Ten Years Experience in Linear Facilities Risk Assessment (LFRA)

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ABSTRACT: Reportedly, the first wide-spectrum example of a geo-environmental risk study dates back to the late 70s when the UK government launched a study of risks associated with a petrochemical facility at Canvey Island, located on the left bank of the Thames River, downstream from London. This study was soon to be followed by another example in the Netherlands. In the 1980s, risk studies were performed in the chemical, petrochemical, railroad, automotive and water treatment industries and today, communities, utilities, mining, forestry and almost all types of industry demonstrate strong awareness of rational Risk Assessment (RA) and in some cases of formal Risk Management (RM).

During the past decades, characterized by the development of the RM culture, a variety of different RM models have been proposed by governmental agencies in various parts of the world. The most structured models appear to have originated in the field of environmental RM. These models are briefly reviewed in the first section of the paper focusing the attention on the difference between Hazard Management and Risk Management.

During the 1980s, the human factor was introduced in RAs for the first time from a qualitative, then, later, a semi-quantitative point of view. Likely motivations for this shift were the accidents at Three Mile Island, Chernobyl, Bhopal and the Challenger explosion in which human error played a major role. If on one hand it can be said that chemical, electronics and nuclear industries have paved the way to geo-environmental RM practices, on the other methods developed for these industries have limited application and may even be inappropriate for the specific needs of heavy industries (such as transportation, energy distribution or mining) exposed to geo-environmental risks in increasingly more congested transportation corridors.

The core of the paper reviews a number of different RA approaches specifically developed for linear facilities (LF) in transportation corridors since the early 90s in Switzerland, Italy, Canada, the US and South America. The applications are compared in terms of methodology, capabilities and resources necessary to their implementation. The paper focuses the attention on the adequate level of detail that each application has to attain as organizations which consider deploying formal RM plans are generally faced with a double challenge. The first challenge is to develop custom tailored RM applications, phasing in their implementation so as not to compromise safety and reliability whereas the second is to provide employees with a high level of confidence by demonstrating that new RM approaches are, indeed, effective and sustainable.

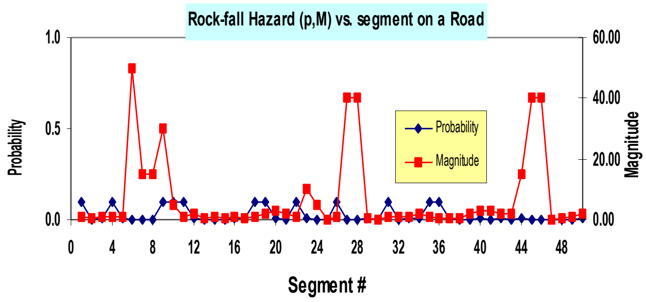
The paper focuses the last sections on the description of the next generation of linear facility RA application, including examples of results and discussion of future methodological research. The links between RA and ISO 14000 (environmental management code) are explicitly considered.

1 INTRODUCTION

During the past decades, characterized by the development of the Risk Management (RM) culture, a variety of different general RM models have been proposed by governmental agencies in various parts of the world, for example:

- Canadian Standard Association (CSA, 1991)
- Scientific Committee on Problems of the Environment (SCOPE, 1980)

Figure 1. Plot of hazard probability p and magnitude M for rock-falls along homogeneous segments of a road



- National Research Council (NRC, 1983)
- Royal Society (RS, 1983)
- Health and Welfare Canada; Health Protection Branch (HPB, 1990a,b)

The most structured models appear to have originated in the field of environmental RM, are still in use, correspond to well recognized standards and abide to strictly defined glossaries.

The term risk (IUGS Committee on Risk Assessment, 1997) is generally defined as the combination of the likelihood p_H of a specified hazard H (a condition with the potential to cause undesirable consequences), and the consequences of the event (harm and/or damage) C_H (a (monetary) measure of the impact of a hazard on

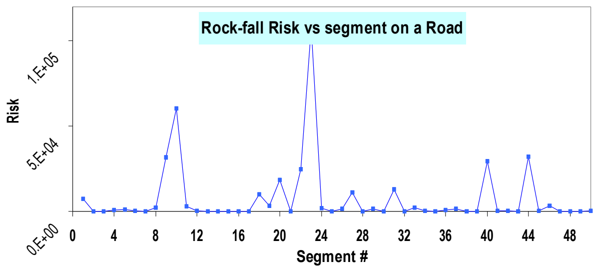


Figure 2. Plot of risk for rock-falls along homogeneous segments of a road. Note that the peaks of risk do not correspond to the peaks of hazard in Figure 1

potential receptors).

