in carrying-out this activity. Ukraine is situated approximately in the geographical centre of Europe. The volume of the shipments of various kinds of RM is significant, including the volume of transit transportation through the territory of Ukraine. Periodical transports of nuclear material consists of:

- import of fresh fuel assemblies from the Russian Federation
- shipment of spent fuel assemblies
- transfer of uranium concentrate via Ukraine from the Czech Republic to the Russian Federation (each shipment represents from 50 to 100 metric tons of uranium concentrate).

Operations of nuclear power industry are associated with transportation of large amounts of nuclear materials (fuel assemblies, spent fuel, radioactive waste, etc.). Larger numbers of NPPs and nuclear facilities mean more transportation operations, higher amounts of cargo and, correspondingly of transportation-related risks:

- First, there are risks of damage of transport containers in the course of accidents (inc. loading, transportation and discharge operations), associated with radiation exposure of personnel and local residents, and environmental contamination.
- Second, terrorists may get access to radioactive materials for a “dirty bomb”.

The regulation system, established by IAEA, was helpful because the transport influence on the environment and people is minimal. Regulation of practical, effective and safe transport should consider influence on the carriers. Radioactive material carriers got outstanding achievements in the sphere of safety. In fact, transport of such materials should be viewed as the model for transport of hazardous materials of other classes.

Experience has demonstrated that the risk involved in the transportation of radioactive material is very low; much lower than the risks associated with the transport of other dangerous goods. Historically, there have been no reported transport accidents involving radioactive material that have resulted in serious radiological consequences. Despite this excellent safety record, plans should be developed, responsibilities defined and preparedness actions should be taken to ensure that an adequate emergency response capability is available when transport accidents involving radioactive material do occur.

Estimation of the potential radiological risks associated with transport of radioactive materials requires input data describing population densities adjacent to all portions of the route to be travelled.

In Ukraine, radioactive waste is usually transported by motor transport while SNF by railway transport, though there are also other transport facilities suggested in the documents. There are transportation rules and requirements for each kind of transport facility.

Radioactive materials can be transported within Ukrainian territory by a juridical or natural person having a license for this activity or single transportation permission issued in accordance with established procedure. The transport rules regulate radioactive material (including radioactive waste) transportation outside the organizations using them. The licenses for this activity and single transportation permissions as well as safety certificates are issued by SNRC of Ukraine. A safety certificate is a document vouching, for example, that this package construction meets the nuclear and radiation safety norms, rules and standards.

Inter-regional and special enterprises “Radon” grant service in collection, transport and storage of low and medium-level solid and liquid radioactive waste, as well as spent SIR’s from different organizations. Radioactive waste is transported using special carriers provided they have a sanitary passport issued by the Ministry of Health of Ukraine.

The requirements to safe transport of radioactive materials and to transport facilities are regulated by Principles of Nuclear and Radiation Safety During Transport of Radioactive Materials. Radioactive materials including radioactive wastes are transported under the agreements set up between the consignors, the consignees and the carriers. The agreement determine mutual obligations of the contractors concerning safeguarding. The van for package transportation should be equipped with radiation shielding, moisture-proof coating, fastening devices, emergency kit and fire-extinguishing means.

Transportation includes planning, selection of the transport facility, development of transportation schemes, formation of operational inspection system, including preparation to shipment, executing of all necessary documents, working out measures directed at accident prevention during transportation, preparation of the load (packaging, marking etc.), examination of loading-unloading equipment, personnel training etc.

The main radioactive material transport questions are connected with transport means (motor, railway, water, air transport and their combinations), transport facilities and ancillary equipment, packaging, marking, transport control system and accident prevention including physical protection; prediction of possible emergency situations and working out measures aimed at their prevention, development of transport infrastructure, including carriers decontamination sites, preparation of documents etc.

5. Planning and Preparing for Emergency Response to Transport Accidents

Ukrainian authorities have signed a number of international agreements that contain regulations relative to convoy procedure, physical protection; civil responsibility, actions in case of emergency and information about them etc. Among these documents there are, for example:

- Convention on urgent information about nuclear accidents;
- Convention on assistance in case of a nuclear accident or a radiation emergency situation.

Special requirements NP 306.6.108-2005 “Regulation for planning measures and actions in case of emergency during transportation of radioactive materials” [17]. This Regulation prescribed requirements to content, procedure of development and approval of emergency actions during transportation of radioactive materials (Class 7 hazardous substances).

Nuclear accident during radioactive material transportation means an event causing loss of radioactive material control and resulted in or might result in radiation influence on people and environment which exceeds the allowable limits, determined by regulations and standards of safety. The accident zone is the area which requires conducting specific measures connected with this event. The main cause of the emergency during radioactive material transportation is transport facility failure, poor organizational management and human factor.

Accidents during spent nuclear transportation, are classified by level of danger, pursuant to the Safety Assessment Report for that transportation. There are three categories of possible accidents regarding TUK-6 and TUK-13:

Level 1 accident:

- the packages suffered mechanical impacts without visible damages;
- the packages suffered heat impact due to fire outside the transporting vehicles.

Accidents of this type present no risk for personal and environment, as the containers passed all tests under IAEA rules and meet the radiation safety standards.

Level 2 accident:

- the packages suffered mechanical impacts and obtained significant damages;
- the packages suffered fire and obtain visible surface burns.

The increased radiation level due to these accidents does not exceed the emergency limits defined by IAEA rules.

Level 3 accident

- the package is partially or totally destroyed, the radiation level and release of radioactive products from it exceed the emergency limits defined by IAEA rules.

The assumption in case of Level 3 accidents is that 10% of fuel elements occurred to be with leakages and the container is totally unsealed. At this assumption 4.44×10^{14} Bq of Kr-85, 2.13×10^{10} Bq of Cs-134 and 2.13×10^{10} Bq of Cs-137 activities will be released in the environment.

6. Emergency Preparedness

Ukraine has established an emergency preparedness and response system in the event of nuclear and radiation accidents in Ukraine. This system is completely applicable to spent fuel and radwaste management facilities, as well as to utilization of ionising radiation sources and transportation of radioactive material. For the last years Ukraine has implemented a number of measures to develop emergency preparedness and response system to radiation accidents and incidents.

Planning of off-site emergency measures, as well as other emergency preparedness and response measures, is incorporated in the Unified State System for Prevention and Response to Man-Induced and Natural Emergencies (USSE). With the purpose of improving the emergency preparedness and response system, and working out actions in case of radiation incidents caused by terrorist acts, in December 2005, SNRCU prepared and conducted emergency exercise with participation of observers from the Security Service of Ukraine and the Ministry of Emergencies of Ukraine. According to the plan of the Ministry of Emergencies of Ukraine, the annual drills and exercises are conducted on the territories that may fall to the areas of potential radioactive contamination in case of accident. The purpose of such exercise is to verify efficiency of the plans on public protection in case of radiation accidents. The regulation No. 431/10711, named «Provisions on Planning of Measures and Actions in the Event of Accidents in Radioactive Material Transport» entered into force on 1 June 2005.

Planning of off-site emergency measures, as well as other emergency preparedness and response measures, is incorporated in the Unified State System for Prevention and Response to Man-Induced and Natural Emergencies (USSE). The USSE consists of four permanent-basis functional and territorial subsystems and is divided into four levels – national, regional, local and enterprise. USSE functional subsystems are established by ministries and other central executive bodies to organise activities intended to prevent emergencies and protect population and territories against their consequences.

In order to assure preparedness of USSE functional and regional subsystems for effective and quick response to emergencies, governmental bodies responsible for subsystems of all levels develop individual plans for response to emergencies that are the most probable for a particular territory, branch or enterprise. Development of individual plans is required by the National Plan for Response to Emergencies elaborated and approved by Resolution of the Cabinet of Ministers of Ukraine No. 1567 of 16 November 2001.

The emergency plan covers the route from NPP to the Ukraine-Russian border for road, water and railway transport schemes. In case of general radiation accident the Ukrainian national emergency plan will be actuated. In case of general radiation accident involving foreign territories the emergency plans of the affected countries will be actuated.

The plan defines the activities of the accompanying and emergency centre teams, further instruction aiming to limitation and elimination of the consequences if having accident during transportation. The emergency plan is developed in accordance with the Ukrainian legislation and international conventions, it is agreed with the due state authorities, including SNRCU, Mintopenergy of Ukraine, Ministry of Health of Ukraine, Ministry of Internal Affairs of Ukraine, SSU and is approved by the Executive Director of NPP.

Therefore supporters of preservation of the special regime of transportation consider the experience of management of safety.

7. Organization of the Emergency Response Actions

The organization of the emergency actions in response of the nuclear events is divided in three types depending on the contamination areas [18, 19]:

- local radiation accident - the radiation level is increased only around the container within the vessel holder or the platform of the vehicle;
- medium sized accident - radioactive contamination within the whole vessel or on the road;
- general radiation accident - radioactive contamination of the river or areas outside the roads with consequences to the population and environment and possible transmission to other countries.

The basic steps in case of an emergency situation for ensure people’s safety by:

- defining and marking the contaminated areas through detection of leakage location by radiometric ;
- dosimetric measurements and limitation of the access to the contaminated areas;
- providing dosimetric pass control.

Elimination of the accident:

- defining measures for elimination the reasons for the activity leakage; cleaning and decontamination of the contaminated area; collecting and storage of the wastes from the accident;
- decontamination of the equipment and tools used, as well as the personnel.

Continuous dosimetric control of all activities and control of the personnel radiation exposures is to be assured trough all the processes. Information for the emergency response actions is regularly submitted to emergency centre. The rescue activities have priority over all other activities related to eliminating or limiting the accident consequences.

Emergency and technical center (SS ETC) depending on the radiation accident scale, the following measures directed at its liquidation are suggested [20]:

- formation of working teams for liquidation of the radiation accident consequences;
- organizing of radiation control;
- providing with service kit;
- providing with accident liquidation means;
- localization of the radiation accident site aimed at carrying out of rehabilitation works;
- decontamination of the area, carriers, loads, equipment and overalls;
- collecting and removal of radioactive matter;
- investigation of the reasons of the accident and executing of documents concerning the accident.

The main goals of SS ETC: - preparedness of Ukraine for quick and effective actions in case of accidents at nuclear power and industrial enterprises in accordance with the international obligations of Ukraine and IAEA requirements on creation of the national system of nuclear accident management - post-accident activity planning in case of transport accidents during radiation dangerous material transportation.

The principal tasks:

- management, preparation and performance of emergency work on post-accident clean-up;
- engineer and radiation survey of emergency objects;
- forecasting of radiation situation in emergency area and propositions on mitigation of a negative accident results for population and environment;
- decontamination of premises, equipment, as well as dust reduction while performing.

In case of an accident (crash, explosion or ignition of packages and vehicles), the radiation hazard may appear as a result of complete or partial destruction of the container and falling of radioactive matter out of it. It may cause increasing of the dose rate and the radioactive matter may penetrate into environment. In case of radiation hazard when it is impossible to estimate the degree of destruction of the packages, the following measures are required to be carried out:

- estimate the radiation situation, determine the limits of the hazardous area and fence it with warning signs, estimate contamination levels of the site, vehicles and loads;
- find people exposed to radiation and send them to medical examination and cleansing;
- start liquidation of the radiation accident consequences.

The contaminated areas, large-size objects and vehicles are decontaminated at the radiation accident site. The other contaminated objects, things and equipment as well as waste from decontamination are packed and transported to decontamination or disposal sites.

Progress has been achieved in developing the system for emergency preparedness and response in the event of nuclear and radiation accidents the last year in Ukraine. The emergency response plans are tested on a regular basis and the emergency preparedness system is verified for actions in emergencies.

References

[1] ECONOMIC COMMISSION FOR EUROPE, European Agreement concerning the International Carriage of Dangerous Goods by Road (ADR), United Nations, New York and Geneva, 2007

[2] IAEA, Advisory Material for the IAEA Regulations for the Safe Transport of Radioactive Material (1996 Edition), IAEA Safety Standards Series No. TS-G-1, Vienna,

[3] IAEA, Advisory Material for the IAEA Regulations for the Safe Transport of Radioactive Material, Safety Guide No. TS-G-1.1, IAEA, Vienna (2002)

[4] IAEA, Planning and Preparing for Emergency Response to Transport Accidents Involving Radioactive Material, Safety Guide No.TS-G-1.2, IAEA, Vienna (2002)

[5] *IAEA, "Quality Assurance for the Safe Transport of Radioactive Material", Safety Standards Series No. TS-G-1.3*

[6] *World Nuclear Transport Institute; WEB: WWW.WNTI.CO.UK*

[7] INTERGOVERNMENTAL ORGANISATION FOR INTERNATIONAL CARRIAGE BY RAIL (OTIF), Convention concerning International Carriage by Rail (COTIF) Appendix B. Uniform Rules concerning the Contract for International Carriage of Goods by Rail (CIM) Annex 1 Regulations concerning the International Carriage of Dangerous Goods by Rail (RID). 2007 Edition.

[8] International Air Transport Association, Dangerous Goods Regulations, 47th Edition, IATA, Montreal and Geneva (2005)

[9] Law of Ukraine "On Nuclear Energy Utilisation and Radiation Safety" No. 39 of 8 February 1995.

[10] *Law of Ukraine "On Permissive Activities in the Field of Nuclear Power Utilization" No. 1370 of 11 January 2000.*

[11] Safety Rules for Storage and Transportation of Nuclear Fuel at Nuclear Energy Facilities. PNAE G-14-029-91, approved by USSR GPAN, 1991.

[12] *NP 306.6.124-2006. Rules and nuclear and radiation safety at transportation of radioactive materials (Ukrainian acronym - PBPRM-2006)*

[13] Regulations for the safe transport of radioactive material: safety requirements — IAEA Safety Standards Series No. TS-R-1, IAEA, Vienna (2005)

[14] Safety Conditions and Requirements (Licensing Terms) for Radioactive Material Transport (NP 306.6/095-204), approved by SNRCU Ordinance No. 141 of 31 August 2004, registered in the Ministry of Justice, No. 1125/9724 of 9 September 2004

[15] Requirements for the safety analysis report on radioactive material transport (NP 306.6.096-2004), approved by SNRCU Ordinance No. 141 of 31 August 2004, registered in the Ministry of Justice of Ukraine No. 1127/9726 of 9 September 2004

[16] Procedure for issuing permits for radioactive material transport (NP 306.6.06/2.080-03), approved by SNRCU Ordinance No. 125 of 24 September 2003 and registered in the Ministry of Justice No. 916/8237 of 9 October 2003 Resolution of the Cabinet of Ministers of Ukraine "On Basic Provisions for Radioactive Material Transportation through the Territory of Ukraine" No. 1332 of 29 November 1997.

[17] Provisions on Planning of Measures and Actions in the Events of Accidents in Radioactive Material Transport (NP 306.6.108-2005), approved by SNRCU Ordinance No. 38 of 7 April 2005 and registered in the Ministry of Justice of Ukraine No. 431/10711 of 22 April 2005

[18] IAEA: International Basic Safety Standards for Protection against Ionizing Radiation and for the Safety of Radiation Sources, Safety Series No. 115, International Atomic Energy Agency, Vienna, 1996

[19] Plan of response to radiation accidents (NP 306.5.01/3.083-04), as approved by Joint Ordinance of the SNRCU and ME No. 87/211 of 17 May 2004 and recorded in the Ministry of Justice, reg. No. 720/9319 of 10 June 2004

[20] SS ETC http://www.energoatom.kiev.ua

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IOS Press, 2008.
doi:10.3233/978-1-58603-899-1-261

An Integrated System for the Hazardous Materials Transport in a Sub-Regional Scale Area

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Abstract. This chapter, after briefly outlining the main features of hazmat transportation and related risk, presents a risk-based approach for planning and managing the hazmat flows on road infrastructures. A dynamic hazmat vehicle routing problem at a sub regional scale is considered modelling transport risk on each link of the network. The considered hazmat routing problem has been stated as a multi-objective mathematical programming problem. The information used in order to pose this dynamic routing problem is relevant to the link risk, the network structure, and the current (and foreseen) hazmat and generic traffic incoming and outgoing the network. It is assumed that the decision maker is a Public Authority which has the responsibility of controlling and managing the road network and traffic flows. The main objective of the Authority is to equalize the risk on the overall network and to minimize the risk for all kinds of road infrastructure users. A territorial analysis has been performed to characterize each link according to the induced risk assessment. A case study relevant to the District of Cuneo, in Northern Italy, is presented to validate the applicability of the approach.

Keywords: Hazardous materials; Transportation planning; Risk analysis; Dynamic hazmat vehicle routing problem.

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Introduction

Transport of hazardous materials (hazmat) is a worldwide problem of growing interest, mainly because of the increasing transported volumes of materials that can be classified as hazardous.

Transport risks are relevant to the occurring of sudden events, generally characterized by a low probability of occurrence, even though they can give rise to extreme impacts on population, goods, services, and environment [1].

Transport risk can be considered at various levels. First of all, transport risk falls within the area of technological risk. In fact, it refers to accidents that may arise in systems closely related to human activities. In general, an accident is an unplanned event or series of events which causes or has the potentiality to cause injury to people and/or damage to property and/or equipment. It includes collisions with a vehicle, object, or person (except suicides) and derailment/left roadway, producing unintended injury, death or property damage. Accident refers to the event, not the result of the event.

The accident is not only dependent on hazmat, as above explained, but also on the truck by which hazmat is transported. Each truck route has an origin and one, or more than one, destinations; thus, a transport route can simply be viewed as a risk source on a segment constituted by a great number of (moving) point risk sources. Furthermore, in a corridor along the route, through the linear risk source, there are people living, in areas with different density population [2].

Despite such significant contributions, at the moment, in the literature, a well established definition of hazmat transport risk can not be found. On the other hand, the literature in this field is growing and deepening the various issues related to transport risk [3]. Thus, it is realistic to assume that, in a very short time, a common framework could be set as regards hazmat transport risk assessment, as regards its evaluation and quantification, as well as the development of strategies allowing this risk and/or the mitigation of its impacts.

In this first section, a brief introduction of different aspects of hazmat transport will be dealt with. In particular, the aim of this work is to define an integrated system to manage the hazmat transport traffic at a sub-regional scale.

Secondly, in section two, general issues regarding transport risk will be discussed, identifying the decision levels and the decision makers, and considering the common issues that can be taken into account when dealing with hazmat transport system. Then, in section three, a dynamic hazmat vehicle routing problem at a sub regional scale is considered. This problem is described and the modelling transport risk on a link of the network, will be provided. Afterwards, the considered hazmat router problem will be stated as a mathematical programming problem, by defining the system model, the objective function, the decision variables, and the constraints. In addiction, section four will present the application of the considered decision model to a case study relevant to the District of Cuneo, in Northern Italy. Finally, in section five, some concluding remarks will end this chapter.

1. Transport risks: decisional levels, decision makers and common issues related to hazmat transport system

1.1. Transport Risk and Decision Levels

Transport is a complex domain, with different decision makers and levels of decision, where investments are capital-intensive and usually require long implementation delays. Furthermore, freight transport has to adapt to rapidly changing political, social and economic conditions and trends [4]. It is thus a domain where accurate and efficient methods and tools are required to assist and enhance the decision makers in the phase of planning, as well in the other decision phases [4].

Actually, in this considered framework, there are different decision makers which have different objectives and competences. Governments, for instance, still regulate several aspects of freight transport. Transport systems are quite complex organizations which engage a great deal of human and material resources and whose design and management require the capability of correctly evaluating costs and benefits, and of determining suitable trade-offs among different conflicting objectives [3].

Four decision levels can be identified, each of them referring to different temporal scales (long, medium, short and real time) and to different spatial/territorial scales (national, regional, sub-regional, and local scale). The four levels are (a) strategic level, (b) tactical level, (c) operational level, and (d) real time level.

Strategic (long term) planning (a) generally refers to decisions concerning large capital investments over long time horizons. Strategic decisions determine general development policies and deeply affect the other four levels of the hierarchy. An example of decision problem at the planning level is that concerning the design of the infrastructure network and/or its upgrade/modification, the location of main facilities (rail yards, multimode platforms, etc.), the resource acquisition, the definition of service and traffic policies, etc. Strategic planning takes place at the international, national and regional levels, where the transport network or services of several carriers are simultaneously considered. State transport departments, consultants, international shippers, etc. are involved in this kind of decision problems [3].

Tactical (medium term) planning (b) aims at ensuring, over a medium term horizon, an efficient and rational allocation of the existing resources in order to improve the performances of the whole system. At this level, data are aggregated, policies are somewhat abstracted and decisions are only sensitive to broad variations in data and in system parameters (such as the seasonal changes in traffic demand) without incorporating the day-by-day information. Tactical decisions may regard the design of the service network, i.e., the route choice and the type of service to operate, general operating rules and work allocation, traffic routing using the available services and terminals, repositioning the resources (e.g., empty vehicles) for use in the next planning period [5].

