WHY ARE TRANSPORT-RISK ANALYSES WRONG?

(a new approach to Transport Risk Analyses with definition of Kinetic Risk Analyses)

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Abstract:
Transport-risk analysis evaluates the risks to which the population is exposed when an accident triggers the release of matter or energy having the hazardousness characteristics of the goods being transported. Actually, the analysis is discontinued in the event-tree when no release occurs. The results of this type of approach can at times be astonishing. Indeed, logically one would expect that, when comparing the risks of transporting the same dangerous substances by road or rail, the road should come out the loser. Instead, all the Transport-risk analyses carried out so far show the risk level to be substantially equivalent.

The logic error lies in neglecting that the main danger in transportation is the mechanical hazard caused by the kinetic energy of the moving masses. Add to this the fact that a road tanker has to have high mechanical strength for safety reasons, and one realises that the likeliest event to occur in case of an accident is not the collapse of the tanker, but that of the other vehicles involved. Based on this consideration, an attempt was made to evaluate the hazard connected to the haulage of harmful goods, taking into account the disruption caused by road or rail haulage on existing traffic. The comparison will be made by the "traditional" (if thus it can be called) method and with the suggested new approach.

1. INTRODUCTION

The drafting of area planning criteria aimed at minimising exposure of the population to industrial risks and those of the transport of hazardous substances is generally based on "area risk studies", developed towards the end of the seventies1 as a method for the assessment and management of the risk of a major accident in an industrial area[2], thus extending application of risk analysis methods, applied hitherto to individual (chemical) plants. This approach has been adopted in Italy in area studies such as the ARIPAR [3], ARTIS [4] and GRIPAL [5] projects.

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[1] Canvey Reports, 1978, UK [Ref. 1][Ref. 2]; Rijnmond, 1982, Holland, [Ref. 4], [Ref. 3]
[2] QARA, Quantitative Area Risk Analysis
[3] [Ref. 5][Ref. 6] Analysis and control of industrial and port risks in the area of Ravenna, 1987-1992
[4] [Ref. 7][Ref. 8] Analysis of the risks in industry and services in Trieste, 1990-1993

The transport risk analyses [6] carried out to date are the result of area risk analyses, in that they have always been applied to specific industrial areas and have therefore been considered a subgroup of the studies carried out in these areas.

It is worthwhile dwelling on the possible definition of a TRA, i.e. analysis of the risk linked to the movement of hazardous substances in a specific area.

It is necessary first of all to identify the relevant hazardous substances, the methods of transporting them, the accident rates and related incidental consequences.

By superimposing these consequences on population distribution the risk arising from an accident with release of material and/or energy can be calculated.

In general TRAs enable a comparison of the various modes of transport: road, rail, sea/river and pipeline. Subsequently the analysis will only cover road and rail land transport which has more homogeneous features.

Rail transport is instinctively considered safer than road transport; this view is however refuted by all the TRAs carried out.

On the bases described above, the TRAs inevitably produce values which are equivalent for the rail transport and road transport risks.

Although generally, but not always, the absolute value of the rail risk is lower, these are however minimal differences and definitely not such as to influence drafting of transport policies.

As proof of the above we can recall that on average, under the same conditions, road transport (in terms of tonnes*km/year transported) is at least one order of magnitude higher than rail.

The result obtained from the TRAs is explained if we note that road transport contributes most to the number of accidents with high frequency and limited consequences, while rail transport accounts for accidents with low frequency and more serious consequences.

All this is based above all on the assumption that a possible accident without leakage has no consequences.

In actual fact we consider that this assumption can be mistaken and will illustrate the reason for this further on.

1.1. Redefinition of the transport risk analysis

We will once again attempt to define the aims of a risk analysis for the transport of dangerous goods.

Given the benefits related to the transport of dangerous goods (without which, for example, a chemical plant could not exist and where raw materials necessarily enter and finished products exit), the risks involved in this activity have to be assessed and compared.

