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Safety of Dangerous Goods Transportation by Road: a Comparison Between QRAM and GIIS Software

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The aim of the work is to develop a comparison between two software able to assess the risk associated with the transport of goods by road: QRAM - Quantitative Risk Assessment Model and GIIS – Global Integrated Information System, implemented within the DESTINATION project - DangErous tranSport To New prevenTive Instruments.
It was thus possible to verify if the outputs obtained with the two software are comparable, although the two analytic models are widely different.
The analysis included two comparisons, α and β: the former considers road users as targets and two accident scenarios, i.e. the petrol pool fire and the Liquefied Petroleum Gas (LPG) jet fire. The latter concerns three accident scenarios, i.e. the petrol and LPG Vapor Cloud Explosion (VCE) and the ammonia release. In this case, road users and population are taken into consideration as targets: residents, industry workforce, tourists and staff of commercial, health and education facilities.
The assessment was carried out on different types of road: highway, state road and provincial roads, in order to study the functioning of the two models with different traffic conditions and exposed population (targets) surrounding the road links.

1. Introduction and aim of the work

The risk assessment associated with dangerous goods transport by road requires the application of quantitative models to estimate a social risk value expressed in fatalities/year for each link of a road network (Bubbico et al. 2004; Bubbico et al. 2006). Using analytical instruments allows to implement decision-making processes aimed at applying measures to infrastructures and/or management in order to mitigate risks. Recent studies (Li, 2017; Hao, 2017) evaluated road routes to enhance-minimize the social risk as a function of specific origins-destinations.

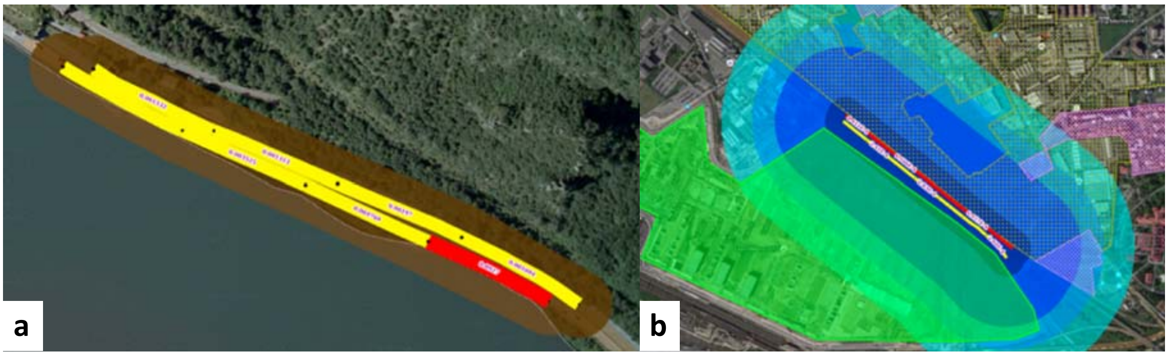

Figure 1: GIIS application in the region of Lombardy (Italy); a) environmental risk and damage area associated with the transport of diesel oil; b) social risk and damage areas associated with the transport of LPG

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Two calculation instruments are therefore considered: QRAM, jointly developed by PIARC and OECD (OECD, 2001; INERIS, 2005), and GIIS (Giacone M.O. et al. 2012; Pastorelli et al., 2013), implemented within the DESTINATION project - DangErous tranSport To New prevenTive Instruments.
The present work aims at comparing the two software in order to evaluate whether their output is comparable, and therefore if the two software may be considered as alternative options.
The QRAM software was implemented to evaluate the risks due to dangerous goods transport along different routes; for example, via the tunnel or an alternative open route (Ruffin et al. 2004).
The GIIS software was developed to evaluate the social and environmental risk associated with dangerous goods transportation. An application (Borghetti et al. 2015) was carried out on vulnerable areas in the region of Lombardy (Italy), as shown in Figure 1.