Operational (short term) management (c) is performed by local management (yardmasters and for example dispatchers) in a highly dynamic environment where the time factor plays an important role and detailed representations of vehicles, facilities and activities, crews, etc., are adopted. Routing and dispatching of vehicles and crews, resource allocation are examples of operational decisions taken at this level [3].

Real time management (d) may be relevant to vehicle tracking and routing in real time, in a highly dynamic environment where, according to the information continuously acquired, on-line decisions are taken whenever it is necessary.

1.2. Problem Characteristics

Spatial scale. Hazmat transport risk could be faced at different spatial scales: large or coarse scale (national, regional, sub-regional areas), at a medium spatial scale (local or municipal scale areas), or at a small and fine spatial scale (impact areas, exposed areas, a specific link of the network, a point of accident).

Temporal scale. A long time scale (years, months) is required to plan rules and regulations about transport risk. In a medium time scale (few weeks, few days), it may be important to evaluate the consequences of a hazardous event on the population and on the environment, so it could be possible not only to manage the forecasted transport, but also to plan the routing and tracking of the hazmat vehicles. In the real-time scale, time is generally divided in steps, and an overall decision horizon may be considered, covering time intervals of equal length T assumed unitary, without loss of generality).

1.3. Decision Makers

Risk assessment evaluations may be carried out and traffic management decisions may be taken by different decision makers, having different roles and responsibilities:

1. Public Authority (Central, Regional or Local);
2. Private network manager/owner;
3. Network user (both individuals and companies).

The public authorities' objective is to ensure that the network is safe and efficient, that hazmat trucks are safe and secure with respect to the driver, the materials transported, to the other network users, and to the population potentially involved. Authorities at different levels take measures to reduce and mitigate the risks associated with hazmat transport. A possible decision pertaining to local authorities is the restriction of hazmat transport to certain links in the network [5]. First, they can manage the hazmat traffic, indicating the route and scheduling the travelling interval of vehicles transporting hazardous materials; second, they can forbid the carriage of hazmat on those highways specified in the bylaws, and, finally, they can impose restrictions or conditions to ensure the safe transport in or by a means of transport, such as safe storage and controls necessary for public safety [4].

In general, the aim of a public/private network manager or owner is to make the infrastructure efficient, supervising the safety and the efficiency of the network, monitoring and control the traffic trend (i. e. flows, densities, traffic speeds) and the meteorological conditions, and providing information and advices to the network users. The cost to provide this service can be obtained either by payment tolls or by public funds.

The network user is interested in receiving information about traffic conditions on the roads, about possible queues, accidents and road yards, and about meteorological conditions.

2. Modelling transport risk on a link: A dynamic hazmat router problem

In this section, a hazmat vehicle routing problem at a sub regional scale is considered. The information used in order to pose this dynamic routing problem is relevant to the link risk, the network structure, and the current (and foreseen) traffic conditions. It is assumed that the decision maker is a Public Authority which has the responsibility of controlling and managing the road network and traffic flows. The main objective of such Authority is to equalize and to minimize the risk on the overall network. To this end, decisions may be taken within a planning framework, that is, with reference to a certain time horizon (e.g. one day) or in real-time, on the basis of continuously acquired information about the traffic and road conditions, and the vehicle positions.

In the considered model, only risk sources generated by road links are taken into account, and the risk is related to the presence on the link of hazmat carrying vehicles. In addiction, the risk over the link is assumed to be dependent on a set of static and dynamic factors, such as state of the road, weather conditions, traffic density, population density, and so on, which enter into the definition of the objective function of the problem, and require the knowledge of various risk layers, which overlap giving rise to the overall risk. The basic risk assessment on the link is related to accident frequency. The ordinary (non-hazmat) traffic is considered as given (even as regards its evolution over time). Besides, no specific model of the physical effects (explosions, pollutant propagation, etc.) consequent to an accident involving a hazmat vehicle is used.

2.1. System Architecture

The problem defined in this subsection is relevant to the planning of hazmat transport, and it will be referred to as hazmat routing problem. In this problem, a central decision maker (DM) has the responsibility of ensuring public safety. The central DM makes use of information relevant to hazmat traffic demand (current and forecasted), as well as to current and forecasted traffic and road conditions.

The problem is formalized assuming that, at time instant t , decisions are to be taken as regards an overall optimization horizon $(t,t+T)$ divided into T intervals of equal length, namely $(t,t+1),\dots,(t+T-1,t+T)$. Once the optimization problem is solved, only the decisions relevant to the first time interval, namely $(t,t+T)$, are actually used. In fact, at time instant $(t+1)$, the same problem is re-initialized, on the basis of new current acquired information, over a shifted horizon corresponding to $(t+1,t+T+1)$, and so on. This iterative procedure defines a so-called “rolling horizon scheme” [6].

In this case study, temporal intervals of 15 minutes over an optimization horizon of 150 minutes will be taken into account.

Before introducing the statement of the hazmat routing problem, it is necessary to explain in detail which information is assumed to be available to the decision maker.

First of all, structural information about the network is supposed to be completely accessible to the DM. The road network is represented through a directed graph whose links are ordered pair of nodes, namely $(i,j)\in A$, $i\neq j$. A is the set of links and $NSET$ is the set of nodes. Let $G=(NSET, A)$ be the network graph. Some nodes represent *origins* $(d \in O)$ of some transport demand for one or several commodities or products, while other represent *destinations* $(d \in D)$ of this traffic. The two sets of origins and destinations are not mutually exclusive.

Each link is characterized by a certain performance function, namely, a functional relationship of type $v_{i,j} = v_{i,j}(\rho_{i,j})$, where $v_{i,j}$ [m/s] is the average speed of vehicles in the link, and $\rho_{i,j}$ [vehicles/km] is the average density function of the vehicles over link $(i,j) \in A$. In addiction, a function $\lambda_{i,j}(\tau)$ is defined as a-dimensional discrete quantity, related to the exposure of the territory in the neighborhood link $(i,j) \in A$, in time interval $(\tau, \tau + 1)$, in term of environment, properties, and people present there.

It is also assumed that the central DM has access, at each time step of the considered decision horizon, to all information regarding the current state and the forecasts as regards the variables characterizing the behavior of the traffic model (relevant to the overall traffic flows in the network).

This information consists of the quantities $\rho_{i,j}(\tau), v_{i,j}(\tau), \varphi_{i,j}(\tau)$, for each link $(i,j) \in A$, and for each time step $\tau = t, t+1,..., t+T-1$, where

$$\varphi_{i,j}(\tau) = \rho_{i,j}(\tau) \cdot v_{i,j}(\tau) \qquad (1)$$
$$(i,j) \in A, \tau = t,..,t+T-1$$

is the average flow on link $(i,j) \in A$ in time interval $(\tau, \tau + 1)$ [vehicles/h]. To generate such information, it may be used a Dynamic Traffic Model (DTM), shown in Figure 1, conditioned by the information acquired in real time at time instant t, as well as the information relevant to the pattern of traffic demand (for all kinds of traffic) over the whole optimization horizon.

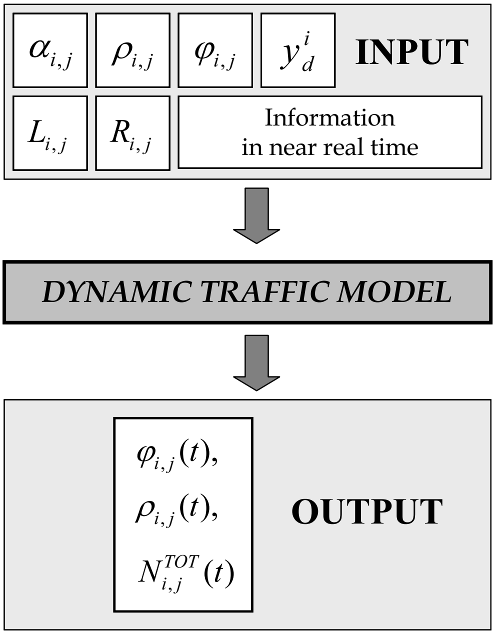

Figure 1. System architecture of the proposed Dynamic Traffic Model (DTM).

Thus, the DTM can be viewed as an external module, with respect to the Hazardous material Router Model (HRM), having the only function to provide the forecasts of the traffic variables (Figure 2).

In the considered model, only risk sources generated by road links are taken into account, and the risk is related to the presence on the link of hazmat vehicles. In addiction, the risk over the link is assumed to be dependent on a set of static and dynamic factors, such as state of the road, weather conditions, traffic density, population density, and so on, which enter into the definition of the objective function of the problem, and require the knowledge of various risk layers, which overlap giving rise to the overall risk. The basic risk assessment on the link is related on the accident frequency. The ordinary (non-hazmat) traffic is considered as given (even as regards its evolution over time). Besides, no specific model of the physical effects (explosions, pollutant propagation, etc.) consequent to an accident involving a hazmat vehicle is used.

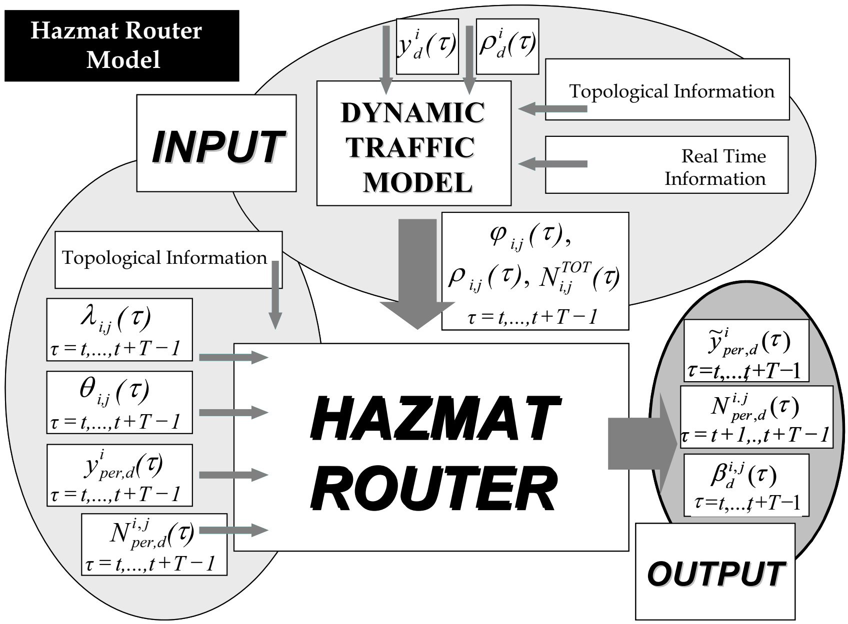

Figure 2. System architecture of the proposed Hazmat Router Model (HRM).

2.2. *Risk model*

In the literature, many authors and many models deal with routing of hazmat trucks with the objective to reduce the risk involved in the transport. Erkut and Osman [7] modelled the risk as the probability of a release event during transport, multiplied by the consequence of that event. Karkazis and Boffey [8] proposed a model that generalized the concept of expected damage on the population in case of an accident. These are only two out of a great variety of contributions regarding risk analysis in transport. However, it is possible to say that, at this moment:

- there is not, in the literature, a well-established and universally accepted approach for the assessment of hazmat transport risk;
- there is not a universally accepted classification of the risk levels;
- there is not a well-established classification of the risk levels related to the transport means (the trucks);
- the data about the hazmat yearly traffic on roads, in Italy and in Europe, are not available.

As regards the evaluation of transport risk on a link, in this work, the risk model adopted regards the risk from normal traffic accident added to the risk linked to major hazard aspects of the hazardous materials transportation [9] and a three step approach is adopted:

- to determine the frequency of an accident involving hazmat release;
- to estimate the magnitude of consequences (fatalities, injuries and property damage), given the level of exposure;
- to determine the risk evaluation.

In [9], the authors propose to evaluate the expected accident frequency per vehicle γ_x as

$$\gamma_x = \gamma_0 \prod_{j=1}^{J} h_{x,j} \tag{2}$$

where γ_0 is the basic frequency (accident km−1 vehicle-1), and $h_{x,j}$ are local amplifying/mitigating parameters. Specifically, for each road segment x, six parameters $h_{x,j}$ have been introduced: four parameters related to intrinsic road characteristics (turns, slope, number of lanes, bridge/tunnel), and two parameters related to meteorological and traffic conditions.

$h_{x,1}$ relevant to the presence of straight roads or roads bend;

$h_{x,2}$ relevant to the presence of slope in roads;

$h_{x,3}$ relevant to the number of ways in each carriageway;

$h_{x,6}$ relevant to the presence of bridges and tunnels;

So, these first four parameters do not change with time, in fact they are static parameters, while the following parameters are of dynamic type:

$h_{x,4}$ referring to meteorological conditions;

$h_{x,5}$ referring to traffic conditions.

In addition, two additional parameters have been proposed, and introduced [11]:

$h_{x,7}$ relevant to the presence of interruptions or of service failures;

$h_{x,8}$ relevant to the average vehicle speed on the considered segment.

Such an information can be either time-invariant (corresponding, for instance, to the average value, evaluated on the basis of historical data) or dynamic (i.e., acquired in real-time and/or averaged over a short past time interval). For instance, Caliendo [12] carried out to establish relationships between crashes and traffic flow, geometric infrastructure characteristic and environmental factors.

The expected frequency per unit length f_x can thus be obtained by multiplying the expected frequency per vehicle by the number n_x of vehicles (for example each year) that are traversing the segment:

$$f_x = \gamma_x n_x \tag{3}$$

Data are a fundamental issue to implement the hazmat router problem. The required information is divided into two main groups: information required to the hazmat router, and information required to the traffic model.

In dealing with the magnitude of the accident, it seemed important to include both the users of the road (on-route) and the population involved (off-route).

The number of accidents, N_S , caused by S event, for each road segment x, derived from the following equations:

$$N_{S,x} = N_{S1,x} + N_{S2,x} \tag{4}$$

$$N_{S1,x} = k\left(\nu A_{L,1_{,x}}\right) \tag{5}$$

$$N_{S2,x} = D\left(A_{L,2,x}\right) \tag{6}$$

$N_{S1,x}$ is the fatality number;

k is the average vehicle occupation factor;

ν is the vehicle density on the road area [vehicles/m^{-2}];

$A_{L,1_{,x}}$ is the road lethal area [m^2];

$N_{S2,x}$ is the off-road fatality number (fatalities);

$A_{L,2_{,x}}$ is the lethal [km^2];

D is the population density [inhabitants/km^2] [9].

The total lethal area $(A_{L,t})$ considering the different concurrent scenarios y and j, will be considered as

$$A_{L,t} = A_y + A_j - [A_y \cap Aj] \tag{7}$$

So, known the frequency of an accident evolving according to the scenario S, and known the magnitude (number of fatality and total lethal area), it is possible to calculate the value of risk associated to each link x ([9], [10], [12], [13]).

2.3. Simulator

The hazmat router model (HRM) needs a Dynamic Traffic Model (DTM) to receive as input:

- $\varphi_{i,j}(\tau)$ the flow of vehicles in each link *(i,j)* $\in A$ at time τ , [vehicles/ 0.25h];
- $\rho_{i,j}(\tau)$ the vehicles traffic density in each link *(i,j)* $\in A$ at time τ , [vehicles/km];
- $N_{i,j}^{TOT}(\tau)$ the number of vehicles in each link *(i,j)* $\in A$ at time τ , [number of vehicles].

HRM is based on observed data, and forecasted data, to evaluate the vehicles trend flow, in the case-study network. Nodes are crossing roads (e.g. trans-national roads, mountain border posts). A vehicle can enter/leave the case-study network through nodes, and nodes are destinations of hazmat vehicles too.

In some nodes, it could be possible to measure traffic information by tools and sensors. Where it is impossible to measure the traffic data, the DTM is used. We do not report the formalization of the model but only the architecture (Figure 2) and part of the data, which are needed to implement the HRM.

Using data contained in “Territorial District Planning – The Mobility System” (2005), the daily average flow value has been reported, and then subdivided in five time intervals, considered as homogeneous with reference to traffic conditions.

Each link of the case-study network has been analyzed. It can be observed that the flow trends have two maxima corresponding to the heaviest flow of vehicles on that link (the first one) in the morning, and (the second one) in the afternoon, as it is shown in Figure 3.

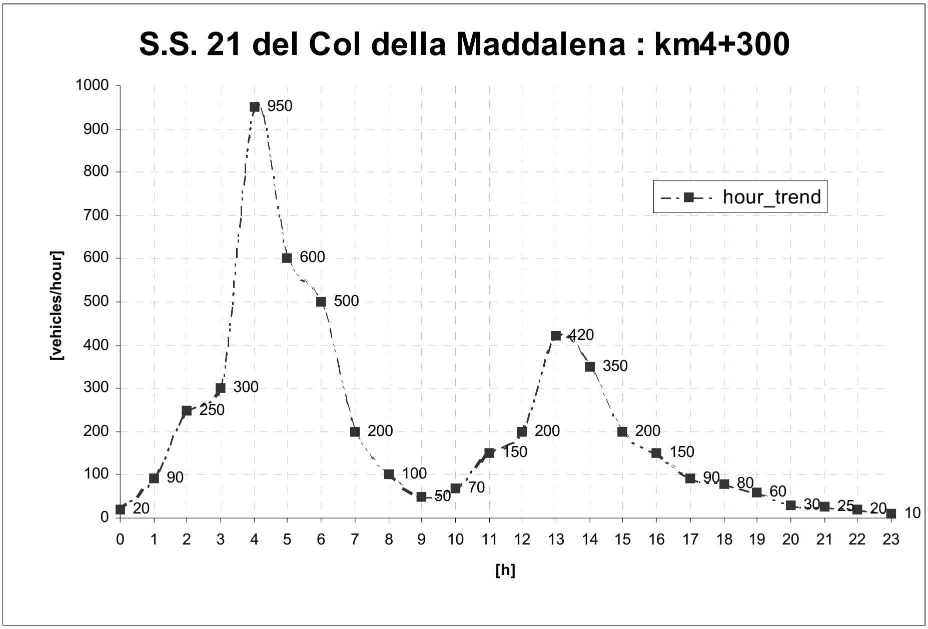

Figure 3. Vehicles flow distribution on a time horizon (24 points of time).

The number of all vehicles on each single link $(i,j) \in A$ is computed as the product between vehicles density and link’s length, calculated by DTM as follows:

$$N_{i,j}^{TOT}(\tau) = \rho_{i,j}(\tau) \cdot L_{i,j} \qquad (8)$$

$$(i,j) \in A \quad \tau = t,\ldots,t+T$$

2.4. Flows Optimization

Several possible approaches may be followed to model the traffic [14], [15], [16]. In this work, a simplified approach has been adopted. Since traffic modelling is not the goal of this work, for sake of simplicity its formulation is not reported. On the other hand, it is worthwhile to underline the key data that are in general requested to feed these Dynamic Traffic Model (DTM):

- average traffic flow data;

- average trend of the daily traffic flow;
- average percentage of routing choices for each node;
- model of the network topology (e.g. the length of the network links);
- vehicle density function.

The average traffic flow data and the trend of the daily traffic flow have been deducted from "Territorial District Planning – The Mobility System" (2005).

The average percentage of routing choice, for each node, has been defined for each time interval.

DTM gives a traffic flow value express in [vehicles/0.25h] for each single time interval, as shown in Table 1. Other input data used to implement DTM are resumed in Figure 1.

Table 1. Vehicles density, $\rho_{i,j}(\tau)$, reported every 15 minutes, for the network links $(i,j) \in A$. For sake of simplicity,only the vaues referred to three couples of links are reported.

Time interval Δt	τ	$\tau+1$	$\tau+2$	$\tau+3$	$\tau+4$
Links	$\rho_{i,j}(\tau)$	$\rho_{i,j}(\tau+1)$	$\rho_{i,j}(\tau+2)$	$\rho_{i,j}(\tau+3)$	$\rho_{i,j}(\tau+4)$
	[vehicles/km]	[vehicles/km]	[vehicles/km]	[vehicles/km]	[vehicles/km]
1_3	12	8	4	1	1
3_1	1	1	1	1	5
2_3	17	16	8	20	14
3_2	16	8	1	1	9
3_4	160	107	53	41	1
4_3	93	53	1	42	1

2.5. Decision Problem

The problem formulation proposed in this chapter is based on the assumption that the decisions of the central decision maker have no significant effect on the congestion conditions in the network, for the whole optimisation horizon. Thus, the DTM can be viewed as an external module, with respect to the routing module, having the only function to provide the forecasts of the traffic variables.