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[5] [Ref. 9] Management of industrial and port risks in the area of Livorno

[6] TRA, Transport Risk Analysis

The risks are linked to the changes which transport can cause to the surrounding environment and in particular the quality of the natural environment and the health and safety of the population.

These changes can be chronic (pollution) and acute (accidents). The first (increased noise, air emissions, dust etc.) do not come within the aims of the risk analysis and are the subject, for example, of environmental impact assessment.

The incidental effects can be human-related and environmental. The analysis is generally performed on human-related effects, taking as an indicator the most serious effect – loss of life – which also represents other effects, such as injury of varying gravity, loss of property etc. The analysis, possibly performed on incidental environmental effects, could refer to pollution of surface and underground bodies of water.

Having identified the range of application of the study, it is then possible to define the events of interest, i.e. rail and road transport accidents which may cause fatalities outside of strictly industrial areas.

This premise is necessary for demonstrating that the risk to be analysed is that of road and rail accidents, linked to the movement of dangerous goods, irrespective of whether leakage from the vehicle occurs.

More explicitly, a death is such both when the road/rail tanker which has hit the person has remained intact and when the causes of the decease are the burns suffered in a possible fire. Controversially it could be maintained that the only difference is the space which the same item of news may be given in the media.

To demonstrate the specific nature of the risks linked to accidents without leakage, the latter has been identified as *kinetic risk*, as opposed to *chemical risk,* arising from accidents with leakage.

1.2. Transport risk analysis

Figure 1 shows the distribution of the accidental death rate in Italy in 1996 [Source ISTAT (Italian Statistics Institute), Ref. 11] and Figure 2 the same distribution referred to transport alone, divided by means of transport [Ref. 13]. The population of Italy in 1996 was 57,461,000 [Ref. 12].

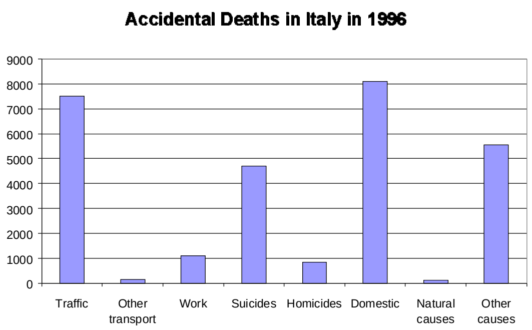

Figure 1 Accidental deaths in Italy in 1996

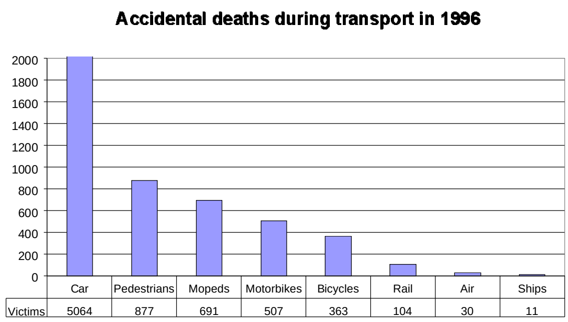

Figure 2 Accidental deaths during transport in 1996

It can be seen that transport can be attributed almost one third of accidental deaths (approximately 8000 cases per annum on average in recent years) while, again from historical data, the average over the past thirty years of deaths from accidents linked to the release of hazardous substances during transport was around 6 deaths/year.

The divergence is clear, even if the causes of death through transport for mere leisure purposes are not of interest for this study. The following is a distinction between road and rail risk. The data are referred, for standardization purposes, to the most recent year for which all the information is available, i.e. 1997.

2. ROAD RISK ANALYSIS

2.1. Goods transported by road

In 1997 the total of goods transported by road (1999 ISTAT annual [Ref. 12]) is given in Table 1. The figures refer to vehicles with working capacity no less than 35 quintals.

Table 1 Total goods transported by road in 1997

Local transport up to 50 km		**Medium-long distance transport**		**Total**	
Tonnes	*Tonnes km (thousands)*	*Tonnes*	*Tonnes km (thousands)*	*Tonnes*	*Tonnes km (thousands)*
496 203 002	**11 344 592**	**657 040 373**	**162 008 037**	**1 153 243 375**	**173 352 629**

By considering the commodity categories relating to hazardous substances, it is possible to calculate the percentage distribution of the same over the total goods transported.

