“The Decision-Funnel Approach for the Prevention of High-Consequence Process Accidents”

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by

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**Abstract:** A series of highly publicized accidental releases of hazardous substances over the past decade and the broad scope of the ensuing regulations aimed at the prevention of future releases, have had major implications for the management of process safety in many firms. Firms in the chemical and oil industries have made considerable progress in developing efficient methodologies for managing process safety. The authors present a composite approach based on the practices developed by the leading firms in these industries. They outline major changes in the operating environment of these firms which have resulted in greater incentives for the prevention of high-consequence accidents and describe how these incentives have contributed to a shift in the focus of firm decision-making from the level of risks to the level of potential consequences under worst-case scenarios. The authors also provide suggestions to help managers develop an environment in their organizations which promotes better safety and which will aid in the successful implementation of a decision-funnel type of methodology.
1. Introduction

The management of risks of accidents, in industrial operations which use hazardous substances, has recently acquired a very high priority for a wide variety of firms. Concerns about such risks were earlier confined to the firms in the chemical and oil industries. However, a series of highly publicized toxic releases in the 1980's -- most notably the ones in Bhopal and Institute, WV -- triggered increasing demands by the public for stringent regulation of hazardous substances. Consequently, the ensuing regulations have affected not just chemical manufacturers but all firms which handle hazardous substances. Consider the broad scope of some of these regulations:

- In 1986, Congress enacted the Emergency Planning and Community Right-to-Know Act (EPCRA) which enforces extensive information disclosure requirements on facilities handling any of the over 300 hazardous substances identified in the regulations.

- In 1992, pursuant to the requirements specified in the Clean Air Act Amendments (CAAA) of 1990, OSHA issued its regulations for process safety management. These regulations cover more than 125 toxic and reactive chemicals and are estimated to affect about 25,000 establishments in 127 industry subgroups.
• Under CAAA, the Environmental Protection Agency (EPA) has been directed to promulgate regulations of even broader scope to cover toxic, flammable, and explosive chemicals that pose hazards to human health or the environment. It is estimated that EPA's regulations will affect about 140,500 facilities.
• An increasing number of states, most notably New Jersey, California, Delaware, Nevada, and Texas, have promulgated their own regulations which require facilities to implement comprehensive risk management programs.

As firms in the chemical and oil industries have been the most direct targets of new regulations and other forms of social reproach, they have made considerable advances in developing efficient decision methodologies and management practices for handling hazardous substances. Over the past three years, we have studied the practices of several chemical firms which have participated in many roundtable discussions organized under the auspices of a Wharton research center. We feel that firms in other industries can greatly benefit from the systematic approach to management of safety that has evolved in these firms. We have termed it the 'decision-funnel approach' because it is built around a funnel-shaped risk screening methodology for prioritizing risks.
The paper will proceed as follows. First, we will describe the increasing incentives for firms to prevent process accidents. We argue that several external changes in the operating environment of firms have resulted in greater incentives for the prevention of high-consequence accidents. In the next section we describe how these incentives have contributed to a shift in the focus of firm decision-making from the level of risks to the level of potential consequences under worst-case scenarios. Then we will present the decision-funnel approach which has emerged in the chemical industry in response to the changes mentioned above. Finally, we offer some suggestions to managers for developing an environment in their organizations which promotes better safety and which will aid in the successful implementation of a decision-funnel type of methodology.
2. Incentives For Better Management of High-Consequence Risks

Until the early 1980's, societal mechanisms for inducing firms to take proactive care to mitigate their environmental risks had relied primarily on the use of ex post liabilities. Until that time, the consequences of process accidents had been limited mostly to the area within the plant boundaries, thus requiring compensation payments only to workers. Under these circumstances firms could rely on purchasing sufficient liability insurance and using litigation to defend themselves against excessive compensation claims arising from such accidents. However, there were some major changes in the operating environment of firms during the early part of 1980s which have necessitated a re-evaluation of this approach to risk management.
2.1 Increase in Consequences of Higher Severity Accidents

The severity of a major process accident refers to the harm caused by the accident. It may include human injuries and fatalities, property damage, environmental damage etc. The consequence of an accident, on the other hand, refers to the actual loss incurred by the firm which includes direct as well as indirect costs of accidents. Before the 1980's, the managerial view was that consequences were more or less proportional to severity. However, with the occurrence of accidents such as the ones in Flixborough, England; Seveso, Italy; and Bhopal, India, the catastrophic potential of hazardous chemicals and their off-site impact was realized for the first time. These accidents shocked not only the lay public but the industry experts as well. As noted by David Buzzelli, Chairman of the Canadian Chemical Producers' Association and CEO of Dow Chemical, Canada:

"Bhopal was a chemical engineer's nightmare for the entire global industry. We routinely talk about 'worst-case' scenarios, but this tragedy was way beyond our worst predictions. It forced us to re-examine everything we do ... We scrutinized every aspect of our operations, our procedures and our management practices. No step in our handling of chemicals could be taken for granted."
The most significant effect of these accidents was that consequences from high-severity accidents were revealed to be much higher than before. Consequently, firms have become vulnerable to significant financial losses which may even lead to bankruptcy. This change was brought about mainly by the following social responses to the increased threat of environmental catastrophes:

2.1.1 Changes in Tort Liability Rules: Many state courts have adopted liability rules which are more favorable to the plaintiffs. The new rules have eased the burden of proof for causation, have made it easier to apply strict liability instead of the earlier standard of negligence-based liability, and have established rules for joint and several liability. There has also been an increase in the level of damage awards based on compensatory as well as punitive damages. For instance, in September, 1994, a jury in Alaska imposed the largest ever punitive fine of $5 billion on Exxon for the 1989 Valdez oil spill. This was in addition to the $3.5 billion paid by Exxon in fines and cleanup costs. Similarly, in 1989, Union Carbide paid $470 million to a compensation fund for the victims of the Bhopal disaster. Thus, the liability costs to firms in the event of a mishap have become more unpredictable and now increase sharply with the severity of harm caused.
2.1.2 Social Amplification of Firm Consequences: As dramatic media coverage of environmental accidents has augmented the salience and dread of such events in the public mind, high consequence accidents can impose additional social costs far beyond the liability costs.

For instance, Exxon's ranking in Fortune's list of the most admired US corporations plummeted from 6th to 110th in the aftermath of the Valdez oil spill. The social reproach penalties may be incurred in the form of increased reputational costs and criticism of corporate executives; lower revenues as customers, suppliers, and distributors may refrain from doing business with the firm; difficulty in hiring employees; and higher compliance costs as the firm may be targeted for more stringent enforcement by regulatory agencies.

2.2 Increased Incentives for Proactive Care

A number of other changes in the business environment of firms have increasingly put the onus of undertaking preventive efforts on the firms. These changes have also been more pronounced for low probability-high consequence risks.

2.2.1 Crisis in the Insurance Industry: In the mid-1980's, high costs of environmental accidents and the unpredictable nature of
future liability costs caused many insurers to withdraw from the market of insuring high consequence risks. In the recent years the market has shown signs of revival but it continues to be thin. With the decline in the insurability of environmental risks, firms have been forced to pay more attention to their own efforts for controlling future losses.

2.2.2 Threat of New Regulations: As the public's awareness of the catastrophic potential of hazardous chemicals turned into "chemophobia", legislative bodies and regulators stepped up their efforts to issue new regulations for the protection of both on-site and off-site parties. While the earlier initiatives were concerned primarily with increasing community awareness and planning for ex post emergency responses to major industrial accidents, recent ex ante regulations focus on the prevention of future accidents. With these sorts of activities on the horizon, firms, particularly in the chemical industry, are recognizing that taking voluntary steps to reduce the consequences of future accidents are in their best interest. As described by Ronald Van Mynen of Union Carbide:

"We'd concluded that an angry or frightened public could shut us down. We realized that we faced two kinds of future: we could be a severely regulated industry with limited growth potential, or we could be one that continues to carry out our traditional mission of innovation, of bringing new and better products to the public ... We are convinced that the difference between the two futures lies in a combination of performance and public interaction", (p. 192).
2.3 Advances in the Technology of Risk Management

In parallel with these changes, there has been a major progress in the technology of risk management. Advances in instrumentation and risk management techniques have allowed decision-making to become ever more sophisticated. Different technologies of care have become available to firms for managing different levels of hazards. These technologies permit progressively higher levels of care to be taken at progressively higher costs and allow process risks to be classified in terms of their probabilities and consequences, costs of assessment, and costs of mitigation. As a result, firms are able to allocate their risk management resources in a manner which is more consistent with the underlying nature of risks and the costs of managing them.