The DTM can be selected according to different criteria: it might be either a commercial product, or a specific module. The required real-time information for the statement of the hazmat router problem, at the generic time instant t, for the optimisation horizon $(t,t+1)$:

- $N^{i,j}_{haz,d}(t)$, [vehicles/time unit], that are the number of vehicles transporting hazmat, having destination $d, d \in D$, on link $(i,j) \in A$ in time interval $(t,t+1)$;

- $y^{i}_{haz,d}(t)$ [vehicles/time unit], that are, the monitored number of vehicles, transporting hazmat, having a destination $d, d \in D$, that, within time interval $(t, t+1)$, arrive (from the external) at node i to enter in the network;
- $z^{i}_{haz,d}(t)$ vehicles/time unit], the number of vehicles, transporting hazmat, having destination $d, d \in D$, that, at time instant t are queued at the *i-th* node, because they have not been allowed to enter the network in time intervals precedent to time t; note that, in this, way, some nodes (i.e., the origin nodes, as regards the hazmat traffic) are modeled as possible storage elements (that does not apply to intermediate or destination nodes).
- $\tilde{y}^{i}_{haz,d}(t)$ vehicles/time unit], that are the number of vehicles, transporting hazmat, having destination $d, d \in D$, that, in time interval $(\tau, \tau+1)$, $\tau = t,..., t+T-1$, are allowed to enter the network at node i.

When no control strategy is assigned at node *i* about queue and track entering the network, the following simplifying assumption is made:

$$y^{i}_{haz,d}(\tau) = \tilde{y}^{i}_{haz,d}(\tau) \qquad (9)$$

$$i \in NSET, d \in D$$

where $\tilde{y}^{i}_{haz,d}(\tau)$ is a decision variable described later on.

Other parameters that are necessary for the statement of the planning problem are: $\vartheta_{i,j}(\tau)$, $(i,j) \in A$, $\tau = t,..., t+T-1$, [a-dimensional], that represent the predicted accident probability for a generic vehicle, relevant to the link $(i,j) \in A$, and to time interval, $(\tau, \tau+1)$.

The decision variables are:

- $\tilde{y}^{i}_{haz,d}(\tau)$ that are the number of vehicles, transporting hazmat, having destination $d, d \in D$, that, in time interval $(\tau, \tau+1)$, $\tau = t,..., t+T-1$, are allowed to enter the network at node i;
- $\beta^{i,j}_{haz,d}(\tau)$, $(i,j) \in A$, $\tau = t,..., t+T-1$, that are the percentage of hazmat vehicles, having destination $d, d \in D$, that, in time interval $(\tau, \tau+1)$, are routed, at node i, towards node j (which is a direct successor of i), on link $(i,j) \in A$.

The state variables are:

- $N^{i,j}_{haz,d}(\tau)$ that are the number of hazmat vehicles, having destination $d, d \in D$, that, at time instant τ are over link $(i,j) \in A$;
- $N^{i,j}_{haz}(\tau) = \sum_{d \in D} N^{i,j}_{haz,d}(\tau)$ (10)

$(i, j) \in A, \tau = t+1,..,t+T-1$, that represent the overall number of hazmat vehicles that, at time instant τ are over link $(i,j) \in A$;

- $z^{i}_{haz}(\tau)$, $(i, j) \in A, \tau = t+1,..,t+T-1$, that represent the overall number of hazmat vehicles that, at time instant τ are waiting for entering the network at node $i \in NSET$.

The objective function is structured in order to take into account the following objectives:

- minimizing the accident overall risk on the network, also taking into account the risk induced on the territorial system;
- minimizing the amount of hazmat traffic flow queued at the origin nodes in the network;
- minimizing the travel time for hazmat vehicles in the network;
- fairly distributing the hazmat traffic over the network.

In detail, the objective function is written as the sum of four terms. The first one is

$$J_1 = \sum_{\tau=t}^{t+T-1} \sum_{(i,j)\in A} \left(\frac{N^{i,j}_{haz}(\tau)}{L_{i,j}} \cdot \left(\sigma \cdot \lambda_{i,j}(\tau) + \mu \cdot \rho_{i,j}(\tau)\right) \right) \tag{11}$$

where $L_{i,j}$ [m] are the lengths of each link $(i,j) \in A$; $\lambda_{i,j}(\tau)$ [a-dimensional] are time dependent measures of the risk related to a possible caused by a hazmat truck on a link $(i,j) \in A$. The term $\mu \cdot \rho_{i,j}(\tau)$ in (11) also takes into account the possible damage to the others network users possibly involved in the accident. This damage is assumed as linearly dependent on the linear density on link $(i,j) \in A$. Coefficients, σ e μ, are used to weight the possible damage on the territory and the possible damage on the traffic network.

The definition of the objective II requires the introduction of the following state equations, representing the dynamics of the hazmat traffic queued at the origin nodes

$$\begin{gathered} z^{i}_{haz,d}(\tau+1) = z^{i}_{haz,d}(\tau) + y^{i}_{haz,d}(\tau) - \tilde{y}^{i}_{haz,d}(\tau) \\ i \in NSET, d \in D, \tau = t,..,t+T-1 \end{gathered} \tag{12}$$

that evolves taking into account the following constraints

$$\begin{gathered} \tilde{y}^{i}_{haz,d}(\tau) \le z^{i}_{haz,d}(\tau) + y^{i}_{haz,d}(\tau) \\ i \in NSET, d \in D, \tau = t,..,t+T \end{gathered} \tag{13}$$

The objective II is written as

$$J_2 = \sum_{\tau=t}^{t+T-1} \sum_{i\in O} \sum_{d\in D} \omega^{i}_{d} \left[z^{i}_{haz,d}(\tau+1) \right] \tag{14}$$

where coefficients ω_d^i may be used to penalize in a different way the queues at the various origin nodes $i \in O$ in the network.

The objective III can be defined after the introduction of coefficients $\alpha_{haz,d}^{i,j}$, $(i,j) \in A$, $d, d \in D$, which are weighting coefficients whose value is established after the determination of the shortest paths from each possible node to all possible destinations, in nominal traffic conditions. If, in nominal traffic conditions, to go to final destination $d, d \in D$, coming from link $(i,j) \in A$, link $(j,k) \in A$ is closer to final destination $d, d \in D$, then it must be

$$\alpha_{haz,d}^{j,k} < \alpha_{haz,d}^{i,j} \tag{15}$$

On this basis, objective III may be written as

$$J_3 = \sum_{\tau=t}^{t+T-1} \sum_{(i,j)\in A} \sum_{d\in D} \alpha_{haz,d}^{i,j} \cdot N_{haz,d}^{i,j}(\tau+1) \tag{16}$$

Finally, objective IV corresponds to the minimization of the maximum gap of risk between each pair of link $(i,j) \in A$, $(k,l) \in A$. Thus, objective IV may be written as

$$J_4 = \sum_{\tau=t}^{t+T-1} \max_{(i,j),(k,l)\in A} \left((\lambda_{i,j}(\tau) \cdot \frac{N_{haz}^{i,j}(\tau)}{N_{i,j}^{TOT}(\tau)} \cdot \varphi_{i,j}^{TOT}(\tau) - (\lambda_{k,l}(\tau) \cdot \frac{N_{haz}^{k,l}(\tau)}{N_{k,l}^{TOT}(\tau)} \cdot \varphi_{k,l}^{TOT}(\tau) \right) \tag{17}$$

In other words, the hazmat trucks are routed equalizing flows with respect to the total flow on each link (their percentage), and the related risk.

The overall objective function to be minimized is $\sum_{i=1}^{4} \gamma_i J_i$, and γ_i, $i = 1,...,4$ are coefficients, with a specific weight opportunely defined by the DM.

A flow conservation equation must be taken into account for each link, namely

$$N_{haz,d}^{i,j}(\tau+1) = N_{haz,d}^{i,j}(\tau) + INPUT_{haz,d}^{i,j}(\tau) - OUTPUT_{haz,d}^{i,j}(\tau) \tag{18}$$

$(i, j) \in A, d \in D, \tau = t,..,t+T-1$

where

$INPUT_{haz,d}^{i,j}(\tau)$ is the number of hazmat vehicles, which enter the link $(i,j) \in A$, in the time step $(\tau, \tau+1)$, with destination $d, d \in D$;

$OUTPUT_{haz,d}^{i,j}(\tau)$ is the number of hazmat vehicles, which depart from link $(i,j) \in A$, at the time step $(\tau, \tau+1)$, with destination $d, d \in D$.

$$N_{haz}^{i,j}(\tau) = \sum_{d\in D} N_{haz,d}^{i,j}(\tau) \tag{10}$$

$(i, j) \in A, \tau = t+1,..,t+T-1$

Let $P(i)$ be the set of predecessor nodes of node i and let $S(i)$ be the set of successors nodes of node i, $INPUT^{i,j}_{haz,d}(\tau)$ can be defined as:

$$INPUT^{i,j}_{haz,d}(\tau) = \beta^{i,j}_{haz,d}(\tau) \cdot \left\{ \sum_{k \in P(i)} \left[OUTPUT^{k,i}_{haz,d}(\tau) \right] + \tilde{y}^{i}_{haz,d}(\tau) \right\} \tag{19}$$

$(i, j) \in A, i \in NSET, d \in D, i \neq d, \tau = t,..,t+T$

$$INPUT^{d,j}_{haz,d}(\tau) = 0 \tag{20}$$

$(d, j) \in A, d \in D, i = d, \tau = t,..,t+T$

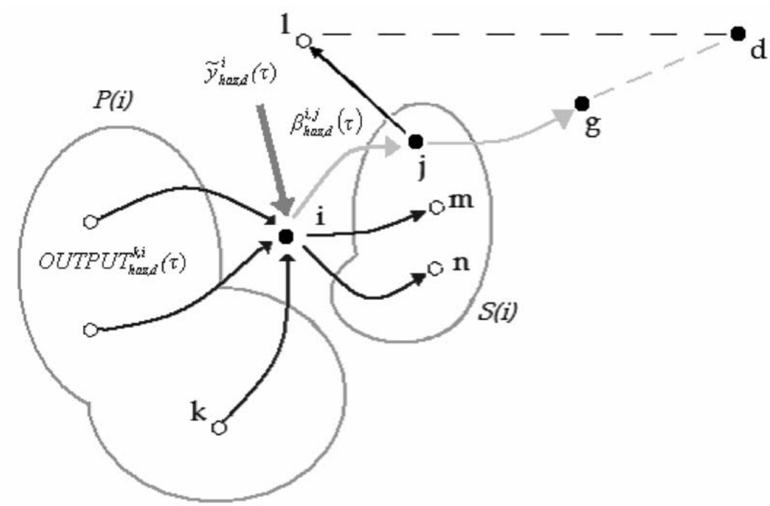

Figure 4. Balance of hazmat vehicles, with their destination $d, d \in D$, on link $(i, j) \in A$. Trucks going in link $(i,j) \in A$ are the sum of all the vehicles arriving from the previous nodes ($OUTPUT^{i,j}_{haz,d}(\tau)$), and the other one arriving from the external network ($\tilde{y}^{i}_{haz,d}(\tau)$), which are admitted into network like a fraction equal to $\beta^{i,j}_{haz,d}(\tau)$.

Constraints (19) express the fact that hazmat vehicles (directed to $d, d \in D$, that going in link $(i,j) \in A$ at the time interval $(\tau, \tau+1)$ are the sum of (a) hazmat vehicles entered in the network from the external roads, in the same time interval, and (b) all the vehicles coming from predecessor nodes of i, multiplied for the decision variable $\beta^{i,j}_{haz,d}(\tau)$. Constraints (20) describe that a hazmat vehicle, arrived to its destination $d, d \in D$, has not to be taken into account at any successive link.

$$OUTPUT^{i,j}_{haz,d}(\tau) = \frac{N^{i,j}_{haz,d}(\tau)}{N^{TOT}_{i,j}(\tau)} \cdot \varphi^{TOT}_{i,j}(\tau) \cdot \Delta\tau \qquad (21)$$

$(i, j) \in A, d \in D, \tau = t,..,t+T$

Constrains (21) define the number of hazmat vehicles having link $(i,j) \in A$ at the time interval $(\tau, \tau+1)$ as a fraction of the hazmat vehicles on the link $(i,j) \in A$) at time interval $(\tau, \tau+1)$, with respect to all the other vehicles on the link. Both in (19) and (21), the hazmat vehicles are supposed to be homogeneously distributed on the link, too.

Finally, constraints (22) define the decision variable $\beta^{i,j}_{haz,d}(\tau)$ as a percentage.

$$\sum_{j \in S(i)} \beta^{i,j}_{haz,d}(\tau) = 1 \qquad (22)$$

$i \in NSET, d \in D, \tau = t,..,t+T$

The definition of risk parameters has been developed both on a well-assessed methodology on risk evaluation and decision-making strategies [9], and on a specific risk analysis in hazmat transport on road [10],[12], and [13]. The $\lambda_{i,j}(\tau)$ are exposure parameters, expressed through a-dimensional discrete quantities. The values of these parameters range between 1 to 4, and they summarize the information relevant to the exposure of the neighbourhood of link $(i,j) \in A$ in time interval $(\tau, \tau+1)$, taking into account the environment, the properties, and the people present there. In this work, $\lambda_{i,j}$ are defined as constants in time and defined as in Table 2.

Table 2. Values of $\lambda_{i,j}$ as derived from a proper combination of vulnerable goods quantity and density population quantity related to the link $(i,j) \in A$.

$\lambda_{i,j}$	Exposed elements	Density population
1	< 10 goods	< 10 ab./m^2
2	10÷100 goods	10 ÷500 ab./m^2
3	101÷1000 goods	501÷5000 ab./m^2
4	> 1000 goods	> 5000 ab./m^2

As a simplifying assumption, $\vartheta_{i,j}(\tau)$ has not been defined in the case study. For the reader's convenience, the overall hazmat routing problem formulation is summarized in the following

$$\min\{\gamma_1 J_1 + \gamma_2 J_2 + \gamma_3 J_3 + \gamma_4 J_4\} \qquad (23)$$

where

$$J_1 = \sum_{\tau=t}^{t+T-1} \sum_{(i,j)\in A} \left(\frac{N_{haz}^{i,j}(\tau)}{L_{i,j}} \cdot \left(\sigma \cdot \lambda_{i,j} + \mu \cdot \rho_{i,j}(\tau) \right) \right) \tag{11.bis}$$

$$J_2 = \sum_{\tau=t}^{t+T-1} \sum_{i\in O} \sum_{d\in D} \omega_d^i \left[z_{haz,d}^i(\tau+1) \right] \tag{14}$$

$$J_3 = \sum_{\tau=t}^{t+T-1} \sum_{(i,j)\in A} \sum_{d\in D} \alpha_{haz,d}^{i,j} \cdot N_{haz,d}^{i,j}(\tau+1) \tag{16}$$

$$J_4 = \sum_{\tau=t}^{t+T-1} \max_{(i,j),(k,l)\in A} \left((\lambda_{i,j} \cdot \frac{N_{haz}^{i,j}(\tau)}{N_{i,j}^{TOT}(\tau)} \cdot \quad \varphi_{i,j}^{TOT}(\tau)) - (\lambda_{k,l} \cdot \frac{N_{haz}^{k,l}(\tau)}{N_{k,l}^{TOT}(\tau)} \cdot \quad \varphi_{k,l}^{TOT}(\tau)) \right) \tag{17.bis}$$

under the constraints

$$z_{haz,d}^i(\tau+1) = z_{haz,d}^i(\tau) + y_{haz,d}^i(\tau) - \tilde{y}_{haz,d}^i(\tau) \tag{12}$$

$$i \in NSET,\ d \in D,\ \tau = t,..,t+T-1$$

$$\tilde{y}_{haz,d}^i(\tau) \le z_{haz,d}^i(\tau) + y_{haz,d}^i(\tau) \tag{13}$$

$$i \in NSET,\ d \in D, \tau = t,..,t+T$$

$$N_{haz,d}^{i,j}(\tau+1) = N_{haz,d}^{i,j}(\tau) + INPUT_{haz,d}^{i,j}(\tau) - OUTPUT_{haz,d}^{i,j}(\tau) \tag{18}$$

$$(i,j) \in A,\ d \in D,\ \tau = t,..,t+T-1$$

$$N_{haz}^{i,j}(\tau) = \sum_{d\in D} N_{haz,d}^{i,j}(\tau) \tag{10}$$

$$(i,j) \in A,\ \tau = t+1,..,t+T-1$$

$$INPUT_{haz,d}^{i,j}(\tau) = \beta_{haz,d}^{i,j}(\tau) \cdot \left\{ \sum_{k\in P(i)} \left[OUTPUT_{haz,d}^{k,i}(\tau) \right] + \tilde{y}_{haz,d}^i(\tau) \right\} \tag{19}$$

$$(i,j) \in A,\ i \in NSET,\ d \in D,\ i \ne d,\ \tau = t,..,t+T$$

$$INPUT_{haz,d}^{d,j}(\tau) = 0 \tag{20}$$

$$(d,j) \in A,\ d \in D,\ i = d,\ \tau = t,..,t+T$$

$$OUTPUT_{haz,d}^{i,j}(\tau) = \frac{N_{haz,d}^{i,j}(\tau)}{N_{i,j}^{TOT}(\tau)} \cdot \varphi_{i,j}^{TOT}(\tau) \cdot \Delta\tau \tag{21}$$

$$(i,j) \in A, d \in D, \tau = t,..,t+T$$

$$\sum_{j \in S(i)} \beta_{haz,d}^{i,j}(\tau) = 1 \qquad (22)$$

$$i \in NSET, d \in D, i \notin D, \tau = t,..,t+T$$

3. Results

3.1. Territorial Description

The Cuneo District has an area of about 6900 [km^2], with more than 540000 habitants, with 250 different municipalities, with a quite varying density of population. The Cuneo District offers a great variety of road networks, 84 [km] of highways, 758 [km] of National main roads, more than 2700 [km] of primary sub-regional roads, and 452 [km] of secondary sub-regional roads and extra urban ways.

This case study deals with the definition of an integrated system for traffic management, in the assumption of a single DM (Cuneo District Authority). The object of the DM is to reduce the hazmat transport risk on its road infrastructure.

The links in bold in Figure 5 show a simplified road network for the Cuneo District which has been taken into account in the case study. It corresponds to the main traffic roads of the Cuneo District.

In the case study, the vehicles are divided into two groups: hazmat vehicles and all the other vehicles, following the model defined in section 2. Hazmat vehicles are supposed to have one origin and one destination in Cuneo District network, where nodes 1 (Colle della Maddalena), 2 (Colle di Tenda), 10 (Saluzzo), 14 (Alba) and 17 (Mondovì) are supposed to be the only origins and destinations.

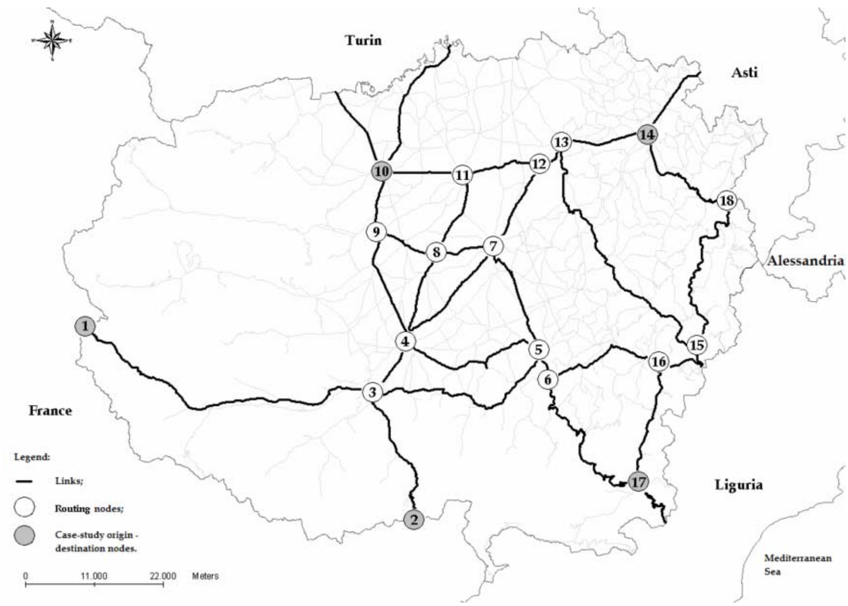

Figure 5. Map of Cuneo district, where the borders, the entrances in and out Cuneo, and the simplified road network (modeled through 18 nodes and 52 directed links) are shown.

3.2. *Results*

The optimization horizon is 2.30 hours. This horizon is subdivided into smaller intervals, $\Delta\tau$ = [0.25 hour], ($\Delta\tau$ is the same as in the DTM), and the simulation horizon is about [2.5 hour] per simulation. Time of simulation, $\tau = t,...,t+T-1$, is comparable with the time spent by a vehicle to go to its destination $d, d \in D$. The number of vehicles entering the network have been subdivided in groups. The first one comes from France, the second one comes from Liguria. For each destination there is a number of vehicles entering the network every 15 minutes, as shown in Table 3. Node 2 has not been taken into account.