2. Data preparation

In order to compare the two software, three study areas were identified that correspond to three different road types: highway, state road and provincial roads, as shown in Figure 2. Each road type is characterized by a specific traffic value, accident rate, percentage of vehicles used for dangerous goods transport and potentially exposed population. 4 km of road are considered, corresponding to eight 500 m-long links. The roads under consideration are the following:

- The highway A9 or Autostrada dei Laghi, which connects the metropolitan area of Milan to Como up to the Swiss border with the Canton Ticino
- The state road SS36, called strada statale del Lago di Como e dello Spluga, which connects the hinterland of Milan with the Swiss border, in the Grisons over the Splügen pass. The SS36 is the main road to access Valtellina, the alpine region upstream the lake of Como within the province of Sondrio
- The provincial road SP342 Briantea, which connects the province of Bergamo to the province of Varese, passing through the province of Como
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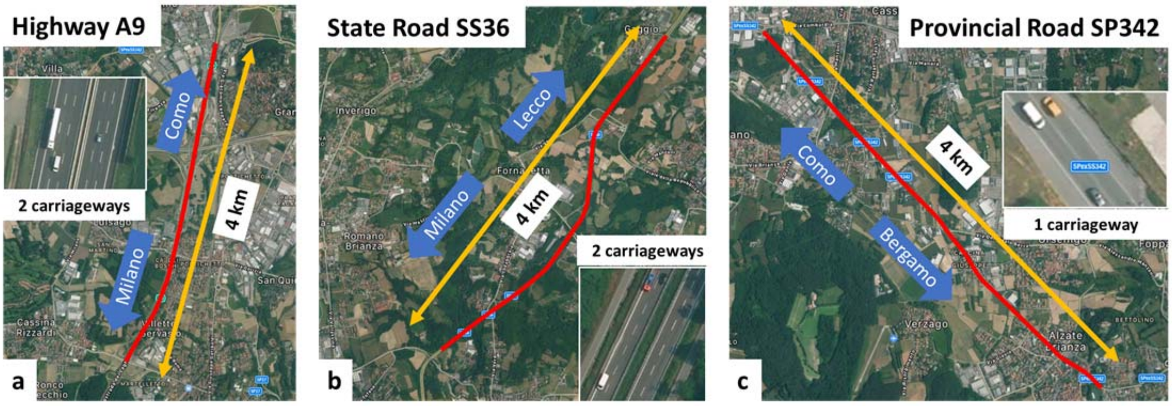

Figure 2: Representation of the three study areas; a) Highway A9; b) State Road SS36 and c) Provincial Road SP 342

After identifying the study areas to compare the two software on, the model substances and the associated accident scenarios were analysed. This activity required a deep analysis of the two calculation models in order to make a comparison, which is based on elements that are as comparable as possible.
While choosing the accident scenarios, data used by the two software were identified: the comparison was made by drawing data from GIIS and using them as input data for QRAM. By means of specific interface screens the latter supports users in entering the data required for processing.
Since the two software are based on different calculation models, operations were carried out to uniform and match the necessary data. In particular, the operations considered parameters associated with traffic, the geometry of the infrastructure and the potentially exposed targets. With reference to the exposed targets, QRAM requires a square grid to be inserted at the margin of the road where the numeric value of exposed people (density) is to be entered. Starting from the polygons in GIIS with the population value (residents, industry workforce, tourists and staff of commercial, health and education facilities) associated, a grid was calculated and manually built by means of a drawing software CAD - Computer Aided Design. The grid, as shown in Figure 3, was built for each of the three different roads and then used in the QRAM software.

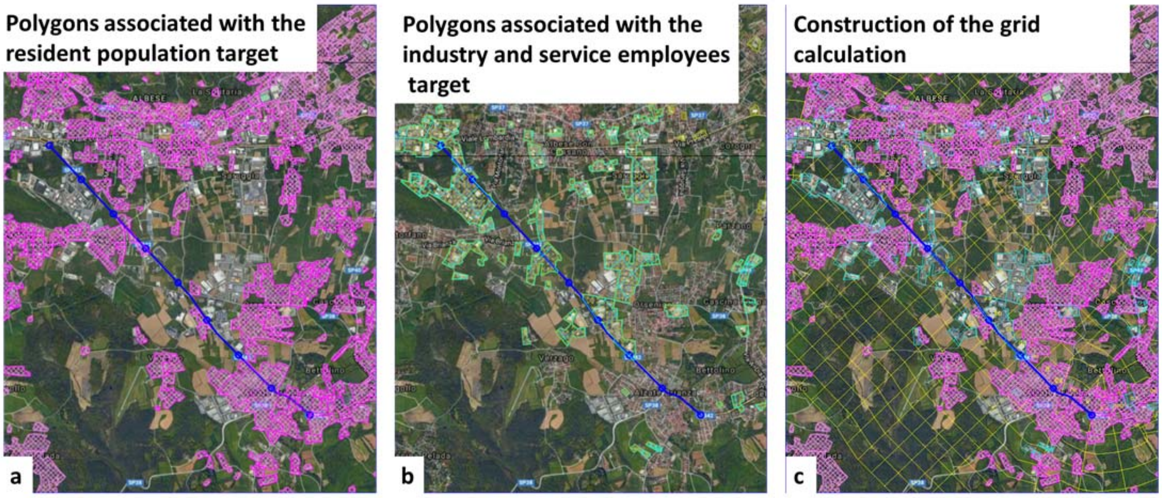

Figure 3: Construction example of the grid calculation starting from the GIIS polygons to which the anthropic targets are associated; a) pink polygons associated with the resident population; b) green polygons associated with industry and service employees; c) yellow grid calculation

