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Logistica e Sicurezza

Real-time risk definition in the transport of dangerous goods by road

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OUTLINE

- Introduction
- Problem Definition
- Proposed approach
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- Conclusion and future works

Introduction

- Transportation of Dangerous goods (DG) represents about the 4.1% of total tonne-kilometre performance of road goods transport in 2007 in the EU-27 and, besides, the two largest categories of dangerous goods transported by road are flammable liquids (58 %) and gases (12 %) [Eurostat 2009].
- Due to the great consequences that an accident involving DG on road can produce to the population, environment and to the road infrastructures, it is important to develop an accurate methodology to define the risk and the economical cost for the delivery paths of the DG trucks.
- Anyway there is not always the possibility for government authority to impose a specific route planning only based on risk minimization enforcing the DG trucks to avoid specific parts of the roadway network mostly sensitive at risk.

Introduction

- In Italy, the National Ministry of Transports and Infrastructures is currently proposing to major companies involved in DG transportation to declare the whole daily trips planning and expected routes covered by their trucks. This might represent an interesting approach to re-allocate the trips during the day in base on the density of DG along roads.
- The definition of risk in the transport of dangerous goods is an open issue. No international standard is currently defined. In addition, the definition of risk is directly related to the possibility to its control at decisional level, for example, by rerouting the traffic.
- In this work, a proposal to define risk at strategic, tactical, operational and realtime level is proposed. A system of systems vision of the definition at operational/realtime level is particularly promising of research aspects both from a SoSE and a technological viewpoint.

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Problem definition

To define a risk able to manage aid decision makers in the transport of dangerous goods, it is useful to refer to a hierarchical classification of the decisional levels that may be associated with the management of that type of transport.

	Time Horizon	*Level of Detail*
Strategic level	years (>2)	national scale
Tactical level	months, years (≤2)	multi-regional scale
Operational level	days	regional scale
Level of control in real-time	seconds, minutes, hours	local scale

Decision Makers

-Public Authorities (Governments, Regional and Local authorities)