Table 2 Road transport of dangerous goods in 1997

	Local tr. up to 50 km		medium-long dist. tr.		Total	
COMMODITY GROUP	*Tonnes (thousands)*	*Tonnes km (thousands)*	*Tonnes (thousands)*	*Tonnes km (thousands)*	*Tonnes (thousands)*	*Tonnes km (thousands)*
Total dangerous goods	31 165	776 521	83 777	19 164	114 942	19 941 020
% of total goods	6	7	13	12	10	12

2.2. Total road transport accident analysis

In medical statistics the number of deaths is higher than the corresponding ISTAT-ACI [Italian Automobile Club] ones for the following three reasons:

- medical statistics are not limited to 7 days but extend also to subsequent years;
- in the causes of death the doctors tend to emphasise the accidents instead of the concomitant causes;
- in accidents some people apparently unharmed have internal injuries which are fatal over the following days.

On the basis of the above explanations, the deaths through road accidents in 1996 [7] are the following: 6 193 for ISTAT-ACI (Road accident statistics [Ref. 13]) and 7 502 for ISTAT-Medical (Causes of fatal accidents [Ref. 11])

[7] Last year in which the ISTAT annual was available [Ref. 11]

This difference can be regularly found (often more markedly) in the statistics of the previous years.

Since, as mentioned, in order to standardise the information, the year 1997 will be taken as reference (given that during this year there were 33 deaths more than in 1996 [Ref. 13]) a death rate of 7535 cases was taken and, more generally:

Table 3 Road accidents in 1997

Deaths	Injuries	Accidents
7 535	270 962	190 031

2.3. Goods transport by road accident analysis

The figures given in the previous paragraph refer to the entire national road system and all vehicles in circulation. The data relating to goods transport in general were then calculated, given that there is no specific information on the transport of dangerous goods. The figures were taken from the ISTAT publication 1997 road accident statistics [Ref. 13].

It should be noted that 9% of accidents are responsible for 15% of all deaths (this can clearly be explained with the difference in weight of the vehicles involved in the accident).

Table 4 Accidents involving transport of goods by road in 1997

	Accidents	Deaths	Injuries
Lorries <35 quintals	649	20	929
Lorries >35 quintals	5 085	342	7 419
Lorries of unknown weight	8 396	349	11 813
Trucks with trailer	1 393	177	2 045
Articulated lorries and buses	1 875	224	2 650
TOTAL	**17 398**	**1 112**	**24 856**
Percentage of total	*9*	*15*	*9*

2.4. Goods transport by road accident rates

From the information given in the previous paragraph the accident rates of dangerous goods transport were obtained.

Since the number of journeys/year, i.e. [8] the trucks/year number, is not available, we hypothesised an average load of 20t per journey. Table 5 gives the summary data.

Table 5 Overall road transport figures

	Total goods	**Dangerous goods**
t km	173,352,629,000	19,941,000,000
t	1,153,243,375	114,942,375
trucks km	8,667,631,450	997,050,000

[8] trucks referring to all vehicles used for transport.

In order to calculate the accident rates of goods transport by road, the data relating to all the goods were taken as a reference, since specific data on dangerous goods transport accidents are not available. By cross-referencing the data of Table 5 with those of Table 6 the following is obtained:

Table 6 Road goods transport accident rates

Deaths	Injuries	Accidents
6.4E-09 deaths/t km	1.4E-07 injuries/t km	1.0E-07 accidents/t km
9.6E-07 deaths/t	2.2E-05 injuries/t	1.5E-05 accidents/t
1.3E-07 deaths/trucks km	2.9E-06 injuries/trucks km	2.0E-06 accidents/trucks km

3. RAIL RISK ANALYSIS

3.1. Goods transported by rail

In 1997 the total goods transported by rail[9] was 82.9 million tonnes (+8.6% over 1996) and the tonnes/km were 25.2 billion with an increase of 8.2% over 1996.