3. QRAM and GIIS comparison

The comparison between the two software was planned as a function of the type of targets: road users and population. Starting from the output of the processing, three analyses were carried out for each *α* and *β* comparison: particular, aggregate and general, as shown in Figure 4.

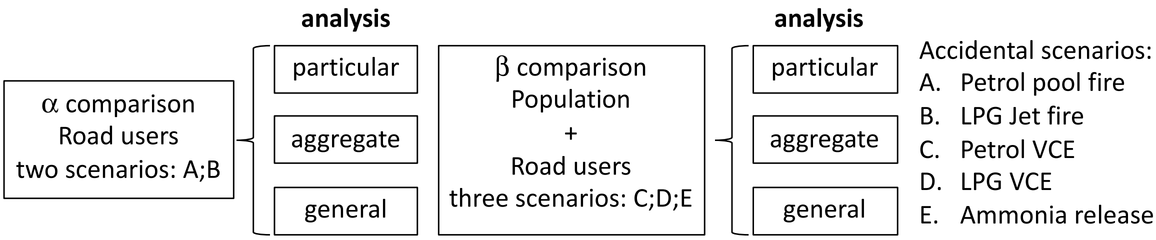

Figure 4: Description of comparisons and analysis performed with reference to the considered accidental scenarios

The *α* comparison between the two software concerns two accident scenarios: the petrol pool fire (scenario A) and the LPG jet fire (scenario B), considering road users as targets (vehicles in the damage area); fatalities per year are evaluated, which affect people implied in one of the two scenarios. These fatalities do not include victims caused by the impact between vehicles, or fatalities that are not directly caused by accident scenarios with dangerous goods. The second *β* comparison concerns petrol (scenario C) and LPG (scenario D) VCE accident scenarios, as well as the ammonia release (scenario E). Road users and population (residents, industry workforce, tourists and staff of commercial, health and education facilities) are taken into consideration as targets. For each of the two software, the particular analysis defines the risk factor $R_{i,s,c}$ for each *i-th* 500 m-long link, each *s-th* accident scenario and each *c-th* road carriageway. The aggregate analysis makes a preliminary estimate for a general road section of the average risk value $\bar{R}_{s,c}$, divided by accident scenarios under consideration and carriageways; the risk value is calculated as in Eq(1):

$$\bar{R}_{s,c} = \frac{\sum_{i=1}^{I} R_{i,s,c}}{I} \qquad (1)$$

Where:

- *i* represents the i-th 500 m-long link that makes up the road section (4 km);
- *s* represents the general accident scenarios considered in the comparison;
- *c* is the carriageway making up the road section;

- $R_{i,s,c}$ is the risk evaluated in the particular analysis;
- I is the total number of links (for each road type it is equal to 8).

A risk value $\bar{R}_s$ is then calculated, which represents the result of the aggregate analysis that calculates the average risk value of the two carriageways, as shown in Eq(2):

$$\bar{R}_s = \frac{\sum_{c=1}^{C} \bar{R}_{s,c}}{C} \quad (2)$$

Where:

- C is the total number of carriageways making up the road link (C=2 for the highway and the state road; C=1 for the provincial road).

At last, the general analysis calculates a risk $\bar{R}$, which represents the average risk values that are associated with the scenarios *s* defined, as reported in Eq(3):

$$\bar{R} = \frac{\sum_{s=1}^{S} \bar{R}_s}{S} \quad (3)$$

Where:

- S is the total number of accident scenarios considered in the comparison (*S* = 2 in the *α* comparison; *S* = 3 in the *β* comparison).

By way of example, some representative results of the *α* comparison for the highway A9 are reported below. Table 1 shows the risk values, expressed in fatalities/year/link referring to the particular analysis. The QRAM software shows higher values than GIIS.