-Dangerous Good transportation companies

-Road Infrastructures Owners

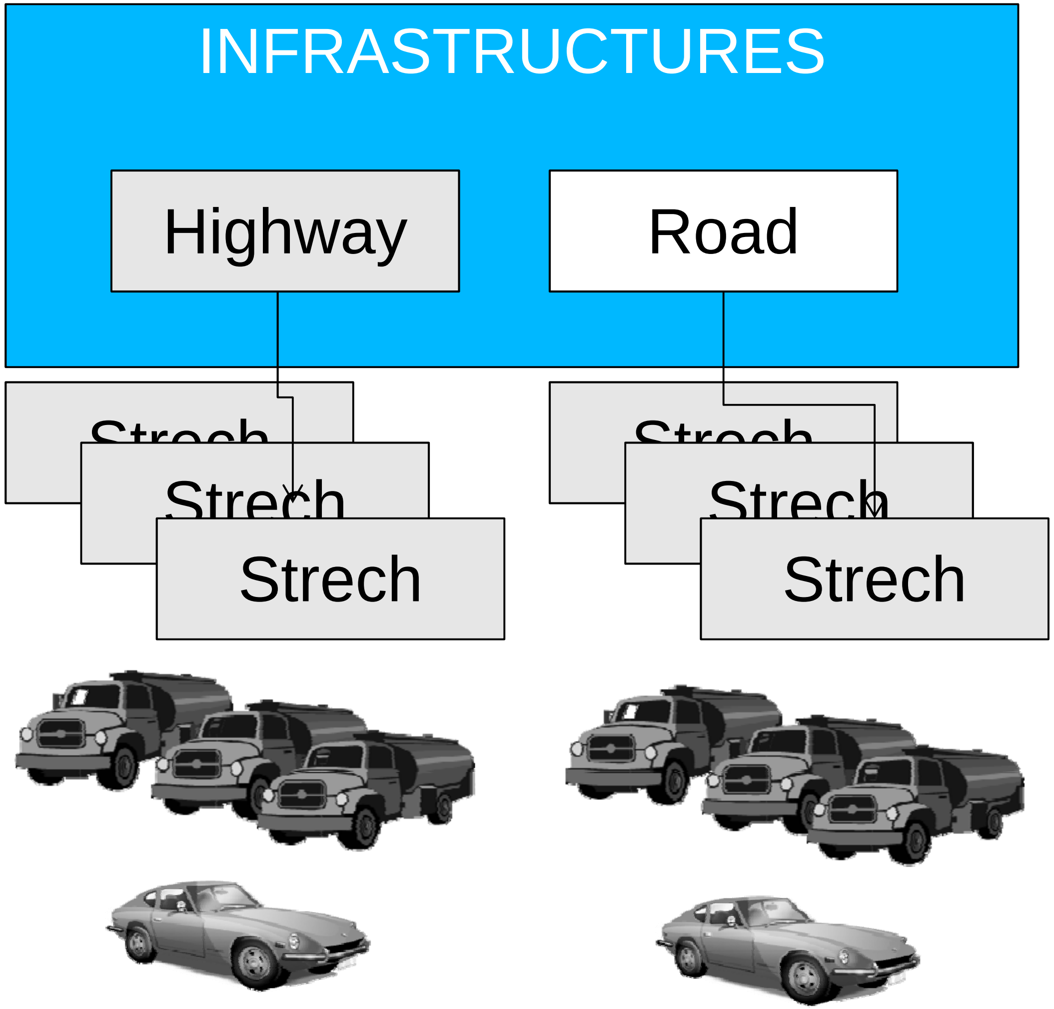
SoS perspectives

Public Authorities

Road Infrastructures owner

DG companies

Road Users



DECISION at STRATEGIC LEVEL, Public Authority Viewpoint

Decision Makers	*Decision on transport*	*Decision on DG transport*
Highest levels of governments (this level requires considerable capital repayable only in the long terms)	DMs decide on the investments in major infrastructures, the type of transport services to be provided and pricing policies involving shippers and carriers.	To prevent or reduce this transport on certain road infrastructures; to prevent or authorize the establishment of a production entity (eg. subject to Seveso legislation); definition of a risk index associated to each stretch of the road infrastructures in order to classify them according to the risk exposure

DECISION at TACTICAL and OPERATIONAL LEVEL, Public Authority Viewpoint

Decision Makers	*Decision on transport*	*Decision on DG transport*
- Multi-regional Entities and Regional Authorities	•The route planning to be followed, •Selection of route with lower general accident rate.	Definition of strategies and policies for the DG vehicle travel schedules to minimize the maximum risk exposure in a region; impose reductions or completely inhibition of DG flows on specific stretch of the road, changing hours for transits on some strings at certain times of the day to minimize the risk for people.

DECISION at REAL TIME LEVEL, Public Authority Viewpoint

Decision Makers	*Decision on transport*	*Decision on DG transport*
- Local Public authorities involved in the monitoring of flow traffic, emergency and recovery in a local area	Decisions necessary to contrast any hitchs in the transport network such as the temporary unavailability of infrastructure or excessive density of vehicles (above all to avoid more DG vehicles in a certain stretch of the network).	To redirect DG vehicles to avoid congested routes, Send messages to the drivers to communicate anomalies or changes in the planning routes, To impose stops to vehicles to avoid critical situations.

Risk definition

In order to describe the proposed methodology to compute the DG risk associated to road infrastructure, it is necessary introduce some specific definitions. There is most literature which define risk R as a function of set of triplets:

$$R=f(s, p, c) \qquad (1)$$

where

- s is a scenario,
- p its probability and
- c its consequences.

Risk analysis can be viewed as the process of enumerating all triplets of interest within a spatial and temporal envelope [1].

[1] Kaplan, S., and Garrick, B.J. (1981) On the quantitative definition of risk, Risk Analysis, 1: 11-27

Vulnerability

Vulnerability is most often conceptualized as being constituted by a components that include *exposure* and *sensitivity* to perturbations or external stresses, and the capacity to adapt.

Exposure can be defined as the elements (people, goods and infrastructures) affected during and after a perturbation or accidental event.

Sensitivity is the degree to which a system is modified or affected by perturbations. Adaptive capacity is the ability of a system to evolve in order to accommodate hazards or policy change and to expand the range of variability with which it can cope.

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Proposed Approach – Risk definition

The vulnerability can be treated as the component associated to the exposure of the risk. The main elements to compute risk associated to DG transport on road are:

1. The definition of territorial vulnerability indexes.
2. Data on traffic flows on the infrastructures associated to common vehicles, heavy vehicles and DG vehicles.
3. Accident probability for each stretch of the roads

1. Territorial vulnerability indexes

The vulnerability assessment shall be calculated according to the three types of exposures:

a) social vulnerability (in numbers of inhabitants and the number of road user in the section of the infrastructure);
b) environment vulnerability (in numbers of specific sensible elements within the impact area);
c) economical vulnerability (in numbers of specific elements or propriety within the impact area).

2. Data on traffic flows on the infrastructures

These data should be obtained as a function of time horizon related to the decision levels. In particular, as regards the definition of risk

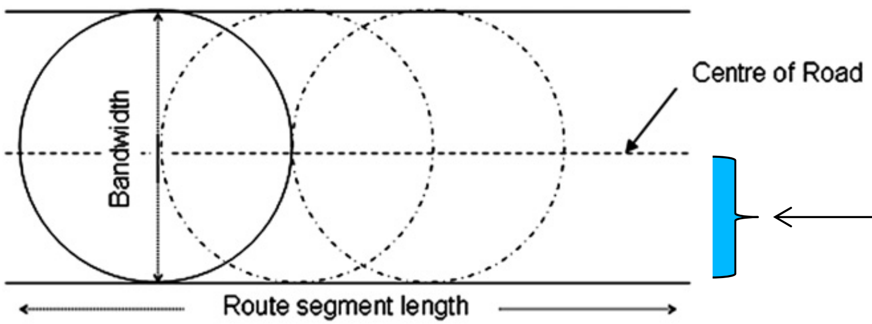
a. at the strategic level, it will refer to annual average flow data,
b. at the tactical level to monthly average data,
c. at the operational level at daily data and
d. at the real-time level the data will come in real time from the monitored DG vehicles and traffic flows from traffic detector (eg. inductive-loop detectors embedded in the pavement of the roadway)