The average journey of one tonne was 304.1 km, recording a slight drop (-0.4% over the previous year).

3.2. Rail transport accident analysis

In 1997, in absolute terms, 73 accidents occurred at the trains, 57 while shunting and 16 at the level crossings which, compared with the accidents of the previous years, express a reverse trend compared to 1992-1996 when the values reached on average 80.8 accidents at the trains, 77.2 accidents while shunting and 22 at the level crossings. The safety indicator, measured in number of typical accidents per million of train km covered, in 1997 takes on the value of 0.42[10].

The table below gives the train km over recent years for the various transport categories.

Table 7 Rail transport distribution by type: TRAINS km (thousands) in 1997

passengers	goods	mail	service	isol. locomotives	Total
256,012	**67,595**	**2,080**	**12,407**	**7,418**	**345,512**

In order to assess the accident rate of goods transport it was assumed that the accident distribution was similar for the various types of transport. Table 7 shows that in 1997 the train km covered in goods transport were 20% of the whole. Consequently the accidents in 1997 were evaluated as follows:

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[9]source: Italian railways; see site www.fs-on-line.com

[10] In 1997 the French national railways (SNCF) had a value of 0.63 while the German counterpart, RENFE, recorded 0.45.

Table 8 Goods transport accidents

	goods transport accidents
at the trains	15
when shunting	11
at the level crossings	3

With reference to the death rate figures, (statistics supplied by the railways), the persons who died following typical accidents were 0.05 per million trains km in circulation in 1997 (identical figure to the average for the period 1992-1997) and numbered 17 cases in 1997.

Of these, those relating to passengers traffic were 0.28 per billion passengers km, equal to a total of 14 people. The remaining 3 fatalities are to be attributed to goods traffic.

The ISTAT-medical data [Ref. 11] differ slightly, with the causes of death attributing to rail traffic 104 cases during the same period (1996, which can be extrapolated to 1997).

In order to valuate the atypical cases not considered in the rail statistics, again in 1997 there were 11 deaths while crossing level crossings, while the 76 remaining cases can be related to suicides. Although these latter victims do not concern the study (being voluntary loss of life for which the railway is only a means), the cases at the level crossings are however risks generated by the activity of transport.

Since the distribution between passenger and goods transport is not known, it was assumed that this does not depend on the type of transport and therefore is proportional to the trains-km covered. As a result the 11 deaths were allocated as follows: 2 cases to goods transport and 9 cases to passenger transport.

On the basis of the above considerations, the death rate linked to rail transport is summarised in Table 9

Table 9 1997 death rate linked to rail transport

	Goods transport	Passenger transport	Suicides
Deaths	5	23	76

As regards accidents and injuries, we obtain:

Table 10 Accidents involving goods transport by rail in 1997

	Accidents	Deaths	Injuries
Goods transport by rail	29	5	24

3.3. Accident rates of goods transport by rail

With the information analysed in the previous paragraph it was possible to obtain the accident rates of dangerous goods transport. Not having found specific information on the transport of dangerous goods, the same distribution as road transport, equal to approximately 10% of the whole, was taken.

Table 11 Overall rail transport figures

	Total goods	Dangerous goods
t km	**25,225,000,000**	**2,522,500,000**
t	**82,900,000**	**8,290,000**
trains km	**345,512,000**	**67,595,000**

In order to calculate the accident rates of goods transport by rail the data relating to all the goods were taken as a reference, specific data on accidents concerning transport of dangerous goods not being available. By cross-referencing the figures of Table 10 with those of Table 11, the following is obtained

Table 12 Accident rates of goods transport by rail

Deaths	Injuries	Accidents
2.0E-10 deaths/(t km)	**9.5E-10 injuries/(t km)**	**1.1E-09 accidents/(t km)**
6.0E-08 deaths/t	**2.9E-07 injuries/t**	**3.5E-07 accidents/t**
7.4E-08 deaths/(train km)	**3.6E-07 inj./(train km)**	**4.3E-07 acc./ (train km)**

