

# Predicting and Confirming the Effectiveness of Systems for Managing Low-Probability Chemical Process Risks

Isadore Rosenthal,<sup>a</sup> Paul R. Kleindorfer,<sup>b</sup> and Michael R. Elliott<sup>c</sup>

<sup>a</sup> Senior Fellow, Wharton Risk Management and Decision Processes Center, Philadelphia, PA 19104-6340; Rosenthal@Wharton.upenn.edu (for correspondence)

<sup>b</sup> The Wharton School, University of Pennsylvania, Philadelphia, PA 19104-6340

<sup>c</sup> School of Public Health and Institute for Social Research, University of Michigan, Ann Arbor, MI 48109-2029

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*This article addresses the role of a facility's process safety management system (PSMS) in preventing low probability–high consequence (LP–HC) accidents. We review the rationale for the hypothesis that a facility's PSMS is the central driver of accident prevention, and we discuss how this rationale has been incorporated implicitly into the OSHA Process Safety Management standard (PSM) in 1992 and explicitly into both the EU Seveso II Directive and the USA EPA Risk Management Program regulation (RMP) in 1996. We then note that the limited process accident incidence data available to date have not resolved the issue of determining or predicting characteristics of a facility's PSMS that are likely to be effective in reducing LP–HC accidents. Based on a variety of considerations, the authors propose retrospective and prospective case-control studies on facilities with and without RMP reported process accidents using candidate survey instruments to test which survey factors appear to have the greatest predictive power for the likelihood of future LP–HC accidents. © 2006 American Institute of Chemical Engineers Process Saf Prog 25: 135–155, 2006*

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## INTRODUCTION

Catastrophic chemical process accidents in the 1970s, such as Flixborough (UK) and Seveso (Italy), led to a major increase in societal concerns about the safety of chemical processing facilities. By and large the initial regulations in response to these concerns, such as Seveso (EU) and CIMAH (UK), focused on preventing accidents through better technical control of the individual aspects of chemical processes covered under these regulations.

The continued occurrence of catastrophic chemical process accidents (Table 1) after the initial set of process safety regulations were put in place led to a new industry and regulatory paradigm [1] regarding the causation of low probability–high consequence (LP–HC) accidents. The principal thrust of the “new” [2] paradigm was, and has remained, that prevention of LP–HC process accidents requires effective process safety management systems on top of appropriate technical practices, since deficiencies in management systems are the underlying (root) cause of most chemical process accidents.

This “new” paradigm was *implicitly* incorporated into the OSHA Process Safety Management standard (PSM) in 1992 and *explicitly* into both the EU Seveso II Directive and the USA EPA Risk Management Program regulation (RMP) in 1996. At the time these regulatory initiatives were launched, projections were made that these regulations would result in significant decreases in the incidence of process accidents. The limited pro-

**Table 1.** Some major “watershed” accident events in the last quarter century.

Accident Location	Date	Type of Event	Some Resulting Consequences	Regulatory Response
Flixborough, UK	1974	Explosion and fire	28 killed, over 100 injured	COMAH 1984
Seveso, Italy	1976	Runaway reaction	Large dioxin environment contamination, massive evacuations, large animal kill	Initial Seveso Directive
Bhopal, India	1984	Runaway MIC reaction	≈2500 people killed and 100,000 injured, high litigation costs	USA Emerg. Planning & Community Right to Know Act—CMA CAER Program
Basle, Switzerland	1986	Warehouse Fire	Massive contamination of Rhine and very large fish kill	Added impetus for changes leading to Seveso II
Pasadena, USA	1989	Explosion and fire	23 deaths, ≈100 injured, over \$1 billion in losses	1990 CAA amendments as well as RMP & PSM process Standards
Longford, Australia	1998	Explosions and fires	Two deaths, gas supply to Melbourne cut for 19 days, losses over \$1.3 billion	Process Regulatory initiatives Victoria
Enschede, Netherlands	2000	Explosion and fire	22 deaths, ≈1000 injured, 350 houses and factories destroyed	Changes to Seveso Directive
Toulouse, France	2001	Explosion and fire	30 deaths, ≈2000 injured, 600 homes destroyed, 2 schools demolished	Changes to Seveso Directive

cess accident data available (reviewed in more detail below) does not appear to support these expectations.

As Appendix A shows, most practitioners continue to believe that an “effective” management system is the key to prevention and that the less than expected decrease in accident incidence has occurred because the newly adopted regulations have not resulted in the hoped for adoption of “effective” process safety management systems by industry. Appendix A also sets forth practitioners’ views on the relationship between process safety and process quality management systems and the key role of management in determining the effectiveness of both types of management systems.

Testing the validity of this belief requires the ability to define and identify the essential elements of “effective” facility process safety management plans. A great deal of research has been done on safety culture and climate survey instruments aimed at predicting the effectiveness of management systems in regard to preventing occupational illnesses and accidents reportable to OSHA (OII), as well as on audit instruments to determine whether effective safety systems are actually in place. Unfortunately, acquiring comparable knowledge on the validity of survey and audit instruments in regard to process safety management plans is very difficult because of the low occurrence of major process accidents, reportable to EPA under RMP, as compared to the occurrence of events reportable as OII.

Approaches and instruments for predicting and verifying process management system effectiveness in preventing low probability (LP) RMP reportable accidents

would be valuable to entities such as chemical firms, regulatory agencies, trade association Responsible Care Programs, and insurance companies. It would allow them to distinguish between facilities more likely to have adequate process management systems and those that do not, and to prioritize inspections and undertake corrective actions more cost effectively, i.e., before rather than after a major accident occurs.

The need for cost-effective predictive instruments has long been recognized. For example, Bellamy [3] notes that one of the drivers of the work undertaken on “Organizational Factors and Safety” for the Major Hazard Group of the Dutch Ministry was to “provide support for their Labour Inspectorate in the inspection of major hazard facilities. The difficulty that the Inspectorate has is that they are faced with an increasing number and range of chemical installations, for which there are limited inspection resources.”

Each of the institutions noted above, i.e., chemical firms, trade associations, insurance companies, etc., needs an instrument that will allow them to focus their limited resources on the firms most likely to have less than adequate process safety management systems. At a minimum, fashioning such an instrument requires two things:

1. Knowledge of the essential attributes that define the presence of effective facility process safety management systems;
2. The ability to collect information that can reasonably predict the relative likelihood that a given

facility's management system has these essential attributes.

This article focuses on the proposition that the epidemiologic accident investigative approaches previously used at Wharton by Kleindorfer, Elliott, Lowe, and associates [4] in their work on RMP reportable accidents, provide an important tool in meeting the two requirements noted above and in overcoming the problems that prevented doing this fully satisfactorily in the past using more conventional analytical approaches. The epidemiologic approach can be viewed as an important supplement to recent developments in probability and statistics concerned with Extreme Event Analysis, which has brought a rich array of mathematical tools to bear on the problem of estimating the parameters of fat-tail distributions characteristic of low-probability, high-consequence events [5]. These analytic tools must be integrated with the management systems we analyze here to provide the logical structure and the infrastructure for collection and validation of the necessary data for operational risk assessment. In particular, as with the evolving practice in other areas of Probabilistic Risk Analysis, it is the synthesis of management systems and underlying analytic tools that provides the supporting pillars of practical and legitimate approaches to chemical process safety.

We review below the regulatory background addressing process safety management. We then examine some of the literature on past attempts to design and validate instruments capable of predicting the effectiveness of systems for managing the prevention of occupational illnesses injuries (OII) in conventional installations, as well as systems designed primarily to manage process safety in higher risk installations, such as offshore oil and gas facilities and those covered under the Seveso directive. (The reader already familiar with the regulatory background to these issues may wish to only skim the background sections.) We then propose some extensions and refinements to previous methodology used for validating safety management system survey instruments, mention the nature of current work by Elliott *et al.* on hypotheses relating OII to RMP incidents, and touch on the approaches likely to be used in future Wharton work aimed at predicting the effectiveness of RMP PSMS. The recommended refinements are based on epidemiologic approaches used at Wharton to analyze and characterize the process safety performance of the approximately 15,000 facilities that report process accidents covered under the EPA RMP regulation. We present our conclusions in the final section.

#### **INCORPORATION OF THE "MANAGEMENT SYSTEM AS ROOT CAUSE" PARADIGM INTO REGULATIONS**

Many of the world's current major regulations aimed primarily at improving process safety were strongly influenced by the first Seveso Directive (82/501/EEC). This directive was issued by the European Union (EU) in 1982 following a number of watershed accidents in the mid 1970s, such as Flixborough in 1974 and Seveso in 1976. The Seveso Directive was focused on technical measures aimed at reducing the likelihood and impact

of low probability-high consequence (LP-HC) process accidents on people, property, and the environment outside the gates of the operating establishment.

Each individual EU country enacted national regulations following the Seveso directive, such as the UK "Control of Industrial Major Accidents Hazard" regulation (CIMAHA) issued by the Health and Safety Executive (HSE) in 1984.