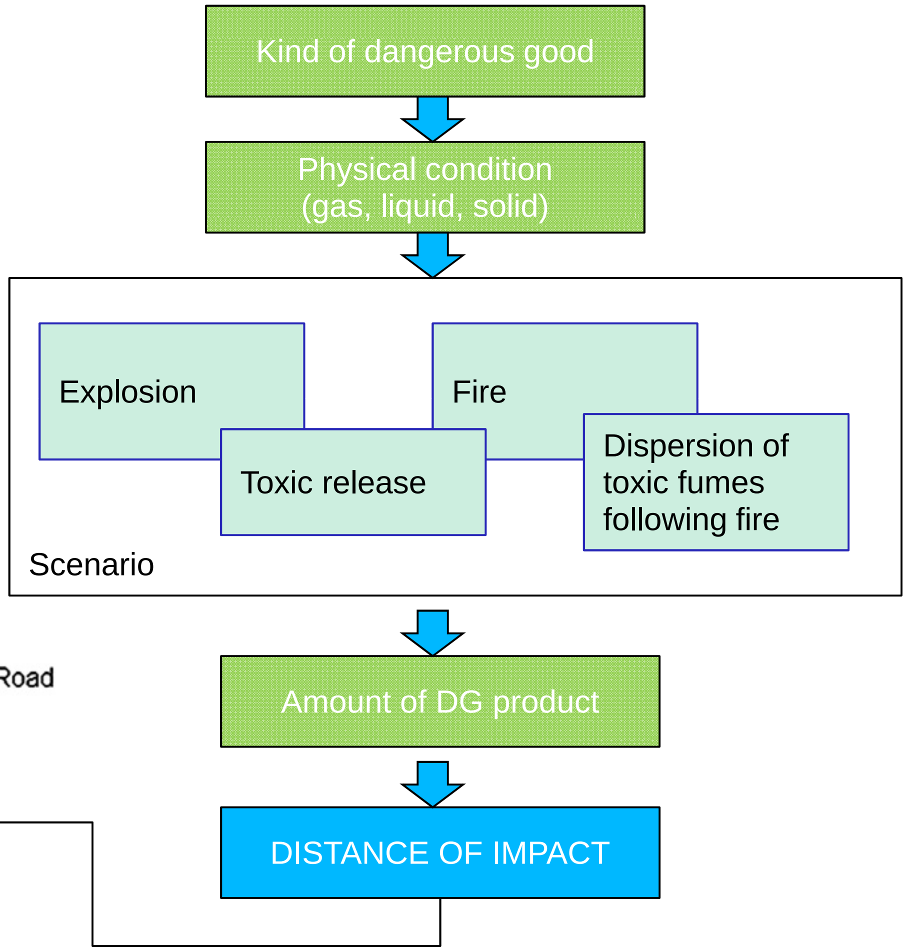
3. Accident Probability

The calculation of the accident probability which is the result of a procedure which receives as input the data flow and accident historical and statistical data per km.

Estimation of impact area

To compute the IMPACT AREA the method proposed by the Italian Civil Protection has been used. The impact distance serves as the radius that defines the impact zone. It is possible to consider the DG shipment over a road segment as the movement of a danger circle along that road segment.





Potential targets exposed

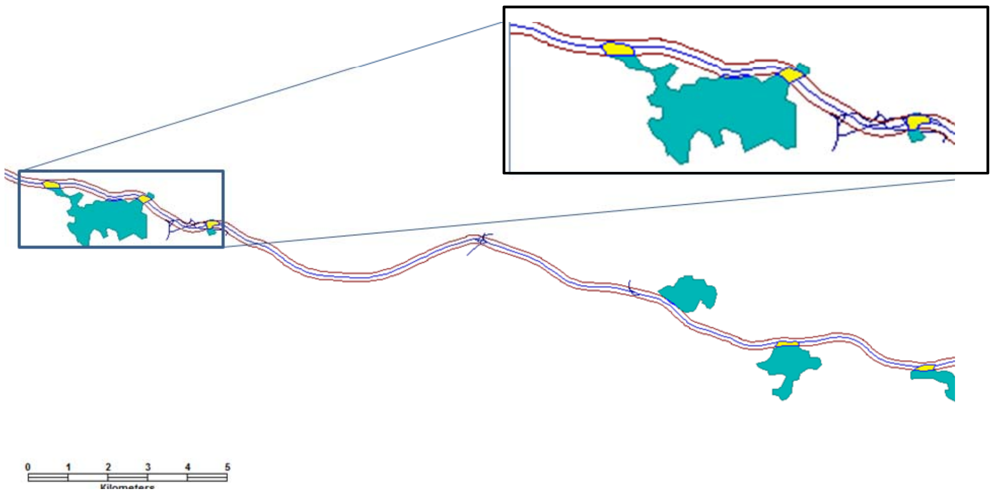
- On-road population mainly includes people (occupants of vehicles) on the road. The on-road population is a function of the average vehicle traffic and the estimated time taken for the vehicles to travel the route length. Taking average vehicle occupancy of 2 people was applied.