Heavy traffic t.g.m.	Hazmat vehicles t.g.m.	Destination: ASTI	Destination: TORINO	Destination: FRANCE	Destination: LIGURIA
4676	234				
Hazmat vehicles Origine: FRANCE [vehicles/0.25h]	3	1	1	0	1
Hazmat vehicles Origin: LIGURIA [vehicles/0.25h]	6	2	3	1	0

Table 3. Daily average hazmat traffic (t.g.m.), every 15 minute, from one origine (France, Liguria) to one destination (Asti, Turin, France, Liguria).

The Hazmat Router Model gives output data, from the beginning of the Model Optimization. These data are useful to investigate the link risk and the risk in the territorial case-study area. Hazmat vehicle queue data at the time interval $\Delta\tau = 1$ (Nodes 1 and 17) and the hazmat vehicle number at the time interval $\Delta\tau = 1$, are respectively:

- $y^{i}_{haz,d}(1)$, the vehicles forecast, which are the vehicles entering the network at the time interval $\Delta\tau = 1$;
- $z^{i}_{haz,d}(1)$, the number of vehicles, which are waiting to enter the network at the time interval $\Delta\tau = 1$;
- $N^{i,j}_{haz,d}(1)$, the number of vehicles on the link $(i,j) \in A$ at the time interval $\Delta\tau = 1$.

This process could be improved in a time horizon of interest, for example a DM could decide a 24-hours horizon, or in case of emergency an operation management horizon.

This model gives information to sub-regional scale about the equalization of risk on the case-study network, characterizing: reduce, if possible, the risk on the whole network, equalizing the risk; avoid that some links are used much more than others; in other words, main path for hazmat routine can not be all the same, but routing has to be a safe activity.

It is possible to know how many hazmat vehicles have to enter the network in different time step. It could be possible that a decision maker needs (a) to close a road for a period of time or (b) to decide which vehicles can enter the road.

The proposed hazmat router model is a non linear optimization problem. The not linearity derives from constraints and objective function formulation. The mathematical formulation is formed by a cost function and by balance constraints. The (continuous) decisional variables that have to be computed are 10280, whereas 3080 parameters that have to be processed in each run of the model.

Due to the large amount of decisional variables characterizing the problem, output data of hazmat router model, namely $\beta^{i,j}_{haz,d}(\tau)$, $N^{i,j}_{haz,d}(\tau)$ and $\tilde{y}^{i}_{haz,d}(\tau)$, can not be easily reported in tabular format and so they have been omitted.

4. Conclusions

A District road network has been described, which has been subdivided in 18 nodes, and 52 links, one for each link direction. Nodes have been subdivided in points of origin and destination for the hazmat tracking, through the Cuneo District roads.

A non linear problem, called Hazmat Router Model, has been formulated, where the variables are continuous. This model has been able to give output data after a quite long period of time (one hour, on a Pentium IV 2 GHz PC). It could be suggested to re-write the hazmat router formulation in a suitable way, to cut down on computational time model, since current time of simulation, $\tau = t,...,t+T-1$, is comparable with the time spent by a truck to go to his destination, d, $d \in D$.

The optimization horizon is 2.30 [h], with a discrete time interval equal to 15 minutes. A rolling horizon model has been applied to the hazmat router problem, with a time window equal to 1 [h].

The developed method needs to information (in quite real time) about generic traffic incoming and outgoing, and about hazmat vehicles input in the road network. Afterward, a territorial analysis has been essential to characterize each link in according to the induced risk assessment. In the near future the developed method could be useful to implement adequate tools, which could aimed to reduce the hazmat transport risk.

This multi-object problem has been solved. This kind of problem is referred to operational risk management and risk assessment in real time according to hazardous material traffic information in a large scale area with a complex grid network.

Surely, another useful target may be to reduce hazmat transport risk by strategic decisions related to the overall goods transport system reduction (by road).

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References

[1]. G.E.G Beroggi, W.A Wollace, 1998. OPERATIONAL RISK MANAGEMENT - The integration of Decision, Communicational, and Multimedia technologies. KLUWER ACADEMIC PUBLISHERS.

[2]. P. Leonelli, S. Bonvicini, G Spadoni, 1999. New detailed numerical procedures for calculating risk measures in hazardous materials transport. Journal of Loss Prevention in the process industries, Vol.12, pp. 507-515.

[3]. Erkut, E., Osman, A., 2007. Designing a road network for hazardous materials shipments. Computers & Operational Research, Vol. 34, pp. 1389-1405.

[4]. http://europa.eu/scadplus/leg/en/lvb/l24007.htm - White Book

[5]. T.G. Crainic, G. Laporte,1997. Planning models for freight transportation. European journal of operational research, Vol. 97, pp. 409-438.

[6]. Jaillet, P., Bard, J. F., Huang, L., Dror, M., 2001. Delivery Cost Approximations for Inventory Routing Problems in a Rolling Horizon Framework. Transportation Science, June 2001.

[7]. Erkut, E., Verter, V., 1995. A framework for hazardous materials transport risk assessment. Risk Analysis 15, 589-601.

[8]. J. Karkazis, T.B. Boffey, 1995. Optimal location of routes for vehicles transporting hazardous materials. European Journal of Operational Research, Vol. 86, pp. 201-215.

[9]. B. Fabiano, F. Currò, E. Palazzi, R. Pastorino, 2002. "A framework for risk assessment and decision-making strategies in dangerous good transportation", Journal of Hazardous Materials, Vol. 93, pp. 1–15.

[10]. D. Giglio, R. Minciardi, D. Pizzorni, R. Rudari, R. Sacile, A.M.. Tomasoni, E Trasforini, 2003. Towards a decision support system for real time risk assessment of hazardous material transport on road, Proceeding IEMSS 2004 (International Environmental and Monitoring Software Society), pp. 1-6.

[11]. Atzei, F., Giglio, D., Minciardi, R., Paolucci, M., Pizzorni, D., Sacile, R., Trasforini, E., Vicini, G., 2004. Instradamento dinamico basato sul rischio nel trasporto di merci pericolose su strada, Atti del Convegno VGR 2004, Pisa
[12]. C. Caliendo, M Guida, A. Parisi, 2007. A crash-prediction model for mutilane roads. Accident Analysis and Prevention, Vol. 39, pp. 657-670.
[13]. B. Fabiano, F. Currò, E. Palazzi, R. Pastorino, 2005. Dangerous good transportation by road: from risk analysis to emergency planning. Jurnal of Loss Prevention in the process industries, Vol. 18, pp. 403-413.
[14]. Jin et al., 2007. A dynamical system model of the traffic assignment problem. Transportation Research Part B, Vol. 41, pp. 32-48.
[15]. Mihaylova et al., 2007. Freeway traffic estimation within particle filtering framework. Automatica, Vol.43, pp.290-300.
[16]. Thomas et al., 2007. The dynamical shortest path problem with anticipation. European Journal of Operational Research, Vol. 176, pp. 836-854.

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The Challenges of Transport of Radioactive Materials and Wastes in Albania

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Abstract. The transport of Radioactive Materials (RM) and Radioactive Wastes (RAW) involves a potential radiological hazard. To ensure the safety of people, property and the environment, appropriate transport regulations to both domestic and international are necessary. The approved Regulation, their principles and objectives, are in order to ensure that the transport of Radioactive Materials is in compliance with IAEA regulations for the Safe Transport of Radioactive Materials. Albanian Government on 27.05.1971 approved "The Regulation of "Safety Transport of Radioactive Materials and Radiation Protection by Ionising Radiation Sources" [1]. Already, this old regulation was abrogated and a new one so-called: "The Regulation of Safety Hazard Materials"; is in force since 18. 04. 1997 approved by Albanian authorities. In this Regulation exist some articles for the safety Transport of Radioactive Material. Since 2001, we have prepared the new Regulation of Safety Transport of RM & RAW in Albania Our Regulation establishes standards of safety, which provide an acceptable level of control of the radiation, criticality and thermal hazards persons, property and the environment that, are associated with the transport of Radioactive Materials. The total activity of radioactive substances transported in Albania (domestic and international) during 2006 has been some thousands Ci of unsealed & solid radioactive sources, mainly ^{99m}Tc; ^{131}I, ^{60}Co, ^{137}Cs, ^{241} Am etc., by import-export procedures, and approximately over 560 type A and Type B packages.

Keywords. Radioactive material, wastes, legislation, regulation.

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Introduction

The transport of radioactive materials has started since was discovered the radioactivity phenomena as well the preparation of first quantities of the natural radioactive materials such as: U, Ra, Po etc.

Necessity for formulation of rules for transport of radioactive materials has started since 1950. On 1957 was established International Atomic Energy Agency (IAEA), which was charged to formulate the rules for transport of radioactive materials. The first regulation so-called: The rules for the safe transport of radioactive materials (Safety Series No.6), was issued on the beginning of 1961. This regulation was revised on 1964, 1967, 1973 1979, 1985 1990 and 1996 years [2]. In the Advisory Commission on Safety Standards of IAEA, parallel with NUSSAC, RASSAC and WASSAC was included the Transport Safety Advisory Committee - TRANSSAC. The transport regulation is accompanied with other publications of IAEA such as: Safety Series No. 7, No. 37, No. 80, which explains all rules for the safety transport of radioactive materials.

The rules, which are recommended by IAEA, constitute the basement of regulation for the safety transport of radioactive materials in national and international scale. However, the transport of radioactive material is often international. National regulations as well the international modal regulations, which are based on the IAEA Regulations, apply to such transport. Our Regulations for ensuring the safety people, property and the environment are formulated primarily according to Albanian national legal framework. The radioactive materials always are transported in package form, which usually are depended from some parameters like: a] quantity of radioactive material; b] from physics form of radioactive material. The radioactive materials are transported based on their sort of packages which are classified as following: 1] exempted packages 2] industrial packages 3] A-type packages 4] B-type packages.

1. Main articles of the Albanian legislation & regulation

New Albanian Radiological Protection Act[3] adopted after ICRP Publication 60, has obligated the National Radiation Protection Commission (NRPC) with the rights to approve the regulations for the different aspects of radiation safety, including the safe transport of radioactive materials inside / outside of Albanian territory.

Several years ago a group of specialists from INP, Ministry of Transport and Ministry of Health was formed for preparations of a draft regulation for the transport of RM & RAW, and consultancy with foreign experts was provided through IAEA. Regulations consider new development in the safe transport process, based at the Regulation for Safe Transport of Radioactive Materials and other publications issued by IAEA[2].

Albanian authorities have paid a special attention to the questions related with the safe transport of radioactive materials since the first issuing of the governmental ordinance on safe handling of the radiation sources[1]. There were defined special rules for the transport in accordance with provisions of the IAEA Safety Series Publication No.6 and categorization of the packages was based on the dose rate at their surface as well at 1 m distance[2]. The responsibilities of the different parts involved in the process of the transport were described along with safety measures of this kind of transport. Special duties were foreseen also for the customs authorities related with the import - export of radioactive materials.

The new safe transport regulation of RM & RAW is composed on fourteen articles, which describe in detail the provision related with this kind of the transport.

Article 1 requires the obligation that the transport of RM is carried out only by special vehicle, which fulfil all requirements for the safety transport in compliance with other regulations for safe handling of RM. This vehicle everywhere is accompanied by legal or physical persons, who are equipped with special license for this sort of the transport issued by Albanian Radiation Protection Commission (ARPC). The transport of the RM is carried out only after approval and issuing a special permission by national competent authority. At the end of the shipment, a copy of the transport document, signed by the consignee shall be sent to the Radiation Protection Office for registration.

In Article 2 are described the definitions related with the transport of RM & RAW with A1 and A2 values, carries, consignor and consignee, low specific activity material, special form of RM & RAW, surface contaminated object, transport index etc.

Article 3 describes radioactive materials, for which the transport regulations do not apply. Such materials are consumer products, natural ores containing radionuclides with activity concentration, which do not exceed 10 times the values of exempted limits.Classification of the transport packages is done in accordance with IAEA documents and namely as excepted packages, industrial packages (LSA and SCO), type A packages and B(U) and B(M) packages and in Albanian Regulation are described in Article 4. This classification is related to the qualities and quantities of RM that shall be transported and to the requirements that they ought to fulfil for preventing or mitigation the consequences of normal or accident conditions of the transport that can be occurred during the shipment,

Article 5 describes the values of non fixed contamination on the external surface of the packages, which shall keep as low as practicable and shall not exceed 4 Bq/cm2 for beta, gamma and low toxicity emitters and 0,4 Bq/cm2 for all other alpha emitters. The contamination assessment shall include the package, the vehicle, the adjacent loading and unloading area, if replacement of the package is performed.

The radiation level limits, which are applied to packages and to vehicles, are described in Article 6. The radiation level for industrial type A and type B packages shall not exceed 2 mSv/h at any point of external surface of the packages. The accumulation of the packages in a single vehicle shall be such that the radiation level under routine condition of the transport shall not exceed 2 mSv/h at any point and 0,1 mSv /h at 2 m from the external surface of the vehicle.

Each package, other than the exempted ones, is in accordance with Article 7, and shall be assigned to one of the three following categories: I-White, II-Yellow and III-Yellow, taking into account both the surface radiation levels and the transport index. The values of the maximum radiation level on the external surface of the packages and of the transport index for mentioned categories are the same with the value recommended by IAEA documents.

Table 1. The values of the maximum radiation level

Category	Maximum radiation level on the external surface of the package	Transport Index
I - WHITE	> 0,005 mSv / h	0
II - YELLOW	0,005 - 0,5 mSv / h	0 to 1
III - YELLOW	0,5 - 2 mSv / h	1 to 10

Article 8 describes the rules for labelling of packages and which kind of vehicle can be used for transport of RM & RAW. Trefoil symbol and other recommended ones, such the orange placard indicating the UN number for the radioactive material transport shall be used for labelling purposes.

Article 9- the process of the loading of the radioactive materials, the transport itself and the down loading is carried out under permanent control of a qualified person on radiation protection matter (radiation protection officer).

Article 10 urges the prohibition the transport of the radioactive materials along with other dangerous materials or foods, with undeveloped photographic films and other light sensitive materials. The transport documentation for accompanying the shipment of radioactive materials is described in the Article 11. This documentation follows the recommendations of IAEA such as the proper shipping name, the name and symbol of each radionuclide, the activity of the radioactive material in the package, the category of the packages, the transport index, the identification mark of component authority approval certificate applicable to the shipment etc.

The last Articles 12, 13, 14, are related with certificate requirements, the customs offices obligations for arrangement of radioactive materials in a special protected area and the necessary steps for clearance purposes. All provisions described in the Radiological Protection Act as well in the Regulations on the Safe Handling of Radioactive Materials are valid for activities carried out during the process of the transport of RM & RAW.

In case of accident during the transport of RM & RAW are applicable the provisions of the Emergency National Plan.

There are some appendices of the regulations: the values of A1 and A2, for different radionuclides, the exempted total activities and activity concentrations, category packages labels, the placard etc.

2. Transport of Spend Radiation Source of Cobalt-therapy 60Co

The transport of the revolving head with cobalt 60Co spend radiation source to the radioactive waste laboratory in INP was made in accordance with recommendation of IAEA and national regulation for transport of radioactive material.

The transport was performed on 28th December 2006, by special truck, when the source activity was calculated and measured finding the A≈37TBq. The packaging consists as a solid metallic construction, including the cobalt 60Co source within the lead shielding. The external dimensions of package were 1156 mm high by 1010 mm long by 900 mm wide. The maximum gross mass was 1500 kg without the stainless steel ends and 1700 kg with stainless steel ends (Figure 1).

Figure 1. External dimension of packages

This type B (U) package was designed to be transported in withstand normal conditions. The shape, size and weight of the inner packaging component (head of the source) determine the best material to be used. The prime consideration is to ensure the minimum movement of the inner packaging, within the outer packaging, in order to comply with the regulatory requirements regarding the minimal increase of the radiation dose rate on the surface / and 1 m distance.

We have affixed the placards with radioactive trefoil sign in four sides of the package, where was included the index transport TI=0-1 (the maximum measured dose rate ≈ 62, 9 μSv/h) and, category II yellow, during transport to disposal repository in INP (Figure 2).

Figure 2. Placards with radioactive trefoil sign.

A technique for the measurement of the source radioactivity and contamination of the operational tools was organized using: direct measurement, using the Field-Spec apparatus positioned near contact with the surface of objects. Indirect measurements are taken using a paper smear to swipe a known area of objects in order to assess whether loose contamination is present. The competent authority has arranged the assessment of radiation doses to persons, driver and accompanying assistant, during transport up to INP destination. The inspector of state policy has had escorted the truck to the INP destination.

Conclusions

Albanian Radiation Protection Commission as National Authority Board has formulated and adapted the Legislation & Regulation for Safe Transport of RM & RAW, ensuring the safety people, environment control and protection, according to Albanian national legal framework, as well as at based at the recommendations of IAEA and other International Organizations.

New Albanian Radiological Protection Act, adopted after ICRP Publication 60, has obligated the National Radiation Protection Commission (NRPC) with the rights to approve the regulations for the different aspects of radiation safety, including the safe transport of RM in Albanian territory.

Our Regulations have established standards of safety to the people and environment, providing an acceptable radiation level and they are formulated primarily according to Albanian Legislations. Regulations consider new development in the safe transport process, describing the main rules for the Safe Transport of RM, issued at the IAEA Publications [4].

References

[1] The worker's rules with Radioactive Material and Ionising Radiation Sources, Act No. 83, dated 27. 05. 1971

[2] IAEA, Regulation for the Safe Transport of Radioactive Material, Safety Standards Series No. ST 1, Edition 1996

[3] "On Ionising of Radiation Protection" Article 3, point (d). Law No.8025, dated 09.11.1995

[4] IAEA, Quality Assurance for the Safe Transport of Radioactive Material, Safety Series, 13, 1994

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Thermoeconomical Optimization Of Net For Energy Resources Transportation

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Abstract. Systems for different kinds of energy resources transportation are potentially dangerous objects. In the design and operation of these systems, the possibility of improving the system's efficiency is very important to explore. The main way of improving efficiency is through optimisation. This paper describes the application of exergy topological models and, in particular, the graph of thermoeconomical expenditure for thermoeconomical optimal design of different kind of nets for energy supply -with circled (CNES) and tree shape (TSESN) structure. The questions of thermoeconomical optimisation of these nets , as well as suggested modelling algorithms, are illustrated in the numerical example of the optimisation of a energy supply system for a city with seven regions of energy consumption for CNES and for twelve regions for TSESN.

Keywords. Optimal design, energy supply nets, thermoeconomic

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Introduction

The processes taking place in complex energy intensive systems are characterized by the mutual transformation of quantitatively different power resources. The thermo-economical optimisation of CNES is based on thermodynamic analysis, which requires the combined application of both laws of thermodynamics and demands the exergy approach ([1], [2]).

Exergetic methods are universal and make it possible to estimate the fluxes and balances of energy for every element of the system using a common criterion of efficiency.

Therefore, the exergetic methods are meaningful in analysis and calculations.

Meanwhile, the increasing complexity of optimisation problems requires more effective and powerful mathematical methods. Therefore, during the last few years, many papers with different applications of exergetic methods and the thermo-economical approach have been published (see for example [3-7]).

The above referenced papers, as well as the author's past investigations [8-13], show that one of the most effective mathematical methods used for exergetic analysis and thermoeconomical optimisation involve graph theory [14,15]. The usefulness of graph models can also be demonstrated by their flexibility and wide range of possible applications.

The exergy topological method includes the sole use or combination of exergy flow graphs [7-9] and thermoeconomical graphs [10-13]. This paper describes the application of exergy topological models and, in particular, the graph of thermo-economical expenditure for thermoeconomical optimisation of circled energy supply nets (CNES) as well as tree shape energy supply nets (TSESN).

1. Method and algorithm of optimal synthesis of CNES

Let's assume that the CNES contains **m** customers and the possible methods of connection of these customers by a net are known.

Then, for this CNES, in accordance with rules given in [10,13], the graph of thermoeconomical expenditure can be built. Shown in Fig. 1 is a graph whose nodes multitude $A=\{a_1, a_2, ..., a_i, ..., a_m\}$ corresponds to the customers and arcs multitude $U=\{a_i, a_j\}$; $i \neq j$; $i = 1, 2, ..., m$; $j = 1,2, ..., m$; to the appropriate parts of CNES between nodes a_i, a_j. Each arc U_{ij} has thermoeconomical expenditure Z_{ij} as it is shown in the matrix of thermoeconomical expenditure (see Fig. 2.) and the graph in Fig. 1.