3. Shift in the Focus of Decision-making From Risk-levels to Hazard-levels

Our study shows that a major impact of these external changes has been that firms have begun to pay more attention to the distinction between the risks and consequences of hazardous accidents in their operations. The risk of an accident is a
measure of the expected loss to the firm. It is defined as the product of the probability of an accident and the consequence of the accident should it occur. Earlier, risk management decisions were based mainly on the level of risk. However, as the following examples show, the level of consequence is increasingly becoming a major factor in firm decision-making, even if the probability of an accident is small.

- In the immediate aftermath of the Bhopal accident, Rohm and Haas conducted a world-wide survey of its plants to determine the exposures of surrounding populations. The plants were ranked on the basis of the potential impact on the population in the event of an accident. Steps were taken to reduce high levels of potential consequences with the objective of avoiding worst-case scenarios.

- Many firms have either reduced their inventories of hazardous substances or have substituted them with less hazardous materials.

- Many firms have closed or relocated plants which were located in densely populated areas. In many cases such decisions were made not because of an increase in the likelihood of an accident but only because there was an increase in the density of the surrounding population.
The decision processes for prioritizing risk mitigation in many firms such as Rohm & Haas, Union Carbide, Exxon, and Dow Chemical attach greater weights to higher levels of potential consequences regardless of the probability of an accident.

In the pre-Bhopal period, corporate decision-making focused on the level of risk in allocating risk management resources to risky operations. No distinction was made between many different situations which may lead to the same level of risk. For example, a low-probability event with a high consequence might have the same risk in expected value terms as a moderate-probability event with moderate consequences, or a high-probability event with low consequences. Under this model, risk management resources were allocated equally to these three risks. In other words, as the occurrence of high consequence events was considered to be unlikely, the risk of such events was low and they were not given any higher consideration than comparable risks which were more likely but whose consequences were lower.

Post-Bhopal, however, there was a shift in focus from the magnitude of risk to the magnitude of consequences. Firms began to pay more attention to medium- and high-consequence events even if their probability (and hence the level of risk) was low. This
change in the behavior of chemical firms can be explained in terms of their risk preferences. Usually firms are assumed to be risk-neutral, i.e. they are expected to base their operating decisions on the level of expected losses. However, when the magnitude of losses is significant relative to their assets, firms can also be risk-averse. Under risk-averse behavior, firms care not only about the expected losses, but also about the possible magnitude of losses, and they tend to undertake greater efforts for avoiding low probability-high consequence events than for higher probability-lower consequence outcomes of comparable risk. Before Bhopal, chemical firms were less aware of the catastrophic potential of their process hazards and their attitude towards the management of these risks was largely risk-neutral. With the occurrence of Bhopal they realized that they could incur losses which were significantly high in relation to their assets. Consequently, they became more risk-averse and began making greater efforts to reduce the probability of high-consequence events.

4. The Decision-Funnel Approach For Managing Risks

The need to differentiate process risks on the basis of their consequences has stimulated the emergence of a decision-funnel approach to risk management. This approach can be conceptualized
as being composed of three steps (see Figure 1). The first step is the definition of a set of corporate risk-action guidelines which enable the decision makers to characterize the degree of risk posed by specific operations. The second step is a multi-tiered hierarchical risk screening methodology. This funnel-shaped methodology is used to assess the risk of individual operations, to mitigate risks which are not low enough, and to abandon unacceptably risky operations. This process is repeated periodically to monitor all the operations of a firm on an on-going basis. The third step is a decision process for making resource allocation decisions for mitigation of high cost-high consequence risks. The following sub-sections describe the three steps of the decision-funnel approach in some detail. For each step, an example is provided to illustrate its implementation by a large multi-national chemical firm. These firms are identified in this paper as MNC1, MNC2, and MNC3.
4.1 Risk-Action Guidelines

The first step in the implementation of the decision-funnel approach is the documentation of guidelines that enable managers to rank relative degrees of risk. In the broadest sense, the guidelines distinguish levels of risk (e.g. unacceptable, moderate, negligible) and relate these levels to actions (e.g. mandated, recommended, or voluntary). Delimiting risk thresholds, which may, for example, be expressed in terms of the amount of hazardous chemical, pressure, temperature, distance to the property fence line etc., are established to classify process risks into a small number of meaningful risk categories. The action guidelines enumerate responses which are appropriate for a particular category of risk. The response may be a recommendation for more rigorous risk analyses to understand the risk better or a set of mitigation actions to reduce the risk. Action guidelines outline the standard operating procedures for risk assessment, operator training and emergency response. Guidelines may also prescribe the frequency and scope of technical and management audit reviews to ensure periodic monitoring of all operations.