- The estimated off-road population along the identified route segments computed by data from the 2010 Census data or by arial visualization according to the different decision levels

Potential targets exposed

Property: all sensible elements contained in the impact area.
1. Residential areas
2. Industries
3. Major Hazard Industries Seveso
4. Public centres..

Environmental: all sensible elements contained in the impact area related to
1. Parks
2. Woods
3. Rivers
4. Lakes and channels..
5. Protected areas, Agricultural areas, ..



Vulnerability at strategic level

1a. Maximum social vulnerability [inhab];	$vul_{\max}^{s,STR}$
1.b. Avarage social vulnerability [inhab];	$\overline{vul}^{\,s,STR}$
2.a . Maximum environmental vulnerability [km^2];	$vul_{\max}^{e,STR}$
2.b Average environmental vulnerability [km^2];	$\overline{vul}^{\,e,STR}$
3.a. Maximum economical vulnerability [€];	$\overline{vul}^{\,p,STR}$
3.b Avarege economical vulnerability [€];	$vul_{\max}^{p,STR}$

Social Vulnerability at strategic level

The social vulnerability considers the sum of two type of information:

1) persons who live in the impact area obtained by Statistics Census and

2) common users of the specific road infrastructure. Those value results from the classical relationship of macroscopic traffic models among traffic density, speed and flow

$$flow\left[\frac{veh}{h}\right] = \delta\left[\frac{veh}{km}\right] speed\left[\frac{km}{h}\right]$$

From the average yearly flows on the specific section of the road, the average value of flows in [veh/h] can be computed. Given an average speed value, it is possible to define the number of vehicle which transit on the specific road section. Hypotizing an average value of two persons for vehicle, it possible to quantified the number of potential users exposed during an DG accident on that road section.

Risk definition at tactical level *(monthly horizon)*

Social risk at the tactical level [inhab]	$risk^{s}_{tactical} = \sum_j \left(Pinc_{veh} vul^{s,TAC}_{\max} flow^{HAZ}_{veh} P_j \right)$
Environmental risk at the tactical level [km^2]	$risk^{p}_{tactical} = \sum_j \left(Pinc_{veh} vul^{p,TAC}_{\max} flow^{HAZ}_{veh} P_j \right)$
Economic risk at the tactical level [€]	$risk^{e}_{tactical} = \sum_j \left(Pinc_{veh} vul^{e,TAC}_{\max} flow^{HAZ}_{veh} P_j \right)$

where

$Pinc_{veh}$	is the accidents probability per kilometer [accident km^{-1}];
$flow^{HAZ}_{veh}$	*monthly* data traffic flows for DG vehicles per km;
$vul^{TAC}_{\max}$	maximum vulnerability computed on *montly* data traffic flows;
P_j	is the probability of occurrence for the scenario j.

Risk definition at operational level *(daily horizon)*

Social risk at the operational level [inhab]	$risk^{s}_{operative} = \sum_j Pinc_{veh} vul^{s,OP}_{operative} flow^{HAZ}_{veh} P_j$
Environmental risk at the operational level [km²]	$risk^{e}_{operative} = \sum_j \left(Pinc_{veh} vul^{e,OP}_{operative} flow^{HAZ}_{veh} P_j \right)$
Economic risk at the operational level [€]	$risk^{p}_{toperative} = \sum_j \left(Pinc_{veh} vul^{p,OP}_{operative} flow^{HAZ}_{veh} P_j \right)$

where

$Pinc_{veh}$	is the accidents probability per kilometer [accident km^{-1}];
$flow^{HAZ}_{veh}$	*daily* data traffic flows for DG vehicles per km;
$vul^{OP}_{\max}$	maximum vulnerability computed on *daily* data traffic flows;
P_j	is the probability of occurrence for the scenario j.

Risk definition at real time level *(hourly horizon)*

Social risk at the real time level [inhab]	$risk^{s}_{realtime} = \sum_j \left[Pinc_{veh} * g\left(\alpha vul^{s}_{\max} + \beta vul^{GPRS}_{\max}\right) * flow^{HAZ}_{veh} * P_j \right]$
Environmental risk at the real time level [km^2]	$risk^{e}_{realtime} = \sum_j \left(Pinc_{veh} * vul^{e}_{\max} * flow^{HAZ}_{veh} * P_j\right)$
Economic risk at the real time level [€]	$risk^{p}_{realtime} = \sum_j \left(Pinc_{veh} * vul^{p}_{\max} * flow^{HAZ}_{veh} * P_j\right)$

$g\left(\alpha vul^{s}_{\max} + \beta vul^{s}_{GPRS}\right)$	Social Vulnerability is a linear combination of the values associated to persons who live in the impact area and the expected number of persons computed by the census of mobile users in GPRS cells.
$flow^{HAZ}_{veh}$	Combination of data about statistic DG flows and *real time data* of DG vehicles coming from GPS devices

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Case study to define social risk for DG transport on road at different decisional levels

The case study focuses on a typical Italian highway which is 105 km long. The highway is divided on 14 stretches.

