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Risk assessment of major hazards : hazardous materials transportation in urban areas

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EVALUATION DU RISQUE D'ACCIDENTS MAJEURS : TRANSPORT DE MATIERES DANGEREUSES EN ZONE URBAINE

Résumé

Parmi les accidents d'origine industrielle, le transport des matières dangereuses contribue pour une large part au total des sinistres. Si la majorité des accidents se situe en zone rurale, l'essentiel des victimes, et des dégâts, se retrouve en milieu urbain, de sorte que le problème concerne au premier chef les grandes agglomérations.

Si certaines villes ont pu organiser un contournement, ce n'est pas le cas général. Encore dans ce cas faut-il considérer les nombreuses exceptions que constituent les livraisons dans la cité. L'approvisionnement en matières dangereuses (essence, gaz liquéfiés, et solvants peintures etc...) est en effet essentiel à la vie de la cité.

Ce risque pose des problèmes de gestion sur plusieurs plans. Tous ne relèvent pas de l'autorité urbaine, non-compétent par exemple pour la définition des règles de conception des véhicules. En revanche les responsables des grandes métropoles ont en charge les problèmes d'infrastructure (mise au point d'itinéraires spéciaux, construction d'équipements de sécurité pour, par exemple, empêcher des déversements d'arriver dans les réseaux potable etc...). Un autre aspect important est l'organisation de l'intervention : les communautés urbaines doivent assurer la formation des équipes d'intervention, les implanter et les équiper de matériel adéquat. Enfin la sécurité d'équipements collectifs (hôpitaux, école, réseaux d'eau ou gaz), leur incombe généralement et oblige à considérer les agressions possibles via les conséquences d'accidents de matières dangereuses.

Dans tous ces cas, des choix sont à faire et des investissements à réaliser. La connaissance qualitative et quantitative du risque permet de guider ces choix ; elle est aussi nécessaire pour définir l'importance des efforts à concentrer, en fonction du niveau de risque.

Le point a été fait ici sur les méthodes d'évaluation quantitative dont on dispose aujourd'hui et sur les réalisations récentes. Il ressort que ces méthodes, mises au point il y a une quinzaine d'années sont maintenant opérationnelles. Elles ne sont plus réservées à des groupes de recherche et sont pratiqués aussi par des bureayx d'études. Grâce à la quantification à laquelle elles aboutissent, nombre attendu des victimes et fréquence de catastrophes, elles sont une précieuse aide à la décision à laquelle les responsables commencent à faire appel.

Contents

1. Scope of the report

Hazardous material traffic through important urban areas is among the most important sources of major hazards, and one of the most difficult to deal with. It is, for example, impossible to define exclusion areas as for industrial facilities, and also it is far more difficult to prepare the emergency response, since nobody knows where the accident is to happen. In addition there is no specialised staff as in a plant to start up the response actions and analyse the situation. In some cities, the city center can be preserved from this traffic. However the question cannot have such a drastic answer in an important urban system. First the needs of the system, industrial but also domestic, require a delivery traffic; second the extent of the urban area can make rerouting impossible.

There are many measures for reducing this risk; rerouting the traffic; shifting the transport mode; specific restriction (tunnels or rush hours); training of emergency response teams and material equipment of those teams; real time survey of sensitive areas (e.g. TV survey in headquarters); improvement of the rail or road network (it is not rare that in a given curve a gasoline spill occurs once a year); protection of sensitive targets (e.g.undergroud drinking water). Other measures are dealing with the training of drivers, the safety of the vehicles, the strenghtening of the tank or package. At last the loading and unloading procedures in industrial areas, gas stations, swimming pools, dry cleaning factories are also efficient risk reduction measures, but the they are usually out of range of the regulatory power of a city. In some instances even the national authority is not competent, as in Europe where the road and rail hazardous material transport regulation is defined by international bodies.

The set of possible risk reduction action is potentially illimited. However, as it is recognised that urban systems require hazardous materials (petroleum of course, but also other ones), the risk cannot be eliminated. At the same time, remedial actions are expensive, and no one can afford to implement everything. Thus risk management has to cope with two problems :

- Selection of the most efficient among all possible measures
- Definition of residual risk levels, beyond which further reduction is not felt necessary.

Those are classical problems of risk management, known as the optimisation problem and the acceptability problem. They require an economic, sociological and political approach. But at the same time it is crucial to be able to assess the level of risk. For that reason, risk assessment has appeared as soon as in the early seventies as a prerequisite to risk management, let it be for the nuclear industry or any industry, or for hazardous material transportation or any hazardous system in a city. In addition, risk assessment implies a risk analysis which is of great interest for identifying adapted risk reduction measures, which are almost impossible to define whithout the knowledge of the hazards and failure sequences.

The interest of risk assessment studies raises no doubts, but not all of them are routine studies. Indeed, those studies were still research works in the seventies. It is therefore necessary to provide here a synthesis on the state of the art in this field. Three questions are adressed here:

- In which field can the methodology be considered as achieved?
- What is the availability of assessment models, must be collected, what are the associated costs?
- From a pragmatic point of view, how can the results be incorporated to risk management?