As Averbach [6] has noted, the US lagged behind the EU in regard to regulations addressing major process accidents: there was no major Federal [7] regulation focused on process safety until after the US Congress required it under the provisions of the Clean Air Act amendments (CAA) of 1990. The 1990 CAA requirements, triggered in good part by the accident at Bhopal (1984) and a subsequent accident at a Phillips plant in Houston, TX (1989) that resulted in 29 deaths, required both OSHA and EPA to take actions in regard to improving process safety. In response to these CAA requirements, OSHA issued its Process Safety Management standard (PSM) in 1992, and EPA issued its Risk Management Program (RMP) rule in 1996.

The OSHA PSM standard focuses primarily on the technical aspects and elements of process safety management systems, e.g., (1) mechanical integrity, (2) inspection and testing, (3) hot work permits, (4) management of change, etc. It only deals implicitly with the issue of integrating these largely technical elements of the prescribed "process safety management system" into the facility's overall production management system.

After a further series of notorious accidents (Table 1), a complete redrafting of the original Seveso Directive was undertaken, leading to the Seveso II directive [8] (96/82/EC), which was adopted in 1996. One of the major new aspects of the new Seveso II regulation was stronger emphasis on the key role of safety management systems in the prevention of process accidents [9].

For example, the preamble of the Seveso II Directive, notes that:

(15) Whereas analysis of the major accidents reported in the Community indicates that the majority of them are the result of managerial and/or organizational shortcomings; whereas it is therefore necessary to lay down at Community level basic principles for management systems, which must be suitable for preventing and controlling major-accident hazards and limiting the consequences thereof.

A guidance document [10] produced by the "Committee of Competent Authorities for the Implementation of the 'Seveso' Directives" expanded on the sense of the above paragraph of the Seveso II Directive as follows:

Council Directive 96/82/EC (SEVESO II) is aimed at the prevention of major accidents involving dangerous substances, and the limitation of their consequences. The provisions contained within the Directive were developed following a fundamental review of the implementation of Council Directive 82/501/EEC (SEVESO I).

In particular, certain areas were identified where new provisions seemed necessary on the basis of an analysis of major accidents which have been reported to the Commission since the implementation of SEVESO I. One such area is management policies and systems. *Failures of the management system were shown to have contributed to the cause of over 85 per cent of the accidents reported. (Emphasis added)*

Against this background, requirements for management policies and systems are contained in the SEVESO II Directive. The Directive sets out basic principles and requirements for policies and management systems, suitable for the prevention, control and mitigation of major accident hazards. The “basic principles for management systems” to be used by the class of installations presenting the highest risks are spelled out in Article 9 of the Seveso II Directive and in further detail in its Annex III:

#### ARTICLE 9

##### Safety report

1. Member States shall require the operator to produce a safety report for the purposes of: (a) demonstrating that a major-accident prevention policy and a safety management system for implementing it have been put into effect in accordance with the information set out in **Annex III**.

The most pertinent parts of Annex III are as follows:

#### ANNEX III PRINCIPLES REFERRED TO IN ARTICLE 7 AND INFORMATION REFERRED TO IN ARTICLE 9 ON THE MANAGEMENT SYSTEM AND THE ORGANIZATION OF THE ESTABLISHMENT WITH A VIEW TO THE PREVENTION OF MAJOR ACCIDENTS

For the purpose of implementing the operator's major-accident prevention policy and safety management system account shall be taken of the following elements.

(a) The major-accident prevention policy should be established in writing and should include the operator's overall aims and principles of action with respect to the control of major-accident hazards;”

(b) the safety management system should include the part of the *general management system (Emphasis added)* which includes the organizational structure, responsibilities, practices, procedures, processes and resources for determining and implementing the major-accident prevention policy;”

(c) The following issues shall be addressed by the safety management system: (i) Organization and personnel —the roles and responsibilities of personnel involved in the management of major hazards at all levels in the organization. The identification of training needs of such personnel and the provision of the training so identified. The involvement of employees and, where appropriate, subcontractors;

*Authors' Note.*

The remainder of Annex III deals with other system

requirements related to the technical and operational elements of a process safety management system. These elements are similar to those required by the OSHA PSM standard.

It should be clear from this very brief review that the Seveso II Directive accepted the new paradigm, which holds that prevention of LP-HC process accidents requires effective process management systems in addition to a set of required technical safety system requirements.

In 1996, EPA issued its major process safe safety regulation [11]. The title of the regulation is: “Accidental Release Prevention Requirements: Risk Management Programs Under Clean Air Act Section 112(r) (7)” (RMP). This regulation addressed the requirements that the US Congress stipulated in the Clean Air Act (CAA) amendments of 1990 regarding actions EPA should take to prevent major process accidents.

In essence the RMP incorporated the major technical elements of the OSHA PSM Prevention Program but with some substantive additional requirements, such as the following:

1. Assessment of potential “reasonable worst case” impacts that might occur outside the facility as a result of accidents (realization of hazards) inside the facility (hazard assessment).
2. Modification of the OSHA emergency response plan requirements.
3. Preparation of a written risk management plan that covers prescribed RMP elements and submission of an executive summary of the plan to EPA.

The RMP management system requirement that is of greatest relevance to the subject of this article is as follows:

#### § 68.15 Management

(a) The owner or operator of a stationary source with processes subject to Program 2 or Program 3 shall develop a management system to oversee the implementation of the risk management program elements.

(b) The owner or operator shall assign a qualified person or position that has the overall responsibility for the development, implementation, and integration of the risk management program elements.

(c) When responsibility for implementing individual requirements of this part is assigned to persons other than the person identified under paragraph (b) of this section, the names or positions of these people shall be documented and the lines of authority defined through an organization chart or similar document.

As the following excerpt from the background discussion preceding EPA presentation of its RMP regulation shows, EPA intended to distinguish between its broader RMP management system requirements and OSHA risk management program requirements that were in essence focused on execution of the technical elements of its prevention program.

#### D. Prevention Programs [12]

EPA has retained the management system requirement proposed in the notice of proposed rulemaking, but only for Program 2 and 3 processes. EPA has moved the management system requirement from the prevention program section to the general requirements section because it should be *designed to oversee the implementation of all elements of the risk management program.* (Emphasis added).

Unfortunately, neither the EU nor EPA appears to have developed their regulatory “management system requirements” in a manner that would allow one to operationally distinguish, a priori, between effective and ineffective risk management systems.

#### THE EFFECTIVENESS OF SECOND GENERATION REGULATIONS IN REGARD TO THE PREVENTION OF MAJOR PROCESS ACCIDENTS

At the time when the above wave of process safety regulations and various associated trade association initiatives were introduced, there was optimism that these measures would lead to very significant reductions in chemical process accidents. An example of such optimism is seen in the cost/benefit analysis [13] that OSHA submitted to justify the significant costs of complying with its 1992 Process Safety Management Regulation (PSM). OSHA projected that: “In Years 6–10, a risk reduction of 80 percent is projected, with 264 fatalities and 1,534 injuries/illnesses (including 500 catastrophic lost-workday injuries) avoided, annually.”

Organization Resources Counselors (ORC), a group that generally expresses positions accepted by industry, agreed with this OSHA accident reduction projection [14].

When EPA introduced its RMP regulation in 1996, it projected an additional, relatively modest, further reduction in the accident rates experienced by OSHA processes that would now also be covered by the provisions of the EPA regulation. The data available to date on the incidence of process accidents covered under these second generation process regulations do not appear to support this agency optimism. In particular, Elliott [15] reviewed the difficulties in arriving at accident rate trends based on the first five years of RMP accident data (for the period 1995 to 1999) and observed that “no statistically significant trend for either reported accidents or injuries could be discerned over this period.”

In Europe, Pitblado [16] concluded in 2004 that the MARS data presented in a paper by Duffield [17] showed no evidence of a significant reduction in the rate of major accidents reported under the Seveso Directives over the last 10 to 20 years and, furthermore, that the MARS data also showed no change in average severity of reported accidents based on the 7-point MARS severity scale. Michalis [18] also concludes, based on an update of the MARS data used by Duffield, that: “There is a clear indication that the total number of major accidents is relatively constant.”

Thus, the limited process accident data cited above and other available information [19] do not appear to fully support regulatory expectations in regard to the incidence of accidents covered under the new genera-

tion of process regulations. Given these findings, one might conclude that either the new paradigm is not valid or present process regulations did not achieve their goal of ensuring that facilities have effective process safety management systems in place.

The authors of this article subscribe to the second explanation and hypothesize that many, if not most, firms do not in fact have effective process safety management systems in operation.

#### APPROACHES TO DETERMINING THE EFFECTIVENESS OF SAFETY MANAGEMENT SYSTEMS

##### Introduction to Section

This section will address the following two questions:

1. Are there validated instruments for predicting or confirming the likely effectiveness of a facility's management system in reducing realization of two classes of events:
  - a. Relatively frequent accidents that primarily result in occupational injuries and illnesses (OII) of the type reportable to OSHA.
  - b. LP chemical process accidents of the type that are reportable to the authorities under regulations such as RMP.
2. What are the major factors that determine the likelihood that a particular firm will adopt an effective facility safety management system for each of these classes of accidents?