			2010 Traffic Flows data (daily)				
Highway			Direction 1		Direction 2		
Stretches	Population density [inhab/km2]	KM	Total vehicles	Freight Vehicle (%)	Total vehicles	Freight Vehicle (%)	Total on the two directions
1	914	0,0	22367,15	15%	16802,60	16%	39169,75
2	329	4,1	8677,53	2%	10069,02	21%	18746,55
3	339	12,0	15689,08	17%	14925,4	17%	30614,48
4	887	18,8	14557,24	16%	13721,4	16%	28278,69
5	951	22,5	14299,15	18%	13428,82	18%	27727,97
6	613	35,2	11972,76	20%	11538,44	19%	23511,19
7	213	43,4	11758,90	19%	10996,24	20%	22755,15
8	272	49,1	11253,42	20%	10732,18	20%	21985,60
9	861	56,1	10698,32	21%	9831,00	21%	20529,32
10	761	68,4	10440,00	21%	9413,53	21%	19853,53
11	408	76,8	9010,31	22%	8585,21	21%	17595,52
12	923	88,7	9655,19	20%	9008,21	20%	18663,40
13	974	97,0	8647,77	22%	8135,60	22%	16783,37
14	455	105	9656,85	18%	9168,77	18%	18825,63

Social vulnerability computation at strategic level

This highway has two lanes for carriageway which run parallels in the two direction so, considering an impact area with a radius of 100 mt, the persons who transit in both two directions can be exposed. Taking into account 60 km /h as average speed vehicle and two persons for vehicles, the index associated to the road users potentially exposed on each stretch of the highway, in case of DG accident, can be computed. The maximum social vulnerability at strategic level can be computed.

stretch	Traffic flows Two direc tions	Vehicular Density (average speed at 60 km/h)	Persons on the stretch (2 inhab per veh)	Persons on the strech (2 inhab per veh)	Resident persons (pop density)	$vul_{\max}^{s,STR}$
	[Veh/h]	[veh/km]	[inhab/km]	[inhab/hm]	[inhab/hm^2]	Value per hm
1	1632,07	27,20	54,40	5,44	9,136	**14,58**
2	781,11	13,02	26,04	2,60	3,294	**5,90**
3	1275,60	21,26	42,52	4,25	3,388	**7,64**
4	1178,28	19,64	39,28	3,93	8,874	**12,80**
5	1155,33	19,26	38,51	3,85	9,506	**13,36**
6	979,63	16,33	32,65	3,27	6,132	**9,40**
7	948,13	15,80	31,60	3,16	2,128	**5,29**
8	916,07	15,27	30,54	3,05	2,724	**5,78**
9	855,39	14,26	28,51	2,85	8,607	**11,46**
10	827,23	13,79	27,57	2,76	7,606	**10,36**
11	733,15	12,22	24,44	2,44	4,075	**6,52**
12	777,64	12,96	25,92	2,59	9,232	**11,82**
13	699,31	11,66	23,31	2,33	9,737	**12,07**
14	784,40	13,07	26,15	2,61	4,549	**7,16**

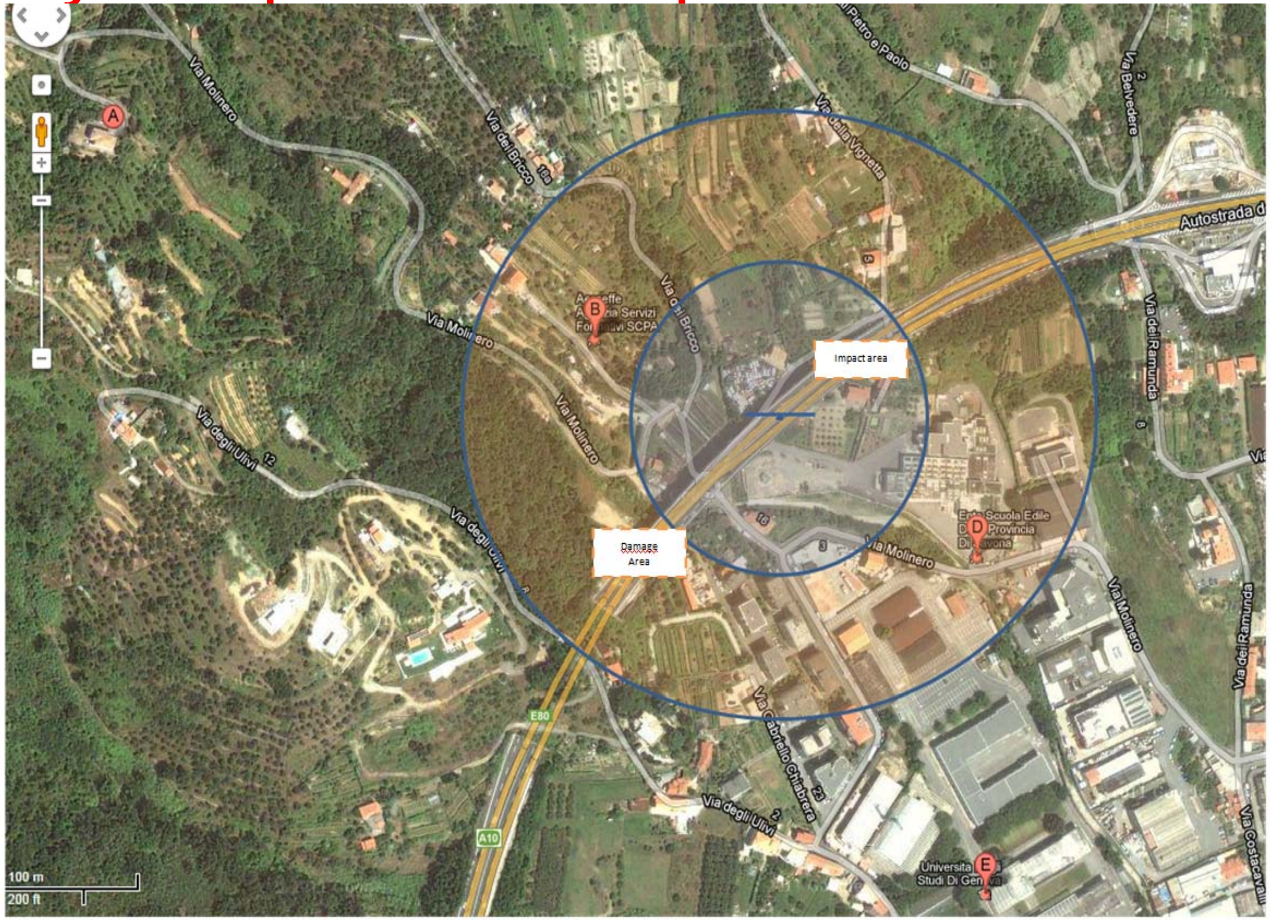
Social vulnerability computation at tactical level