The questions of the feasibility of a risk assessment study, of the applicability of its findings and of the profitability of such a process cannot be answered on a theoretical basis. Therefore the present analysis will rely on some of the most important risk assessment studies in order to see why they have been launched, how they have been applied, what decisional problem was behind them, and how it has been handled. What is also of interest is the nature of the feedback to

Probabilistic Risk Assessment and Risk Spectrum

What is a PRA ?

When dealing with rare events (core melt-down in a Nuclear Power Plant, or, here, Burst Out of Propane road tanker in urban area), statistics are not available. In order to predict the probability and consequences of such accidents, one has to analyse the accidental sequence of such accidents, one must split it into a set of sub-events that can either be observed (road accident with speed in excess of 100 km^{-1}, ignition...) or directly computed (extension of a gazeous explosion).

How to deal with the results ?

This general approach is called the PRA methodology. As a result, the decision-maker is provided with the whole set of possible accidents, each of them being associated with its probability and consequence. A common synthetic index for the risk is then the mathematical expectation (e.g. the yearly expected number of deaths). However this single figure is often unsatisfactory since it does not tell whether it is attributable to rare events of important consequences, or to less severe but frequent accidents.

Graphical representation of the risk spectrum

The question that remains to be dealt with is therefore the characterization of the risk spectrum, i.e. the relative importance of major events vs usual accidents. Graphical representation has became well known. It is called Farmer's curve (from one of its first users) or f-N curve (for frequency number of deaths) or CCDF function (Cumulative Consequence Distribution Function). On the graph, one can read in regard to a number of death, the probability of occurrence, per year, of an accident resulting in at least that number of death . An example from study 12 is provided here. Here, it appears that an accident with at least one death is to be expected every 100 year. An accident with at least 10 deaths is expected with about the same probability, while it is once in every 100 000 years that 1 000 victims would be observed.

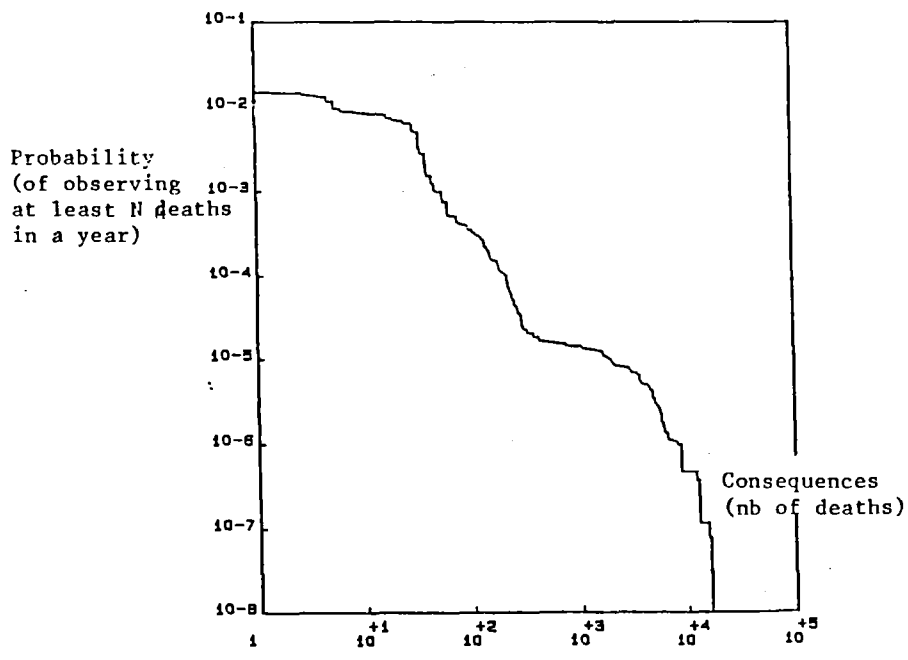

Fig. : A typical f-N curve : an hazardous material route through a city center (from /12/).

the safety level or to safety costs, if any returns were searched for. Those studies are sometimes specific of urban problems, others are generic of rail and road hazardous transportation of a given product or set of products. However, all of them mainly deal with urban problems, since the accidents occuring in urban areas are not numerous (a few percent of the total), but account for the greater part of the risk for human populations.

2. Description of typical risk assessment studies.

A dozen of pubished studies have been analysed, either trough published material or personnal contact with authors. A common format has been used and the main headlines were as follows.

1. Identification of the study

Who did it, who paid it, for whom, what is dealt with?

2. Claimed purpose

Is it an exhaustive PRA (Probabilistic Risk Analysis) is there a decisional problem behind it, is there a decision aiding analysis?

3. Assessment process

Have all the steps of a PRA been completed, with which thoroughness ? Have some results been borrowed or previous models used? Are the models which have been set up of general use ? What about economic analysis, for safety option costs, for effects ?

4. Financial aspects

Who paid for it, or shared the costs, Is it a research work or an engineering study? Does it profit to or from other work?

5. Results

What are the nature and formats of the computed indices?How is uncertainty dealt with? What can be derived from the analysis?