The discussion will examine the two questions posed above in regard to the relatively frequent occupational injuries and illnesses (OII) of the type reportable to OSHA before it focuses on the area of greater interest to the authors, LP process accidents. Before beginning these discussions, it will be valuable to examine the following comparison [20] of the differences between the incidence of reportable RMP and OII events.

The average facility covered under the RMP as of 1999 had about 158 fulltime employees and reported an OII rate of approximately 2 (2 reportable events per 100 employees), which means that the average facility experiences about 3 OII reportable injuries per year.

There were 15,430 facilities covered under RMP at the time that EPA collected data on RMP reportable accidents for the five-year period preceding June 1999. These facilities reported 1970 covered process accidents for the five-year reporting period, which gives an average incidence rate of 0.026 ( $1970/5 \times 15,430$ ) or one reportable RMP event in 40 years per facility. The average number of OII that occurred as a result of an RMP reportable accident was about 1. Thus, the average facility reported an OII incidence rate that is more than a hundred times greater than the RMP incidence rate for reportable RMP accidents.

This comparison casts light on three important points:

1. On average, the incidence of RMP reportable accidents will have little impact on a facility's multi-year OII trend line.

2. It may be possible over a reasonable time period to verify whether an individual facility's management system, or a change in such a system, was effective in preventing accidents leading to OII by relying solely on data reportable by the facility to OSHA.
3. It is not possible to verify whether an individual facility's management system, or a change in such a system, was effective in preventing accidents leading to RMP reportable accidents by relying solely on data reported by the facility to EPA.

As noted, the section of this article entitled "Some Past Studies on Predicting and Confirming the Effectiveness of Facility Safety Management Systems in Preventing OII Reportable to OSHA" will examine some of the literature on the underlying theory, methodology, development, and evaluation of survey instruments aimed at predicting the effectiveness of a facility's system for managing prevention of OSHA reportable OII. As noted, the comparatively high incidence of OII makes research on such instruments relatively easy to accomplish. However, there are lessons to be learned from these OII studies that are applicable to studies of all classes of safety management systems.

In "Some Past Work on Predicting and Confirming the Effectiveness of Process Safety Management Systems in Preventing Low Probability Process Accidents," the authors examine some of the literature on the underlying theory, methodology, development, and evaluation of survey instruments aimed at predicting the effectiveness of facility process safety management systems in preventing LP process accidents. The article reports on some of the findings of this past work and discusses its conclusions in regard to the value of survey and audit instruments in predicting safety management system effectiveness.

We also note the difficulties in executing the reported research work on LP process accidents, which had to be based on metrics other than LP process accident incidence data. The investigators were forced to adopt such surrogate metrics due to the absence of adequate data on the incidence of LP process accidents of the type reportable to authorities under the RMP or Seveso regulations. The findings should be examined in the light of such difficulties.

### **Some Past Studies on Predicting and Confirming the Effectiveness of Facility Safety Management Systems in Preventing OII Reportable to OSHA**

There is a large literature on almost every aspect of management systems aimed at preventing the relatively high probability events leading to OSHA recordable illnesses and injuries (OII).

Donald [21] has published an interesting review of some of this literature over the 1970–1998 period. Her report, prepared for the Prevention Division of the Workmen's Compensation Board of British Columbia, contains discussions and synopses of more than 60 articles focused on organizational factors and approaches affecting the occurrence of OII. Another review of the literature, focused on OII from a different perspective, was published by Stubbs [22]. It contained the following observation on

the safety culture and climate, concepts that play key roles in the debate on the factors that determine the effectiveness of safety management systems:

The trend in literature is to treat culture as a set of core values and climate as an expression of these values with *safety culture* being a subset of the larger *organizational culture* (Guldenmund [23]; Hale [24]). The quote 'the way we do things around here' has been used in several articles to provide a succinct description of culture.

This section of the article will discuss a limited selection of this research work chosen to illustrate conclusions and findings representative of the consensus findings in the literature regarding approaches for preventing events that result in OII. It will also examine studies on the use of survey instruments to predict and evaluate whether a facility has an effective prevention system in place.

One prominent investigator of survey instruments aimed at characterizing safety management systems, Petersen [25], summed up his conclusions regarding the value of such instruments as follows:

After many years of perception survey development and testing, the author [26] and colleagues [27] found that such a survey provides a better predictor of the future safety record than any other indicator tested and helps to clearly target what needs to be done to improve safety systems in organizations.

Work done by Carder and Ragan [28, 29] leads them to a similar conclusion and presents a concrete, documented example of the usefulness of survey instruments for predicting the effectiveness of facility management systems in regard to the prevention of events leading to OSHA OII.

Ragan, in his capacity as corporate safety director of a company with about 6000 employees and 50 plus facilities, together with Carder, a consultant, were involved in a corporate-wide effort aimed at improving health and safety performance. Working with a task force, they soon recognized the need to develop a tool to identify the specific aspects of a facility's management systems that determined its safety and health performance in regard to OII. After surveying possible approaches to the development of such a tool, they concluded that the best approach would be to fashion a modified survey instrument built on the framework of the Minnesota Safety Perception Survey work done by Bailey and Petersen. The modified instrument they developed had a series of questions on seven factors.

After many years of work with their survey instrument, Carder and Ragan concluded that the following four factors (determined by responses to their survey instrument) were most relevant to prediction of a facility's incidence of reportable OII (i.e., OII safety management system effectiveness):

1. management's demonstration of commitment to safety,
2. education and knowledge of the workforce,
3. effectiveness of the supervisory process, and
4. employee involvement and commitment.

## GMNA\*: Total Recordables per 100 Employees

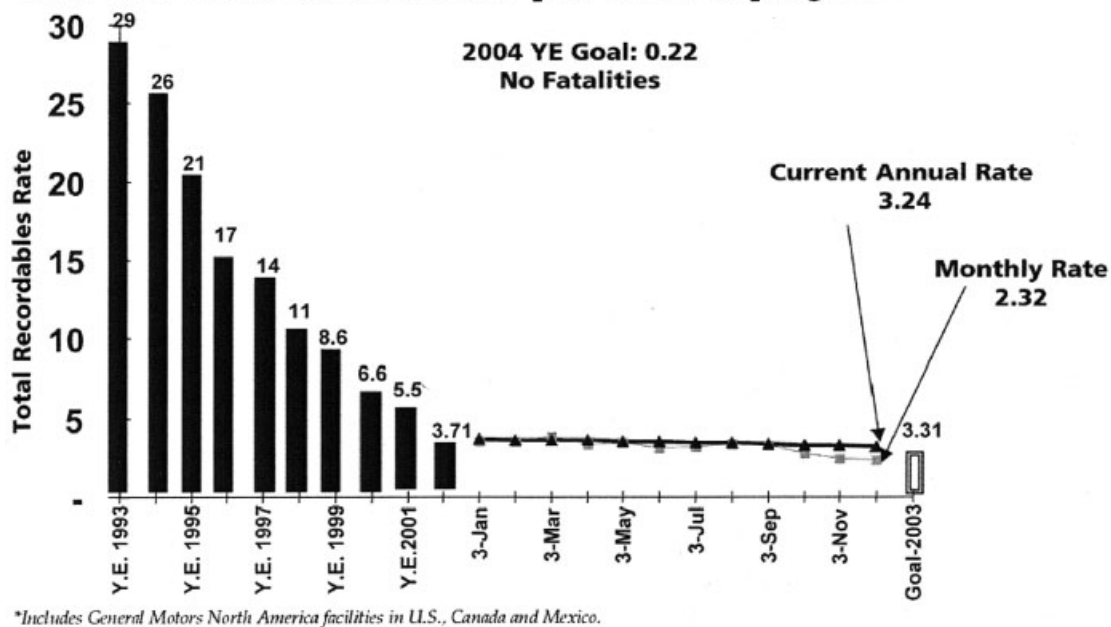


Figure 1. GMNA\*: Total recordable illnesses and injuries per 100 employees (OII).

The authors noted that acceptance of the predictive importance of these four factors was relatively universal and that they were employed in the National Safety Council's safety perception survey instrument, the "Safety Barometer," the Coyle [30] Survey instrument, and the Dow company's self assessment process.

The results from administration of their survey instrument to employees and management in the company's facilities over a period of years led Carder and Ragan to the following conclusions:

1. Survey instrument results are a statistically valid predictor of injury incidence. Survey scores for 12 facilities correlated with three-year average OII results with a significance beyond the 0.0005 level (Pearson coefficient [31] of  $-0.87$ ).
2. Survey instrument results can also be used effectively as a diagnostic tool for guiding improvements in management system safety effectiveness.
3. The first four of the seven factors listed above—(a) management's demonstration of commitment to safety, (b) education and knowledge of the workforce, (c) effectiveness of the supervisory process, and (d) employee involvement and commitment—have above average validity in predicting safety performance.
4. Employee responses have greater validity than manager responses, though both correlate with facility OII performance.