4. COMPARISON OF THE CHEMICAL AND KINETIC RISK ON A LOCAL SCALE (DANGEROUS GOODS TRANSPORT)

The following is the information which can be obtained from applying the suggested methods to a typical industrial area affected by production sites, chemical plants and the transport of dangerous goods, mainly by road and by rail. For confidentiality reasons we will not supply specific references to the area in question, which extends for around 35*15 km, but we would like to point out that the comparison was made possible by having performed, during a specific study, valuation of the chemical risk linked to the transport of dangerous goods in the areas. The transport of dangerous goods in the area in question is in line with the national averages and was equal to:

Table 13 Hazardous substances transported in the area in question

	t dangerous goods	(t km) dangerous goods
Rail	150,000	5,700,000
Road	2,000,000	58,000,000

having considered an average distance of approximately 35 km both by road and by rail.

4.1. Calculation of the chemical risk

The chemical social risk in the area in question is shown in Figure 3.

Examining the graph F-N shows a significant diversification of the main causes in the various bands of the same graph.

In particular it can be seen that, in the bands with low consequences / high frequencies (events with < 10 deaths), the main risk is represented by road transport. In the band of average consequences / average frequencies (events characterised by 10-100 deaths), the dominant contribution is also the road one. In the band of high consequences / low rates however the main contribution is that of rail traffic.

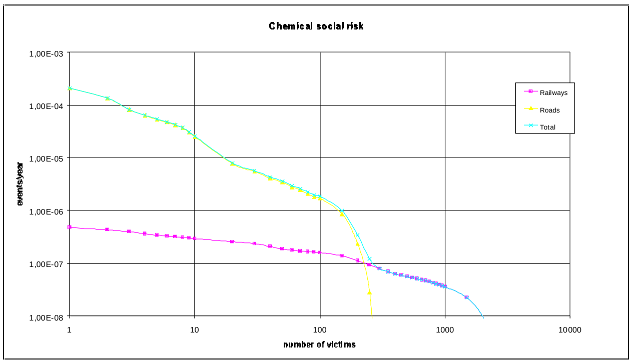

Figure 3 Chemical social risk graph

4.2. Calculation of the kinetic risk

From what has been said in the previous paragraphs, and in particular in Table 6 and Table 12, it is possible to valuate the kinetic risk for transport of dangerous goods in the area in question. Referring to the t km transported in the area it is possible to obtain the following kinetic risk values:

Table 14 Total kinetic risk induced by the transport of hazardous substances

	Deaths	**Injuries**	**Accidents**
Rail	0.0011	0.0054	0.0066
Road	0.3640	8.1410	5.6980

The figure is obviously underestimated, given that in the quantities transported only the hazardous substances prone to a major accident are calculated, while obviously the substances which are less hazardous and those not hazardous should also be counted.

It also has to be considered that the transport of the aforesaid substances also continues beyond the boundaries of the area analysed, so that the t km will be higher. However we preferred to maintain alignment with the analysis performed for the chemical risk, so as to allow a comparison between the two types of risks. The graph of the social kinetic risk was plotted by distributing the values calculated in the previous paragraph by accidents involving on average 1 to 6 people and is shown in Figure 5 below.

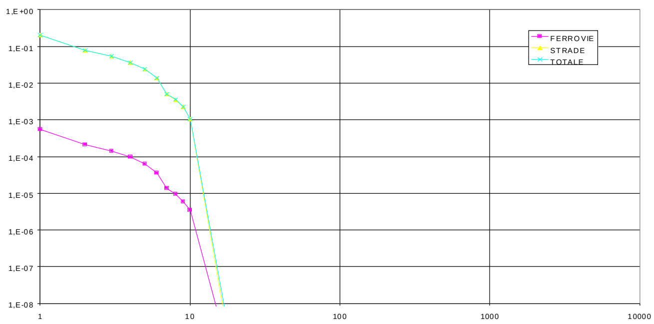

Figure 4 Kinetic social risk graph

4.3. Overlapping of the chemical and kinetic risk

From the overlapping of Figure 3 and of Figure 4 it is possible to obtain the graph shown in Figure 6 below.