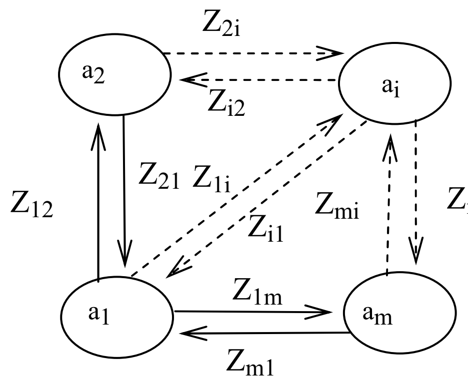

Figure 1. Graph of thermoeconomical expenditure

Then, by minimising the sum shown in Eq. (1), the problem of optimal thermoeconomical synthesis can be solved.

$$Z_{\Sigma}^{\min} = \min \sum_{i} \sum_{j} Z_{ij} \tag{1}$$

	a_1	a_2	...	a_j	...	a_m
a_1	Z_{11}	Z_{12}		Z_{1j}		Z_{1m}
a_2	Z_{21}	Z_{22}		Z_{2j}		Z_{2m}
...						
a_i	Z_{i1}	Z_{i2}		Z_{ij}		Z_{im}
...						
a_m	Z_{m1}	Z_{m2}	...	Z_{mj}	...	Z_{mm}

Figure 2. Matrix of thermoeconomical expenditures corresponding to graph in Figure 1.

Given below is the matrix form of a special algorithm for the optimal synthesis of CNES based on the finding of a Hamilton contour [14] in the graph of thermoeconomical expenditure $Z_U = (A, U)$.

The algorithm consists of following main steps:

Step 1. Calculate the possible thermoeconomical expenditure $Z_{ij} = Z(a_i, a_j)$, $\forall a_i \in A$, $\forall a_j \in A$ and form a square matrix of size **m x m** for the thermoeconomical expenditure (See Figure2.).

Step 2. Find a minimum element in each i-th line of the matrix $Z_i^{\min} = \min \{Z_{ij}\}$, j= 1,2..., m; i = 1,2..., m and subtract the element from all elements in this line.

Step 3. Check: are there any matrix columns that do not include zero elements?

If yes, then go to step 4.

If not, then each line and each column contain at least one zero member. Proceed to step 5.

Step 4. Find, in each j- column, that does not include the zero elements, a minimum element. This element will be Z_j^{min} = min $\{Z_{ij}\}$, i = 1,2..., m; j = 1,2..., m. Now subtract Z_j^{min} from all elements of this column. The result will be an inclusive matrix yielding one zero element in each column and each line.

Step 5. Calculate the sum: $Z_\Sigma^0 = \sum_i Z_i^{min} + \sum_j Z_j^{min}$

This sum, Z_Σ^0, is the lower boundary of a set of the solutions and can be accepted as the root tree for the thermoeconomical expenditure.

It is understandable that if step 4 was not executed, then $Z_j^{min} = 0$.

Step 6. Select an arc, (a_k, a_l), for which

$$R^{max}(a_k, a_l) = \max \{R(a_i, a_j)\}$$

$R(a_i, a_j)$ – the sum of the least element of i-th line and j-th column of a matrix. Zero element is located is the interception of these i-th line and j-th column.

Step 7. Find, in the tree of thermo-economical expenditure, a dangling vertex with the least boundary.

Step 8. Form the new vertex with a boundary equal he sum of the boundary of vertex in step 7 with value $R^{max}(a_k, a_l)$.

An adequate contour for this vertex will not use an arc (a_k, a_l).

Let's designate this property through $\overline{S}_{kl}$.

Step 9. Eliminate the k-th line and l-th column in the matrix corresponding to an element $R^{max}(a_k, a_l)$. Then the size of the matrix will decrease by a unit.

Step 10. Exchange a symbol, ∞, for the thermoeconomical expenditure of arcs, which permits finding contours of length smaller than the **m**-size.

Step 11. Check: Is the size of the matrix obtained in step 10 more than that of a unit?

If yes, then go to a step 12.

If not, then go to a step 19.

Steps 12,13,14, and 15 repeat steps 2, 3, 4, and 5, but these calculations are done with the matrix obtained in step 10 (instead of the initial matrix used in previously).

Step 16. Add the sum obtained in step 15 to the value for the boundary of vertex from which one splitting was done (in the first step, this is the boundary for a root tree of thermoeconomical expenditure).

The final result will be the boundary for the new dangling vertex - a contour will use an arc (a_k, a_l) that is adequate for the condition in step 6.

Step 17. Find the dangling vertex with the least boundary. If there are only a few dangling vertices with the same boundaries, then select a vertex that is characterized by property $S_{kl.}$ This step is essential in order to find arcs that are included in a Hamilton contour.

Step 18. Check: is the vertex found in step 17 built by applying the property $\overline{S}_{kl}$? If yes, then go to a step 6.

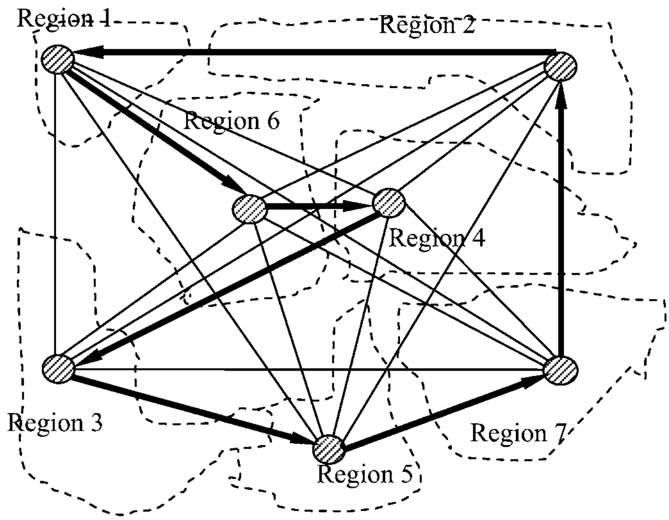

Figure 3. Scheme CNES with seven region of energy consumption

If is not, then go to a step 9.

Step 19. The problem is solved - optimal pairs of elements (customers) a_i and a_j are found that correspond to the appropriate vertex sequence. By starting from the root tree and finishing with the dangling vertex for a matrix of unit size, the single contour CNES, with the minimum thermoeconomical expenditure in accordance with Eq. 1, can be determined.

2. Numerical example of optimal synthesis of single contour CNES

Let's consider a problem of an optimal synthesis, single contour CNES for a city with seven regions of energy consumption (see scheme in Figure 3.)

The graph of thermoeconomical expenditure is given in Figure 4, and the matrix of thermoeconomical expenditure, $\mathbf{M_1}$, is found in Figure 5.

Applying the aforementioned algorithm to matrix $\mathbf{M_1}$ allows one to obtain the initial sum (see step 5) for the root tree of thermoeconomical expenditure shown in Figure 10.

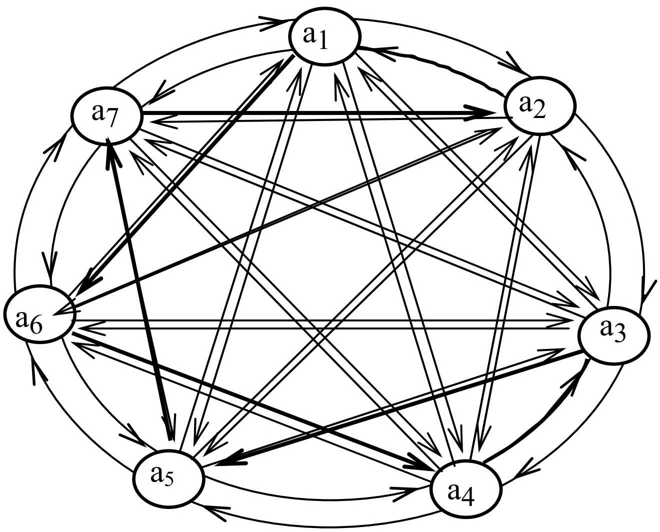

Figure 4. Graph of thermoeconomical expenditure for scheme in Figure 3

	a_1	a_2	a_3	a_4	a_5	a_6	a_7
a_1	∞	**1050**	**1850**	**1200**	**6300**	**1100**	**1900**
a_2	**1050**	∞	**1700**	**1600**	**900**	**2500**	**400**
a_3	**1850**	**1700**	∞	**200**	**1200**	**1550**	**1500**
a_4	**1200**	**1600**	**200**	∞	**400**	**800**	**900**
a_5	**6300**	**900**	**1200**	**400**	∞	**300**	**450**
a_6	**1100**	**2500**	**1550**	**800**	**300**	∞	**950**
a_7	**1900**	**400**	**1500**	**900**	**450**	**950**	∞

	a_1	a_2	a_3	a_4	a_5	a_6	a_7
a_1	∞	**0**	**800**	**150**	**5250**	**50**	**850**
a_2	**750**	∞	**1300**	**1200**	**500**	**2100**	**0**
a_3	**1650**	**1500**	∞	**0**	**100**	**1350**	**1300**
a_4	**100**	**1400**	**0**	∞	**200**	**600**	**700**
a_5	**6000**	**600**	**900**	**100**	∞	**0**	**150**
a_6	**800**	**2200**	**1250**	**500**	**0**	∞	**650**
a_7	**1500**	**0**	**1300**	**500**	**50**	**550**	∞

Figure 5. (Continue in the following page)

	a_1	a_2	a_3	a_4	a_5	a_6	a_7
a_1	∞	**0**	**800**	**150**	**5250**	**50**	**850**
a_2	**650**	∞	**1300**	**1200**	**500**	**2100**	**0**
a_3	**1550**	**1500**	∞	**0**	**100**	**1350**	**1300**
a_4	**100**	**1400**	**0**	∞	**200**	**600**	**700**
a_5	**5900**	**600**	**900**	**100**	∞	**0**	**150**
a_6	**700**	**2200**	**1250**	**500**	**0**	∞	**650**
a_7	**1400**	**0**	**1300**	**500**	**50**	**550**	∞

Figure 5. Matrixes of thermoeconomical expenditures M_1-M_3

The matrices of solution, $\mathbf{M_1}$-$\mathbf{M_{23}}$ (see Figure 5- Figure 9), as well as the tree of thermoeconomical expenditure (see Figure 10), are obtained as a result of applying the suggested algorithm.

It is easy to see that the optimal single contour CNES (in Figure 4 and Figure 5 - designated by bold lines) contains the appropriate sequence of nodes (customers): (a_1, a_6, a_4, a_3, a_5, a_7, a_2, a_1).

The minimum thermoeconomical expenditure for this optimised CNES is 4400.

	a_1	a_2	a_4	a_5	a_6	a_7
a_1	∞	**0**	**150**	**5250**	**50**	**850**
a_2	**650**	∞	**1200**	**500**	**2100**	**0**
a_3	**1550**	**1500**	∞	**100**	**1350**	**1300**
a_5	**5900**	**600**	**100**	∞	**0**	**150**
a_6	**700**	**2200**	**500**	**0**	∞	**650**
a_7	**1400**	**0**	**500**	**50**	**550**	∞

	a_1	a_2	a_4	a_5	a_6	a_7
a_1	∞	**0**	**150**	**5250**	**50**	**850**
a_2	**650**	∞	**1200**	**500**	**2100**	**0**
a_3	**1450**	**1400**	∞	**0**	**1250**	**1200**
a_5	**5900**	**600**	**100**	∞	**0**	**150**
a_6	**700**	**2200**	**500**	**0**	∞	**650**
a_7	**1400**	**0**	**500**	**50**	**550**	∞

	a_1	a_2	a_4	a_5	a_6	a_7
a_1	∞	**0**	**50**	**5250**	**50**	**850**
a_2	**0**	∞	**1100**	**500**	**2100**	**0**
a_3	**800**	**1400**	∞	**0**	**1250**	**1200**
a_5	**5250**	**600**	**0**	∞	**0**	**150**
a_6	**50**	**2200**	**400**	**0**	∞	**650**
a_7	**750**	**0**	**400**	**50**	**550**	∞

Figure 6. (Continue in the following page)

	a_1	a_2	a_3	a_4	a_5	a_6	a_7
a_1	∞	**0**	**800**	**150**	**5250**	**50**	**850**
a_2	**650**	∞	**1300**	**1200**	**500**	**2100**	**0**
a_4	**1550**	**1500**	∞	**0**	**100**	**1350**	**1300**
a_5	**0**	**1400**	∞	∞	**200**	**600**	**700**
a_6	**5900**	**600**	**900**	**100**	∞	**0**	**150**
a_7	**700**	**2200**	**1250**	**500**	**0**	∞	**650**
	1400	**0**	**1300**	**500**	**50**	**550**	∞

Figure 6. Matrixes of thermoeconomical expenditures M_4-M_7

	a_1	a_2	a_3	a_4	a_5	a_6	a_7
a_1	∞	**0**	**0**	**150**	**5250**	**50**	**850**
a_2	**650**	∞	**500**	**1200**	**500**	**2100**	**0**
a_3	**1550**	**1500**	∞	**0**	**100**	**1350**	**1300**
a_4	**0**	**1400**	∞	∞	**200**	**600**	**700**
a_5	**5900**	**600**	**100**	**100**	∞	**0**	**150**
a_6	**700**	**2200**	**450**	**500**	**0**	∞	**650**
a_7	**1400**	**0**	**500**	**500**	**50**	**550**	∞

	a_2	a_3	a_4	a_5	a_6	a_7
a_1	**0**	**0**	∝	**5250**	**50**	**850**
a_2	∞	**500**	**1200**	**500**	**2100**	**0**
a_3	**1500**	∞	**0**	**100**	**1350**	**1300**
a_5	**600**	**100**	**100**	∞	**0**	**150**
a6	**2200**	**450**	**500**	**0**	∞	**650**
a7	**0**	**500**	**500**	**50**	**550**	∞

	a_2	a_3	a_4	a_5	a_6
a_1	**0**	**0**	∝	**5250**	**50**
a_3	**1500**	∞	**200**	**100**	**1350**
a_5	**600**	**100**	**100**	∞	**0**
a_6	**2200**	**450**	**500**	**0**	∞
a_7	∞	**500**	**500**	**500**	**550**

	a_2	a_3	a_4	a_5	a_6
a_1	**0**	**0**	∞	**5250**	**50**
a_3	**1400**	∞	**0**	**0**	**1250**
a_5	**600**	**100**	**0**	∞	**0**
a_6	**2200**	**450**	**400**	**0**	∞
a_7	∞	**450**	**350**	**0**	**500**

Figure 7. Matrixes of thermoeconomical expenditures M_8-M_{11}

	a_1	a_2	a_4	a_6	a_7
a_1	∞	**0**	**50**	**50**	**850**
a_2	**0**	∞	**1100**	**2100**	**0**
a_5	**5250**	**600**	**0**	**0**	**150**
a_6	**50**	**2200**	**400**	∞	**650**
a_7	**750**	**0**	**400**	**550**	∞

	a_1	a_2	a_4	a_6	a_7
a_1	∞	**0**	**50**	**50**	**850**
a2	**0**	∞	**1100**	**2100**	**0**
a_5	**5250**	**600**	**0**	**0**	**150**
a_6	**0**	**2150**	**350**	∞	**600**
a_7	**750**	**0**	**400**	**550**	∞

	a_1	a_4	a_6	a_7
a_1	∞	**50**	**50**	**850**
a_2	**0**	**1100**	**2100**	∝
a_5	**5250**	**0**	**0**	**150**
a_6	**0**	**350**	∞	**600**

	a_1	a_4	a_6	a_7
a_1	∞	**50**	**50**	**850**
a_2	**0**	**1100**	**2100**	∝
a_5	**5250**	**0**	**0**	**150**
a_6	**0**	**350**	∞	**600**

	a_1	a_4	a_6	a_7
a_1	∞	**0**	**0**	**850**
a_2	**0**	**1100**	**2100**	∞
a_5	**5250**	**0**	**0**	**0**
a_6	**0**	**350**	∞	**450**

	a_3	a_4	a_5	a_6
a_3	∞	**0**	**0**	**1250**
a_5	**100**	**0**	∞	**0**
a_6	**450**	**400**	**0**	∞
a_7	**450**	**350**	**0**	**500**

	a_3	a_4	a_5	a_6
a_3	∞	**0**	**0**	**1250**
a_5	**0**	**0**	∞	**0**
a_6	**350**	**400**	**0**	∞
a_7	**350**	**350**	**0**	**500**

Figure 8. Matrixes of thermoeconomical expedeture M_{12}-M_{17}

	a_3	a_4	a_5
a_3	∞	**0**	**0**
a_6	**350**	**400**	**0**
a_7	**350**	**350**	**0**

	a_3	a_4	a_5
a_3	∞	**0**	**0**
a_6	**0**	**400**	**0**
a_7	**0**	**350**	**0**

	a_4	a_6	a_7
a_1	**0**	**0**	**850**
a_5	**0**	**0**	**0**
a_6	**350**	∞	**450**

	a_4	a_6	a_7
a_1	**0**	**0**	**850**
a_5	**0**	**0**	**0**
a_6	**0**	∞	**100**

	a_4	a_6
a_1	**0**	**0**
a_6	**0**	∞

	a_4
a_6	**0**

Figure 9. Matrixes of thermoeconomical expenditures M_{18}-M_{23}

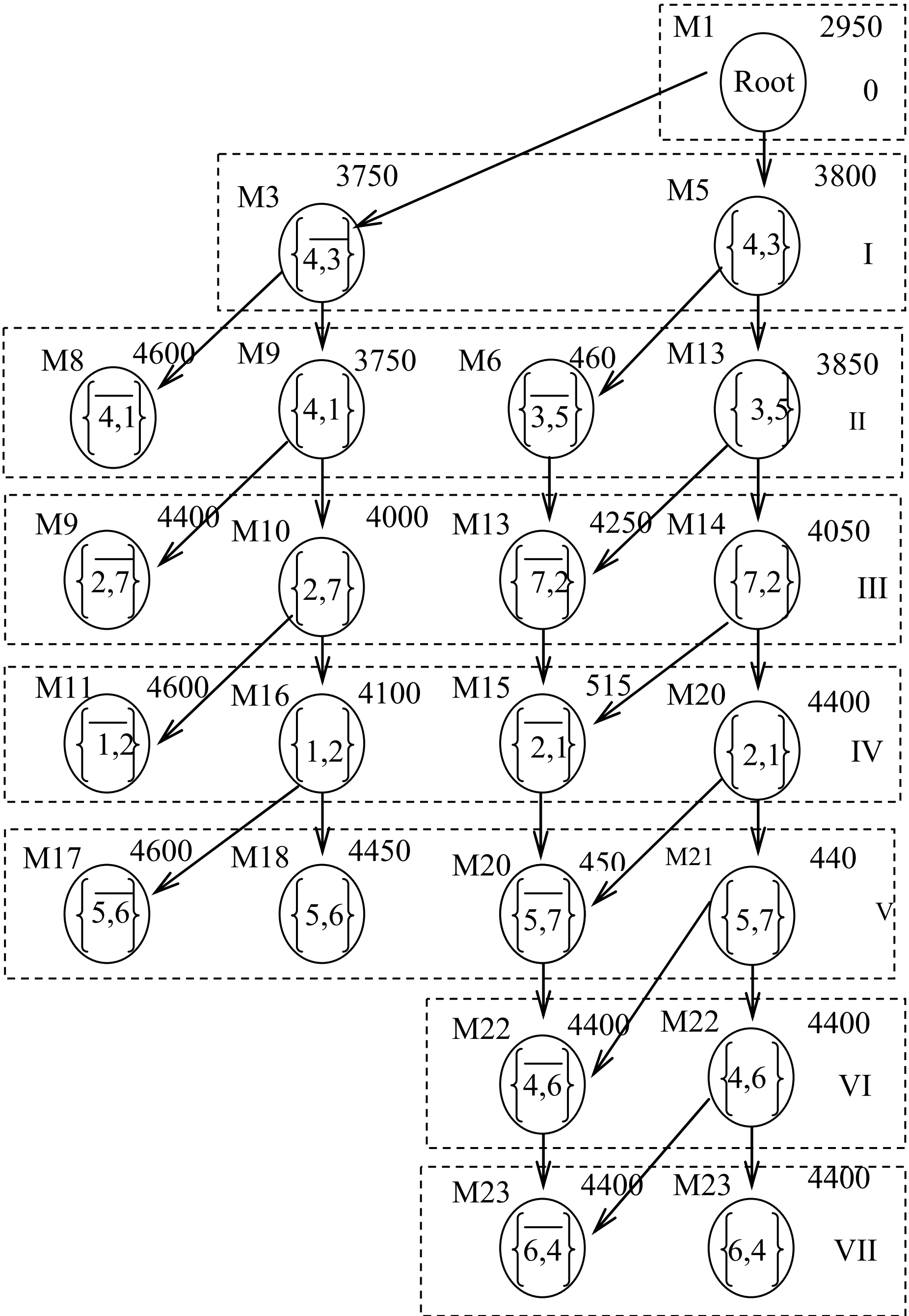

Figure 10. Tree of thermoeconomical expenditure

3. Optimal synthesis of tree shape energy supply nets (TSESN)

In general there are two main options:

- arbitrary location of energy source among consumers (in region of one of them)
- fixed region for location of energy source.