The guidelines focus on the unacceptability, rather than the acceptability, of risk. This focus is deliberate as no public
sector agency or private firm is willing to state outright that some particular level of risk is acceptable. The idea of the guidelines is to highlight the necessity to admit that some risks are more serious than others and to commit to a process which addresses the most serious risks first. Such codification of guidelines is a necessary ingredient to a procedurally-rational decision process.

The process of establishing guidelines is usually the responsibility of a corporate-level safety group and is carried out with input and consultation from engineering, manufacturing, and operations groups. The resources used to establish risk guidelines include past company experiences, published guidelines by other firms for similar risks, publicly available data on past accidents, regulatory decisions and guidelines, societal risk data, and databases compiled by industry and trade associations (such as Chemical Manufacturers Association, or American and European Institutes of Chemical Engineers) and organizations like the World Bank and the World Health Organization. Each firm also has a great deal of its own organizational learning embedded in the definition and communication of such guidelines. As risk management practices evolve and new risk standards are adopted by industry leaders in
safety management, competitive benchmarking can be used to update corporate guidelines to stay abreast of industry best practices.

Corporate safety experts from the firms who participated in the Wharton study described the following as the most challenging aspects of establishing risk-action guidelines.

- The guidelines should be systematic and complete. They should foresee all possible realizations of risks and recommend proactive and reactive actions to deal with them.
- Excessively conservative thresholds and guidelines tend to exclude viable projects, thwart innovation and productivity, and lead to misspent resources. On the other hand, excessively liberal thresholds may lead to the inclusion of unacceptably risky projects. The guidelines should be realistic but they should encourage and drive the line managers to achieve continual improvements towards better levels of safety.
- The underlying sources of risk, like the processes, raw materials, products, technology, equipment, and the environment change frequently. As a result, risks and their acceptable thresholds also fluctuate frequently and unpredictably. The risk management system must be cognizant
of the dynamic nature of risks and it should be flexible enough to incorporate these changes into the guidelines in a timely manner.

Sidebar 1 illustrates how the risk-action guidelines are formulated at MNCL.

4.2 Risk Screening Funnel

The second step of the decision-funnel approach is a multi-tiered hierarchical risk screening methodology for assessing and mitigating risks. The basic principle behind this methodology is that, when faced with uncertain or incomplete information about a specific risk, the firm should at first make conservative assumptions in estimating the risk. For risks that appear to be serious based on such conservative assumptions the cost of mitigating them should be considered before progressing to more realistic assumptions and using assessment techniques of greater cost and sophistication.

The use of such a methodology has lately become widely prevalent in the larger chemical firms. Most of the firms typically use three or four different levels of assessment. The
risk assessment screens are hierarchically arranged in the shape of a funnel, ranging from a "low cost-least accurate" screen to a "high cost-most accurate" screen (See Figure 1). In the wide mouth of the funnel, relatively simple risk assessment procedures and conservative risk assumptions (based on rules-of-thumb heuristics, gut-level judgments of experts, and simple macro-level projections) are used which are conserving of resources but which may significantly overestimate risk levels. Lower down the funnel, screens are designed to be progressively more rigorous and hence more time consuming and expensive. In these screens risk assumptions become more realistic and risk assessment procedures become more accurate. They identify, model, and analyze each source of risk at a micro-level. Multi-functional teams of analysts and detailed quantitative techniques may be used to obtain more accurate representations of risks. At any stage of screening, some of the risks will be confirmed as low enough to not require any further action. For some of the other risks, the assessment process will reveal process modifications which will mitigate the risks so as to avoid the need for further assessment. These risks are removed from the funnel, mitigated, and then rescreened. The remaining risks drop down the funnel for further assessment using higher level procedures. Operations whose level of risk is
unacceptably high or for whom the cost of mitigating risks is prohibitively expensive exit from the bottom of the funnel.