Event's consequences C_H should not be confused with event's magnitude. Indeed, hazards with similar magnitude (for example rocks of a given mass located at a given elevation above a road) can produce very different consequences C_H as a function of the impact location, the potential targets and the local environment. C_H can be seen as the sum of components such as direct costs, replacement costs, indirect costs (loss of business etc.), social costs, political costs, public reaction costs etc. In many instances the combination of p_H and C_H takes the form of a multiplication, thus leading to the risk $R_H = p_H \times C_H$. Thus a Quantitative Risk Assessment (QRA) requires a numeric estimation of the probability of an event occurring coupled with the numeric assessment of the cost of damages or consequences of the event occurring. Both of these quantities are subject to uncertainties leading to various degrees of uncertainty in the definition of risk (Hogarth, 1975, Fischhoff & Al., 1977, Granger & Henrion, 1990) and require a probabilistic approach.

Once numeric values of risk are defined on an annual or lifetime basis, it is possible to engage in Risk Management (RM), i.e. the complete process of RA and risk control (Can/CSA, 1991) (Figure 3) , i.e. the result of a rational approach to risk analysis and evaluation, and the periodic monitoring of its effectiveness. Practical risk reduction measures may be taken, such as the installation of passive mitigative structures (e.g. protective nets for rock-fall, barriers to hinder vehicle movement, automatic shut-off valves) or active ones (e.g. rock support structures, clearance screening, removal of the hazard source).

Figure 3. Diagram of a typical RM organization and sequence

RM must not be confused with Hazard Management (HM), where hazards are identified and prioritized by probability (likelihood) p_H, and intensity (magnitude) M_H without accounting, however, for the consequences C_H of their occurrence (Figure 1).

For example, a hazard map demonstrates (Figure 4) where the hazard potential is present, with what likelihood, and may indicate a range of magnitude of the events, but not their potential consequences. All too often, even nowadays, mitigative strategies are influenced by perceived hazard magnitudes without a true appreciation of the actual risk involved, leading to erroneous allocation of mitigative investments (Figure 1 & 2).

2 A REVIEW OF EARLY (1970-1980) GENERAL RA APPLICATIONS

Reportedly, the first wide-spectrum example of a geo-environmental risk study dates back to the late 70s when the UK government launched a study of risks associated with a petrochemical facility at Canvey Island, located on the left bank of the Thames River, downstream from London. This study was soon to be followed by another example in the Netherlands.

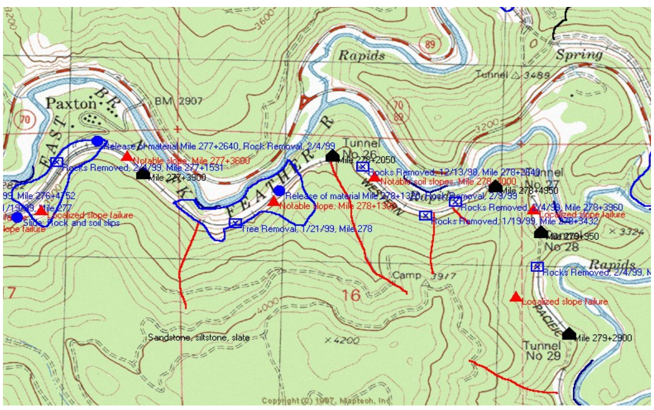


Figure 4. Hazard map along a railroad in California. This shows the localization of potential hazards without any assumptions on probability or magnitude

In the 1980s, risk studies were performed in the nuclear (ANS, 1983) chemical, petrochemical, railroad, automotive and water treatment industries including human error analysis at various degrees of detail.

If it can be said that chemical, electronics and nuclear industries have paved the way to geo-environmental RM practices, the strictly controlled reliability and safety processes of these industries (Ericson, 1969) have lead to risk assessment methods that may have limited application and may even be inappropriate for the specific needs of heavy industries (such as transportation, energy distribution or mining) exposed to geo-environmental hazards and greater uncertainties.