The validity of the four most important "effectiveness" factors that Carder and Ragan and others have identified is reinforced in two recent articles that describe the origins and outcomes of actions by General Motors [32] and Fort Dearborn [33] aimed at moving these companies from being industry laggards in occupational safety and health, to becoming leaders.

For both of these companies, achieving OII safety leadership required an order of magnitude reduction in OII. The decision to pursue this goal was a strategic decision that required both restructuring of the firm's hierarchy of values (a culture change elevating the importance of safety) as well as the commitment of significant physical and management resources over a multi-year period.

The events and reasons that caused the two companies to initially seek such safety improvements were very different: high worker compensation costs and OSHA warnings in one case (Fort Dearborn) and Board of Directors' concerns in the other (GM). However, analysis of the management programs used by the two companies shows that each of their programs addressed the four primary factors identified by Carder and Ragan.

Figures 1 and 2 show the reductions in OII achieved by GM and Fort Dearborn and illustrate two points:

1. Significant reductions in OII are achievable by translating changes in a firm's management culture into its safety management system;
2. The ability to use OII data to track a single firm's progress in reducing its OII incidence, since OII incidence is high enough for large firms to allow meaningful tracking even at the low OII levels that characterize very good safety performance.

### Some Past Work on Predicting and Confirming the Effectiveness of Process Safety Management Systems in Preventing Low Probability Process Accidents

Much of the work in the literature on predicting and confirming the effectiveness of process safety management systems parallels the work described above,

## Lost Workday Rate, 2001 to Present

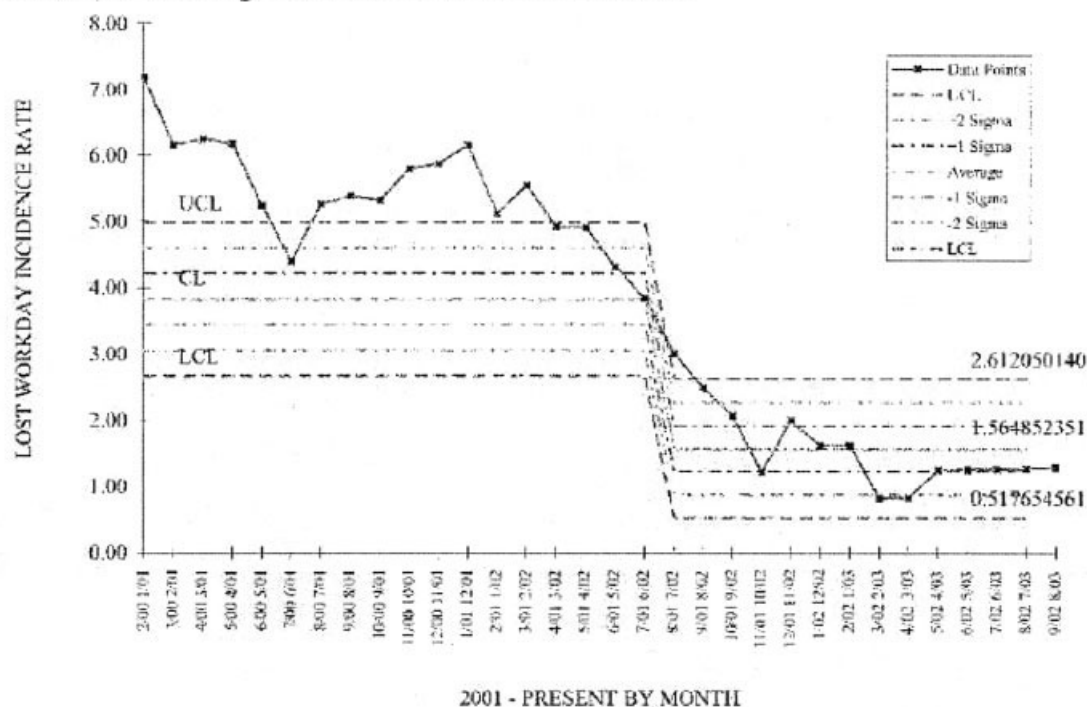


Figure 2. Fort Dearborn Company: lost workday rate.

which dealt with the much more frequent accidents leading to conventional OII.

Experience with the use of two classes of instruments will be explored:

1. Survey instruments for *predicting* the likely effectiveness of a facility's process safety management system and identifying aspects of the management system that are likely to need attention;
2. Audit instruments for *evaluating* the actual effectiveness of a facility's process safety management system and identifying deficient aspects of the management system.

Underlying the design of most of the survey instruments aimed at predicting the effectiveness of safety management systems for all classes of risks is the concept that a facility's "Safety Culture"<sup>1</sup> is the major determinant of the effectiveness of its safety management systems for all classes of risks. In this sense, as the DeJoy reference shows, the thinking of practitioners interested in preventing LP-HC process safety parallels that of practitioners focused primarily on relatively HP-LC events leading to OII [34].

A recent article by Zimolong [35], which comments on the research aimed at determining the effectiveness of LP process management systems, summarizes some of the literature's observations on "safety culture" as follows:

<sup>1</sup>Many researchers draw distinctions between safety culture and safety climate. However, the authors do not believe such distinctions are of significance in regard to the points being discussed in this article, and the term safety culture will be used to encompass both concepts.

The concept of safety culture has largely developed since the OECD Nuclear Agency (1987) observed that the errors and violations of operating procedures occurring prior to the Chernobyl disaster were evidence of a poor safety culture at the plant and within the former Soviet nuclear industry in general (Pidgeon [36]). Safety culture has been defined as "that assembly of characteristics and attitudes in organizations and individuals, which establishes that, as an overriding priority, plant safety issues receive the attention warranted by their significance" [37]). Over 30 studies using safety climate questionnaires have been published so far. Glendon [38] and Flin [39] have summarized most of them in an approach to identify key factors of safety climate.

Zimolong also feels that examination of safety management practices should be considered as an adjunct to the assessment of safety climate within an organization. From a functional point of view, "safety culture represents an implicit control system in the form of a socialization program. It is a value-based system based upon the organization's mission, values, business details, customers and the expectations of the employees [40]."

There is considerable controversy on the elements of "safety culture," and even on how one should define the term "safety culture." Many practitioners have problems with the International Atomic Energy Agency (IAEA) definition of safety culture cited above by Zimolong. For example, Hurst [41] notes that a shortcoming of the IAEA definition is that it only describes the



ideal safety culture and he makes the following comments:

We have taken the view that two important parts of the safety culture are the underlying beliefs and attitudes to safety and their tangible manifestations in the form of safety management systems. Our definition of safety culture would also cover both “good and “poor” safety cultures.

Hurst’s article also notes that the Confederation of British Industry suggests that, “the safety culture of an organization are the ideas and beliefs that all members of the organization share about risks, accidents and ill health.”

A recent article by Mearns *et al.* [42] centers on assessing the safety climate, safety management practices, and safety performance of oil and gas companies. This research was part of a project entitled “Benchmarking offshore safety,” run in collaboration with the Health and Safety Executive and 13 oil and gas companies that were the subjects of the study.

The Mearns article also contains an excellent discussion of the literature on the use of safety culture-climate instruments for evaluating the safety climate in particular installations.

Mearns outlines the research covered by her paper as follows:

Installations were assessed on their safety climate, safety management practice and safety performance.

Safety performance was assessed in two ways: first, by official accident and incident rates, and second by the proportion of respondents in the safety climate surveys who reported experiencing an accident in the previous year. The following hypotheses were advanced:

1. Favorable safety climate at installation level will be associated with lower proportions of employees experiencing an accident.
2. Favorable safety climate at installation level will be associated with lower numbers of official accident reports.
3. Respondents providing favorable safety climate scores at the individual level will be less likely to have experienced an accident.
4. Proficient safety management practice on an installation will be associated with lower proportions of employees experiencing an accident.
5. Proficient safety management practice on an installation will be associated with lower numbers of official accident reports.”

For reasons discussed in the article, a sixth hypothesis, “0,” was added to the original five during the course of the study:

0. True differences between installations in their accident proportions will be reflected in the safety climate scores of accident and no-accident groups in a consistent direction.

Mearns concludes that their work provided overall support for the ability of their Offshore Safety Ques-

tionnaire (OSQ) and Safety Audit Questionnaire (SAQ) instruments to predict process safety performance. The specific conclusions drawn from evaluation of the climate and safety management instruments are presented in Table 2.

The major reason for presenting the results of this study in such detail is not the unusual nature of conclusions drawn on the posed hypotheses, which are with some few exceptions generally in line with literature expectations, but rather to point out the difficulty in obtaining enough hard incident data (LTI and RIDDOR [43]) to test the validity of the six posed hypotheses.

For example, the Mearns article notes that:

Rates for fatalities and major injuries in each year are not presented because frequencies were low, although the RIDDOR (Reporting of Injuries, Diseases and Dangerous Occurrences) rate does make use of both measures. Missing data (–) precluded the calculation of four lagging indicators in year one and one in year two.