Two types of errors might arise at any stage of assessment. A Type I error would arise when a risky operation is incorrectly screened out as one of negligible risk, i.e. the assessment procedure underestimates its risk. A Type II error would arise when a negligible risk operation is not screened out, i.e. the assessment procedure overestimates its risk. The hierarchy of screens is designed to meet the following two conflicting requirements: (i) to minimize Type I errors, and (ii) to screen out the largest possible number of negligible risk operations using relatively low cost screens. As Type I errors may lead to serious consequences, precedence is given to minimization of such errors. This is achieved by using relatively conservative risk assumptions.

However, this increases Type II errors as a greater number of risks are overestimated and need further assessment. For more accurate screens, more realistic risk assumptions are used. This is possible because, as the level of confidence in the quality of assessment increases with more accurate screens, the thresholds for classifying risks can be relaxed. The multi-tiered approach is cost-effective because some operations are screened out as having
negligible risk at each stage and the higher cost screens are used for progressively smaller numbers of risks.

An important feature of the risk screening funnel is the trade-off between the costs of risk assessment and those of risk mitigation. The lower the cost of risk mitigation relative to that of risk assessment, the more likely it is that the risk mitigation route will be chosen instead of proceeding into the next tier of risk assessment sophistication. The higher the costs of risk mitigation, the greater is the incentive to drop to a deeper tier of the risk assessment funnel. This trade-off process produces helpful detail about risk, yet avoids unwarranted costs associated with in-depth assessment.
The risk screening funnel can serve as a useful tool for continuous safety evaluation and improvement. It establishes a framework which enables regular and effective monitoring of a portfolio of risky operations. Continuous safety evaluation and improvement is usually constrained by the scarcity of capital, manpower, and managerial resources to identify, evaluate, and prioritize risks. However, the multi-tiered nature of risk screening in which progressively fewer risks require more sophisticated risk assessment, overcomes this problem by facilitating a cost-effective and timely deployment of the risk management resources, to the operations where they are needed the most.

Sidebar 2 describes the risk screening methodology used by MNC2.
4.3 Decision Process for Mitigating High Cost-High Consequence Risks

In most firms, the plant manager or local management is usually given the authority to implement low cost risk mitigation measures. But decisions regarding other measures, such as major alterations to process, product, or technology, which may have broader strategic implications and which are typically needed if the hazard levels are very high, often require the participation of high-level management. The questions asked by these decision makers are how high is the risk, what are the costs (including strategic impacts) of implementing risk mitigation measures, what is the return on this investment (risk mitigation/dollar), and how do the risk and risk mitigation/dollar in this situation compare with other risk mitigation projects in the firm which are competing for the scarce resources. Risk screening produces a list of alternatives for reducing risks, and cost-estimates for and a measure of reduction in risk achieved by each alternative. Decision-makers must, however, select mitigation alternatives so as to optimize the overall reduction in risk for the firm as a whole per unit of investment.
Figure 3 displays the methodology being used by some firms to aid in making such decisions. Risk mitigation projects and their costs are plotted on an organization-wide basis. The plot is then segmented into different priority regions. The downward slope of the segmentation ensures that if two mitigation projects lead to the same level of reduction the one requiring lower investment will be preferred. Region 3 includes highest priority projects because of highest reduction in risk per investment dollar. Region 2 includes medium priority projects where the organization may commit to long range efforts toward gradual improvement. Projects in Region 1 should be considered only if they require modest effort for improvement given (relatively speaking) the lower reduction in risk and the high cost of risk reduction.

Once these regions have been identified by higher management, individual risk mitigation projects can be automatically prioritized depending on their position on the organizational plot. The scope of the plot can be tailored to suit the organizational structure and culture; e.g. it may be division-wide or organization-wide. Sidebar 3 illustrates how this decision making methodology was used at MNC3 in an actual situation.

5. Suggestions for Managers
Our empirical study of the larger firms in the chemical industry shows a fundamental change, over the last decade, in their procedures for management of process safety. Safety considerations have now acquired a high profile with the direct involvement of senior corporate executives. Firms are increasingly adopting proactive approaches which aim to prevent accidents and to limit their consequences. Best industry practices for process safety management are becoming comprehensive -- they integrate process technologies, facilities, human resources, and management procedures. Firms are using state-of-the-art techniques for more rigorous and frequent evaluation of process hazards. They are encouraging organization-wide employee education and participation to achieve higher safety goals. Finally, they are striving to enhance their credibility and to ease public's concerns of "chemophobia" by effective risk communication and by implementing emergency response measures. The emergence of this renewed emphasis on process safety management is being endorsed by industry associations such as the Chemical Manufacturers Association which has codified it in its Responsible Care Program.
5.1 Implementation of the Decision-Funnel Approach

A successful implementation of the decision-funnel approach is best achieved within the following framework of an organization-wide dedication to safety.

