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Dangerous Goods Transportation by Road: a Risk Analysis Model and a Global Integrated Information System to Monitor Hazardous Materials Land Transportation in Order to Protect Territory

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DESTINATION project, started in 2010 in the framework of the Italy/Switzerland Operational Program for Transfrontier Co-operation 2007-2013, was born to answer to the increasing needs of public bodies to share data on hazardous material land transportation and to develop instruments and methodologies to ensure territorial and environmental protection.
The partnership is made of 5 members: Canton Ticino, Piedmont Region as Leader of the project, Lombardy Region, Autonomous Region of Aosta Valley and Autonomous Province of Bolzano Alto Adige. Technical partners working on DESTINATION are CSI Piemonte, 5T S.r.l. and Laboratorio Mobilità e Trasporti del Politecnico di Milano.
One of the main objective of the project is the definition of a risk analysis model of the land transportation of hazardous materials, able to take into account even environmental vulnerabilities. It will constitute the basis to a new information system design called GIIS (Global Integrated Information System), in order to contribute to road accident prevention, real-time monitoring of Dangerous Goods Transportation by road (DGT) through On Board Units and fixed points (gates) and more efficient emergency management.
In this paper we describe the DGT risk model designed and the main features of the Information System that is going to be developed.

1. Introduction

In Europe a relevant quota of goods transport is made by road. In recent years European Union programmes are concentrating their attention on transport safety, on initiatives aimed at reducing road accident occurrence, at monitoring road traffic as well as implementing measures to monitor hazardous material land transportation.
Control on dangerous goods has always been focused on productive plants, but in the last years more attention has been paid to monitoring transport of dangerous goods by road (Benza et al., 2007), to prevent accident occurrence and minimize the potential damages due to an accident involving a vehicle transporting hazardous materials (Fanelli et al., 1999). Other studies and researches conducted were aimed to obtain a more effective planning of the activity of transport of dangerous goods (Romano et al. 2010), to manage crisis situations (Pastorelli et al., 2010) and to analyse criteria for risk definition (Maja et al., 2008).

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ADR (2010) is the European Agreement concerning the International Carriage of Dangerous Goods by Road whose aim is to guarantee a high level of safety in all transport operations, focusing its attention on the requirements road vehicle carrying dangerous goods have to be compliant with and on the driver training.
Dangerous Goods Transport by road represents about the 5-6% of the entire amount of transported goods in Europe and according to the laws and regulations in force it is not required to monitor and control the route of vehicles transporting hazardous materials.
DESTINATION project starts up from the awareness of this lack in legislation with the overall objective to create an instrument and a methodology useful to enrich knowledge on DGT and on the anthropic and environmental vulnerability, in order to protect territory.
The main problem in DGT risk assessment is that the accident location and the vulnerabilities around are unpredictable. The aim of the project is to design and implement Global Integrated Information System (GIIS) for data acquisition on dangerous goods transport by road, on anthropic and environmental vulnerabilities and on the resilience of territory, that will be the input data set for the calculation of the risk associated to the land transportation of hazardous materials.
The risk analysis model is based on different scenarios depending on the accident type and on the dangerous goods substances transported.
The data acquisition activity required the localization of critical points where there will be installed gates able to recognize ADR license plates and the identification of private transport companies in order to install On Board Units (OBU) on their vehicles. Gates and OBU will be connected to the GIIS through an interface to transmit data on ADR vehicles transits.
The so-called GIIS will process a risk map of all the area of the project and will be able to display the risk at a local scale, depending on the user needs. Simulation features will also be available according to the needs of public and private stakeholders.

2. The DGT Risk Analysis Model

The first step has been a survey on the whole territory involved in the project to determine the main needs of public and private stakeholders. Moreover an accurate survey on geographical, anthropic and environmental data available has been performed to identify a common data set.
The next step has been the definition of a methodology of DGT risk analysis taking into account data availability on dangerous goods transportation, such as “road accident occurrence”, “road traffic”, and on the territory such as “anthropic and environmental vulnerability” and "resilience".