3 A REVIEW OF RECENT (1990-*) LFRA APPLICATIONS

The 90s brought an astounding number of risk analysis applications (Einstein, 1988, Fell, 1994, Morgan, 1992, 1997, Duschinsky & Wick, 1996) in various fields, but only a few address the specific needs of Linear Facilities Risk Assessment (LFRA), despite the fact that linear facilities are running in increasingly more congested transportation corridors and are becoming absolutely critical to our society. Linear facilities are physical links between two geographic points allowing transit of goods, energy, information or people by means of discrete traffic (roads, railroads) or continuous flow (pipelines, channels, cables, fiberoptics).

This section reviews a number of different LFRA approaches developed since the early 90s in Switzerland, Italy, Canada, the US and South America. The applications are compared in terms of methodology, capabilities and resources necessary to their implementation.

3.1 *Methodological Approaches*

3.1.1 *Chardonne Model*

This program (Oboni, Angelillo, 1993) was conducted since the early 1990s for a Swiss community threatened by rock-falls from a series of unstable linear cliffs. From time to time rocks would impact houses, roads and other assets. The system was geared towards the allocation of remedial funds to various sectors of the cliffs, after a risk based prioritization was performed. The system is designed to subjectively quantify risk to engineered structures, and to propose monitoring or mitigative action through an event tree framework.

3.1.2 *CN Rock-fall Management Program*

An international review was conducted to define the state of the art and practice in rock-fall protection, particularly for linear transportation corridors (Abbott & Al.., 1998a). Despite the existence of various rock-fall hazard rating systems (BGC-OA, 1995), a very limited number of rock-fall RA methodologies had been developed by the mid '90s. Thus a methodology for rock-fall RA was specifically developed for Canadian National RR (CN) (Figure 5): it uses a strictly defined observational approach to assign probabilities to various topographic, geologic and anthropogenic features (Abbott & Al.,1998b); mitigative influences of signals, track circuits and remedial works are integrated; consequences were introduced in a simplified way by "derailment categories".

Figure 5. Derailment probability calculation along a railroad in Canada.

Hundreds of miles of tracks were studied and analyzed with a custom tailored database which includes Bayesian updates procedures based on information gathered by a custom tailored event data acquisition system.

3.1.3 *Mining/Industrial Pipelines*

The mining industry is reacting to the lessons learned from highly publicized tailings incidents occurred in the last 5 years. Guidelines prepared by the Mining Association of Canada (MAC 1998) and Government of West Australia (1998) recommend third party RA on all phases of mine development including design, construction, operations and closure.
A QRA process was specifically developed (Oboni et al. 1997, Oboni et al. 1998, Oboni and Oldendorff, 1998, Bruce and Oboni, 2000, Mehling, Oboni and Bruce, 2000) in order to enable mine owners and operators to efficiently and successfully identify potential areas of concern, assess mitigative methodologies, and prioritize and allocate resources.

When the QRA method is used systematically and coherently, the numeric nature of the results allows the comparison of the risk exposures within a mine or a population of mines belonging to one or more corporations. QRAs also may provide a platform for decision making based on the comparison of the assessed risks with Quantitative Risk Tolerability Curves (QRTC), (Bruce & Oboni, 2002).

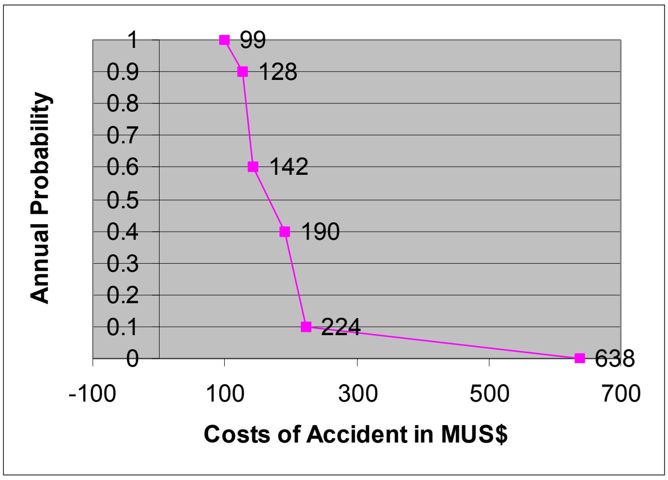


Figure 6. Risk Tolerability Curves (RTC) derived for a large mining project in South America (20 years reserves taken into account; tolerability will reduce as reserves deplete)

A RTC is a function in the p,C quadrant dividing two regions: to the left and below the function risks are considered as acceptable, to the right and above the RTC, risks are considered as inacceptable. RTC are to be developed for each particular client/operation and can change with time. RTCs can be derived either by testing the risk appetite/averseness of key personnel, either by applying a well defined financial data analysis methodology developed by the same authors (Figure 6).