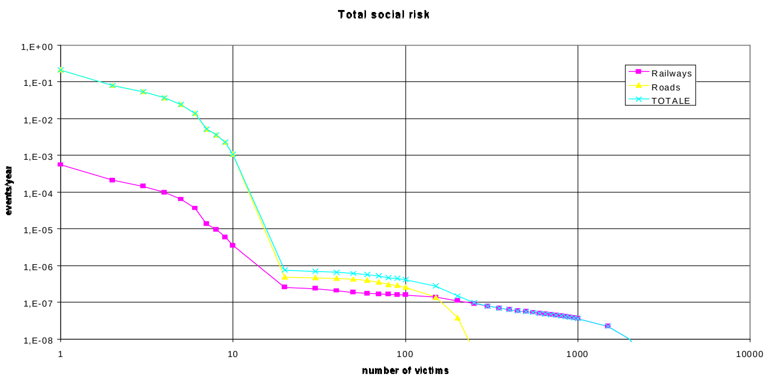

Figure 5 Overlapping of the chemical and kinetic social risk graphs

4.4. Final considerations with reference to a local scale

Examining Figure 5 is cause for comment.

The greater value of the kinetic risk compared to the chemical risk is clear, despite the kinetic one having been underestimated due to the considerations stated in paragraph 4.2 [11]

In order to compare the different quantities numerically, the integrals of the graphs of Figure 3, Figure 4 and Figure 5 have to be calculated, or the sum of all the contributions of the various accident hypotheses, to compare the overall risk in terms of deaths/year. The following summary table may be useful:

Table 15 Table summarising the different contributions to the risk

	Chemical risk (deaths/year)	Kinetic risk (deaths/year)	Total risk (deaths/year)
Railways	9.30E-05	1.10E-03	1.19E-03
Road	1.10E-03	4.25E-01	4.26E-01
Total	1.20E-03	4.26E-01	4.27E-01

Above all it can be seen that the integral of the graph of Figure 4 (kinetic risk) is 0.426, while that of the graph of Figure 3 (chemical risk) is 0.0012, i.e. the kinetic risk is over three hundred times higher than the chemical one.

It is equally clear from Table 15 that the road contribution is considerably higher than that of rail, i.e. approximately 12 times for the chemical risk, 400 times for the kinetic one and 350 times for the total one.

[11] Calculation of only the hazardous substances prone to major accidents, with transport continuing even beyond the area boundaries

A better comparison between road and rail risks needs to consider *Table 13*, that shows a ratio of 10:1 between road and rail transport. The *Table 15* should then be modified evaluating the risks per transport unit, i.e. per (tonnes*km).

Table 16 Table summarising the different contributions to the risk per transport unit

	Chemical risk (deaths/year t km)	**Kinetic risk (deaths/year t km)**	**Total risk (deaths/year t km)**
Railways	1.60E-11	2.00E-10	2.16E-10
Road	1.90E-11	6.40E-09	6.42E-09
Total	3.50E-11	6.60E-09	6.64E-09

The last table gives some general conclusion:

- the chemical risk doesn't seem to be particularly different between rail and road transport
- the road kinetic risk is 30 times higher than rail kinetic risk
- generally the kinetic risk is 200 times higher than chemical risk

These results are fully and clearly understandable, given the daily occurrence of road accidents. As a result any greater use of rail transport would significantly reduce the accident risk for the population.

It could be said that the better training of the driver of vehicles transporting hazardous substances reduces the accident rate of the specific transport.

Without figures on this, it is not possible to verify this statement (even if in any case the order of magnitude of the problem would not change), but it should also be noted that the road accident rate was considered in this analysis as constant, i.e. independent of the interference induced by the increase in heavy traffic linked to the transport of dangerous goods examined, while an uncontrolled increase in heavy traffic can definitely lead to a higher accident rate.