2.1 The DGT risk formula

The parameters and their functional dependencies have been defined also taking into account the need of optimizing the implementation of the algorithm in the GIIS.
To determine the connection of each parameter to the elements of major interest, 4 "subscripts" have been defined:
- arch road (i)
- ADR substance (j)
- incident scenario with a specific threshold and a consequential damage area (k)
- type and susceptibility of targets (m)

The general risk formula is the following:

$$R_{Dest} = \sum_i R_i = \sum_i \left(P_{is,i} \times \sum_j \left(P_{ADR,ij} \times \sum_k \left(P_{sc,ijk} \times \sum_m \left(Fp_m \times E_{ikm} \times S_{km} \times \left(1 - C_{ff,ikm}\right)\right)\right)\right)\right) \quad (1)$$

Where:
R_{Dest} = “Destination” cumulated risk (deaths/y), (damaged m^2/y), (€/y)
R_i = cumulated risk referred to the *i-th* arch (deaths/arch/y) (damaged m^2/arch/y) (€/arch/y)
$P_{is,i}$ = road hazard referred to the *i-th* arch (vehicles involved in accident/arch/y)
$P_{ADR,ij}$ = occurrence probability of a car accident involving a *j-th* ADR substance referred to the *i-th* arch (ADR vehicles involved in accidents/vehicles involved in accidents)
$P_{sc,ijk}$ = occurrence probability of a *k-th* incident scenario with a specific threshold and a

consequential damage area (*k*), involving the *j-th* substance, on the *i-th* arch (incident scenario/ADR vehicles involved in accident)

$Fp_{,m}$ = presence factor of the potentially exposed target referred to specific temporal sets

E_{ikm} = *m-th* target potentially exposed to a *k* incident scenario with a specific threshold and a consequential damage area (*k*), involving the *j-th* substance, on the i-*th* arch (exposed inhabitants/incident scenario), (exposed m^2/incident scenario), (estimated € of damage/incident scenario)

S_{km} = susceptibility of the *m-th* target (deaths/exposed inhabitants), (damaged m^2)/(exposed m^2), (damage in €/estimated € of damage)

$C_{ff,ikm}$ = resilience/copying capacity of the *m* target potentially exposed to a *k* incident scenario with a specific threshold and a consequential damage area *(k)*, involving the *j-th* substance, on the *i-th* arch (multiplicative factor from 0.10 to 0.20)

The formula is structured as a sequence of additions and multiplications, in order to simplify the implementation in the GIIS and to give the possibility to break it down in "prime factors", being able to have as a result not only the cumulated risk on the examined area, but also some intermediate results. For example it could be useful in emergency planning to calculate the addition of the exposed targets in an area, which will be expressed as follows:

$$\sum_m E_{ikm} \tag{2}$$

Similarly it is possible to calculate for each road arch (i), without considering the occurrence probability of a car accident or the real DGT traffic, the damage originated by an incident involving a specific substance (j):

$$\sum_k \left(P_{sc,ijk} \times \sum_m \left(E_{ikm} \times S_{km} \times \left(1 - C_{ff,ikm}\right)\right)\right) \tag{3}$$

This result could be used to evaluate substances that should not transit on a specific road or to define specific DGT routes.

2.2 Pis,i (Occurrence Probability of car accident)

The parameter Pis,i represents the probability of each road elements to be interested by a generic car accident.

After a first attempt trying to find a relation between Pis and road features, road traffic intensity and weather conditions, the calculation of this parameters in the GIIS will be as follows:

$$P_{is} = Inc \times p_{terr} \tag{4}$$

where:

Inc = car accident occurrence (accidents/km/year)

p_{terr} = factor that increases the value of Inc, taking into account the domino effect of territorial elements (landslides, floods, avalanches)

The factor Inc will be calculated using historical statistics with a method able to avoid the possibility that road links could be characterized by a value of 0 accidents.

2.3 P_{ADR} (Occurrence probability of car accident involving a vehicle transporting hazardous land materials)

The historical statistic do not report information on the type of vehicles involved in generic car accidents. The quota of accident involving vehicles transporting dangerous goods (ADR vehicles) is unknown, so it is assumed that P_{ADR} correspond to the ratio of traffic quota of dangerous goods transports to the generic traffic:

$$P_{ADR} = k_{inc,pes} \times k_{traff,ADR} \tag{5}$$

where:

$k_{inc,pes}$ = ratio of heavy traffic involved in car accidents to the generic traffic (heavy vehicles involved in car accidents/circulating vehicles involved in car accidents)

$k_{traff,ADR}$ = ratio of ADR traffic to heavy traffic (ADR traffic/heavy traffic)

Real time monitoring through gates and OBU placed on trucks will allow in the long term to improve the methodology with real data on ADR transits.
There have been considered 58 hazard of interest for DESTINATION project and 10 model substances (Table 1) that represent the main incident scenarios. So the parameter PADR will be a vector of 68 lines (58+10) having different values for each road arch.