Similar difficulties were noted in an earlier study by Hurst [44]. This study focused on establishing the ability of a “Safety Attitude Questionnaire [45]” (SAQ) and a candidate process management audit instrument (PRIMA [46]) to predict a facility’s process safety management system performance in preventing the occurrence of major process safety accidents. The Hurst study was done with six conventional chemical facilities that were covered as major hazard sites under the Seveso II directive, in four EU countries. Two of the six facilities were located in the UK.

[The authors note that it is of great value to review papers by Bellamy [47] that describe much of the work done in the European Community to develop the I-Risk instrument, which subsequently largely replaced use of PRIMA and was designed to relate more effectively the conduct and findings of a physical process audit to the elements of a facilities risk management plan.]

The Hurst study experienced similar problems to those encountered in the Mearns study: it could not establish robust correlations between their instrument’s predictions and actual performance using solely loss of containment rate (LCR) and (Lost Time Injury Rates) (LTI) data as measures of performance.

Although the Hurst article concluded that strong support was found for the ability of the SAQ survey product to predict process safety performance, it also concluded that the research showed that “the quality of the LTI and LCR is poor for the six sites audited.” The LCR data used in the study was defined to be equivalent to the LTI and LCR data that UK facilities are required to report to the HSE under RIDDOR.

This dearth of data is not surprising after one examines the number of LCR Process Safety Dangerous Occurrences reported under RIDDOR by chemical processing facilities covered under COMAH.

Examination of Table 3, which was taken from Travis [48], shows that the average number of reported RIDDOR dangerous occurrences experienced by all UK facilities covered under the UK COMAH (Control of Major Accident Hazards) regulation, is around 150 per

**Table 2 Part I.** Summary of results on test of hypotheses.

Hypothesis	Year 1	Year 2
0: True differences between installations in their self-report accident proportions will be reflected in the safety climate scores of accident and no-accident groups in a consistent direction	Supported	Supported
1: Favorable safety climate at installation level will be associated with lower proportions of employees experiencing an accident	Communication significantly associated with accident proportion. Trend in coefficients supportive.	No scales significantly associated with accident proportion. Trend in coefficients not supportive.
2: Favorable safety climate at installation level will be associated with lower official accident reports	Involvement—LTI $\geq 3$ — — Trend in coefficients supportive overall. Trend in coefficients with RIDDOR supportive.	Involvement—RIDDOR Communication—dangerous occurrences Communication—RIDDOR Trend in coefficients not supportive overall. Trend in coefficients with RIDDOR supportive.
3: Favorable safety climate at individual level will be associated with a lower likelihood of accident involvement	DFA confirms hypothesis Best predictors: <ul style="list-style-type: none"> <li>• satisfaction with safety activities</li> <li>• perceived management commitment</li> <li>• willingness to report incidents</li> <li>• general unsafe behaviour</li> </ul>	DFA confirms hypothesis Best predictors: <ul style="list-style-type: none"> <li>• work pressure</li> <li>• involvement in health and safety</li> <li>• general unsafe behaviour</li> </ul>
4: Proficient safety management practice at installation level will be associated with lower proportions of employees experiencing an accident	Accident proportion associated with management commitment and health promotion/surveillance. All coefficients in predicted direction	Accident proportion fails to associate with any SMQ element; all coefficients in predicted direction
5: Proficient safety management practice at installation level will be associated with lower official accident rates	<ul style="list-style-type: none"> <li>• Health promotion/surveillance <math>\geq 3</math></li> <li>• H&amp;S auditing—dangerous occurrences</li> <li>• H&amp;S auditing—RIDDOR</li> <li>• Total SMQ score—LTI <math>\geq 3</math></li> </ul> Trend in coefficients is supportive	<ul style="list-style-type: none"> <li>• Management commitment—dangerous occurrences (NB: But direction of coefficient disconfirmatory of hypothesis)</li> <li>• H&amp;S auditing—LTI <math>\geq 3</math></li> <li>• Operator/contractor interfacing—visits to rig medic for first aid</li> <li>• Total SMQ score—LTI <math>\geq 3</math></li> </ul> Trend in coefficients supportive

year. There are about 1200 UK facilities covered under COMAH, the UK regulation for implementing the EU Seveso Directive; therefore, the average facility experiences approximately 1 RIDDOR loss of containment (LCR) dangerous occurrence incident in 10 years. It is, therefore, not surprising that there are problems in using LCR RIDDOR data in arriving at conclusions on survey instrument effectiveness based on studies of a few facilities over a few years.

These types of difficulties have led investigators to

use “softer data,” such as “self reported accident rates,” to help establish instrument efficacy. While such surrogate metrics may be valid for facilities that voluntarily agree to participate in studies of the effectiveness of their accident management systems, it may lead to a selection bias in that only above average firms may volunteer for “safety studies,” i.e., firms that have a management that is concerned about process safety.

It is also interesting to note that the average UK facility covered under COMAH, i.e., Seveso II, experi-

**Table 3.** Major accident and process safety dangerous occurrences occurring annually in the UK at COMAH occurring at establishments [table taken from Travis5].

	99/00	00/01	01/02	02/03	03/04
COMAH major accidents	10	4	4	2	1
Process Safety Dangerous Occurrences reported under RIDDOR					
i. Failure of a pressure system (including a closed vessel or pipework)	9	7	13	17	13
ii. Electrical short circuit or overload attended by fire or explosion	7	8	7	10	7
iii. Explosion or fire due to the ignition of any material	27	23	21	23	15
iv. Escape of flammable substances	53	38	53	50	53
v. Escape of substances or pathogens	69	48	69	48	54
vi. Unintentional explosion or ignition	2	3	1	0	2
vii. Uncontrolled or accidental escape from a pipeline; bursting, explosion, or collapse of a pipeline	10	10	15	7	8
	177	137	179	155	152

**Table 4.** On-site injuries and deaths resulting from RMP accidents during reporting period.

	Mean or Total	Std Dev'tion	Min	Max	Number of Observations
On-site injuries to workers/contractors					
Total on-site injuries	1,987				1,969
Injuries per accident	1.0091	2.828	0	67	1,969
Injuries per FTE per acc.	.0207	.0783	0	1	1,951
On-site deaths to workers/contractors					
Total on-site deaths	32				1,968
Deaths per accident	.0163	.218	0	6	1,968
Deaths per FTE per acc.	.0003	.0070	0	0.25	1,950

Source: ref. 50.

ences only one Seveso “Paragraph 9” reportable process accident in about 300 years, whereas the average facility covered under RMP experiences a reportable accident [49] about every 50 years. Further insight into the character and incidence of RMP reportable accidents can be gained by examining Tables 4, 5 and 6, taken from work published by Kleindorfer [50] *et al.*

#### A NEW APPROACH TO ASSESSING THE EFFECTIVENESS OF PROCESS SAFETY MANAGEMENT SYSTEMS IN PREVENTING RMP REPORTABLE ACCIDENTS

As the above discussions show, it is difficult to establish the performance of instruments aimed at predicting or confirming the likely effectiveness of an LP process safety management system when such studies must rely on surrogates for the actual incidence of the targeted process accidents. This problem has been recognized for some time.

For example, Amendola [51] notes that:

However, *there are new intriguing and challenging issues in considering indicators and performance measurement in relation to major accident prevention.* Indeed, statistical feedback concerning quality, environment and Health and

Safety at workplace can quite reasonably be obtained from parameters such as manufacturing waste products; service availability; customer satisfaction and feedback from users; pollutant emissions to air, water and soil; energy consumption; working-hours lost because of professional illness or incidents. *Unfortunately such easily measured indicators are not available to analyse performance in major accident prevention [Cacciabue et al. 1994].* Since a major accident is a very rare event, the absence of a major accident in an establishment is not *per se* an indicator of a high-quality management system. On the contrary, the analysis of major accidents in establishments, where no such event had ever occurred, has in most cases resulted in the identification of faults in the management systems (such as hazards incompletely identified, poor training, inadequate procedures, failure to learn from near-misses etc.). For the evaluation of a Major Accident Prevention Policy, indicators have to be established, enabling the production of figures from which conclusions can be drawn as to the

**Table 5.** Non-employee injuries and deaths resulting from RMP accidents during reporting period.

	Mean or Total	Std Dev'tion	Min	Max	Number of Observations
Non-employee injuries					
Total injuries to public responders for all accidents	63				1,968
Injuries to public responders per accident	.032	.5537	0	21	1,968
Total on-site injuries to other members of the public for all accidents	104				1,968
On-site injuries to other members of the public per accident	.0528	1.390	0	59	1,968
Total hospitalizations for all accidents	215				1,968
Hospitalizations per accident	.109	1.931	0	80	1,968
Total other medical treatment for all accidents	6,057				1,968
Other medical treatment/accident	3.078	104.51	0	4,624	1,968
Non-employee deaths					
Total public responder deaths	0				1,968
Total on-site deaths by other members of the public	0				1,968
Overall non-employee deaths/accident	0				1,968

Source: ref. 50.