Table 1: Results of the α comparison for road users - particular analysis performed for the highway A9. For each of the eight links, two scenarios are considered: Petrol Pool fire and LPG Jet fire

α comparison - particular analysis - Highway A9 - $R_{i,s,c}$ [fatalities/year/link]					
	Accidental scenario	A carriageway		B carriageway	
		QRAM	GIIS	QRAM	GIIS
Link 1	Petrol Pool fire	4.40E-01	8.05E-05	4.40E-01	8.05E-05
	LPG Jet fire	3.01E-01	1.70E-06	3.01E-01	1.70E-06
Link 2	Petrol Pool fire	1.34E-02	2.44E-06	1.18E-02	2.13E-06
	LPG Jet fire	9.11E-03	5.14E-08	8.03E-03	4.49E-08
Link 3	Petrol Pool fire	9.40E-02	1.72E-05	1.18E-02	2.13E-06
	LPG Jet fire	6.44E-02	3.63E-07	8.03E-03	4.49E-08
Link 4	Petrol Pool fire	1.34E-02	2.44E-06	1.18E-02	2.13E-06
	LPG Jet fire	9.11E-03	5.15E-08	8.03E-03	4.49E-08
Link 5	Petrol Pool fire	1.34E-02	2.44E-06	1.17E-02	2.13E-06
	LPG Jet fire	9.11E-03	5.15E-08	7.99E-03	4.49E-08
Link 6	Petrol Pool fire	1.34E-02	2.44E-06	1.18E-02	2.13E-06
	LPG Jet fire	9.11E-03	5.15E-08	8.03E-03	4.49E-08
Link 7	Petrol Pool fire	1.34E-02	2.44E-06	1.18E-02	2.13E-06
	LPG Jet fire	9.11E-03	5.15E-08	8.03E-03	4.49E-08
Link 8	Petrol Pool fire	1.34E-02	2.44E-06	1.18E-02	2.13E-06
	LPG Jet fire	9.11E-03	5.15E-08	8.03E-03	4.49E-08

Table 2 shows the results of the aggregate analysis performed within the *α* comparison for the highway A9, whose risk values are on average with respect to the number of links and carriageways.

Table 2: Results of the α comparison for road users - aggregate analysis performed for the highway A9

α comparison - aggregate analysis - Highway A9 - $\bar{R}_s$ [fatalities/year/link]		
Accidental scenario	QRAM	GIIS
Petrol Pool fire	7.104E-02	1.298E-05
LPG Jet fire	4,857E-02	2,739E-07

Table 3 also shows the results of the general analysis performed within the *α* comparison for the highway A9, whose risk values are on average with respect to the number of links, carriageways and accident scenarios under consideration. In this case, too, the QRAM software shows higher values than GIIS.

Table 3: Results of the α comparison for road users - general analysis performed for the highway A9

α comparison - general analysis - Highway A9 - $\bar{R}$ [fatalities/year/link]	
QRAM	GIIS
5.980E-02	6.627E-06

Regarding the *β* comparison, Table 4 summarizes the particular analysis performed for the provincial road SP 342, considering road users and population as targets.

Table 4: Results of the β comparison for road users and population - particular analysis performed for the Provincial Road SP342. For each of the eight links, three accidental scenarios are considered: Petrol VCE, LPG VCE and Ammonia Release