As the process has been successfully applied to over 40 projects and a variety of industries in 5 continents, databases of risks have been prepared to manage and store data from various client's operations, allowing bench-marking of the risk profile of one operation versus "the world". For a single mine the application can be linked to a geographic information system (GIS) for easy data retrieval and manipulation and it can be integrated in a seamless process to loss control data acquisition system and the ISO 14000 event record. The integration of these three programs (QRA, Loss Control and ISO 14000) leads to obvious positive results in terms of ease of operation and financially.

3.1.4 *Oil and Gas Pipelines*

The Canadian Standard Association (CSA) has published specific guidelines for RM (CAN/CSA, 1997) and regulators encourage its use (US-D.O.T., 1999; CAN/CSA, 1999).

Commercially available models (Nessim, Stephens, 2002) include the analysis of the probability of failure of the pipeline under loads imposed on the line (internal pressure, third party impact), material properties (yield strength, fracture toughness), line condition (number and size of defects, defect growth rates), pipe behavior under loads etc. Data base of pipe failures have been prepared and are used as statistical back-ground. Consequences in terms of loss of life, environmental spills, financial are included in the analysis.

It should be pointed out that commercially available models generally do not offer detailed analysis of hydro/geo-hazard generated risks.

Custom tailored models published by Savigny & Rinne (1991) and Savigny & Al. (2002) display objective hazard identification methodologies, but using indexes in a "stack" rating system, they come short of defining probabilities of occurrence and therefore cannot be used, in the present state of development, to define risk. Porter & Savigny (2002) also use indexes, propose to use a hazard rating to prioritize actions and RA only on high hazard locations, thus conflicting with the concept of risk based decision making.

An extension of the CN Rock-fall RA methodology has been proposed (Porter & Al., 2002): it constitutes an attempt to work in the conceptually clear risk framework, but covers unfortunately only one type of hazard.

3.2 *Discussion*

There is a fundamental difference between most of the custom tailored methodologies summarized above and the “commercially available” ones: the first group uses micro-models to define probabilities and consequences, whereas the second one uses statistical data. Micro-models are algorithms to compute probability of occurrence and consequences of a hazard hit based on empirical rules, event trees or simplified mathematical models.

Because of the diversity of the hazards potentially impacting on a linear facility and the general paucity of available data this author believes that micro-models and ulterior Bayesian updates represent the most reliable alternative when dealing with hydro/geo-hazard generated risks.

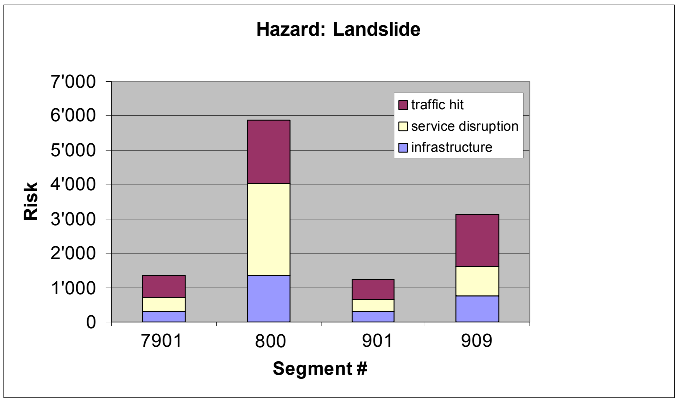


Figure 7. Right: an example of a segment of mountanous road. Left: Relative value of various risk categories for a selected hazard (landslide), on four segments of a road

Moreover, as acquiring data for the micro-models represents a large portion of a QRA implementation investment, it is necessary to carefully custom-design each micro-model to obtain the suitable level of detail. It is fundamental to avoid “paralysis-by-analysis” or “paralysis-by-excessive-need-of-data” and to proceed with QRAs at screening level already, allowing to pinpoint at an early stage sectors of a LF presenting the highest risks, thus leading to sound risk-based decision making (RBDM).