**Table 6.** Property damage and non-medical off-site consequences resulting from RMP accidents during reporting period.

	Mean or Total	Std Dev'tion	Min	Max	Number of Observations
On-site property damage (\$ millions)					
Total on-site damage	\$1,041				1,966
Damage per accident	\$0.529	\$6.641	\$0	\$219	1,966
Off-site property damage (\$ millions)					
Total off-site damage	\$11.7				1,967
Damage per accident	\$0.006	\$0.108	\$0	\$3.8	1,967
Off-site consequences					
Total number of evacuations	174				1,968
Total number of evacuees in all accidents	31,921				1,968
Number of evacuees per accident	16.22	140.97	0	3,000	1,968
Total number of accidents involving shelter in place	97				1,968
Total number of individuals confined to shelter in place in all accidents	184,839				1,968
Number of individuals confined to shelter in place per instance	93.9	1,913.4	0	55,000	1,968
Number of accidents with effects on the ecosystem					
Fish or animal kills	19				1,970
Minor defoliation	55				1,970
Water contamination	25				1,970
Soil contamination	29				1,970
Any environmental damage	104				1,970

Source: ref. 50.

strengths and weaknesses in the design and operation of the SMS. *This presents a new challenge for R & D in management science, both concerning*

*the identification of the indicators themselves and the statistical techniques needed for their analysis* [Amendola 1998]. (*Emphasis added*)

The authors believe that it should be possible to robustly meet the “new challenge for R & D in management science,” posed above by Amendola, by using the accident epidemiologic [52] approaches and enhanced RMP\*INFO accident databases created by Kleindorfer, Elliot, Lowe, and their coworkers [53]. These epidemiological tools should be able to test the validity of specific hypotheses regarding RMP accident causation and also verify the ability of a specific survey instrument to predict whether a given management system is likely to be effective in reducing the incidence of RMP accidents.

In a sense, accident epidemiology methodology would be used to study a wide range of factors that might determine the onset and course of low probability incidents. The following are examples of possible objectives for such studies:

1. Identifying the characteristics of facility populations likely to experience defined LP incidents (e.g., reportable RMP accidents)
2. Testing the validity of postulated LP HC incident causative factors (inadequate aspect of a safety management system or other deficiencies)
3. Studying differences between populations of facilities that do and those that do not experience LP RMP accident events
4. Evaluating the degree to which specific postulated corrective measures remove or reduce the frequency or severity of the system disturbances (incidents) in question.

The population of RMP covered firms would be divided into sub-populations with and without a particular type of accident event in a specified time period. Sub-populations would be further divided to arrive at groups of firms with and without specified accidents that are matched as closely as feasible in regard to all of the demographic aspects firms are required to furnish EPA. If the RMP data does not allow the desired demographic differentiation, additional research could be done on such firms since the RMP\*INFO database has useful identifiers, such as their Dun and Bradstreet number.

Responses to safety and culture survey instruments, audits, or other available data could be used to identify the presence of specific features of a firm's safety culture, safety management systems, or any other aspect of its operation hypothesized to be efficaciously or deleteriously related to the frequency of process accidents. Epidemiologic techniques would then be used to examine possible correlations between the RMP accident frequency of sub-populations with and without the specific factor being studied

Elliott, Kleindorfer, Wang, DuBois, and Rosenthal are presently conducting a study of this type [54], using OSHA OII data. This study will test correlations between a facility's effectiveness in reducing the incidence of relatively frequent occupational illnesses and injuries reportable to OSHA and its effectiveness in reducing the likelihood of an RMP reportable accident.

The results of this study should bear directly on the following observation made by Dalzell [55] in regard to differences between systems for effectively managing

risks leading to conventional occupational accidents (OII) and those for managing major accident risks leading to RMP accidents:

The management of occupational health and safety has latterly been much improved and continues to improve throughout the industry. *However, there is a serious disconnect between the management of occupational safety, health and indeed environmental risk management and the management of major accident hazard risks (Emphasis added).* Most line management tends to assume that the responsibility for the latter is that of the risk management specialists and not part of their role.

Hopkins, [56] in his discussion of the Longford fire, comes to conclusions that are similar to those of Dalzell, but for different reasons:

To understand the paradox of how a company with such an enviable safety record<sup>2</sup> was so inattentive to the hazards which led to the fire, we need to make a distinction between, on the one hand, high frequency low severity events such as slips, trips and falls, which result in injuries to single individuals and, on the other, low frequency high severity incidents such as explosions and major fires, which may result in major fatalities. LTI data are largely a measure of the number of routine industrial injuries; explosions and fires, precisely because they are rare, do not contribute to the LTI figures in the normal course of events. LTI data are thus a measure of how well a company is managing the minor hazards which result in routine injuries; they tell us nothing about how well major hazards are being managed. *Moreover, firms normally attend to what is being measured, at the expense of what is not. Thus a focus on LTI can lead companies to become complacent about their management of major hazards (Emphasis added).* This is exactly what seems to have happened at Esso.

While many practitioners are inclined to accept these observations by Dalzell, Hopkins, and others, it does not appear to be backed by factual analysis.

The reason that many practitioners agree with Dalzell's and Hopkins's observations is that OII incidence is heavily impacted by “slips,” “falls,” and “struck by” accidents that are not directly related to process safety. Such OII accidents occur for the most part during relatively frequent routine operational activities, where prevention of the realization of a hazard (accident) is often dependent on a single barrier, such as training, or an easily overcome physical device. An employee working under pressure is susceptible to defeating such barriers in order to maintain production or quality or because of personal problems.

On the other hand, occurrence of a relatively infrequent RMP accident generally requires the breaching of

<sup>2</sup>Dalzell is referring to the facility's record in regard to LTI (Lost Time Incidents).

multiple barriers, which results from management system failures in regard to rectifying the generally slower, stepwise breaching of individual barriers over extended periods of time. In many cases, the stepwise breaching of such barriers (“Misses”) does not result in product quality changes or process throughputs, but they do substantially increase the likelihood that a reportable RMP accident will occur.

There are obviously a number of hypotheses that one could postulate in regard to the relationship between RMP accidents and OII or other factors. For example:

1. Management system effectiveness in reducing OII incidence is a sufficient indicator of facility management system effectiveness in reducing RMP reportable accidents.
2. Management system effectiveness in reducing OII incidence is a necessary, but not sufficient indicator of facility management system effectiveness in reducing RMP reportable accidents.
3. Management system effectiveness in reducing OII incidence does not correlate with facility management system effectiveness in reducing RMP reportable accidents.

If the planned OII/RMP study shows a correlation between OII performance and RMP accident incidence rates, the result might be due to number of things. For example, it may be the case that effective OII management systems coincidentally generate practices that are effective in ensuring safe chemical process operations, or that facilities that generate effective systems for reducing OII reportable accidents have safety cultures that also ensure that their management systems will have features that address the hazards associated with processes covered by the RMP regulation.

However, if this OII/RMP study shows that above average OII performance is a necessary but not sufficient condition for above average RMP accident incidence rates, this may indicate the existence of a positive safety culture that is lacking in the know-how needed to design an effective LP process safety management system or perhaps the motivation to do so. As the Fort Dearborn case shows, good OII performance is relatively quickly reflected in significant reductions in Worker Compensation costs, while the savings from avoiding process accidents are less tangible immediately and certainly less predictable time-wise.

Of course, the OII/RMP study may show no association between OII and RMP accident rates. The absence of any apparent associations could lead to the testing of additional hypotheses on this absence of relationship between these two aspects of an overall facility safety management system [57].

The OII/RMP study should be relatively simple to execute compared to a study that would seek to predict or establish the effectiveness of a particular type of process safety management system feature since much of the data and information required for examining possible OII/RMP relationships was contained in EPA and OSHA databases. This will not be the case if one sets out to validate survey instruments that are predictive in regard to the likely effectiveness of systems for

managing the safety of processes with the potential for LP–HC accidents since these predictive tools require the ability to obtain a large number of confidential employee responses to survey instruments.

The need for instruments with the ability to measure (audit) and/or predict the effectiveness of a facility’s LP process safety management system has existed for some time, as shown by the discussion and work on the Safety Attitude Survey Questionnaire (SAQ) in Hurst’s previously cited 1995 article. The Center for Chemical Process Safety (CCPS) of the AIChE also recognized this need and developed the ProSmart tool to meet this need in the late 1990s. Perry’s (CCPS) paper on ProSmart [58] describes its purpose and benefits as follows:

The purpose of ProSmart is to help companies identify and use qualitative and quantitative indicators of the performance of PSM Systems to aid in continuous improvement”. . . the benefits that ProSmart is expected to provide are:

- Reduce risk of catastrophic accidents.
- Improve cost-effectiveness of PSM activities.
- Benchmark against PSM performance expectations.
- Justify that PSM resources have been well spent.
- Help establish priorities for PSM improvements.