As well as for CNES in this case can be built the appropriate graph of thermoeconomical expenditure and its matrix (see Figure 11 and Figure 12).

Given below a special algorithms for the optimal synthesis of TSESN are based on the finding of a optimal frame [13] of graph of thermoeconomical expenditure $Z_U = (A, U)$.

Let's start from the TSENS with arbitrary location of energy source.

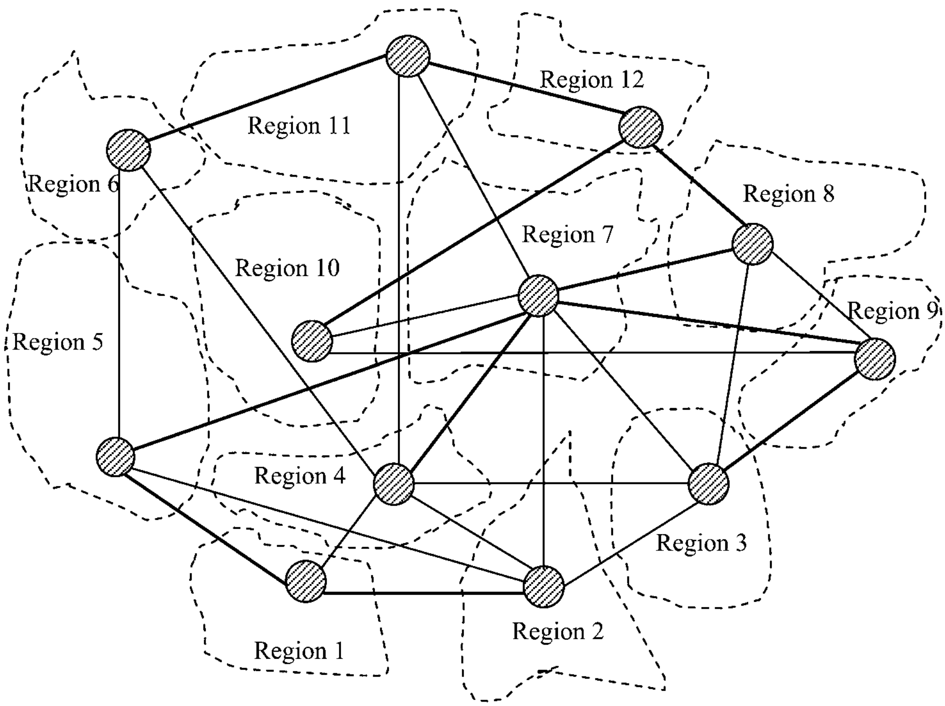

Figure 11. Scheme TSESN with twelve region of energy consumption

4. Method and algorithm of optimal synthesis of TSESN with arbitrary location of energy sources

In this approach the optimal frame is built by growing one of subtrees G_s which consists from more than one node. The single nodes are considered like a separate subtrees. The subtree G_s "grows" in result of addition of nodes (α_s, a_j), $a_j \notin G_s$ with a minimal thermoeconomical expenditure. This procedure proceeds up to the moment when the number of arcs reaches m-1.

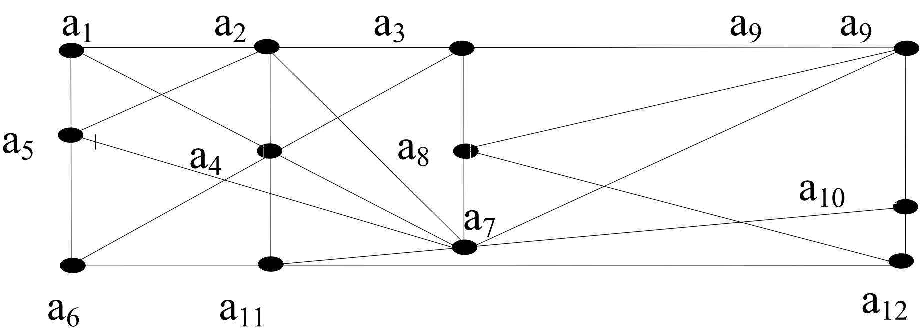

Figure 12. Graph of thermoeconomical expenditures of scheme in Figure 11.

		a_2	a_3	a_4	a_5	a_6	a_7	a_8	a_9	a_{10}	a_{11}	a_{12}
a_1		3000		5500	2500							
a_2	3000		7500	9000	4000		5500					
a_3		7500		4000				9000	3000			
a_4	5500	9000	4000			5000	3500				8500	
a_5	2500	4000				7500	4500					
a_6				5000	7500						1500	
a_7		5500		3500	4500			4500	2000	6500	6000	
a_8			9000				4500		7000			2000
a_9			3000				2000	7000		9500		
a_{10}							6500		9500			1000
a_{11}				8500		1500	6000					3500
a_{12}								2000		1000	3500	

Figure 13. Matrix of thermoeconomical expenditures of scheme in Figure 11

Then the built tree will be optimal according to Eq.(1). Algorithm starts with a giving for each node $a_j \in G_s$ note (α_j, β_j) , where α_j is the nearest to a_j node from subtree G_s , and a β_j - is the thermoeconomical expenditure of arc (α_j, a_j) . On each step of algorithm a node a_j* with a minimum note β_j adds to G_s in result of addition of a node (α_j^*, a_j^*).

The algorithm consists of the following main steps:

Step 1. Accept $G_s = \{a_s\}$, where a_s - is the arbitrary node and $U_s=\emptyset$ (U_s is a multitude of arcs in optimal frame)

Step 2. For each node $a_j \notin G_s$ find α_j corresponds to

$Z_j(\alpha_j,a_j)= \min[Z_j(a_i,a_j)]=\beta_j,\ a_i \in a_j^*$,

and give a note $[(\alpha_j,\beta_j)]$ for node a_j.

If such node α_j is absent, then give a note $[0,\infty]$ for node a_j.

Step 3. Take a node a_j^*, with $\beta j^*=\min [\beta j]$, $\forall a_j \notin G_s$ and note $G_s = G_s \cup \{ a_j^*\}$, $U_s = U_s \cup \{ \alpha_j^*,a_j^* \}$

If $| G_s | = m$, than stop. Nodes U_s give the optimal frame.

If $| G_s | \neq m$, than go to step 4.

Step 4. For $\forall a_j \notin G_s$, $a_j \in \Gamma a_j^*$, make such notes:

If $\beta j > Z(a_j^*,a_j)$, than accept $\beta j = Z(a_j^*,a_j)$, $\alpha_j = a_j^*$ и and go back to step 3.

If $\beta j \leq Z(a_j^*,a_j)$, than go to step 3.

In result on a step 3 (when $| G_s | = m$) will be constructed an optimal frame of graph of thermoeconomical expenditure $Z_U = (A, U)$ corresponding to optimal energy supply net (Eq.(1)).

5. Numerical example of optimal synthesis of TSESN with arbitrary location of energy source

Let's consider a problem of an optimal synthesis, of TSESN for a city with twelve regions of energy consumption (see scheme in Figure11).

In accordance with a roles given in [10-13] can be built the appropriate graph of thermoeconomical expenditure $Z_U = (A, U)$ (Figure 12.) and its matrix of thermoeconomical expenditures (Figure 13.).

Few first steps of above described algorithm are given below:

Step 1.Choose $a_s=a_1$, $G_1=\{a_1\}$, $U_1=\emptyset$.

Step 2. Accept notes for nodes a2,a4,a5: [a2,3000], [a4,5500], [a5,2500]. For all others nodes notes are $[0,\infty]$.

Step 3. It is easy to see that node a5 has a minimum note βi. Then build an arc (a1,a5) and G1={a1,a5}, U1={a1,a5}

Step 4. New notes for a2,a6,a7:

a2 : $\beta 2$ = 3000<Z(a2,a5)=4000 so it is OK;

a6 : $\beta 6=\infty>$ Z(a5,a6)=7500, then note for a6 is [a5,7500];

a7 : $\beta 7=\infty>$ Z(a5,a7)=4500, then note for a7 [a5,4500].

As a4 $\notin \Gamma$ (a5) its note is retained.

Return to step 3.

Step 3.New notes:

For a2 : [a1,3000]; for a4 : [a1,5500]; for a6 : [a5,7500]; for a7 : [a5,4500].

The min note βi corresponds to node a2 and as $\alpha 2$=a1 the new node is (a1,a2). It results to: G1={a1,a5,a2}, U1={(a1,a5),(a1,a2)}

Step 4. New notes:

for a3 : [a2,7500]

for a7 : [a3,5500] (is retained)

for a7 : [a5,4500] (is retained)

As a6 $\notin \Gamma$ (a2) its note is retained [a5,7500].

Step 3. The min note βi corresponds to node a7 and as α 7= a5 , the new node is (a5, a7,).

It results to:G1={a1,a5,a2,a7}, U7={(a1,a5),(a1,a2),(a5,a7)}

In result of proceeding with this procedure the optimal frame of thermoeconomical graph is built (Figure 14).

The minimal thermoeconomical expenditure

$$Z_{\Sigma}^{opt} = \sum_{j=1}^{10} Z_j = 3000+3000+2500+3500+4500+1500+2000+2000+1000+3500=31000$$

The optimal energy supply net with one energy source is shown by bold lines in Figure 11. It is clear that in this case the energy source has to be located in region 7.

6. Method and algorithm of optimal synthesis of TSESN with fixed region of energy source location

In this case it is possible to use the approach of the "shortest way" [13] in application to the graph of thermoeconomical expenditure Z_U = (A, U).

Similar to the previous algorithm this one also works with notes for nodes but in this case the note gives thermoeconomical expenditure of a way between the source "s" and corresponding node.

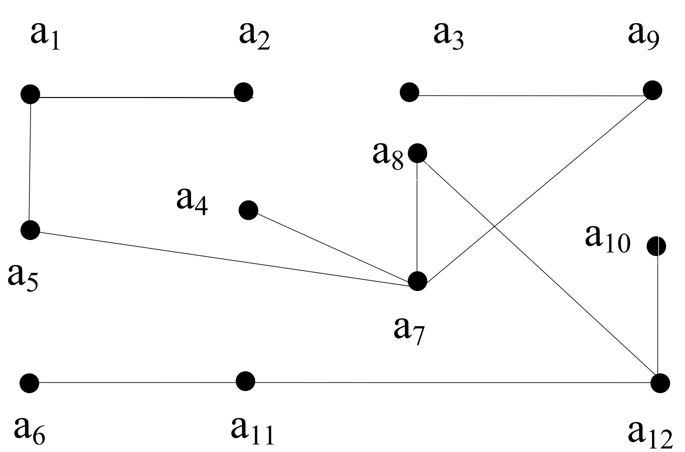

Figure 14. Optimal frame of thermoeconomical graph in Figure 12

At each step of algorithm one of the temporary notes becomes the permanent and gives the minimal thermoeconomical expenditure of this part of net.

The algorithm consists of the following main steps:

Step 1. Accept the note $\ell(s) = 0$ and consider it as a permanent.

Accept notes $\ell(a_i) = \infty$, $\forall a_i \neq s$ and consider them as temporary.

Accept p= s and go to a new notes.

Step 2. For $\forall a_i \in \Gamma(p)$, with temporary notes change these notes in accordance with

$\ell(a_i) \leftarrow \min[\ \ell(a_i),\ \ell(p) + Z(p,a_i)]$

Step 3. Among the nodes with temporary notes find one a_{i*} with

$\ell(a_{i*}) = \min[\ \ell(a_i)]$

Step 4. Accept a note $\ell(a_{i*})$ as a permanent and $p=a_{i*}$.

Repeat steps 2-4 up to the moment when all notes became permanent what corresponds Eq.(1).

7. Numerical example of optimal synthesis of TSESN with fixed region of energy source location

Let's consider a problem of an optimal synthesis, of TSESN for a city with nine regions of energy consumption with location of energy source in region 1(see scheme in Figure 15.).

Appropriate graph of thermoeconomical expenditure Z_U = (A, U) is shown in Figure 15 and its matrix of thermoeconomical expenditures in Figure 16.

Few first steps of above described algorithm are given below:

Step 1. Accept $\ell(a_1)$ = **0**, $\ell(a_i) = \infty$, $\forall a_i \neq a_1$, p= a_1 Bold number means that the notes are permanent. All others notes are temporary.

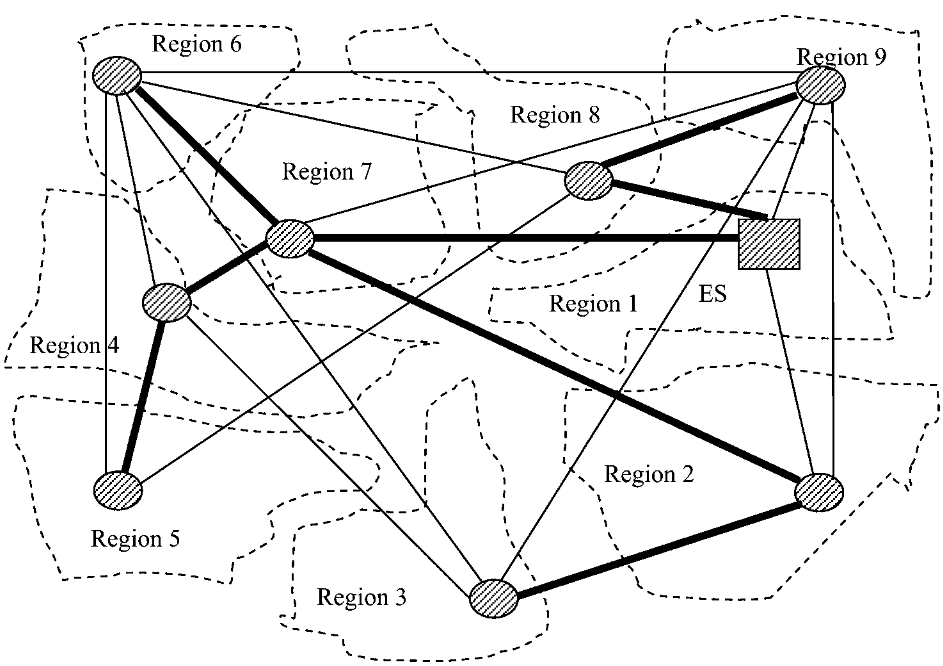

Figure 15. Scheme TSESN with nine region of energy consumption

First iteration.

Step 2. Here is: $\Gamma(p)= \Gamma(a_1) =\{a_2, a_7, a_8, a_9\}$- all notes are temporary.

$\ell(a_2)=\min[\infty,0+5000]=5000$

$\ell(a_7)=1500$, $\ell(a_6)=3000$, $\ell(a_9)=6000$

Step 3. Min[5000,1500,3000,6000, ∞]=1500 and corresponds to a node a_7 .

Step 4. Now node a_7 has a permanent note $\ell(a_7) = 1500$.

Step 5. There are nodes with temporary notes so go back to the Step 2.

Second iteration.

Step 2.Here: $\Gamma(p)= \Gamma(a_7) =\{a_2, a_4, a_6, a_9\}$- all notes are temporary.

	a_1	a_2	a_3	a_4	a_5	a_6	a_7	a_8	a_9
a_1		5000					1500	3000	6000
a_2	5000		9000				1000		6500
a_3		9000		12500		10000			3500
a_4			12500		2500	8000	2000		
a_5				2500		5000			
a_6			10000		5000		7000	7500	4500
a_7		1000		2000		7000			12000
a_8	3000				11500	7500			2500
a_9	6000	6500				4500	12000	2500	

Figure 16. Matrix of thermoeconomical expenditures of scheme in Figure 15

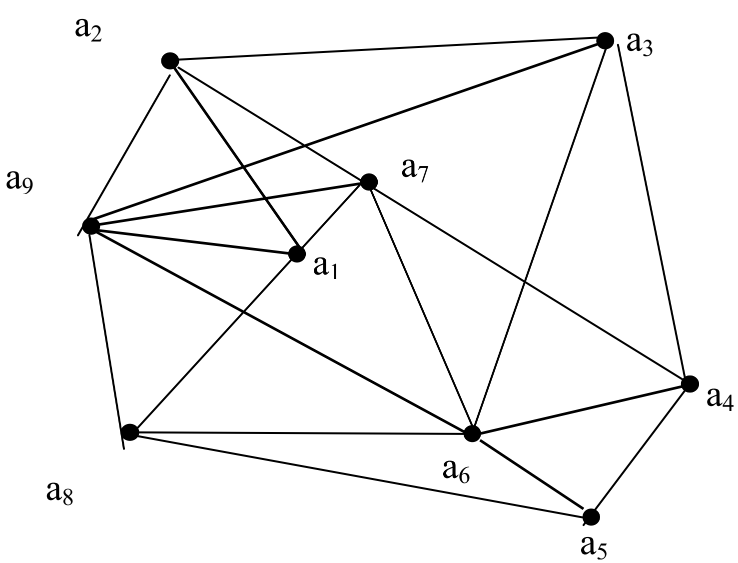

Figure 17. Graph of thermoeconomical expenditures of scheme in Figure 11

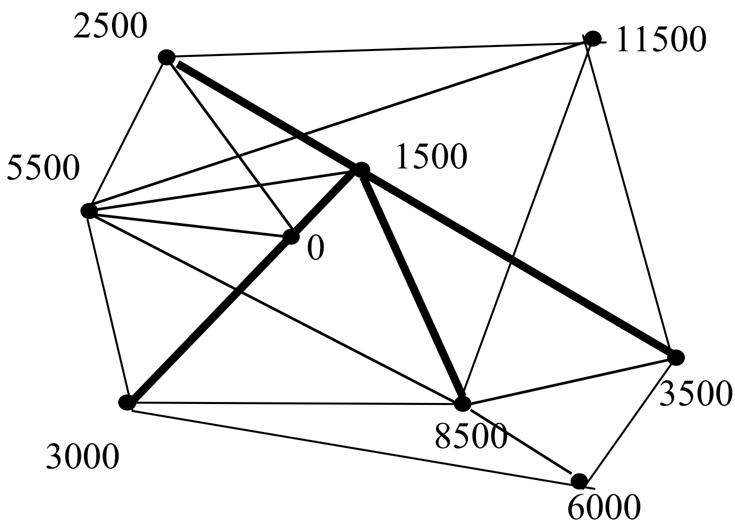

Figure 18. Graph of thermoeconomical expenditures with i-th permanent notes of nodes.

ℓ(a_2) = min[5000,**1500**+1000]= 2500,

ℓ(a_4) =3500, ℓ(a_6) =8500, ℓ(a_9) =6000.

Step3. Min [2500,3500,8500,3000,6000,∞]=2500 and corresponds to a node a_2.

Step 4. Now node a_2 has a permanent note

ℓ(a_2) =**2500**, p=a_2.

Step 5. There are nodes with temporary notes so go back to the Step 2.

In result of proceeding of this procedure the thermoeconomical graph with the permanent notes of all nodes is built (Figure 18).

The minimal thermoeconomical expenditure is

Z_Σ^{opt}=11500+6000+8500+5500+=31500.

The optimal energy supply net with one energy source is shown by bold lines in Figure 15.

8. Conclusion

The problem of optimisation for energy supply nets has to be solved separately from the problem of optimisation of other energy intensive systems. On the basis of the unique features of such a systems, it is possible to build an effective procedure for optimisation. In compare with direct enumeration method the time of seeking of optimum is reduced more than in 100 times. In this paper, the authors develop

and analyse a graph of thermoeconomical expenditure through an unique approach. The suggested method allows one to reduce the thermoeconomical expenditure at 5-8%.

The method is illustrated with three numerical examples for different kinds of energy supply nets optimisation.

References

[1] M. Moran, H. Shapiro, Fundamentals of Engineering thermodynamics, John Wiley & Sons Inc., New York, 2004.

[2] S. Tutns, Thermodynamics Concepts and Applications, Cambrigr University Press, 2006.

[3] M. Rosen , J. Etele,, Aerospace System and Exergy Analysis, Int. J. Exergy, 2004, Vol 1, N 4, pp. 411-425.

[4] C. Koroneos, D. Rivas, Exergetic analysis of Integrated Power Production Solar system. Proc. of International Conference ECOS-06, Heraclion, Greece, 2006, pp.126-134.

[5] F. Branko et al., Thermodynamic and Thermoeconomic analysis of a Brazilian Natural gas Thermal Power Plant, Proc. of International Conference ECOS-06, Heraclion, Greece, 2006, pp.203-209.

[6] J. Ertesvag, H. Kvamsdal, Bolland, Exergy analysis of a gas-turbine combined cycle power plant with precombustion CO2, Energy, 2005, N1, pp 25-39.

[7] H. Ozturk, Experimental evaluation of energy and exergy efficiency of a seasonal latent heat storage system fro green house heating, Energy Conversion & Management, 2005, 46, pp 1523-1542.