Each of the selected studies is given here a short presentation showing the main characteristics of the methodology and some of its results.

PNL-gasoline [1] (USA - Whole country)

The study is an assessment of the risk of transporting gasoline by truck. It was completed in 1978 as the fourth in a series of assessments of the risk of transporting energy materials. The probabilistic risk assessment methodology used in this study is now quite standard. It was developed in the previous studies that dealt with radioactive materials. The results are related to the year 1980. Risk is expressed in terms of fatalities among the public, accounting for the occupants of other vehicles trapped in the accident, and for drivers of gasoline tank trucks. A risk spectrum (Probability-Consequence, or f-N, or Farmer's curve) is given with and without traffic deaths included. The risk to any individual in society is compared with risks from various accidents or natural disasters and found acceptable. Uncertainty analysis is made only through sensitivity studies that are also used to evaluate a few risk reducing measures but without any further conclusion. Although generally conservative, often due to lack of data, the results are presented as the most realistic possible using existing information.

PNL-propane [2] (USA - Whole country)

The study is an assessment of the risk of transporting propane by truck and train. It was completed in 1980 as the seventh in a series of assessments of the risk of transporting energy materials. The risk assessment methodology used in this study is the same as in the case of gasoline and the results are presented in the same way. The shipping system is assumed to be the same as in the mid-1970s and propane is assumed to be shipped in tank trucks, bobtails or rail tank cars. The annual expected number of deaths in the public resulting from these releases in 1985 is 15 (11 from tank truck, 0.5 from train). Additional deaths per year may be expected from drivers, firefighters and other people in the immediate vicinity of the accident. The f-N spectrum of risk shows that accidents involving ten or more public fatalities are to occur at a rate of one every six years. The resulting risk is shown to be less than many other commonly accepted risks in our society. Sensitivity studies were used to test the effect of key assumptions on the analysis results. The same remark as for the gasoline applies here as for the generally conservative character of the results

PNL-Puget Sound [3] (USA - Puget Sound)

In 1980 the Puget Sound Council of Governments initiated a regional assessment of hazardous materials transportation in the central part of the Puget Sound region. The study performed by Battelle is part of this assessment. Five commodities were selected (LPG (Liquified Petroleum Gaz, chlorine, methanol, motor fuel anti-knock compound and sodium hydroxide), one in each of the most common DOT (Department Of Transportation) hazardous material classes, the transport mode being either truck or rail. Release sequences were identified using a fault tree approach for specific transportation equipment. Extensive use was made of the previous BNWL (Battelle North West Laboratory) studies on gasoline, propane or chlorine with modifications where appropriate to assess release probabilities given an accident. Specific data were developed on the transportation environment including accident rates, weather conditions and population densities along the route. Risk spectra are presented and several sensitivity analyses were done to determine the effect of assumptions made in the analysis and of risk reduction strategies: steps taken at the accident scene, mitigating actions for the public, rerouting. Costs of these actions were not quantified. The study is considered to provide a benchmark for similar regional studies.

A community model [4] (General application)

The report covers the phase I of a three phase preparedness program, the other two phases dealing with organizational and training aspects. Besides a review of existing literature on risk analysis or assessment, the main effort was the development of a risk model and the associated user's manual to use by local communities (cities below 50,000 or rural areas) in order to assess their risk from the transportation of hazardous materials according to all modes: highway, rail, air, water and pipeline. The research team, supported by a local advisory committee, chose not to have an analytical approach. The model is strictly empirical although attempts were made to insure that it does not violate existing "risk" theory. The user is led step-by-step through a series of tables using only resources and data readily available. A risk factor and a consequence factor are determined for each one-mile segment of the route then multiplied to give a risk index readily translated in a level of risk. The latter can then be compared with the index of the level of preparedness obtained from a questionnaire resulting to determine the community vulnerability and finally a level of response plan is suggested. After testing on two towns (45,000 and 1,500) it was concluded that the model is easy to implement and the results appeared reasonable. Of course any conclusions regarding its general utility would have to wait for the test of time.

ADLittle-Liquified Natural Gas [5](USA - New England urban area)

In 1978 before the projected three-fold increase in the LNG imports of the Everett terminal and the resulting likely increase in LNG trucking in the New England area, the MTB and state and local governments were interested in evaluating both the current and future risks associated with LNG trucking operations from the Everett import terminal. The study was sponsored by the MTB. After the gathering of information on the transport system, data on accidents and design of trucks were examined to develop estimates of accident rates and probabilities of accidents involving a release of cargo. An estimate of potential consequences of accidents was also made according to criteria defining the conditions under which persons might be seriously or fatally injured in a major accident. Hazards models describing fires and flammable vapor cloud travel were employed to estimate areas of risk. Probabilities of vapor cloud hazard areas were estimated allowing for the spatial distribution of potential sources of ignition. Results appear in the form of risk profiles (Probability-Consequence or f-N curves). Sensitivity analysis gives an uncertainty factor of about 4 in either direction. Risks resulting from the study were compared with (and found well below) risks from other activities. Risk profiles of the following options are compared but no attempt is made to assess their costs: route or operation modifications, training, emergency response, transport by barge or rail, or substitution by LPG trucking.