For the selected road (stretch 1) segment, the DG traffic represents the 3,45% of the total freight traffic. Like at strategical level, the social vulnerability at tactical level is computed as the sum of people who transit on the highway (based on monthly traffic flows data) and population density in the impact area.
Besides, the accident probability for the selected highway is 8,63E-07 [acc km^{-1}] and the probability that scenario associated to the GPL explosion has 10^{-2} order of magnitude.

	DG Traffic flows Two directions	Persons on the stretch (2 persons for veh)	Resident Persons	Accident probability	Probability for GPL explosion	vul^{TAC}_{max}
	[Veh/h]	[inhab/ hm]	[inhab/ hm^2]	[Acc/hm]	[Acc/hm]	**value per hm**
January	184,67	4,87	9,14	8,63E-08	0,001	**2,23E-07**
February	208,07	4,74	9,14	8,63E-08	0,001	**2,49E-07**
March	235,18	5,18	9,14	8,63E-08	0,001	**2,90E-07**
April	237,42	6,66	9,14	8,63E-08	0,001	**3,24E-07**
May	233,17	6,70	9,14	8,63E-08	0,001	**3,19E-07**
June	234,54	7,53	9,14	8,63E-08	0,001	**3,37E-07**
July	253,22	9,24	9,14	8,63E-08	0,001	**4,01E-07**
August	234,64	9,44	9,14	8,63E-08	0,001	**3,76E-07**
September	261,92	6,75	9,14	8,63E-08	0,001	**3,59E-07**
October	250,67	5,53	9,14	8,63E-08	0,001	**3,17E-07**
November	237,36	4,69	9,14	8,63E-08	0,001	**2,83E-07**
December	212,55	4,99	9,14	8,63E-08	0,001	**2,59E-07**

Social vulnerability computation at operational level

At operational level, the time horizon is daily and a deep analysis of the impact area has to be done.
In the selected impact area, two training schools and a industry appear. At operational levels, the definition of residents can be refined according to the specific working day and location.



Social vulnerability computation at operational level

The social risk at operational level increases during the working days Tuesday and Friday. Special attention, for this stretch of the highway, should be given forcing a reduction of DG flows or allowing transits during the night to minimize social risk.

	DG Traffic flows Two directions	Persons on the stretch (2 persons for veh)	Resident Persons from arial visualization	Accident probability	Probability for GPL explosion	$vul_{\max}^{OP}$
	[Veh/h]	[inhab/hm]	[inhab/hm2]	[Acc/hm]	[Acc/hm]	Value per hm
Monday 01/07/2010	276,3	7,9	100,0	8,63E-08	0,001	1,884E-05
Tuesday 02/07/2010	262,0	9,3	100,0	8,63E-08	0,001	2,097E-05
Wednesday 03/07/2010	114,0	10,5	100,0	8,63E-08	0,001	1,037E-05
Thursday 04/07/2010	79,7	9,6	100,0	8,63E-08	0,001	6,618E-06
Friday 05/07/2010	261,5	9,2	100,0	8,63E-08	0,001	2,084E-05
Saturday 06/07/2010	275,0	6,5	50,0	8,63E-08	0,001	7,701E-06
Sunday 07/07/2010	285,9	6,7	50,0	8,63E-08	0,001	8,270E-06
Monday 08/07/2010	292,7	7,7	100,0	8,63E-08	0,001	1,938E-05
Tuesday 09/07/2010	263,6	10,1	100,0	8,63E-08	0,001	2,299E-05
Wednesday 10/07/2010	107,2	10,7	50,0	8,63E-08	0,001	9,901E-06
Thursday 11/07/2010	79,3	9,8	100,0	8,63E-08	0,001	6,706E-06
Friday 12/07/2010	263,9	9,6	100,0	8,63E-08	0,001	2,190E-05
Saturday 13/07/2010	275,1	6,8	50,0	8,63E-08	0,001	8,059E-06
Sunday 14/07/2010	243,9	7,0	50,0	8,63E-08	0,001	7,360E-06

Social risk computation at real time level

There are many new Information Technology Systems (ITS) that promise to reduce the effects of transportation hazards. The suite of geospatial technologies including the global positioning system (GPS), geographic information systems (GIS), and remote sensing also hold much promise to improve the amount of information available to transportation users, planners, and emergency responders.