*Top management commitment and support:* An essential requirement for implementing the decision-funnel approach is an unambiguous corporate commitment to safety which begins at the top of the organization. Senior management must recognize that safety plays a critical role not only in protecting corporate profitability but also in ensuring that the firm projects the image of a responsible corporate citizen. Top management must display leadership, involvement and commitment in developing an organization-wide culture which emphasizes that safety is both important and achievable. The decision-funnel approach helps in this endeavor by communicating the corporate sponsorship of safety management programs to all managers and employees through the instrumentality of guidelines (risk thresholds and the procedural, control, and investment guidelines) which are established as part of this approach.
Cross-functional consideration of safety issues: The experience of firms in high risk industries such as the nuclear, chemical, and oil industries has shown that a holistic approach which encompasses technologies, personnel, equipment, and management practices is essential for the most effective management of safety. Firms should strive to develop a corporate culture in which managers and supervisors across different levels and functions of the firm cooperate in assessing risks and in developing solutions to mitigate them. The corporate decision processes must be structured to recognize the importance of safety by ensuring that the risks of process accidents are considered as major factors in making business decisions.

Employee involvement and empowerment: The most safety-conscious firms encourage the involvement of employees at all levels of the organization by instilling a work ethic in which everyone feels responsible for safety. They invest in raising the employees' awareness of risks through adequate training and education, through documentation of the process hazards and safe operating procedures, and by keeping their employees informed about any changes in processes and operating procedures. Firms must also empower employees by encouraging them to spot potential safety problems, by incentivizing employee suggestions for safety improvements, and by
facilitating unfettered communication on safety issues between management and employees.

**Proactive approach to safety:** Firms must adopt a management approach which promotes prevention of accidents. Such an approach begins with an emphasis on safety in the design stage of products and manufacturing processes. It includes systematic and detailed process hazard analyses for identifying sources of potential risks.

It requires that any changes in process chemicals, technologies, equipment, or procedures are evaluated to assess their potential impact on safety. Finally, any accidents that do occur must be investigated thoroughly to determine and to correct the root cause(s) of problems.

**Continuous evaluation and improvement of safety:** Good safety management systems must establish a framework which enables regular and effective monitoring of risky operations. This includes definitions of safety levels and periodic audits to monitor risks and to verify compliance with the guidelines. A maintenance program must be in place to assure the continued mechanical integrity of processes and equipment. Continual improvements in safety should be encouraged by incremental fine-tuning of safety
goals and by adopting the state-of-the-art safety practices prevalent in the industry.

**Consideration of community and environmental concerns:** A comprehensive safety management system should consider both the on-site and off-site impact of potential risks. Socially responsible firms foster an environment of openness and mutual trust between their management and the neighboring community by communicating potential risks to the community and by implementing emergency preparedness and response measures in collaboration with community groups.

**Emphasis on safety in relationships with external business partners:** The most safety-conscious firms adopt a "cradle-to-grave" approach to safety in their business transactions with other firms. They emphasize safety in all stages of the life-cycle of their products -- from the procurement of raw materials to the final disposal of their products in an environmentally safe manner. They ensure that their suppliers, distributors, and customers are aware of the inherent risks of all hazardous substances and that they also have proper safety management systems in place.

*5.2 Other Applications of the Decision-Funnel Approach*
The approach described in this paper may also be easily adapted for many other situations where an organization faces a large portfolio of complex and dynamically changing risks which must be assessed and mitigated on a regular basis. In managing such a portfolio of risky projects, two types of situations may arise. In one situation the nature of risks and projects is such that the number of projects decreases sharply as their risk increases from low to high. For most projects the risk is clearly low enough for them to remain in the portfolio. The risk of the projects with unacceptably high risk must either be mitigated to within acceptable levels or the projects must be abandoned (i.e. removed from the portfolio). The burden of proof is to confirm by the best assessment techniques available that certain projects must be abandoned. Some examples of such problems are a portfolio of chemical and nuclear operations (with risks of hazardous releases), a fleet of oil tankers (with risks of oil-spills), management of a corporate portfolio of strategic business units (with risks of sub-optimal return on investment). The second situation is the reverse of this. Here, the nature of risks and projects is such that the number of projects decreases sharply as their risk decreases from high to low. For most projects the risk is clearly too high for them to remain in the portfolio. For other projects it may either be possible to mitigate their risk to within acceptable levels or
it can be shown that they must be retained in the portfolio. The burden of proof here is to confirm by the best assessment techniques available that certain projects must be retained. Some examples of such problems are characterization of oil-wells, management of innovation (research and development projects and introduction of new products), analysis of chemical compounds to develop pharmaceutical drugs etc. Conceptually, the decision-funnel methodology is well suited for both types of problems.