Table 1: Model substances

Kemler Number	ONU Number	Substance
225	1073	oxygen, refrigerated liquid
23	1049	hydrogen, compressed
23	1075	petroleum gases, liquefied
25	1072	oxygen, compressed
263	1040	ethylen oxyde (+nitrogen)
268	1005	ammonia, anhydrous
30	1202	gas oil
33	1203	gasoline
336	1230	Methanol
63	2023	epichlorohydrin

2.4 P_{sc} (Occurrence probability of a scenario)

$P_{sc,ijk}$ is the probability that from a road accident involving an ADR vehicle a series of events determine a hazardous material release with a consequential scenario with a specific threshold and a specific damage area (buffer).
This parameter is a function of the probability of release, depending on the type of container used (atmospheric or pressure tank) and on the extent of the loss and the trigger probability:

$$P_{sc}(p) = P_{pc} \times P_{inn} \tag{6}$$

where :

$P_{sc(p)}$ = probabilistic component of P_{sc} (incident scenario/accident ADR vehicles)

P_{pc} = probability of loss (ADR vehicles with loss/accident ADR vehicles)

P_{inn} = trigger probability (incident scenario/accident ADR vehicles)

11 standard incident scenarios have been chosen to be considered in DESTINATION project, that can damage human and non-human targets, including pool fire, flash fire, fire ball, jet fire, release in water and soil and toxic gases and vapor release.

2.5 Fp (Presence factor), E (Potential exposed targets), S (Potential exposed targets susceptibility) and C_{ff} (Coping capacity)

The parameter E express the potential targets exposed to the different scenarios.
The GIIS will have to calculate and display the DGT risk for the targets listed below:

Table 2: Human targets considered in the risk analysis model

Human Targets	Non-human targets
Resident population	Structures
Industries employees	Woods
Hospital employees and users	Protected areas
School employees and users	Agricultural areas
Shopping center employees and users	Ground Waters
	Surface waters

The calculation of consequences will be made by overlaying the damage area to the target maps exposed to a specific incident scenario. The areas related to human targets could be expressed as number of equivalent inhabitants. For non-human targets it will be necessary to find a way to give them a common unit.
The parameter S represents the fact that not all targets potentially exposed could be really damaged, whereas the C_{ff} is defined as the resilience or coping capacity, which means the capability of the territory to face the damage reducing it.
The parameter Fp is able to quantify the actual presence of targets considering different time sets (for example weekday or weekend).

3. GIIS features

The GIIS will be designed as a modular system, able to give features for preventive, passive and active safety. It will be structured according to the Implementing rules of INSPIRE Directive, whose aim is to create a European Union spatial data infrastructure.
The user will be able to process and view a DGT risk map on a selected area. Road sections will be displayed with different colors to show different levels of DGT risk.
The system will provide also simulation features, e.g. inserting on the map the point where an accident could occur to verify impact areas, vulnerabilities and to evaluate the potential environmental and anthropic damage.
The GIIS will be designed to be able to provide features such as infomobility services, giving to the driver information on weather conditions, traffic, parking areas, presence of other ADR vehicles on the same route. This features could be provided to all those transport companies who will install On Board Units on their vehicles.
The system is ready to create a new vulnerable “item” on the map or a new infrastructure and simulate how DGT risk changes.

4. Conclusions

The risk analysis model developed in DESTINATION provides a support for all the stakeholders (private and public) involved in hazardous material land transportation in all its phases, increasing knowledge of the data set available on territorial and environmental vulnerabilities of each partner.
A better knowledge of the DGT risk, in fact, will be able to influence decision-making processes in urban planning, new infrastructures planning and management and route planning.
Beside the GIIS, a result of the project could also be the base for the definition of guidelines useful to influence legislation on dangerous goods transportation by road.
Overcoming the technical issues, the project gains the target of coordinating difference experiences on the DGT matter that are active in Italy through the agreement with the Minister of Infrastructure. Furthermore, the GIIS developed by the project is part of the official information systems of the public bodies that are involved in the project and so it is guarantees the use of the GIIS during years.

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