At real time level, in fact, the definition of risk for DG transportation implies to receive timely data about DG vehicle positions, traffic flows, and the expected value of people really present in the impact area, e.g. by quantification of GPRS mobile users in the specific cell.

Social risk computation at real time level

DG vehicle position by GPS on the stretch	The danger circle along that road segment
Receiving real time traffic flows data by inductive-loop detectors	It is possible to estimate highway users in that section in real time
Number of GPRS mobile users in a selected cell.	It is possible to estimate people in the danger circle. The average value for mobile traffic in a cell can be from 5 to 12 erl/km^2 (erlang is hours of traffic in the hour). Assuming an average value of 3 min of call for user, *from 100 to 250 users per km^2 can be estimated.*
Analysis of the exposed sensible targets in the neighbouring of the accident point	People resident/arial visualization

Social risk computation at real time level

Streches	Traffic flows Two directions	DG Traffic flows Two directions	Mean speed	Persons on the stretch (2 persons for veh)	Mobile User	Resident Persons from arial visulization	Accident probability	Probability for GPL explosion	DG risk at real time level
	[veh/min]	[veh/min]	[km/min]	[ab/hm]	[ab/hm2]	[ab/hm2]	[Acc/hm]	[Acc/hm]	value per hm
1	27,2	0,93844	1,67	3,3	23	75,0	8,6E-08	1,0E-03	8,2E-09
2	13,0	0,44914	1,63	1,6	18	35,0	8,6E-08	1,0E-03	2,1E-09
3	21,3	0,73347	1,83	2,3	25	14,0	8,6E-08	1,0E-03	2,6E-09
4	19,6	0,67751	1,68	2,3	10	65,0	8,6E-08	1,0E-03	4,5E-09
5	19,3	0,66432	1,83	2,1	22	15,0	8,6E-08	1,0E-03	2,2E-09
6	16,3	0,56329	1,75	1,9	12	12,0	8,6E-08	1,0E-03	1,3E-09
7	15,8	0,54518	1,65	1,9	24	14,0	8,6E-08	1,0E-03	1,9E-09
8	15,3	0,52674	1,67	1,8	20	9,0	8,6E-08	1,0E-03	1,4E-09
9	14,3	0,49185	1,63	1,7	12	40,0	8,6E-08	1,0E-03	2,3E-09
10	13,8	0,47566	1,83	1,5	13	43,0	8,6E-08	1,0E-03	2,4E-09
11	12,2	0,42156	1,68	1,5	15	30,0	8,6E-08	1,0E-03	1,7E-09
12	13,0	0,44714	1,83	1,4	21	70,0	8,6E-08	1,0E-03	3,6E-09
13	11,7	0,40210	1,72	1,4	17	37,0	8,6E-08	1,0E-03	1,9E-09
14	13,1	0,45103	1,70	1,5	20	24,0	8,6E-08	1,0E-03	1,8E-09

The main goal of this approach is define a series of thresholds values to classify each sectors of the road infrastructures.