[8] V. Nikulshin, C. Wu, Thermodynamic analysis of energy intensive systems based on exergy-topological models, Exergy-an International Journal, 2001, Vol.1, pp. 173-180.

[9] V. Nikulshin, V. von Zedtwitz , Optimization of heating systems with renewable energy sources, Proc. of the 18-th International Conference on Efficiency, ECOS-05, Trondheim, Norway, pp.439-446, 2005.

[10] V. Nikulshin, C. Wu, Method of thermodynamic analysis and optimization of energy intensive systems on exergy flow graphs, Proc. of International Conference on Power and Energy Systems, Las Vegas, Nevada, USA, 1999 pp.489-491..

[11] C. Wu, V. Nikulshin, Method of thermoeconomical optimization of energy intensive systems with linear structure on graphs, International Journal of Energy Research, 24, 2000, pp.615-623.

[12] V. Nikulshin, M. Bailey ,V. Nikulshin, Thermodynamic analysis of air refrigerator on exergy graph, Thermal Science, Vol.10, No1, 2006, pp. 99-110.

[13] V. Nikulshin, V. von Zedtwitz, The "entropy-cycle" method for thermodynamic analysis of energy intensive system, International Journal of Exergy, Vol. 4, No. 1, 2007, pp.74-86.

[14] F. Harary, Graph Theory. Narosa Publishing House, New Deli, 1995.

[15] V.K. Balakrishnan Graph Theory, Shaumm's Outline Service, New York, 997.

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Traffic Optimization in Hazardous Materials Transport on Roads Flowing Towards One Critical Infrastructure

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Abstract. A preliminary approach to model the hazardous material vehicles flowing towards one critical road infrastructure is presented. Two different approaches are shown. The first one, macroscopic approach, aims to define a problem in which the state and the control variables correspond to the number of vehicles, for which the integrity condition may be relaxed, in order to obtain a continuous-variable decision problem. The second one considers a problem at a microscopic level, in which the granularity of the process is explicitly taken into account, so that the state and the control variables are directly related to each vehicle. Some preliminary results are shown on a case study referred to a highway connecting to a tunnel.

Keywords. Critical infrastructure, traffic, transport, flow control, hazardous material.

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1. Introduction

The transportation of hazardous materials (hazmat) on road has important consequences in the overall traffic management. This fact is more evident when a vehicle requires to move towards a critical road infrastructure, such as a tunnel or a bridge. Safety and security aspects have led critical infrastructure operators to close their infrastructure to hazmat transport or to impose circulation limitations (vehicle quotas per hour, each hazmat transportation preceded by an emergency car…), creating long queues and delays in operations.

The possibility to acquire and to communicate information in real-time from three main different sources (infrastructure, vehicle, driver) and in cooperation among several vehicles, drivers, and infrastructure elements, can lead to the possibility to control the problem in order to mitigate the risk of accidents. In fact, several control possibilities will be more and more achievable, such as for example "stop & go" functions for speed control and maintenance of predefined distances between vehicles; vehicle to vehicle and vehicle to infrastructure communication for negotiation of priorities in the traffic flow or for early warning against on-coming traffic that may violate rules (i.e. incompatible proximity of two or more hazmat vehicles), etc…

The control of traffic networks has been the subject of a great amount of literature from different viewpoints.

One of the first work on traffic flow control in tunnels appeared in 1970 [1]. In that work, a controller was able to determine the number of vehicles between two points in a tunnel and the speed of each vehicle at both points. Using these input variables, the controller could decide if the entering traffic flow rate should be lowered by the use of a sign "pause here – then go". Since then, several works followed, in the direction of the definition of an intelligent transportation system. In this respect, the scientific community has progressively become aware of the need to shift the control on the vehicles [2], enhancing "competition, coordination and cooperation" aspects [3], and vehicle-vehicle communications [4, 5]. In addition, the "scale" of the problem has become more and more relevant, and different models have been proposed at macroscopic, mesoscopic and microscopic level, such as in [6]. The transportation infrastructure is so increasingly monitored by sensors placed on the infrastructure, on the vehicles and in some cases on the drivers themselves, becoming a relevant data source with the aim to improve safety and security [7].

In this work, a preliminary study as regards the possibility to define optimal control strategies for the hazmat traffic flowing towards one critical road infrastructure (e.g. as in the case study a tunnel) is introduced. Specifically, the simplified model that is studied is related to part of a highway with one-way direction, on which the hazmat traffic can flow from several entrances. Several parks are available on the highway in order to control the flow towards the tunnel where the hazmat traffic has strong limitations (for example, just one hazmat vehicle is allowed in the tunnel). The traffic can also be limited at the entrances.

It should be taken into account that the aim of this study is to introduce a preliminary mathematical formulation of the problem allowing the definition and the verification of future real-time distributed control strategies. Forthcoming work will be devoted to the development of such strategies, which can be based on different assumptions about the information acquisition scheme and the decisional architecture.

2. Problem definition

A given number of vehicles transporting hazardous material has to use a highway and to reach one critical infrastructure (e.g. a tunnel). Some park areas are present both near the highway entrances and along the highway. The vehicles may stop in the parks near the highway entrances, and, during the travel, they may stop in the parks positioned along the highway. So, parks may be taken into account as inventories in which the state of the system is represented by the vehicles that are present at a specific time instant. The flow dynamics of hazardous material vehicles on the highway has also to be modeled. Two main decisions can be taken: the number of vehicles that have to leave a park near a highway entrance in a specific time interval *(t, t+1)*; the number of vehicles that have to leave and to enter a park along the highway in a specific time interval *(t, t+1)*. The decision making problem is formalized with the objective of minimizing both the number of vehicles in the park areas and the maximum number of vehicles (per unit length) in every tract of the highway, with the constraint that, for each discrete time interval *(t, t+1)*, only a fixed number of vehicles is allowed to enter the tunnel.

The present work represents a first attempt to formalize a decision model to attain the optimal management of flow of vehicles in order to reduce the risk due to hazmat transportation. Two possible approaches can be followed:

- to define a problem at a macroscopic level, in which the state and the control variables correspond to the number of vehicles, for which the integrity condition may be relaxed, in order to obtain a continuous-variable decision problem;
- to consider a problem at a microscopic level, in which the granularity of the process is explicitly taken into account, so that the state and the control variables are directly related to each vehicle.

A further issue concerning the formalization of the decision problem lies in the fact that the presence of different decision makers interested in managing the vehicles has generally to be taken into account, even at the macroscopic level. At a microscopic level, a different decision maker may be associated to the behavior of each single vehicle.

In the following, the macroscopic and microscopic decision problems are formalized in the simplifying assumption of a single decision maker.

Figure 1 shows the schematic representation of the decision framework: the highway directed towards one critical infrastructure is modeled as a line divided in N highway tracts. Each tract is denoted by an index i, $i = 0,\ldots,N$-1, and the N-th tract corresponds to the tunnel. Let Γ be the set of the indexes correspond to the tracts in the highway to which a park is associated. Moreover, let Φ be the set of indexes of the tracts in the highway to which a highway entrance (that has also always one park for the traffic waiting for entrance) is associated. In this work, a time and space discretization is used as a simplification to formalize the decision problems. Thus, the subdivision of the highway in tracts corresponds to the adopted spatial discretization.

All the hazmat vehicles are assumed to be equivalent and indistinguishable. All of them have a destination requiring the transit through the critical infrastructure, so that the possibility to leave the highway is not taken into account.

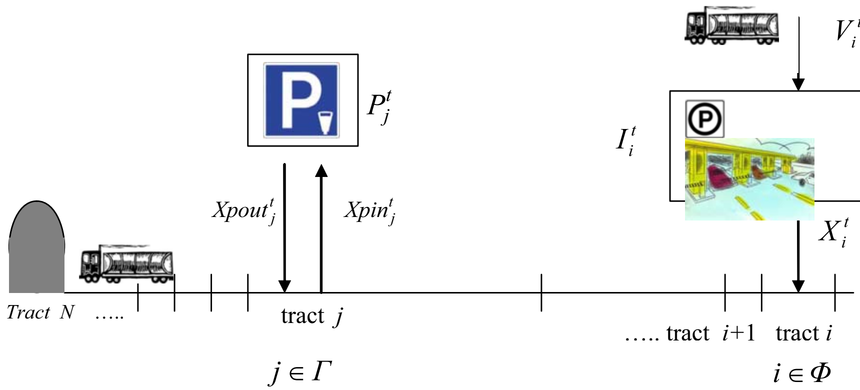

Figure 1. Schematic representation of the system model.

In Figure 1, the parameters, the state and control variables for the macroscopic decision problem are shown. The physical inputs of the whole system are the quantities V_i^t, i.e., the (known) number of vehicles entering the park near the highway entrance in tract *i*, in time interval *(t, t* +1), *t* = 0,…,*T*-1. These vehicles may stop in the park and, after a certain number of time intervals, enter the highway. The decision variables correspond to the number of vehicles that enter (or leave) the various parks (X_i^t , $Xpout_i^t$, $Xpin_i^t$) in a specific time interval (*t*, *t* +1), while the state variables correspond to the inventories and the number of vehicles per tract of the highway (I_i^t , P_i^t , N_i^t). Finally, all vehicles must reach the tunnel, which lies in tract i = *N*.

3. The macroscopic system model

3.1. The system state equation

The optimization problem relevant to the macroscopic model may be stated as follows, making reference to the variables and quantities that are indicated in the scheme represented in Figure 1.

Three different kinds of state equations have to be introduced, regarding, respectively

- the parks at each highway entrance;
- the parks area along the tracts;
- the highway tracts.

3.1.1. The entrance park state equations

The entrance park state equations are:

$$I_i^{t+1} = (I_i^t + V_i^t - X_i^t) \qquad i \in \Phi \quad t=0,\dots, T\text{-}1 \tag{1}$$

where

- I_i^t is the number of vehicles stored, at time instant *t*, in the park near the entrance in tract *i*, i.e., the inventory of the entrance park area, in tract *i* in time interval (*t*, *t*+1);
- X_i^t is the number of vehicles that enter the highway, in tract *i*, in time interval (*t*, *t*+1), from the entrance park area;
- V_i^t is the (known) number of vehicles that enter the entrance park in tract *i*, in time interval (*t*, *t*+1).

3.1.2. The park area state equations

The park area state equations are:

$$P_i^{t+1} = (P_i^t + X_{PIN}{}_i^t - X_{POUT}{}_i^t) \qquad i \in \Gamma \quad t=0,\ldots,T\text{-}1 \tag{2}$$

where

- P_i^t is the number of vehicles that are present in the park area in tract *i* in time instant *t*;
- $X_{PIN}{}_i^t$ is the number of vehicles that enter the park area from the highway, in tract *i*, in time interval (*t*, *t*+1);
- $X_{POUT}{}_i^t$ is the number of vehicles that leave the park area and enter the highway, in tract *i*, in time interval (*t*, *t*+1).

3.1.3. The highway tract state equations

These state equations describe the evolution over time of a state variable that represents the number of hazmat vehicles (per unit length) present in a specific tract of the highway. The speed of these vehicles is related to the overall vehicle density over the considered tract. It is assumed that the vehicle flow can be represented through an average speed, which is common to hazmat and non-hazmat vehicles. In agreement with the literature dealing with traffic models, it is assumed that the (average) vehicle speed is never so high to allow the complete covering of a highway tract within a single time interval (of course, this may be also seen as a constraint over the space discretization of the highway).

The general structure of such state equations is:

$$N_i^{t+1} L_i = N_i^t L_i + [X_{i,i\in\Phi}^t + X_{POUT}{}_{i,i\in\Gamma}^t - X_{PIN}{}_{i,i\in\Gamma}^t + \varphi_{i-1,i}^t - \varphi_{i,i+1}^t]\Delta t$$

$$i=0,\ldots,N\text{-}1 \quad t=0,\ldots,T\text{-}1 \tag{3}$$

with

$$\varphi_{i,i+1}^t = N_i^t vel_i^t \qquad i=0,\ldots,N\text{-}1 \quad t=0,\ldots,T\text{-}1$$

$$\varphi_{-1,0}^t = 0 \qquad t=0,\ldots,T\text{-}1$$

where:

- N_i^t is the number of (hazmat) vehicles per unit length that is present in the highway road in tract *i* in time instant *t* (with a slight abuse, this number is considered also as representative of the number of such vehicles in time interval (*t*, *t*+1));

- $X_{i\in\Phi}^{t}$ is the number of vehicles that enter the highway, in tract *i*, in time interval (*t*, *t*+1); this term is only present when there is a highway entrance in correspondence of the highway tract, i.e., $i \in \Phi$;
- $X_{PIN}{}_{i,i\in\Gamma}^{t}$ is the number of vehicles that enter the park area from the highway, in tract *i*, in time interval (*t*, *t*+1); this term is present only when a park is present in correspondence of the highway tract, i.e., $i \in \Gamma$;
- $X_{POUT}{}_{i\in\Gamma}^{t}$ is the number of vehicles that leave the park area and enter the highway, in tract *i*, in time interval (*t*, *t*+1); this term is present only when a park is present in correspondence of the highway tract, i.e., $i \in \Gamma$;
- $\varphi_{i,i+1}^{t}$ is the flow of vehicles that leave tract *i* and enter tract *i*+1 in time interval (*t*, *t*+1);
- L_i is the *i-th* tract length;
- Δt is the time interval length;
- vel_i^t is the (average) velocity in tract *i* in time interval (*t*, *t*+1), which is assumed to be imposed by the ordinary traffic (i.e., non hazmat), assuming that the hazmat vehicle flow is only a negligible part of the overall traffic flow.

3.2. Hazard assessment

The hazard of accidents depends on different structural and environmental parameters that may vary for each time interval and for each highway tract, and on the number of vehicles [8, 9]. In this work, the hazard HAZ_i^t is simply represented as a time-varying a-dimensional parameter $\eta_{HAZ}{}_i^t$ multiplied by the number of vehicles in the specific tract. That is,

$$HAZ_i^t = \eta_{HAZ}{}_i^t N_i^t \qquad i=0,\ldots,N-1 \qquad t=0,\ldots,T-1 \tag{4}$$

3.3. The decision variables

The control variables of the optimization problem are the variables X_i^t , $X_{PIN}{}_i^t$, and $X_{POUT}{}_i^t$, which have been defined above. Another decision variable is *NUM*, i.e., the maximum number of vehicles (per unit length), for every tract of the highway.

Despite these variables are integer by definition, in order to make simpler the solution of the problem, they have been considered as real, relaxing the integrity constraint.

The state variables of the optimization problem are variables I_i^t , P_i^t , and N_i^t, which have been defined above.

3.4. The optimization objectives

Two objectives are considered:

- the minimization of the (overall) number of vehicles waiting in the park areas and in the entrances *Cp*;
- the minimization of the maximum number of vehicles, per unit length, for every tract of the highway and over the whole time horizon, *NUM*.

The objective function is $J = Cp + \alpha NUM$, where

$$Cp = \sum_{\substack{i=0 \\ i\in\Phi}}^{N-1}\sum_{t=0}^{T-1} I_i^t + \sum_{\substack{i=0 \\ i\in\Gamma}}^{N-1}\sum_{t=0}^{T-1} P_i^t \tag{5}$$

being

$$N_i^t \le NUM \qquad i=0,\dots, N\text{-}1 \qquad t=0,\dots, T\text{-}1 \tag{6}$$

where α is a weighting parameter.

3.5. The constraints

Different classes of constraints are considered in this model: (given) initial and boundary conditions for state variables, non-negativity constraints, constraints for control and state variables and tunnel constraints, expressed as

$$N_N^t \le Tunnel_{\max} \qquad t=0,\dots, T\text{-}1 \tag{7}$$

that means that the number of hazmat vehicles that are allowed to transit, for each time interval, through the critical infrastructure, which is located in tract *N*, is limited.

The resulting optimization problem is a linear programming one.

3.6. Application to a specific example

The optimization problem has been solved for a system characterized by 30 highway tracts, i.e. N=29, with two highway entrances in correspondence of i=1 and i=24 (i=0,..,N-1), and a park area for i=10. The optimization horizon is T=30 minutes, while the time interval is 1 minute, and the spatial interval, that is the length of each tract, is 1 km.

A value of velocity equal to 1 km/minute (60 km/h) has been assumed for each tract and each time interval.

Finally, the following parameter values have been used:

$$Tunnel_{\max} = 1\,;\ \eta_{HAZ}{}_i^t = 10\,;\ I_{\max} = P_{\max} = 10\,;\ \alpha = 1\,.$$

In the considered case study, 20 vehicles have been assumed to enter the system at specific instants (see Table 1).

Table 1. Summary of results as vehicle arrivals for the macroscopic decision problem

Tract	Time	Number of vehicles V_i^t
1	1	6
1	2	4
1	3	2
1	4	2
24	23	2
24	24	2
24	25	1
24	26	1

The application of the proposed decision scheme provides the following results for the optimal solution: optimal cost = 22, *NUM* = 8.

Besides, in Table 2, the optimal values of the non-zero control variables is reported.

Table 2. Optimal control variables for the macroscopic decision problem.

Tract	Time	Number of vehicles		
		X_i^t	$Xpin_i^t$	$Xpout_i^t$
1	1	6		
1	3	6		
1	4	2		
24	23	1		
24	24	1		
24	25	2		
24	26	2		
10	10		6	
10	11			6

The obtained optimal results have been compared with the results deriving from the application of an "no stop" policy, according to which, for the same arrival pattern as above, all vehicles arriving at the highway entrances are allowed to enter the highway and do not stop at the parking areas along the highway.

A significant comparison of the results provided by the application of the two policies may be carried out by evaluating the *overall hazard* defined as

$$HAZTOT = \sum_{i=0}^{N} \sum_{t=0}^{T-1} HAZ_i^t \tag{8}$$

Namely, it has been obtained $HAZTOT = 4120$ for the optimal management policy, and $HAZTOT = 4250$ for the "no stop" policy.

4. The microscopic optimization problem

The system model now takes into account each single vehicle that may enter a highway tract, may stop in the park areas along the highway, and finally has to reach the end of the highway, represented by a tunnel. The state variables refer to the presence/absence of a vehicle k in the parks or in a highway tract in a specific time interval. The control variables define whether access is allowed or not to a specific vehicle k in time interval (t, t+1) in a specific highway tract (i, i +1), and the decision to enter or leave a park during the travel.

This microscopic model differs from the previous one because control and state variables are related to each single vehicle. The model is more complicated than in the macroscopic case. The complexity of the optimization problem grows exponentially with the increase of the binary variables related to each vehicle. However, the formulation can give an idea of the decisions to be taken for each vehicle and its analysis may represent an interesting step towards more effective statements of optimal decision problems. In case an on-line implementation is sought, more efficient methods than the application of mathematical programming techniques should be used. In addition, the present formulation still refers to a centralized decision making approach, whereas it seems more convenient to apply a decentralized decision framework.

4.1. The system model

Five different classes of state equations are introduced, respectively referring to

- the parks at each highway entrance;
- the time spent by the vehicles in the parks before highway entrance;
- the park areas along the tracts;
- the time spent by the vehicles in the park areas;
- the highway tracts.

4.1.1. The entrance park state equations

The main difference from the macroscopic model lies in the fact that both state and control variables are binary to indicate the presence of vehicle k, k=1, …, K, in a specific tract i, $i = 0,\ldots,N$-1, and at time t, $t = 0,\ldots, T$-1.

The equations for the park near the entrance are

$$I_{k,i}^{t+1} = (I_{k,i}^t + V_{k,i}^t - X_{k,i}^t) \qquad t=0,\ldots, T\text{-}1, \quad k=1,\ldots, K, \quad i \in \Phi \tag{9}$$

where:

- $I_{k,i}^t$ indicates the presence/absence (1/0) of vehicle k (binary state variable) in the park near the entrance in tract i, in time interval (t, t+1);

- $X_{k,i}^{t}$ is a binary variable that is equal to 1 if vehicle k leaves the park near the entrance in tract i and enters the highway in time interval (t, t+1), and 0 otherwise;
- $V_{k,i}^{t}$ is a binary parameter that is equal to 1 if vehicle k enters the park near the entrance in tract i in time interval (t, t+1), and 0 otherwise;
- Φ is the set that includes the indexes of the tracts where there is an entrance to the highway.