6. Conclusion

Contemporary risk management systems must be well equipped to manage process risks on an on-going basis. They must have the expertise to not only weed out operations that are too risky but also to regularly monitor the ones that are currently deemed to be safe and to reassure the management and the public about the efficacy of their monitoring procedures. The development of such systems, begun many years ago, has recently assumed a new stature. Our empirical evidence shows that the best of the larger firms in the chemical industry have made significant progress in achieving environmental competence by operationalizing corporate risk guidelines and probabilistic risk management methods so as to
manage episodic (low probability-high consequence) hazards in a manner that is conserving of resources.
ENDNOTES

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2. The Wharton Risk Management and Decision Processes Center, under the direction of Howard Kunreuther and Paul Kleindorfer has organized roundtable discussion conferences on topics such as "Firm Decision Processes: How Firms Develop Plans to Manage Risks Associated With a Hazard That Has the Potential to Injure Residents in the Community" and "Decision Processes Used By Firms in Arriving At Their Process Safety Criteria". Attendees at these informal discussion sessions have included firms represented by multi-functional managerial teams, members of government agencies, insurance firms, faculty, and graduate students.


5. Adapted from the presentation by a participating firm in the Wharton Risk Management and Decision Processes Center Roundtable.
Figure 1: The Decision Funnel Approach
Figure 2: Risk-Action Guidelines
Figure 3: Selection of Risk Mitigation Alternatives Based on Reduction in Risk and Cost of Mitigation
SIDEBAR 1: How Risk-Action Guidelines Are Developed at MNCI* 

MNCI's corporate risk management program requires a systematic analysis of the consequences of all foreseeable accidental releases in the firm's hazardous processes. The damage potential for each type of accident is classified in terms of standardized and quantitative thresholds. Appropriate managerial action guidelines are associated with each classification of damage potential. These guidelines, which are in the form of risk management flow-charts, guide managers to take appropriate risk containment or mitigation actions and to activate community emergency response plans in the event of an accident. The risk of accidents with high damage potential is analyzed further by assessing the probability of the accident. The combination of the probability and damage potential of such accidents is used to determine risks to individuals and to classify releases based on risk threshold guidelines. Risk reduction guidelines are specified to mitigate the risks of high-risk accidents.

The type of accidents may be classified as a toxic release, fireball, pool fire, jet flame or uncontained vapor cloud explosion (UVCE). The guidelines for handling toxic releases, for instance, are developed as shown in Figure 2. A toxic release whose damage potential is limited to a transient effect (such as increased irritation and unpleasant odor), is classified as a Level 1 release. If a release has a potential of causing serious human injury, it is classified as a Level 2 release. If a release can lead to life threatening health effects, it is classified as a Level 3 release. The classification of hazard levels is based on concentration values of the toxic material in the ambient atmosphere. Each hazard level can be interpreted as the cut-off boundary that defines the outer edge of a specific hazard zone. For instance, the particular cut-off value between levels 2 and 3 might be defined as: "the maximum airborne concentration below which it is believed that nearly all individuals could be exposed for up to one hour without experiencing or developing life threatening health effects". Similar definitions exist for cut-offs between levels 1 and 2, and also 'safe' and level 1. Different action levels guidelines, i.e. ERPG-1, ERPG-2, and ERPG-3, are suggested to handle releases with different damage potential. The risks of Level 2 and Level 3 releases are analyzed further to classify them as those with unacceptable risk, those for which risk reduction is desirable, or those which pose negligible risk.