Examples of the type of specific issues addressed by ProSmart are described in another article [59], and these examples indicate that ProSmart is intended to act as both an audit as well as a guidance tool. While conceptually, ProSmart is an excellent instrument for auditing and improving the effectiveness of process management systems, its application appears to require extensive resources and it does not appear to have had wide acceptance to date. In addition, there have been no robust studies confirming ProSmart’s ability to identify management system effectiveness in preventing RMP reportable accidents. If this type of study were undertaken, the epidemiologic approach put forward could be used to establish how effectively ProSmart can identify the quality of process safety management programs

There also has been considerable research on the use of “Near Miss” [60, 61] systems as a means of tracking the reliability of one or more of the “barriers” put in place to prevent the realization of a hazard with adverse consequences. Though Near Miss systems can be a very powerful tool for maintaining process integrity [62], relatively little work has been done on tracking the impact of the use of this tool on the incidence of RMP process accidents at facilities that utilize it. This is another instance in which the epidemiologic approach put forward above could be used to establish efficacy.

What this article wishes to emphasize is that the RMP\*Info system provides a unique opportunity to validate the ability of a specific audit, survey, near miss, or other tool to predict the likelihood of LP–HC events. Since RMP\*Info provides a (population) cohort of facilities at risk for LP–HC events, a “nested case-control” study can be conducted by sampling at random 100

facilities that suffered a given category of LP–HC events in a recent time period and 100 facilities, matched on facility characteristics such as processes, chemicals, and regulatory environment, that did not suffer the equivalent event during the time period. For example, the survey instrument being evaluated can be administered in both sets of facilities, and exposures that are statistically significantly associated with LP–HC event risk determined. The same facilities could also be subjected to a prospective study that would be completed five years later when the next five-year batch of RMP data is available. The sample of 100 is arbitrary; a larger sample may be required to provide sufficient power to detect weaker predictors of risk, at the cost of the additional surveys.

If none of the existing survey instruments were as effective as desired, a new survey tool might be developed that uses employee input in a confidential fashion with a focus on factors related to LP–HC risk, such as timeliness of maintenance, perceived management support for process safety, adherence to management of change procedures, prompt correction of audit deficiencies, training adequacy, etc. Development of such survey tools would involve assembling focus groups of specialized “experts,” including line employees, managers, and engineers, to generate a listing of potential risk factors; conducting “cognitive interviews” to determine if respondents are interpreting questions in preliminary versions in the expected manner; and the employment of other standard techniques to minimize respondent burden and maximize participation rates.

It is clear that some type of validated instrument would be very useful for both evaluating the current effectiveness of a firm’s process safety management system and also for tracking whether unintended impacts on safety result from changes in the way a company manages its overall business. Even the best company’s safety management practices can deteriorate for any one of a number of reasons, and the impact of policy changes may not manifest itself on safety performance until a major accident or a significant deterioration in OII occurs.

Scott [63] describes an example of such a change: the impact of an apparent shift at DuPont in the emphasis that management placed on improving the company’s competitiveness in the 1985–1988 periods. He notes that as a result of economic pressures, DuPont restructured itself into “a far leaner organization.” As this change was occurring, Scott notes:

... we also began changing our corporate culture in fundamental ways. The emphasis was on ever-better marketing, together with further improvements in quality of product and in work performance. Although it had not been intended to downgrade safety, it was emphasized far less as a major corporate program. It was assumed that, given our corporate culture, safety at DuPont could be counted upon to take care of itself for a time while management focused its main attention on executing the new programmes. We were wrong, very wrong about this.

The article goes on and notes that, as a result of this change in emphasis, the signals to employees got jumbled and they felt that “safety had been lowered as a corporate priority” and, consequently, “people were tempted to keep things going in the presence of minor problems to prevent costly downtimes.” The impact of this change in the emphasis on safety manifested itself rather quickly.

Scott notes that:

In one of our most safety-conscious departments, the number of lost-work day cases increased from one or two a year to 10 in the first six months of 1987. That trend fairly represented what was going on in the whole company.

The article by Scott concludes with a discussion of the actions taken to correct this situation at DuPont plants he wrote about. The author speculates that the change in DuPont culture during the interval studied also probably led to reduced emphasis on maintaining the barriers preventing the realization of process hazards and increased the likelihood of LP–HC process accidents.

## CONCLUSIONS

Conventional statistical analysis of accident data, employee surveys, and process audits have been used to validate instruments for predicting and confirming the likely effectiveness of systems for managing the prevention of OII. However, conventional statistical techniques are not able to robustly validate instruments with similar capabilities in regard to the LP process accidents that must be reported to EPA under their RMP regulation.

Companies operating chemical processes, insurance companies, trade associations, labor unions’ Responsible Care programs, Local Emergency Planning Associations (LEPCS), OSHA, and EPA all obtain value by preventing process accidents. They should, therefore, be interested in having a validated survey instrument that they could use to determine the likely effectiveness of a facility’s process safety management system before, rather than after, a major accident occurs.

The key issue here is establishing the validity of candidate survey and audit instruments. An important element of this validation process will be corroborating the statistical association of accident frequency and severity outcomes with predictors that include the results of various audit and candidate survey instruments. This approach would build naturally on the accident epidemiology approach developed at the Wharton risk center using the RMP data. In particular, existing or new survey instruments could be validated retrospectively and prospectively using a case-control study design, where both cases and facility-type-matched controls are sampled at random from the RMP\*Info database.

Appropriate administration of the candidate survey instruments is another task that is difficult to accomplish. One approach for accomplishing this could be through a cooperative effort by EPA, OSHA, unions, and chemical and insurance trade associations that incorporated measures to ensure that, while the results on any individual facility were made available to that facility, the results and identity of evaluated facilities

and responding employees were kept completely confidential in regard to public disclosure or use in legal proceedings.

A cooperative effort [64] by the UK Health and Safety Executive (HSE) and the Chemical Industries Association (CIA) aimed at collecting individual inputs on improved process safety management plans is currently underway. The successful joint HSE Industry-Regulatory agency programs noted above and some preliminary discussions reveal that such a cooperative approach on validating instruments as a tool for guiding improvements in facility process management systems may be feasible.

## APPENDIX A

### **Practitioner Acceptance of the Paradigm that Management System Inadequacies Are the Root Cause of Most LP–HC Process Accidents**

The proposition that management system inadequacies are the Root cause of most process accidents gradually emerged in the 1970s. It was implicitly accepted by the US chemical industry by 1989, as shown by the following excerpts, taken from “Technical Management of Chemical Process Safety” published by the chemical industry sponsored Center for Chemical Process Safety of the American Institute of Chemical Engineers (CCPS).

Prevention of chemical process accidents requires the implementation of comprehensive process safety management systems. Effective process safety management systems can, and do, vary a great deal in how they are implemented. However they always address the need for managing the process safety related aspects of technology, facilities, personnel, hazardous materials and emergency response [65].

An axiom of incident investigation is that process safety incidents are the result of management system failure. Invariably, some aspect of a process safety management system can be found that, had it functioned properly, could have prevented an incident [66].

Of course, many causes of incidents can be attributed not to management system failures, but to specific technical or human failures, such as equipment breakdown or operator error. However, experienced incident investigators know that such specific failures are but the immediate cause of an incident and that *underlying each such immediate cause is a management system failure, such as a faulty design or inadequate training* [67]. (*Emphasis added*)

In a recent article, Smullen [68] noted that which has been repeatedly reported in the literature:

The goal of every incident investigation process is to get to root cause. Most processes recognize that there are usually multiple causes to any incident. Terms like initial, immediate or primary cause can complicate the search for root cause. For this process we defined root causes as those causes that when controlled will achieve permanent change.

*We observed as others had, that control will almost always require some change in the management system. (Emphasis added)*

Quadri [69] sums up the findings of an investigation of a refinery accident as follows:

The most part of the lessons to be learned are leading rather to managerial features, than to physical or more direct causes.

In Italy a specific approach has been developed and applied to perform the analysis of accidents with the main objective to identify deficiencies in the Safety Management System (SMS), that can be connected to the accident itself or anyhow shown related, by events and circumstances, to the accident.

Drogaris [70], in his analysis of major accidents notified to the European Commission’s Major Accident Reporting System” (MARS) prior to 1991, identified safety management system deficiencies as the major root cause of the accidents reported:

Managerial and or organizational omissions (in any one of the following types: lack of safety culture, inadequate safety organization, pre-determined safety procedures not observed, insufficient or unclear procedures, insufficient training and/or supervision, negligence in clarifying the causes of previous accidents, etc.) account for the causative factors for about 90% of the accidents of which the causes are known.

The Chemical Safety Board (CSB) accident investigation reports [71] almost invariably maintain that Process Management System inadequacies have been the root cause of the preponderance of the cases they have investigated; and Beard [72], in his analysis of the literature dealing with offshore fire safety management systems, also essentially concludes that inadequate process safety management systems are the root cause of most “catastrophic” accidents.

After the fact, it is somewhat surprising that it took so long for a practitioner consensus to emerge on acceptance of the paradigm that “management systems are the root cause of the large majority of process accidents,” given that practitioners generally accept the precepts of the Quality Movement and one of its key precepts is that:

85% of the quality variations in a system under control arise from common causes that can only be corrected by management (Shewhart [73]).