TNO-LPG [6] (Netherlands)

In 1983 TNO issued the final report of the LPG study for the Dutch Ministry of Housing, Physical Planning and the Environment. Work had began much earlier in 1978 when TNO initiated the development of the probabilistic risk assessment methodology resulting in textbooks known as Yellow and Red Books. The motivation for the LPG risk assessment was essentially to provide a basis for the government's policy in this area, and also to derive from the findings suggestions of methods for reducing risks. The study was monitored by the supervisory Committee set up by the Minister. The study addressed storage (including transshipment) as well as transport through four modes: truck, train, inland waterways and pipelines. Use was made as far as possible of the data and models already available at TNO. Effects were translated into fatalities and other casualties among the public only and into distances over which buildings and installations might suffer damage. Resulting risks are presented in graphical form as f-N curves and the uncertainties attached to the estimates of probability or effects and damage are presented in detailed tabular form. Methods were suggested to reduce risks and some findings were later directly taken into account by the regulatory bodies.

Technica-Rijnmond [7] (Netherlands, Rijnmond urban area)

The Technica study into the risks from transportation of liquid chlorine and ammonia in the Rijnmond area was initiated in 1983 and cosponsored by the VROM Department and the Rijnmond Public Authority. Earlier in 1980 a preliminary study was done by A.D. Little on the risk assessment methodology from hazardous materials transportation. The general objective was to get more insight into hazardous materials transportation in the Rijnmond area where another study was also made on LPG. More specifically general recommendations were to be drerived from the results of the analysis. Technica used their SAFETI package and gave two representations of risk: individual risk contour plots and risk profiles for the individual materials and transport modes (sea, inland waterways, road, rail) as well as for groups of modes. Accidents are assumed to be distributed with their corresponding probabilities every 100 m along each route and consequences are assessed based on population densities within 3 km of the route and recorded on a 500 x500 m grid. Risks were expressed in graphical form as f-N curves.

Lautkaski-chlorine [9] (Finland - Whole country)

In 1976 an assessment has been made of the risk to the public from the transportation of liquid chlorine by train in Finland. Fourteen typical train accidents were selected and their probabilities of occurrence were estimated using the accident file of the Finnish State Railways. The probability of a chlorine leak was assessed for each type of accident separately using four leak size categories. The most frequent cause of leakage involves impact or valve damage. Depending on the leak category, the chlorine release rate is determined with its time dependence, and a gaussian plume dispersion model is applied to calculate hazard areas. Two threshold values are taken for concentration inducing lethality and medium or severe injury . A simple model is used to define the population density along the route allowing for the presence of people either outdoors or indoors. A severe accident in a switch yard is considered to occur once in 7000 years leading to some 3500 injuries. The Probability-Consequence or f-N risk curve is used to compare the resulting risk to some other risks including those due to nuclear reactor accidents are compared. Risk reduction actions dealing with design, operation and emergency were recommended on the basis of their effectiveness on the risk level.

HSE-Train [9] (United Kingdom - Whole country)

In 1985, at the request of the Advisory Committee on Dangerous Substances, HSE initiated a study on the assessment of risk from the transportation of hazardous material by train. The main objective was to get an insight into this question. Chlorine, LPG, Petroleum spirit and Ammonia were supposed to be representative of all the transported materials. The analysis focused on a number of given routes and an exhaustive PRA was performed. The methodology is not entirely new, tools have been developed prior to this study, but specific developments had to be carried out, an important part of the process consisting in reaching the consensus on the proper way to adapt models. The risk to the public is expressed in terms of expected deaths, no account is taken of the potential damage to property or the environment. Extensive use of statistical data on accidents is made to estimate scenario or failure occurrence probabilities. Results will be expressed in the form of expected deaths and f-N curves.The study which is not yet completed, will eventually evaluate the risk control system. Practical recommendations and, if deemed necessary, regulatory changes will be proposed. The study is expected to serve as a reference for scheduled work on road and sea transport.

Waterloo University [10] (Canada, general, applied to Toronto)

The Institute for Risk Research (IRR) of the University of Waterloo (Canada) has just completed a study on the management of risk from the handling and transportation of dangerous goods. This work has been done for the Ontario State authorities and cosponsored by IIASA and Transport Canada.The objective is to develop a generic methodology for the determination of policy options. An application to the Ontario situation is done in order to prove the feasibility. It is an exhaustive PRA. Chlorine, LPG and sulfuric acid were the materials selected, being representative of the risk from the whole traffic. Deaths are not the only envisaged impacts, casualties and property damages can also be handled. The focus is on the decision aiding aspect. Comparison of alternative option for routing is proposed. An application of the methodology is in progress for the Toronto metropolitan area. A package has been developed to support the future applications. An interesting feature is that it permits the uncertainty analysis through an improved Monte Carlo type simulation.