SIDEBAR 2: Risk Screening Methodology Used by MNCZ

MNCI uses a three-tier hierarchical risk screening funnel. Operational data from all risky operations is evaluated in the first tier called the Hazard Ranking Model. Comprehensive hazard checklists are used to survey a variety of dimensions of each hazard, such as toxicity, flammability, and explosivity. Inexpensive risk assessment methods based on simplified algorithms, heuristics, and computerized routines are used to identify potential sources of risk, to create a score for ranking operations by their risk potential, and to categorize them into hazard levels. Worst-case scenarios (using most conservative thresholds and worst-case assumptions such as simultaneous release of the largest single inventory of each hazardous substance) are used to consider both damages and probabilities. Hazard levels established in this tier determine the timing and priority of further reviews of risks which are non-negligible.

At the second-tier screen, called Risk Review, these risks are subjected to a more rigorous and costly set of review procedures that can be thought of as simplified quantitative risk analyses. In this stage, multi-functional teams identify and prioritize the risk of potential accidents and create a list of scenarios along with an estimated frequency of occurrence and consequences. Risk assessment techniques such as "what-if" analysis, Fault Tree Analysis, Hazard and Operability study, and Failure Mode and Effects Analysis are used. Scenarios are constructed to identify contributing events and the order in which they must occur for a scenario to take place. Conservative estimates of probabilities of such occurrences and the severity levels of damages are calculated. Risk estimates are compared to numerical risk prioritization criteria to classify them into priority levels. The idea is to use techniques that permit identification of risks by using rather conservative probability estimates. Although these assumptions are more accurate than those used in the first tier, they still require an order of magnitude fewer resources than would be needed to conduct full-blown quantitative risk analyses. As a result of the more realistic assumptions used, some operations may be found to have negligible risk. For others, inexpensive options for mitigation may become apparent.

Operations which are found to have serious risk potential during the second review are scrutinized more accurately using elaborate state-of-the-art techniques generally referred to as Quantitative Risk Analysis (QRA). In QRAs, analysis is conducted at a much finer level and with more precision by investigating lower level components and processes of the operation. Data on process chemistry, equipment and process failure rates, operator error, weather conditions, population densities, material inventories, and distance from fence-line are taken into account to conduct failure, dispersion, and consequence analyses. Aggregation procedures are used to obtain integrated risk estimates by combining the effects contributed by each source of risk. QRA has the advantage that it uses accurate data and detailed analysis tools. Its major drawback is that it is time-consuming and can prove to be very expensive. The result of QRA may show that a risk is actually significantly lower when the simplified and conservative assumptions of the second tier are replaced by more realistic assumptions. The QRA can also serve to identify specific remedies which did not become apparent in earlier screens. In such cases, actions might be taken to mitigate the risk, and the process is then rescreened. In other cases, the QRA confirms that the level of risk is indeed unacceptable or the cost of mitigating risks is prohibitively expensive.

SIDEBAR 3: Community Exposure Decision of MNCF

The following scenario which occurred at MNCF illustrates an application of the procedure for decision-making which is described in the text. Over the years, since the initial acquisition of a remotely located fluorocarbon manufacturing plant, there had been a substantial increase in the population of its adjacent communities. Even though there had been no increase in the probability of accident or failure, a director of manufacturing was concerned about the increase in potential consequences of human injury in case of a mishap.

A decision-funnel type of process confirmed that the plant did indeed pose an unacceptable risk to the surrounding community and that risk mitigation required high priority action. The risk analysis team made fourteen suggestions for reducing the risk. After each suggestion was analyzed to determine the reduction in risk contributed by it per unit of investment, four top options were found to be viable. They included various shut down and enclosure procedures, and implementation of a community awareness and emergency response program to better inform and educate the public. Many of the improvements and upgrades required only small investments and could be implemented at the plant level. However, quantitative risk assessment confirmed that the greatest risk was a hydrogen fluoride tank car unloading facility. Recommendations to mitigate this risk were to enclose the unloading facility, storage tanks, and associated pumps in a ventilated building with emergency scrubbers for ventilation discharge. Implementation of these recommendations entailed substantial costs. A project was written and sent to a management group comprised of production managers, the regional vice-president, and members of the firm's health, safety, and environmental group. A comparison of the risk levels and cost effectiveness of this risk mitigation project with those of competing risk mitigation projects in other facilities of the firm justified this cost and the project was approved. Thus by combining input from various levels in the organization, the perspective of the entire firm was reflected in selecting the best risk mitigation alternatives.