4.1.2. The time spent in the highway entrance inventory

Let $Agei_{k,i}^{t}$ be the state variable that represents the time (units) already spent by vehicle k up to time instant t in the park near the highway entrance in tract i ($i \in \Phi$). Such state variables vary according to

$$Agei_{k,i}^{t+1} \lambda_{k,i}^{t} = (Agei_{k,i}^{t} + 1)(1 - \sum_{f=1}^{t} X_{k,i}^{f}) \lambda_{k,i}^{t}$$
$$t=0,\dots, T\text{-}1 \quad k=1,\dots, K \quad i \in \Phi \tag{10}$$

$$Agei_{k,i}^{t+1}(1 - \lambda_{k,i}^{t}) = Agei_{k,i}^{t}(1 - \lambda_{k,i}^{t})$$
$$t=0,\dots, T\text{-}1 \quad k=1,\dots, K \quad i \in \Phi \tag{11}$$

where

$$\lambda_{k,i}^{t} = \begin{cases} 1 \quad if \quad \sum_{f=1}^{t} V_{k,i}^{f} = 1 \\ 0 \quad if \quad \sum_{f=1}^{t} V_{k,i}^{f} = 0 \end{cases}$$
$$t=0,\dots, T\text{-}1 \quad k=1,\dots, K \quad i \in \Phi \tag{12}$$

The variation of the state variable $Agei_{k,i}^{t}$ (that is set equal to zero when t = 0) depends on the presence/absence of vehicle k in the park. If vehicle k has not entered the park before time t, $Agei_{k,i}^{t}$ does not vary (and is equal to zero), otherwise it is incremented according to the time the vehicle spends in the park. Moreover, $Agei_{k,i}^{t}$ is zero when the vehicle leaves the park.

The variable $\lambda_{k,i}^{t}$ has been introduced to activate or not the state equation that increments the vehicle "age".

4.1.3. The park area state equations

Analogously to equation (9), the following state equations can be introduced as regards the park areas along the highway

$$P_{k,i}^{t+1} = (P_{k,i}^{t} + X_{PIN}{}_{k,i}^{t} - X_{POUT}{}_{k,i}^{t}) \qquad t=0,\ldots,T\text{-}1 \quad k=1,\ldots,K \quad i \in \Gamma \qquad (13)$$

where:

- $P_{k,i}^{t}$ is a binary variable indicating the presence/absence of a vehicle in the park area along tract i in time interval $(t, t+1)$;
- $X_{PIN}{}_{k,i}^{t}$ is a binary variable equal to 1 if the vehicle enters the park area along tract i from the highway in time interval $(t, t+1)$, and 0 otherwise;
- $X_{POUT}{}_{k,i}^{t}$ is a binary variable equal to 1 if the vehicle leaves the park area along tract i and enter the highway in time interval $(t, t+1)$, 0 otherwise;
- Γ is the set that includes the park areas in the highway.

4.1.4. The time spent in the park areas

Expressions similar to those reported as regards the time spent by the vehicles in the entrance parks can be written with reference to the time spent in the park areas along the highway. Namely, the following symbol substitutions must be introduced in equations (10)-(12): $Agep_{k,i}^{t} \rightarrow Agei_{k,i}^{t}$, $X_{POUT}{}_{k,i}^{f} \rightarrow X_{k,i}^{f}$, $X_{PIN}{}_{k,i}^{f} \rightarrow V_{k,i}^{f}$.

4.1.5. The highway tract state equations

The state equation is formulated in terms of the presence/absence of a specific vehicle in each highway tract and as a function of the control variables. To this end, a further definition is required:

- $\gamma_{k,i}^{t}$ is a binary variable that is equal to 1 if vehicle k is present in part i in time interval $(t, t+1)$, and 0 otherwise.

To simplify the model, the following assumption is made: the length of each tract is such that, at the speed that characterizes each tract (that is supposed to be given and fixed by the ordinary traffic flow) no vehicle can jump, within a time interval, from a tract i to a tract $(i+2)$, and has necessarily to enter tract $(i+1)$ (unless it is decided to send it to a park along tract i). Clearly, this assumption is substantially relevant to the choice of the space discretization. With this assumption, the following equations hold

$$\gamma_{i,k}^{t+1} = \gamma_{i-1,k}^{t} + X_{k,i}^{t} + X_{POUT}{}_{k,i}^{t} - X_{PIN}{}_{k,i}^{t}$$
$$i=1,\ldots,N \quad k=0,\ldots,K \quad t=0,\ldots,T\text{-}1 \qquad (14)$$

4.2. Hazard assessment

Even for the microscopic model, the hazard HAZ_i^t is evaluated via a time-varying parameter $\eta_{HAZ}{}_i^t$ multiplied for the number of vehicles in the specific tract. Moreover, there is a factor of the hazard that depends on the specific vehicle: let INS_k be the hazard associated to a specific vehicle (characterized by the insurance class of the driver, vehicle conditions, etc.).

In this way,

$$HAZ_i^t = \eta_{HAZ}{}_i^t N_i^t + \sum_{k=0}^{K} \gamma_{i,k}^t INS_k$$

i=0,…, N-1 k=0,…, K t=0,…, T-1 (15)

4.3. The decision variables

The control variables of the optimization problem are $X_{k,i}^t$, $X_{PIN}{}_{k,i}^t$, $X_{POUT}{}_{k,i}^t$, and *NUM* (similarly defined as in the macroscopic model). The state variables of the optimization problem are $I_{k,i}^t$, $Agei_{k,i}^t$, $P_{k,i}^t$, $Agep_{k,i}^t$, $\gamma_{k,i}^t$, and $N_{k,i}^t$.

4.4. The objectives

In this case, the objectives are:

- the minimization of the overall number of vehicles in the park areas and in the entrances *Cp*;
- the minimization of the maximum number of vehicles in every highway part *NUM*.

The objective function is $J = Cp + \alpha NUM$, where

$$Cp = \sum_{\substack{i=0 \\ i\in\Phi}}^{N-1}\sum_{t=0}^{T-1}\sum_{k=0}^{K} I_{k,i}^t + \sum_{\substack{i=0 \\ i\in\Gamma}}^{N-1}\sum_{t=0}^{T-1}\sum_{k=0}^{K} P_{k,i}^t \qquad (16)$$

with

$N_i^t \le NUM$ i=1,…, N t=0,…, T-1 (17)

4.5. The constraints

Different classes of constraints are considered in this work: initial and boundary conditions, non-negativity constraints, constraints on the binary variables, specific rules for the fleet management, and tunnel constraints. In the following, only the most relevant of such constraints will be detailed.

4.5.1. Binary variables conditions

Since a binary variable is defined for each vehicle, each tract, and each time, it should be guaranteed that the same vehicle does not appear more that once in the system. To this end, the following constraints have been introduced.

$$\sum_{i=0}^{N}\sum_{t=0}^{T-1} V_{i,i\in\Phi,k}^t \le 1 \qquad k=0,\ldots,K \qquad (18)$$

$$\sum_{t=0}^{T-1} X^t_{i,i\in\Phi,k} \leq 1 \qquad i=0,\ldots,N\text{-}1 \quad k=0,\ldots,K \tag{19}$$

$$\sum_{i=0}^{N} \sum_{t=0}^{T-1} X^t_{i,i\in\Phi,k} \leq 1 \quad k=0,\ldots,K \tag{20}$$

$$\sum_{i=0}^{N} X^t_{i,i\in\Phi,k} \leq 1 \qquad k=0,\ldots,K \quad t=0,\ldots,T\text{-}1 \tag{21}$$

$$X^t_{i,i\in\Phi,k} \leq I^t_{i,i\in\Phi,k} \quad i=0,\ldots,N\text{-}1 \quad k=0,\ldots,K \quad t=1,\ldots,T\text{-}1 \tag{22}$$

$$X^t_{i,i\in\Phi,k} \leq V^t_{i,i\in\Phi,k} \quad i=0,\ldots,N\text{-}1 \qquad k=0,\ldots,K \quad \mathrm{t}=0 \tag{23}$$

$$\sum_{i=0}^{N} I^t_{i,i\in\Phi,k} \leq 1 \qquad k=0,\ldots,K \quad t=0,\ldots,T\text{-}1 \tag{24}$$

$$\sum_{i=0}^{N} \sum_{t=0}^{T-1} \gamma^t_{i,k} \leq 1 \qquad k=0,\ldots,K \tag{25}$$

$$\sum_{t=0}^{T-1} Xpin^t_{i,i\in\Phi,k} \leq 1 \quad i=0,\ldots,N\text{-}1 \qquad k=0,\ldots,K \tag{26}$$

$$\sum_{i=0}^{N} Xpin^t_{i,i\in\Phi,k} \leq 1 \qquad k=0,\ldots,K \quad t=0,\ldots,T\text{-}1 \tag{27}$$

$$\sum_{i=0}^{N} \sum_{t=0}^{T-1} Xpin^t_{i,i\in\Phi,k} \leq 1 \qquad i=0,\ldots,N\text{-}1 \qquad t=0,\ldots,T\text{-}1 \tag{28}$$

$$\sum_{t=0}^{T-1} Xpout^t_{i,i\in\Gamma,k} \leq 1 \qquad i=0,\ldots,N\text{-}1 \qquad k=0,\ldots,K \tag{29}$$

$$\sum_{i=0}^{N} Xpout^t_{i,i\in\Gamma,k} \leq 1 \qquad k=0,\ldots,K \quad t=0,\ldots,T\text{-}1 \tag{30}$$

$$\sum_{i=0}^{N}\sum_{t=0}^{T-1} Xpout_{i,i\in\Gamma,k}^{t} \le 1 \qquad k=0,\dots,K \tag{31}$$

$$Xpout_{i,i\in\Gamma,k}^{t} \le P_{i,i\in\Gamma,k}^{t}$$
$$i=1,\dots,N \qquad k=0,\dots,K \qquad t=0,\dots,T\text{-}1 \tag{32}$$

$$Xpin_{i,k}^{t} \le \gamma_{i-1,k}^{t} \quad \text{or} \quad Xpin_{i,i\in\Gamma,k}^{t} = \begin{cases} 0 & if\ \gamma_{i,i\in\Gamma,k}^{t} = 0 \\ Xpin_{i,i\in\Gamma,k}^{t} & if\ \gamma_{i,i\in\Gamma,k}^{t} = 1 \end{cases} \tag{33}$$
$$i=0,\dots,N\text{-}1 \qquad k=0,\dots,K \qquad t=0,\dots,T\text{-}1$$

$$\sum_{i=0}^{N} \gamma_{i,k}^{t} \le 1 \qquad k=0,\dots,K \qquad t=0,\dots,T\text{-}1 \tag{34}$$

4.5.2. Rules for the management of the vehicle fleet

The following rule must be applied in the fleet management:
"At a given entrance, if a vehicle is waiting in the park for a time equal to $Agei^{\max}$*, then it should leave the park"*

$$X_{i,i\in\Phi,k}^{t} = \begin{cases} 1 & if\ Agei_{i,i\in\Phi,k}^{t} = Agei^{\max} \\ X_{i,i\in\Phi,k}^{t} & if\ Agei_{i,i\in\Phi,k}^{t} < Agei^{\max} \end{cases}$$
$$i=0,\dots,N\text{-}1 \qquad k=0,\dots,K \qquad t=0,\dots,T\text{-}1 \tag{35}$$

A similar constraint holds even for the parks along the highway, namely

$$Xpout_{i,i\in\Gamma,k}^{t} = \begin{cases} 1 & if\ Agep_{i,i\in\Gamma,k}^{t} = Agep^{\max} \\ Xpout_{i,i\in\Gamma,k}^{t} & if\ Agep_{i,i\in\Gamma,k}^{t} < Agep^{\max} \end{cases}$$

$$i=0,\dots,N\text{-}1 \qquad k=0,\dots,K \qquad t=0,\dots,T\text{-}1 \tag{36}$$

4.5.3. Tunnel's capacity

$$N_N^t \le Tunnel_{\max} \qquad t=0,\dots,T\text{-}1 \tag{37}$$

4.6. Application to a specific example

The optimization problem has been solved for a system characterized by 30 highway tracts, i.e. N=29, with two highway entrances in correspondence of i=1 and i=24 (i=0,..,N-1), and a park area in i=10. The optimization horizon is T=30 minutes, while the time interval is 1 minute, and the spatial interval is 1 km. The parameters have been so specified: $Tunnel_{\max} = 1$; $\eta_{HAZ}{}_i^t = 10$; $INS_k = 5$; $I_{\max} = P_{\max} = 10$; $Agep_{\max} = Agei_{\max} = 1$; $\alpha = 1$. The optimal results have been derived for 20 vehicles entering the system at specific instants (see Table 3).

The optimal value of the objective function is 22, with *NUM* equal to 9.

Even in this case a comparison has been carried out with the results provided by an "no stop" policy. In this case, it has been obtained *HAZTOT* = 6195 for the optimal management policy, and *HAZTOT* = 6360 for the "all-pass" policy.

The software package Lingo 9.0 (www.lindo.com) has been used to solve the optimization problem. The computational time to run the microscopic model applied to the specific case study is about 15 minutes.

Table 3. Results concerning the vehicle arrival for the microscopic system.

Vehicle	**Tract**	**Time**	$V_{k,i}^t$
1	1	1	1
2	1	2	1
3	1	3	1
4	1	4	1
5	24	23	1
6	24	24	1
7	1	1	1
8	1	2	1
9	1	3	1
10	1	4	1
11	24	23	1
12	24	24	1
13	1	1	1
14	1	1	1
15	24	25	1
16	24	26	1
17	1	2	1
18	1	1	1
19	1	2	1
20	1	1	1

5. Conclusion

In this work, two different decision problems for hazardous material vehicles moving towards one critical road infrastructure have been presented. The first one is based on the choice to consider as a state variable the number of vehicles present in a specific highway tract at a specific time instant. On this basis, a macroscopic (linear) optimization problem can be stated. The formulation of the second decision problem (microscopic) is based on the representation of the state of each single vehicle. In this case, the optimization problem turns out to be mixed (continuous-binary) nonlinear. This second model allows considering specific constraints for the different vehicles, and allows to control the single vehicle behavior over time and space. Results for the different case studies are obtained and compared with a “no-stop” policy. In particular, the proposed decision models allow to control the hazardous material flows and to reduce the overall hazard of incidents and the hazard near the critical infrastructures (represented by the tunnel, in this case). That is true both for the macroscopic and the microscopic model.

The main problem regards the efficiency of solution of common optimization software for nonlinear mixed integer programming. This is an NP-Hard problem, and specific and efficient optimization techniques should be developed, exploiting the special structure of the related optimization problems. Future developments will be devoted to the development of such alternative approaches for the (microscopic) optimization problem. Besides, an approach to be adopted in the case of a decentralized (cooperative or competitive) decision making scheme is also urgently needed.

References

[1] R. F. Cunningham, C.F. White, Vehicular tunnel traffic-flow control, *IEEE Trans. on Vehicular Technology*, **19** (1), 120-128, 1970.

[2] E.J. Davison, U. Ozguner. Decentralized control of traffic networks, *IEEE Trans. on Automatic Control*, **28** (6), 677-688, 1983.

[3] G. Knieps. Competition, coordination and coordination. A disaggregated approach to transportation regulation, *Utilities policy*, 201-207, July 2003.

[4] B. van Arem, C.J.G. van Driel, R. Visser, The impact of cooperative adaptive cruise control on traffic-flow characteristics, *IEEE Trans. on Int. Transp. Syst.*, **7** (4), 429-436, 2006.

[5] G. Vashitz, D. Shinar, Y. Blum, In-vehicle information systems to improve traffic safety in road tunnels, *Transportation Research Part F*, **11**, 61-74, 2008.

[6] K. Li, P. Ioannou. Modeling of traffic flow of automated vehicles, *IEEE Trans. on Int. Transp. Syst.*, **5** (2), 99-113, 2004.

[7] D. Zeng, S.S. Chawathe, H. Huang, F.Y. Wang, Protecting information infrastructure, IEEE intelligent systems, 9-11, September-October 2007.

[8] B. Fabiano, F. Currò, E. Palazzi, R. Pastorino, A framework for risk assessment and decision-making strategies in dangerous good transportation, *Journal of Hazardous Materials* **93**, 1–15, 2002.

[9] B. Fabiano, F. Currò, A.P. Reverberi, R. Pastorino, Dangerous good transportation by road: from risk analysis to emergency planning, *Journal of Loss Prevention in the Process Industries* **18**, 403–413, 2005.

Conclusions

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Advanced Technologies and Methodologies for Risk Management in the Global Transport of Dangerous Goods
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Dangerous Goods Transportation and Related Research Challenges in the Human and Societal Dynamics

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With respect to other technological risks, risks related to the transportation of dangerous goods (DGs) are characterized by their mobile and complex nature. This complexity brings many scientific and professional teams from wide fields to interest themselves in this problematic: behaviours psychology, transportation ergonomics, risk management, regulation and logistic procedures, road-related infrastructure, computer sciences and so on.

In addition to aspects bound to the real-time localization of the vehicles and to related forthcoming technologies as the Galileo system, advanced information systems are likely to have a predominant influence in the management of DGs transportation in the different modes. For example, new methodologies and technologies will be more and more required to manage the control access to key infrastructures and to certain geographic zones, the definition of a determinate low risk itinerary, the effects of higher DGs concentrations in parking areas and the real-time definition of safety distances between vehicles. Indeed, for territorial authorities, it will become more and more crucial to have intelligent information systems for alarms and incidents management.

Specifically, the contribution of intelligent transportation systems should at first facilitate the following actions:

To ensure software components and telecommunication technologies integration. Most senders and carriers of DGs use a teleprocessing system to follow-up and to control vehicles as well as tools for management of DGs carried according to their

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nature and related rules. In this case, these systems have to be compatible when change of approaches and technologies is detected among loaders, carriers, infrastructures managers, etc.

To provide all required information to operators and carriers for certain tasks: verification of compliance with DGs declaration for the management by different operators; geo-localisation; containers tracking with radio communication, statistics, etc. Make the availability, integrity and privacy of DGs data.

The tracking technological solutions currently proposed follow two main approaches.

The first one assumes that it is not possible to access information on single vehicles transporting DGs. In order to know the flows of TDG, it is necessary to position a kind of technology on the roads which allows to "observe" and "recognise" the orange signs identifying the DGs transported. The main advantage of this approach is that no technological requirement is needed on the vehicle. The main disadvantages are those of the difficult optical identification in particular cases (e.g. vehicles in motion, dirty signs, insufficient lighting, badly placed signs, etc.), the utter lack of knowledge of the state of the goods carried (e.g. quantity, temperature, etc.) and the lack of information about the vehicle's routing.

A possible evolution of such technologies should be the shift of optical identification of the sign towards the electronic identification of the sign through the equipment of the vehicle with passive RFIDs (Radio Frequency Identifier).

The second approach follows the idea of installing on the vehicle technologies for the monitoring of the goods and the journey of vehicles carrying DGs. It also aims at the real-time transmission of such information to a remote centre of data processing. The main advantage of such approach is the chance to acquire a large amount of information on the vehicle, also using technologies already present on the vehicle itself (such as the CAN, or the electronic counter for tankers). By means of a simple telephone data channel such as the GPRS it is possible to know with the help of the GPS technology where the vehicle is at every moment and the state of the vehicle and the goods. By using the transmission channel to the vehicle, it is possible to control the vehicle and send instruction on the least hazardous routing, authorising or denying the passage on some roads. The main disadvantages are those of the necessary costs of the equipment for the vehicle with such technologies – although the equipment costs accounts for an additional 1-2% on the cost of the vehicle and the transmission cost is quite low, corresponding to the flat tariffs of GPRS telephone transmission data. Other disadvantages are caused by difficult networking in high-risk routings (e.g. in tunnels or roads winding in woods with bad GPS reception, mountain roads with weak or missing GPRS signal, etc.). However it has been noted that poor GPS reception in tunnels can partially be corrected with the use of data regarding the speed acquired by the vehicle's odometer. From the tests, it has also been seen that the routings covered by vehicles have good GPRS networking.

A natural evolution of such systems will be the use of the Galileo European location system, the possible use of cameras on the vehicle using broad-band transmission channels such as UMTS.

If it is used on a larger scale, i.e. on more survey stations on the infrastructures and if for some types of transports real-time technologies on the vehicle are required as compulsory, the model presented will integrate the two approaches and considerably improve the monitoring and control of such transport.

From the methodological point of view, some possible instruments to support decisions have been analysed. Despite the several research efforts, there is not a general accepted definition of risk, in the different modes of DG transport, most of all as regards a real time definition of risk. It has been highlighted that informative contributions acquired in real-time endogenous (location, goods transported, etc.) and exogenous (traffic and road surface conditions, weather) to the road transport of DGs may considerably improve.

The evaluation of the aftermath of an accident can be simulated to underscore possible risks. Likewise, routing techniques can be used to minimise such risks. This of course represent the most urgent research challenge in the human and societal dynamics.

As regards the most wanted shift to modes of the transport of goods in general – including dangerous – different from that of the road, it is also true that over the next decade some transport – such as the haulage of oil products for instance – will necessarily use the road. In the short run, even the progressive introduction of hydrogen in the fuelling of cars to reduce polluting emissions will have a role in the transport of hydrogen from the large production sites - such as for example the production of hydrogen as a by-product of oil refining – to service stations by means of tankers, with tremendous consequences for risk management.

In conclusion, we believe this book to be a useful guide for the practical carrying out of monitoring centres of the flow of DGs on the road as well as a good reference for experiences of different research groups spread all over the world.

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