CEPN-propane [11](France - Whole country)

In 1982 the French Ministry of Environment sponsored a study to demonstrate the feasibility of the methodology for assessing risk from the transportation of hazardous materials and to examine how it can help decision making in this field. The first phase was devoted to a review of existing practical tools for each of the steps in the framework of probabilistic risk analysis. The referenced report deals with the second part of the study, showing that risk assessment should not restrain itself to a simple quantification of the risk level. The need to account for the risk control system parameters is stressed, because it allows to identify and evaluate the different risk reducing actions. Risk indicators adapted to the different potential hazards originating from a hazardous materials transportation accident are shown to depend on the decision framework and on well defined objectives for the study. After a review of the French risk management system for hazardous materials transportation, two PRA studies are presented on the transportation in France of propane and of uranium hexafluoride.

CEPN: Lyon [12] (France, Lyon)

In 1985 the French Ministry of Environment sponsored a study for assessing the risks from transportation of hazardous materials in the south of Lyons France. The objective was to quantify the level of risk from the local traffic and as well to get an insight into the spatial dependencies of the assessed risks on the different routes. The risk management problem was to decide upon the opportunity of a rerouting of a part of the traffic through the werstern suburbs of the area. Two itineraries (city center and rerouting) were thus compared, on the basis of the risks linked to four products : chlorine, ammonia, motor spirit and LPG. Traffic data were based on a local authority survey. The risks resulting from one year traffic are presented both globally (for the whole area) and locally for each 1 km x 1 km cell of the corresponding grid. Risk is expressed in terms of expected deaths or as standard Probability-Consequence curves. The rerouting would reduce the overall risk from .5 to .15 death per year, a low figure for road casualties, but a very high one for a major hazard risk. Expected economic losses are also estimated for traffic interruption, as well as the cost of the rerouting. A cost-benefit analysis showed that the rerouting is worthwhile as soon as some weight is put on accidents of major consequences, even with a very light weighting factor such as 2 (risk aversion against catastrophic events).

Other studies

It is not possible to describe all the work done on those subjects but it is worthwhile to quote a couple of analyses of interest. For instance the PNL performed numerous studies in the radioactive transportation field (19), on chlorine (13) similar to the above described ones. Westbrook (16) in Great Britain and the UCLA (17) were also engaged in studies on the same material. Lautkaski, besides the chlorine study assessed risks from the transportation of LPG, sulfur dioxide and ammonia (15). The Technica study on the Rijnmond area has also been preceded by a feasibility study of A.D. Little which is of interest (18). An original study has been conducted by the BASLER consulting group on the transport of explosives for the Swiss Army. The scope is limited to a few kilometers but the interaction with cost-benefit analysis is quite exemplary (14). Another study from PICKARD, LOWE & GARRICK is also well applied to decision making problems, but the anonymous character of the material did not allow to take it into consideration. In this respect an important work on the nuclear waste management problem introduced beyond the risk assessment, sophisticated decision aiding methods along with the weighting of the various risk criteria (20). On the routing problem, Kessler's study on the Dallas- Fort Worth area is quite representative of what can be done (24). Enlarging the scope to other transportation modes (pipeline, barge and sea-going ship) would have led to consider studies such as the Mossmoron (22), Felixtowe Dock (25), or TNO-LNG ship studies.

3. Main characteristics

According to the scheme used the main outcomes of the review can be seen on table I.

Table I: Main features of the studies

Study	A	year	cost (1987$)	PRA	local	impacts
PNL-gasoline	Y	1978	100,000	Y	N	nb of deaths(public)
PNL-propane	Y	1980	90,000	Y	N	nb of deaths(public)
PNL-Puget	Y	1981	60,000	Y	Y	deaths + injuries
ADLittle-LNG	Y	1979	110,000	Y	N	nb of deaths(public)
Russell's model	Y	1981	?	N	Y	qualitative index
TNO-LPG	Y	1983	1,500,000	Y	YN	nb of deaths(public)
Technica	Y	1985	150,000	Y	Y	nb of deaths(public)
Lautkaski	Y	1979	?	Y	N	nb of deaths(public)
HSE-rail	N	1987	100,000	Y	N	nb of deaths(public)
Waterloo	Y	1987	200,000	Y	Y	deaths+other losses
CEPN-propane	Y	1985	40,000	Y	N	nb of deaths(public)
CEPN-Lyon	Y	1986	40,000	Y	Y	nb of deaths(public)

A=free access, cost in rounded figures

An interesting aspect is that the studies focus on a quite broad set of topics. Thus, there are many ways to categorize the studies. One is to quote the subject which is the most intensively worked out. It appears that a few studies have centered their efforts on the reliability field and/or on the computation of consequences. The most characteristic from this point of view are TNO, HSE, PNL on propane and chlorine, Lautkaski, CEPN on LPG, and Technica studies.

On the other hand the remaining studies took for granted the results of available physical, chemical and biological models, possibly with some simplifications, and focused on points which are upstream or downstream in the risk assessment process (e.g. road accident data elaboration, emergency response capabilities or population data distribution along the route). The most representative of this approach is the Kansas University Community Model, but the University of Waterloo, the PNL-Puget Sound, and the CEPN-Lyon studies enter in this category. In some cases the borderline is difficult to draw (Puget Sound), but generally it is easy to see that the main concern of the authors is on one side or the other.