β comparison - particular analysis - Provincial Road SP342 - $R_{i,s,c}$ [fatalities/year/link]							
	Accidental scenario	QRAM			GIIS		
		population	road users	Total	population	road users	Total
	Petrol VCE	3.07E-05	9.77E-05	1.28E-04	1.04E-05	6.76E-05	7.80E-05
Link 1	LPG VCE	3.93E-06	2.65E-05	3.04E-05	4.42E-06	1.90E-06	6.32E-06
	Ammonia release	1.06E-05	8.63E-06	1.92E-05	2.95E-09	1.06E-07	1.08E-07
	Petrol VCE	7.67E-06	2.36E-05	3.13E-05	9.22E-06	1.63E-05	2.55E-05
Link 2	LPG VCE	1.37E-06	6.39E-06	7.75E-06	4.17E-06	4.58E-07	4.63E-06
	Ammonia release	3.65E-07	2.19E-06	2.56E-06	1.48E-09	2.55E-08	2.69E-08
	Petrol VCE	1.44E-04	3.45E-04	4.89E-04	3.29E-04	2.39E-04	5.67E-04
Link 3	LPG VCE	2.73E-05	9.35E-05	1.21E-04	1.36E-04	6.70E-06	1.43E-04
	Ammonia release	1.81E-05	3.05E-05	4.85E-05	1.19E-07	3.73E-07	4.91E-07
	Petrol VCE	2.14E-06	2.07E-05	2.29E-05	5.03E-06	1.45E-05	1.95E-05
Link 4	LPG VCE	2.47E-07	5.61E-06	5.86E-06	2.11E-06	4.60E-07	2.57E-06
	Ammonia release	1.73E-08	1.93E-06	1.94E-06	1.37E-09	2.26E-08	2.40E-08
	Petrol VCE	5.55E-05	1.81E-04	2.36E-04	1.22E-04	1.80E-04	3.01E-04
Link 5	LPG VCE	1.04E-05	4.91E-05	5.94E-05	5.16E-05	3.80E-06	5.54E-05
	Ammonia release	6.92E-06	1.60E-05	2.29E-05	2.46E-08	2.80E-07	3.05E-07
	Petrol VCE	1.43E-05	3.01E-05	4.44E-05	2.60E-05	2.08E-05	4.68E-05
Link 6	LPG VCE	2.76E-06	8.14E-06	1.09E-05	1.12E-05	5.84E-07	1.18E-05
	Ammonia release	2.74E-06	2.79E-06	5.53E-06	6.95E-09	3.24E-08	3.94E-08
	Petrol VCE	3.95E-04	3.26E-04	7.21E-04	1.08E-03	2.26E-04	1.31E-03
Link 7	LPG VCE	7.91E-05	8.86E-05	1.68E-04	4.63E-04	6.35E-06	4.69E-04
	Ammonia release	7.90E-05	2.88E-05	1.08E-04	3.11E-07	3.53E-07	6.63E-07
	Petrol VCE	5.03E-04	3.27E-04	8.30E-04	8.50E-04	2.26E-04	1.08E-03
Link 8	LPG VCE	9.86E-05	8.86E-05	1.87E-04	3.61E-04	6.35E-06	3.67E-04
	Ammonia release	1.06E-04	3.04E-05	1.36E-04	2.33E-07	3.53E-07	5.85E-07

Among the several in-depth analyses carried out within this work, Table 5 shows the percentage evaluation of the two elements that define the risk for a road link. In this case, the aim was to estimate and compare the risk associated with the population with the risk associated with road users.

Table 5: Results of the β comparison related to the in-depth analysis for the estimate of the percentage distribution of the risk associated to the population and to road users

β comparison – In-depth analysis for the estimate of the percentage distribution of the risk associated to the population and to road users				
	QRAM		GIIS	
	population risk	road users risk	population risk	road users risk
Highway A9	14 %	86 %	12 %	88 %
State Road SS36	4 %	96 %	23 %	77 %
Provincial Road SP342	63 %	37 %	77 %	23 %

4. Conclusions

This work aimed at analysing and comparing two software: QRAM – Quantitative Risk Assessment Model, developed by PIARC, and GIIS – Global Integrated Information System, implemented within the DESTINATION project - DangErous tranSport To New prevenTive Instruments.
Both instruments provide for the quantitative analysis of the risk associated with dangerous goods transportation by road. A comparison was made on three different types of road (highway, state road and provincial road); eight 500 m-long road links were chosen for each of them (the length of the section is 4 km).
A first phase focused on the analysis of the two software in order to understand their operation and identify any comparable features. Two comparison methods were then defined as a function of accident scenarios and anthropic targets. Three analyses were carried out on each comparison: the particular, aggregate and general analysis.
Almost all analyses show higher risk values for QRAM than for GIIS. The difference is supposed to be associated with the different analytical formulation of the two calculation models. In QRAM, risk is processed based on an event tree analysis, i.e. a graphical representation of the potential evolutions of each specific trigger event. In GIIS, the risk value associated with a specific accident event is deduced from a parametric formula that summarizes each significant feature of risk analysis, and which may be considered as an extension of the standard risk definition resulting from the multiplication of the probability that a given scenario may occur, together with its consequences.
As far as the risk associated with population is concerned, in both software the provincial road shows higher risk values with respect to the state road and the highway. This result depends on the highly anthropized context crossed by the road, where there is a greater number of potential targets exposed at the margin of the infrastructure.
Considering the risk associated with road users, both software identify the highway as the type of road showing a greater risk value: also in this case the result is in line with expectations, as this infrastructure shows a higher value of traffic and vehicles used for dangerous goods transport.
At last, in the β comparison an in-depth analysis was carried out to identify the percentage distribution on the three road types between the risk associated with population and road users with respect to the total risk. The distribution of the risk within the two software on the three study areas is therefore evaluated, by maintaining comparable percentages between the two types of potentially exposed targets. This in-depth analysis allowed to observe a significant affinity between the two software in this field: even though the absolute risk values in the two software are different, they show a comparable percentage distribution.

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