5. EVALUATION OF THE KINETIC RISK ON A MACRO/NATIONAL SCALE (GOODS TRANSPORT IN GENERAL)

The contents of the previous paragraph should be assessed on a national scale; they depart from the problem of the transport of dangerous goods, yet relate to the entire Italian goods transport system.

The current system of transporting goods by road caused as many as 1112 victims in 1997.

In recent years fatalities at work have been:

Table 17 Fatalities at work in Italy in recent years (source INAIL[12] www.inail.it)

Year	1996	1997	1998	1999	2000
Fatalities at work (total)	1,160	1,235	1,297	1,257	1,148

[12] National Institute for Insurance against Accidents at Work

It should be noted that the road fatalities caused by goods transport are of the same order of magnitude as the total fatalities at work.

In the same year the number of victims caused by rail transport was equal to 5 deaths.

Another interesting datum is that among the whole fatalities at work, about 15% (166 in 1997) involves truck drivers.

It should be noted that the market today prefers road transport for reasons of reliability and infrastructures and that the rail network is currently inadequate for significant transport increases.

Nevertheless greater confidence by the firms in the reliability of the rail service would lead to an increase in activity. It is however assumed in theory that it is possible to move to the railways all the goods traffic which travels by road and which does not travel locally (i.e. over 50 km)

With reference to Table 1 the goods transported over medium-long distances in 1997 were equal to 162,008,037,000 t km.

On the basis of the accident rate figures calculated in this study moving transport from road to rail would mean 1037 less road fatalities and 32 more by rail, with a balance of 1000 less per year.

The importance of this information is evident, and has never been considered in Italy (but also in other countries) when drafting transport policies.

More generally the reduction in injuries and accidents can be similarly evaluated, as shown in the table below:

Table 18 Hypothesis of reduction of damage

	Road	Rail	Difference
Deaths	1,039	32	1,007
Injuries	23,229	154	23,075
Accidents	16,259	186	16,073

According to an ACI-ISTAT survey [Ref. 14], road accidents in 1997 caused 19 billion EUR in social costs (336 EUR per inhabitant), equal to 2% of the GDP.

The survey considered in millions EUR the medical (288) and administrative costs (3,609), the moral and biological injury (2,309), loss of income by the victims (4,816) and material damage (8,070).

According to what is indicated in Table 4 the accidents related to the transport of dangerous goods account for between 10% and 15% of the whole.

As a result the reduction in the accident rate would involve, among other things, also a saving of at least 2,58 billion EUR a year.

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7. ESSENTIAL PERSONAL PROFILE

dr.ing. Edoardo Galatola, Nuclear Engineering Degree – University of Pisa, 1982, born in Naples I, December 29, 1957

Mr. Galatola joined E.N.I. group in 1985, then he established Eidos and Icaro that he left, while establishing Sindar (a safety and environment engineering company) in 1998 where he is managing director.

Main activities of Mr. Galatola and its companies deal with studies on Major Industrial Hazards (Chemical and Petrol-chemical Establishments), Risk Analysis of the Transport of Dangerous Goods, Risk Area Analysis, Environmental Assessments, Safety at Work, Safety and Environmental Management Systems, Emergency Management and Civil Protection Planning, Environmental Engineering, Software Tools for Risk Analysis, Safety, Environment Protection and training.

He published papers (more than 30) and lectured on above arguments in national and International Congresses (>60), and teached the subjects in public and private courses (>50).

Mr. Galatola is advisor of JRC (Revision of Seveso I Directive), Ministry of Interior - Department of Civil Protection (Off-site Emergency plans), ANPA - National Agency for the Environmental Protection (developing standards for risk analyses), Federchimica and Assogasliquidi - National chemical and LPG Associations (developing standards for the associates), Trenitalia and Italferr - Italian Railways companies (risk analyses and safety design), Ministry of the Environment (safety and risks standards), Regione Lombardia (risk assessment), CEPAS - the italian personnel certification organism (certified Safety Lead Auditor).