Integration of the data and results within a database, if possible a database allowing bench-marking with peers in the industry, a GIS compatible application and finally the Bayesian update of pertinent information are of paramount importance for enabling sound RBDM. In order to enable Bayesian updating, it is necessary to implement as soon as possible a well designed event data acquisition system.

Finally the integration of QRA, Loss Control data (including investigation on the root causes of each accident) and ISO 14000 environmental event record represents a modern, efficient way of managing data, information to enhance the results brought by each discipline and attain a well balanced RM program.

4 A RECENT LFRA APPLICATION

Lately a new generation of LFRA applications (Oboni & Polithema, 2002) has been developed and deployed on a mountainous road network in northern
Italy. This generation of LFRA encompasses multi-hazard (11 in the case under consideration) identification, micro-models based probability and cost of consequence analysis and uses GIS and Databases for display, analysis and querying of information.

The applications gives for each homogeneous road segment the total risk (i..e. the risk generated by the 11 hazards) split into three categories (Figure 7):

a) the infrastructure risk, i.e. the probability of hazards hitting the segment and provoking damage to the road or its ancillary structures;

b) the traffic risk, i.e. the probability of hazards hitting the traffic (or being hit by a vehicle) on the segment and provoking damage to vehicles, people, or the environment (spills)

c) the service risk, i.e. the probability of hazards hitting the segment and provoking a disruption in the service of the road (dependent on traffic)

The same results are obviously also available selectively for each one of the 11 hazards (Figure 7, right & 8).

The integration of the application in the Civil Protection action planning is already underway. Future research includes the implementation of real-time updating of the events, on-line follow-up of Civil Protection actions and the use of satellite imagery (Synthetic Aperture Radar, SAR) to monitor specific events.

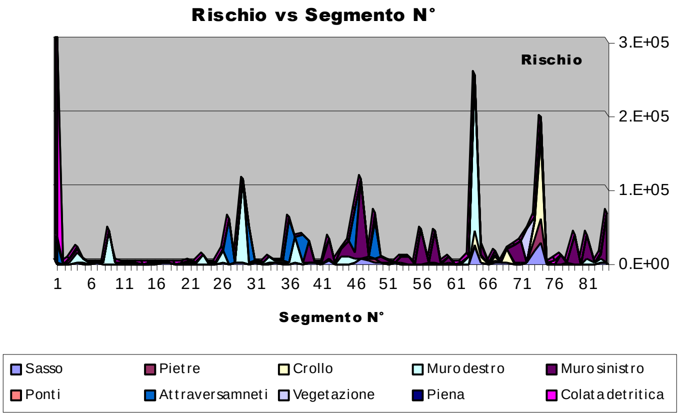


Figure 8. Plot of risk vs. distance (expressed by segment N°). Such a plot documents zone that must be protected first

5 CONCLUSION AND RECOMMENDATIONS

Terms such as quantitative risk management (QRA) and risk-based decision making (RBDM) generally give readers the misleading impression that these tasks are the exclusive domain of high-stakes decision-makers hidden in the boardroom. QRA and RBDM should be included in daily business decisions, where every penny counts and where high-level concepts developed in the boardroom may by far less significant than immediate bottom-line decisions made at the mid-management level.

Although managers generally try to avoid “complex mathematics”, hard numbers are crucial in differentiating risks incurred, sometimes by hundreds of components of a similar system (which can be anything, from a road homogeneous segment to a valve, a tank along a pipeline) leading to the need for QRAs.

After almost two decades of trial-and-error evolution, today simplified QRA methods in the form of database applications based on micro-models for each hazard are available to managers in different industries, after due customization. Micro-models are designed in order to avoid “paralysis by excessive data need”, a common problem, specially when the system to be studied is large.

The most advanced applications are GIS compatible, allow bench-marking with peers, and offer various levels of integration with Loss Control and/or ISO14000. Loss Control integration should encompass root cause investigations in order to lead to proper mitigative actions. Specific modules have been prepared to allow repeatable root cause analysis. Integration is the key to the implementation of sustainable and robust RM systems.

Modern QRA applications can be applied by company personnel after adequate training and with the guidance of an expert. QRA has to be democratized; it not an elitist tool to be kept in management’s hands, but rather is a discipline that should be applied to daily business decisions at any level of a corporation.

If used systematically and coherently, QRAs provide a comparison of risk exposures, which can be benchmarked on an international scale across components belonging to one or more corporations.

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