It is less easy to see whether a study is generic or not. The only clear example are the Community Model and may be the University of Waterloo studies. A major work like the TNO-LPG is originally a specific analysis but it contains so many theoretical developments that it can be considered as generic. Most cases are hybrid. A connected problem is to determine the relative extent of research versus engineering work. The PNL analyses are typical: a generic methodology is used and pinpoint research work is performed on the "missing links" of the PRA scheme.

Table II : Type of returns from the studies

Study	New models	Regulatory changes	Acceptability considerations	Applications expected
PNL-gasoline	yes	no	yes	
PNL-propane	yes	no	yes	
PNL-Puget	no	no	yes	
ADLittle-LNG	no	no	yes	
Russell's mode				yes
TNO-LPG	yes	yes	yes	
Technica	yes	no	yes	
Lautkaski	no	yes	yes	
HSE-rail	yes?	yes	yes	
Waterloo				yes
CEPN-propane	yes	no	yes	
CEPN-Lyon	no	no	yes	

The returns of these exercises are found in quite different fields and it is difficult to give an accurate picture of them (table II). An important output of one out of two studies is that models (often for the physical consequences of releases) have been made available, and that consensus has been reached on many of them. In only one case, may be two depending on the results of the HSE study, regulations have been directly derived. However, a lot of thought is given to the regulation policies and most of the studies are inputs in these processes (cf for example the CEPN study in France, the Waterloo study in Canada or earlier the Lautkaski study in Finland or the Puget Sound study). The use of the results or of the analysis itself in discussions about acceptability pertains to this kind of returns. Quite often, nothing did happen because of the study and not in spite of the study. Also some returns are to be found in improvements of safety devices or in the computer models. The use in emergency response planning is also one of these indirect, but effective returns, thanks to better defined scenarios. The last two returns are clearly linked to the amount of original work encompassed in the analysis. The use of the results in acceptability problems is not too much dependent on the accuracy of the final results, but the opportunities for discovering interesting safety options imply a very precise description of all the system's components.

The costs of performing the studies range over more than one order of magnitude, the size of the system under analysis is not the main reason for these differences. The two major contributors, in this sample, are the amount of research work and the rigidity of the peer review process. It seems that the approach in the Netherlands has been modified for this reason : instead of a steering committee meeting more than 20 times for the TNO study, an a posteriori review, leading eventually to rework some phases, has been prefered to the "continuous" approach. Nevertheless these two aspects are associated with interesting returns.

Knowing that all studies but two have been conducted by institutes whose primary goal is research, it can easily be understood that few studies have been paid at their real cost. The official cost is usually an underestimate because a lot of research work made elsewhere in the laboratories is incorporated. But as it was also an opportunity to develop more general models there are also reasons for the cost to be an overestimate. With the exception of the Finnish study where it seems that railway and insurance companies co-sponsored, the fundings have always come from national or local authorities.

At last, the decision analysis content of the studies is still quite simple, the usual way being to compare two options on the basis of the expected number of deaths or of the f-N curve for these effects. And the need for more cost-effectiveness analyses is recognised as well as for more assessments of the global detriment of accidents (casualties and their valuations, economic damages).

4. Issues for the development of risk management.

Some issues are of importance today when looking at the posibilities of developments of risk management methods. They have been highlighted by the previous syntheses.

At first, it is not very realistic to predict an explosive development of probabilistic risk assessment in the near future, even though it is strongly recommended by many instances (e.g. Transportation Research Board of the National Research Council of the United States [a]). However, the central administration in the U.S., in France [j], in Great Britain, in the Netherlands [f], in Canada and in Finland do support such studies, and have been working on a conceptual framework to include their findings within the decision making processes. Here again the idea is that transportation is a good field for developing risk management methodologies, since the regulations are less rigid than for fixed installation. In the nuclear field, the official recognition of an optimisation requirement implies the use of risk assessment [c]. Nonetheless it remains that some obstacles are still ahead. Before the speading of PRA studies as natural inputs to a regulatory or technical decision making process, a few points need to be clarified which are reviewed here.

There must be a clear decisional framework .

What can be called the "system for safety control of hazardous material transportation" is indeed complex and involves many different actors whose tasks are somewhat different. At a first glance one could distinguish the regulatory, the industrial and the emergency response systems. On all of them the city authorities have some influence, on none they have an unquestionable preeminence.

All actors in the system are working under pressure from the economy of the product, from the insurance system or from public opinion. This is not specific of transportation. What is more specific is that the important industries, such as the petroleum and chemical industry are less involved in transport activities: The persons in charge of transportation are the carriers, which are generally small companies, except for the national european railway companies and they do not have the organisation and research capabilities of the major industries. Their concern in safety is not focused on the major hazards and they do not claim specific skills in this field. To make this point clear, one must remember that transportation is by itself a dangerous industry. The death rates for job accidents is the highest among other industries.