Numerous process safety experts have now expressed their belief that most process accidents arise in essence from defects in process quality and that, therefore, Shewhart’s observation also applies to preventing process accidents.

For example, Olsen [74], a manager of process safety at Exxon chemical, noted that:

Whether you follow the precepts of ISO 9000, TQM, or Malcom Baldrige –Whether your “guru” is Deming, or Crosby, or Peters or Ishikawa or a



personnel saint, there is no doubt Quality and process safety have much in common.

Adams [75] notes that the Management Oversight Risk Tree (MORT) system, developed by Johnson [76] for the United States Atomic Energy Commission and widely used in the chemical industry, postulates that most risk losses (accidents) are caused either by:

1. Management system factors
2. Risks that management consciously assumed.

Endorsements of the safety-quality relationship in regard to OII are also prevalent. Two recent examples are:

1. A paper by Herrero [77] that discusses the relationship between quality and safety management principles and analyzes this relationship using data collected from a Spanish company over a long time period;
2. An article by Williamsen on Six Sigma Safety [78].

If one accepts the safety-quality analogy, it follows that as with quality a safety culture is a necessary, but not sufficient, condition for having an effective program and, further, that management controls about 85% of the factors leading to accidents (defects), with employees having the ability to control the remaining 15%.

Some practitioners, focused primarily on prevention of OII, do not appear to accept this 85/15 division of responsibility. They believe that workers are responsible for most OII and point to OII decreases greater than 50% obtained with Behavior Modification programs as proof of their contention. The authors believe that when adoption of behavioral modification tools achieves such very high OII improvements, it is because the factors that led to the start of a behavior modification program in the first place resulted from a broader, increased top management commitment to safety.

This change in commitment to safety is likely to be expressed in an explicit or implicit safety management plan that leads to other accident prevention measures and practices in addition to initiating an employee behavior modification program. Leaving aside the impact of other safety measures, at a minimum plant managers will be asked about safety results more often once increased resources are allocated to a behavioral safety modification program and are, therefore, likely to press their staff more in regard to all aspects of safety performance.

Krause [79], an acknowledged leader in the field of behavioral safety, apparently agrees with the view that major responsibility for safety rests with top management, and he places behavior modification programs as only one of several actions and programs that corporate management may recommend to its facilities:

Safety leadership begins at the corporate level where directives and objectives are established. The corporate level recommends safety management systems and site-level mechanisms such as incident investigation, safety committees, safety action item tracking systems, hazard analysis, behavior observation and feedback.

One final observation on the subject of accident Root cause attribution: Despite the strong evidence identifying

inadequate process safety management systems as the root cause of most major process accidents, industry accident investigations rarely voice this conclusion because of concerns about liability. These concerns are expressed in the following comments by the Chemical Manufacturers Association (CMA) [80] in 1984:

Findings of accident investigations that are characterized as "Root causes" could have a very prejudicial effect in legal proceedings [81].

Rosenthal [82] discusses industry's liability concerns and offers evidence that well-founded liability concerns cause most firms' process accident investigations to rarely attribute the Root cause of an accident to deficiencies in the firm's process safety management system, particularly those accidents that involve injury to people or entities other than company property and employees.

## APPENDIX B

Excerpt from "Safety Climate, Safety Management Practice and Safety Performance in Offshore Environments," by Kathryn Mearns, Sean M. Whitaker, and Rhona Flin.

### 5.1. Safety climate scores and safety performance

There was partial support for the idea that installation safety climate predicts the proportion of respondents reporting an accident on each installation. This support was confined to year one: scores on the OSQ communication scale were significantly correlated with self-reported accident proportions, and all eleven scales were associated with accident proportions in the expected direction. Communication was also significantly correlated with the rate of dangerous occurrences and the RIDDOR rate provided by the official installation figures. Communication of health and safety issues to the workforce has been viewed as a key stage of organisational learning that proceeds from accident/near miss investigations, safety audits or changes to procedures. It is a key aspect in the PRIMA safety management tool of Hurst et al. (1996), as well as the HSE safety climate survey tool. Lee (1998) lists communication in his nine characteristics of low accident plants, and it emerges as an important factor in the success of safety programs (Harper et al., 1997; Tan-Wilhelm et al., 2000).

The OSQ scale addressing involvement in health and safety decision-making was significantly associated with LTI53 in year one and RIDDOR in year two. A sense of involvement may be fostered by immediate supervisors during day to day tasks as well as the specific design of safety programs but in both cases evidence suggests that high involvement promotes safer working practice (Simard and Marchand, 1994; DePasquale and Geller, 1999). The OSQ scale in year one was more general in its scope, covering involvement in the formulation of health and safety objectives, discussing the effectiveness of the safety management system, discussing procedures for risk con-

trol, and auditing health and safety. In year two the emphasis was on decision making and work planning. In both cases involvement in health and safety emphasizes personal responsibility, and perceptions by the workforce that safety interventions are based on pragmatic concerns and a 'welfare before profit' philosophy within the company.

The safety climate scores were also considered at the individual level as predictors of self-reported accidents. When all scales were included in each year, the proportion of correct classifications exceeded 68%. However, this value is not high and there was little consistency in the set of best predictors; only general unsafe behavior featured in both sets. In all cases, unfavorable scores on the OSQ scales predicted an increased likelihood of reporting an accident. The causal direction to this relationship is questionable because experience of an accident may bias perceptions and attitudes toward safety. However, respondents who experienced an accident and those who did not provided similar scores across installations with high and low accident proportions. This suggests that accident experience does not necessarily bias ratings to any large degree.

## 5.2. Safety management practices and safety performance

Safety management practice displayed wide variation across installations. In year one, lower self-reported accident proportions were observed on installations with favorable SMQ scores for management commitment, and health promotion and surveillance. In both years all coefficients were in the correct direction. In both years, favorable total SMQ scores were associated with lower rates of lost time injuries. Health and safety auditing was implicated in both years. Contrary to the hypothesis, management commitment was positively associated with the rate of dangerous occurrences in year one. It may be the case that high rates of dangerous occurrences the previous year motivated a higher level of management commitment and that changes in management commitment were reactive rather than proactive."

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### 1. Historical Background

Major accidents in chemical industry have occurred world-wide. Increasing industrialisation after the Second World War also led to a significant increase of accidents involving dangerous substances. In Europe, in the 1970's one major accident in particular prompted the adoption of legislation aimed at the prevention and control of such accidents.

The Seveso accident happened in 1976 at a chemical plant manufacturing pesticides and herbicides. A dense vapour cloud containing tetrachlorodibenzo-paradoxin (TCDD) was released from a reactor, used for the production of trichlorofenol. Commonly known as dioxin, this was a poisonous and carcinogenic by-product of an uncontrolled exothermic reaction. Although no immediate fatalities were reported, kilogramme quantities of the substance lethal to man even in microgramme doses were widely dispersed which resulted in an immediate contamination of some ten square miles of land and vegetation. More than 600 people had to be evacuated from their homes and as many as 2.000 were treated for dioxin poisoning.

In 1982, Council Directive 82/501/EEC on the major-accident hazards of certain industrial activities (OJ No L 230 of 5 August 1982) –so-called Seveso Directive –was adopted. In the light of severe accidents at the Union Carbide factory at Bhopal, India in 1984 where a leak of methyl isocyanate caused more than 2.500 deaths and at the Sandoz warehouse in Basel, Switzerland in 1986 where fire-fighting water contaminated with mercury, organophosphate pesticides and other chemicals caused massive pollution of the Rhine and the death of half a million fish, the Seveso Directive was amended twice, in 1987 by Directive 87/216/EEC of 19 March 1987 (OJ No L 85 of 28 March 1987) and in 1988 by Directive 88/610/EEC of 24 November 1988 (OJ No L 336 of 7 December 1988). Both amendments aimed at broadening the scope of the Directive, in particular to include the storage of dangerous substances.

## 2. The Seveso II Directive

The Seveso Directive required a review of its scope by the Commission by 1986. Also, the Member States, in accompanying resolutions concerning the Fourth (1987) and the Fifth Action Programme on the Environment (1993), had called for a general review of the Seveso Directive to include, amongst others, a widening of its scope and a better risk-and-accident management. A resolution from the European Parliament also called for a review.

On 9 December 1996, Council Directive 96/82/EC on the control of major-accident hazards (OJ No L 10 of 14 January 1997)- so-called Seveso II Directive - was adopted. Member States had up to two years to bring into force the national laws, regulations and administrative provisions to comply with the Directive. From 3 February 1999, the obligations of the Directive have become mandatory for industry as well as the public authorities of the Member States responsible for the implementation and enforcement of the Directive.

The Seveso II Directive has fully replaced its predecessor, the original Seveso Directive. Important changes have been made and new concepts have been introduced into the Seveso II Directive. This includes a revision and extension of the scope, the introduction of new requirements relating to safety management systems, emergency planning and land-use planning and a reinforcement of the provisions on inspections to be carried out by Member States.

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