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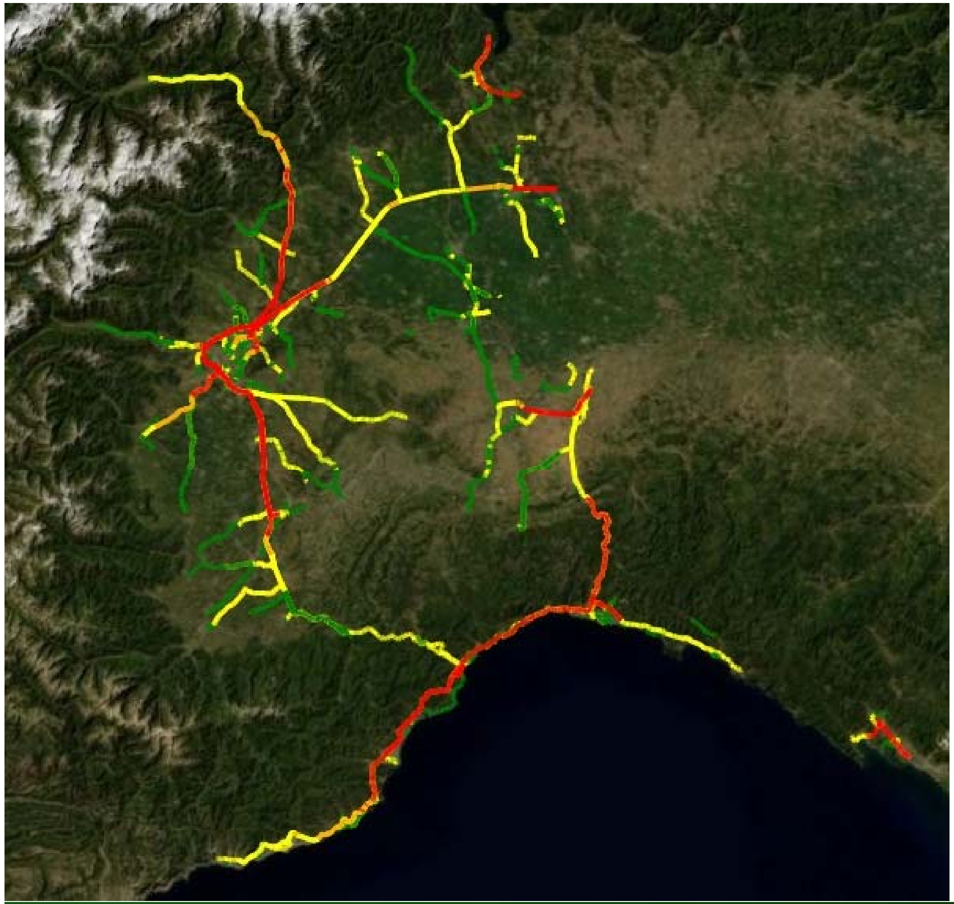
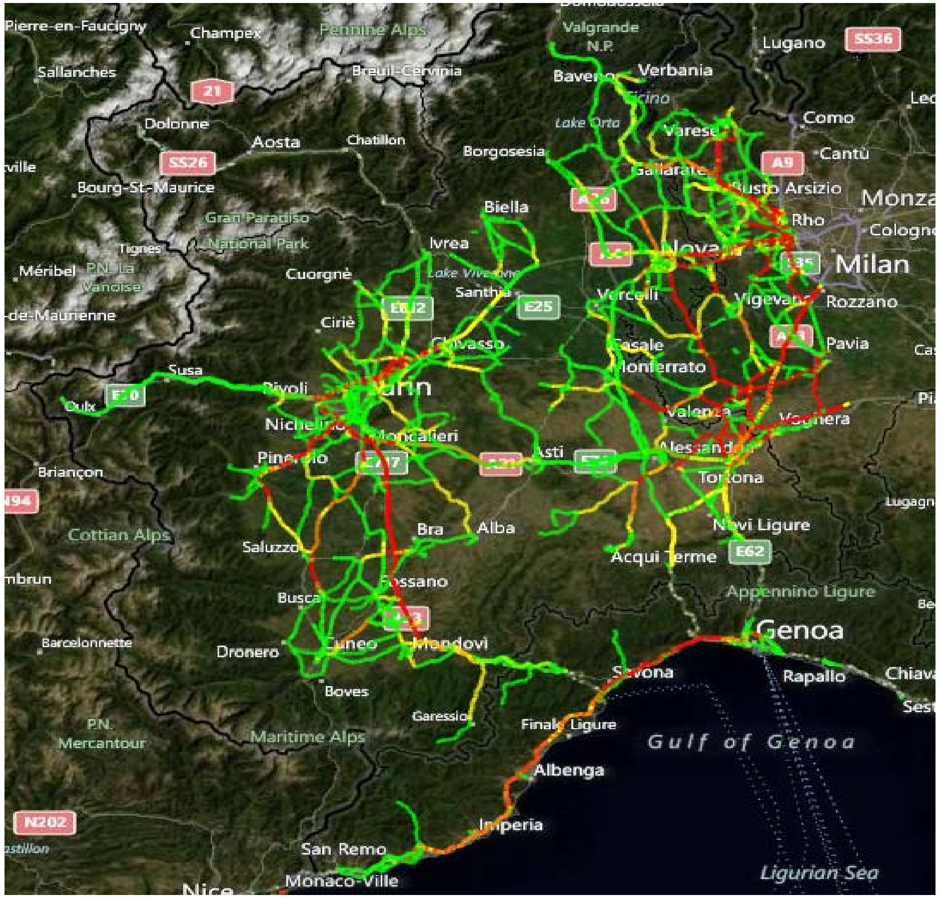
Importance of real time data

PLANNED tours



REAL tours



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Conclusion

- The proposed methodology to estimate the risk index associated to each road section in the different decision levels aims at *proposing an objective method to categorize each infrastructure* versus DG transportation risk.
- The presented approach promises to be useful to *support governments and the different decision makers involved in the DG transport* in allocating resources to the phases of management: mitigation, preparedness, emergency response and recovery.
- The proposed method is based on the different availability of data according to different decision levels.

Future developments

As a future development of this work, *the current analysis will be implemented from the DG fleet manager viewpoint*.

Each DG transportation company could be able to certificate its transport providing objective information about the planned routing of its vehicles. For each planned routing vehicle, the DG company could compute the impact of its DG transports on the social, environmental and economic exposure.

By the daily transmission of those parameters to the competent public authorities, the DG company should certificate an effective effort to minimize risk in its vehicle routing planning, obtaining, when possible, economical or operative facilitations.

THE END