As already said the urban community is not the only one among the actors. Broadly speaking the product classification, the operating rules, the design specifications, the placarding and to some extent the definition of judicial responsabilities are defined at the national and international levels. The routing questions, the enforcement of the legislation, the alert network and the organisation of the emergency response are left to the lower levels.

These distinctions explain how the risk assessments do have different objectives according to the nature of a requiring authority. They do advocate also for risk management as a tool for rationalisation among all those regulations. Without pretending to exhaustivity, some points must be listed about which risk assessment has been advocated for: reduction of accident rates, design improvement of package and specific devices, assessment of the potential liability to insure, authorisation of a new product, definition of regulations or of a policy for the

management of a given risk, identification of priorities in safety research information of the public and of professionnals (eg potential rescuers), emergency preparedness, routing and public hearings... Any of these points involves a function that a "Safety Control System" must perform. Without quoting all of them, it can be seen that they are directed to different actors of the system. Some of them were the explicit goal of the screened studies, others can benefit from returns of these studies.

Assessment for acceptability questions.

All the studies examined but one (the Kansas University community model), can more or less be used to judge the acceptability of the risk level associated with the system under study. In most cases an f.N. curve (also called "Farmer Curve", or "risk profile", or "Probability-Consequence Curve") has been displayed. Very often also the original drawing from the WASH-1400 is the support for this display.

Even in studies more devoted to risk management, a digression is made to compare with other products or transport modes thanks to the Farmer curve (i). So far the risk assessment studies do not go further than a presentation of such results. It must be said that there are no safety criterion to compare with. Even in the Netherlands, where a societal risk target applicable to the f-N curves exists, it is not applicable for transportation. The results are used only to define exclusion distances and therefore allow rather to answer routing questions. In most of the studies the f-N curves are widely used in a comparative manner, either for comparing the activity under study to others, or in order to compare alternative options within the study. The presentation of synthetic risk indices (i.e. the mathematical expectation with or without restrictions) can go along with the Probability-Consequence curve.

There is indeed a lack of explicit criteria for deciding whether a risk is acceptable or not. The point is nit very simple, as we are dealing with major hazards. The .5 deaths predicted yearly in Lyons (Cf [12]), is a very small figure compared to road casualties on the very same itineraries. It is however more important than the same index for more than ten nuclear power plants. There is no doubt that there is still som work to do to manage such considerations. Nevertheless the knowledge of such an order of magnitude is already interesting, especially in comparative studies, and, anyway it is a prerequisite for further developments on acceptability.

Many different decisions can result from the studies.

It is necessary to distinguish the actual way some decisions and regulations were arrived at from the formal process which might be used in the future. In two cases, the HSE study and the TNO study, a major regulatory evolution was linked to the study. The research teams were asked to analyse the system, assess the risk, eventually jointing out a couple of suggestions, but not to propose directly a regulation or regulatory system.

Even when one of the issues is to know if a new regulation is deemed necessary, within the assessment process, pinpoint improvements are also put forward that can be voluntarily put into operation. This way of increasing the safety seems satisfactory to many people. In urban systems it can be one of the best ways to improve safety, since regulation is not always possible. One must never forget that the risk assessment study outcome can also be the decision not to implement a new regulation. A lot of risk reduction measures are advanced all the time. When they can be discarded , one can say that the role of the risk assessment has been fulfilled.

Sometimes safety options can be proposed on the basis of pure engineering judgment, sometimes the effectiveness can be assessed on a risk estimate basis. The success of these recommendations is very dependent on the way the concerned authorities and operators can be involved in the assessment.

An other matter is routing, which gave rise to much more developments at the local level. Generic studies, like the Waterloo one, allow the local authorities to develop applications. The Federal Highway Administration has also developed a document, the "Guidelines for applying criteria to designate routes for transporting hasardous Materials" (e), which have been widely diffused and gave rise to some published applications (24). The risk analysis is usually less developped in this case (it relies largely on the more "classical" risk assessments), but the decision analysis is more sophisticated. It is typically a case where cost-effectiveness analysis apply easily. Also the results can have a trivial use, since in many cases, decision makers do not even know whether a measure increases or decreases the risk (Cf transit restrictions in road tunnels).

The last point in which the risk assessment studies have been used is emergency preparedness. The Kansas Vulnerability model directly adresses this subject, but experience has been gained through all other studies. Development of accident scenarios, models for the physical consequence of an escape have permitted to define more efficient responses. The knowledge of the network and accident probabilities would allow optimization of the location and equipment of emergency centers. In the most recent years these last two subjects have given rise to a considerable amount of work in the United States, (a, b, d,).

Classical decision aiding tools can be implemented

The comparison of options which have been performed in some of the risk analyses may look as a very primitive input for decision making. Nevertheless the knowledge of the efficiency of a safety device is something very important and quite new in this field. As already quoted, it may happen that the people do not know whether the effect is positive or negative.

In most studies, the bases for more sophisticated decision aiding techniques are available. On the other hand, the methodology for performing cost-effectiveness, cost-benefit and multi-attribute analyses has been made avalaible for a while. The cost-effectiveness methods have been tested for more than 10 years in the nuclear field. They still remain a mere input in a far more complex decision making process, but they are recognized as valuable tools. Using some of the work incorporated to the Canadian Study, E. Saccomano performed a risk-benefit analysis on routing strategies (Saccamano in [a]). The results showed that the "minimum accident" (i.e. minimizing the number of accidents) route was not cost effective. The minimum risk (i.e. minimizing the expected losses from accident) routes were the best solutions yielding a saving on the risk of approximately CND $ 20 millions yearly for the 500 millions vehicles km traffic in Toronto, with an increased expense of CND $ 10 millions for the trucking industry. Other studies of this kind have been performed, by the Basler Compagny on explosive moves (14) or by Pickard and Lowe on an anonymous chemical [i]. or by the CEPN on the transit of radioactive packages under the Mount Blanc Tunnel [k]. Numerous other examples could be found, they have in common to have been performed on a small scale, and seldom for administrations so that they do not appear in research records. They do require additive work in assessing the costs of options and in valuating the components of the risk, but they usually heavily rely on the work from major studies such as the ones which were analysed. In parallel more generic decision-aiding approaches have been developed in order to use the output of risk assessment. One is for example the risk-cost analysis of Abkowitz [g]. Another is the risk-cost model of ISPRA/IIASA which is a user friendly model for multi-attribute selection of alternatives routes.

Risk assessment has become a recognised methodology

One of the most positive returns of the recent studies is that they allowed an agreement on many methodological tools. The general sequence is usually the same: Analysis of the systems - Traffic

data collection - Accident data collection - Event trees - Package failure modes and thresholds - Physical models for the consequence of the escape (pool evaporation, gas dispersion, explosion model) - Dose-response relationships (to toxic, thermal or overpressure stresses) - Assessment of letal areas. Population density data collection - Sheltering and escape effect.

Among the interests of the heaviest studies is the fact that the discussion ended up with some agreement on plausible model, for gas dispersion or toxicity for example. There are two benefits, since it is now possible to regulate with reference to some physical models, and since people doing further research or engineering work in the field have more models and data available, if not complete packages, and that they know how most of the partners feel about them. This is quite a recent and drastic change.

The costs are decreasing...may be too much

In the early eighties, it was necessary to make some research or at least implement existing models for each of the steps in order to complete a probabilistic risk assessment. It is now possible to make a very quick study using only readily available materials. The costs have therefore been greatly reduced. However it is not recommended to do so without a careful look at the validity of the underlying assumptions and data, and this usually should had to rework part of the models and collect better data.

The studies examined here range from about 30.000 to 900.000 $, and average at about 150.000 $. Today it may be assumed that this kind of studies might be twice cheaper. In absolute figures these are not very high costs and they usually correspond to about 1 man-year of work. It remains to be seen if the cost of the study should be compared with the measure cost, or with the net benefit from it. In the first case the cost is generally very small.

When one considers the cost of training the emergency response system of the US federal government (7 millions yearly), which is only a small part of the whole emergency response system (1,5 millions people in the US might act in a hazardous material emergency), it is clear that a small improvement of the system is worthwhile a study. The property damages due to road and train accidents with hazardous materials range between 10 millions $ and 100 millions yearly and most people think they are much nearer from the higher limit (d). As to the cash flow if the road transport industry for these materials, it should be between 10 and 20 billions $.

In fact there has been many discussions about the costs of the studies , but the costs of their object, the traffic accidents and their consequences is almost unknown.

It is interesting to consider what makes a study expensive. First it is the data collection, second comes the implementation of the models, third it might be necessary to make some experiments, and fourth it might also be necessary to rework the study after a meeting with the steering committee. In none of the analysed studies were important experiments required, but this could be the case if an embarrassing point appears. The traffic data collection can be a long experience process. However in many cases the people asking the study are directly interested in it so that they often collect the data for themselves and supply them to the study (cf. Puget sound and Lyon study). The second point will see a great deal of reduction in costs for an equivalent quality. The process which consists in going through regular meetings with discussion in committee is a very slow and a pretty expensive one, although often fruitfull as it might be the only way to involve all the people responsible for risk management. Clearly all these factors allow to lower the costs but one must take care that the lack of a specific analysis can make a study useless.

5. Conclusions

There is no doubt that, thanks to the pioneering studies of the late seventies and the early eighties, a methodology has been made available that allows risk management of hazardous transportation in urban areas. This approach can easily be extended to the management of other similar risks (storages and to some extent natural hazards). The methodology is both technically available and affordable. The insertion within the decision making processes deserves still some efforts. It has be seen that the applications are broad and numerous. They range from route selection to emergency preparedness, with some insights into acceptabililty considerations. One limit to the use of such studies, aiming to an objective assessment of the risk, is the complexity of the decision problems, where many factors are to be considered, the most subtle being the one linked to acceptability.

However, as such studies develop, those factors start to be clarified, and decision makers learn how to use risk indices in this context. So at the present time it can be said that risk analyses are a valuable input into the decision making process in most cases. And, as more experience is acquired the uses are broader. As any technical innovation risk assessment modifies the approaches to the questions it is dealing with. It seems impossible now to treat those kinds of risks as was done ten years ago.

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