MODELS FOR MULTI-STRATA SAFETY PERFORMANCE MEASUREMENTS IN THE PROCESS INDUSTRY

A Dissertation

by

NIR KEREN

Submitted to the Office of Graduate Studies of
Texas A&M University
in partial fulfillment of the requirements for the degree of

DOCTOR OF PHILOSOPHY

December 2003

Major Subject: Interdisciplinary Engineering

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Major Subject: Interdisciplinary Engineering

ABSTRACT

Models for Multi-Strata Safety Performance Measurements in the Process Industry. (December 2003)

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Measuring process safety performance is a challenge, and the wide variations in understanding, compliance, and implementation of process safety programs increase the challenge. Process safety can be measured in three strata: (1) measurement of process safety elements within facilities; (2) benchmarking of process safety elements among facilities; and (3) use of incident data collection from various sources for industrial safety performance assessment.

The methods presently available for measurement of process safety within facilities are deficient because the results are strongly dependent on user judgment. Performance benchmarking among facilities is done within closed groups of organizations. Neither the questionnaires nor the results are available to the public. Many organizations collect data on industrial incidents. These organizations differ from each other in their interests, data collection procedures, definitions, and scope, and each of them analyzes its data to achieve its objectives. However, there have been no attempts to explore the potential of integrating data sources and harnessing these databases for industrial safety performance assessment.

In this study we developed models to pursue the measurement of samples of the strata described above. The measurement methodologies employed herein overcome the disadvantages of existing methodologies and increase their capabilities.

DEDICATION

I dedicate this work to my beloved Irit, On, and Lyn for sacrificing their “old life”, and for supporting me in enhancing my knowledge in pursuing a Ph.D. degree.

ACKNOWLEDGEMENTS

I express sincere gratitude to my advisor and committee chair, Dr. Sam Mannan, for providing academic as well as moral support for the successful completion of my research. I also express gratitude to Dr. Harry West for his guidance and for enriching my knowledge and my research. Furthermore, I thank Dr. Alex Mintz for his spiritual support and encouragement throughout the entire path of pursuing this degree. I am also thankful to Dr. William Rogers for his reviews and comments.

I would like to express my appreciation to Dr. Marietta Tretter and Dr. William Richmond for serving on my committee. Thanks also to Donald Jenkins, Roy Sanders, Adrian Sepeda, and Skip Early for serving as a panel of experts in this study.

A great deal of appreciation to our families and friends for supporting us in this endeavor, and for strengthening our hands in the times when we needed it most.

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CHAPTER I

INTRODUCTION

Background

The fallout of dioxin caused by a runaway reaction at Seveso, Italy, in 1976, and the 1984 disaster of Bhopal, India, led to major changes in laws over the world. Federal and industrial entities devoted major efforts toward risk reduction and hazard control. Most of the organizations in the chemical industry integrated their systems for safety. The numbers of fatalities and injuries were parameters that safety performance was measured with until the late seventies. Major progress was accomplished since the seventies. Organizations, academicians, and legislators realized that since the number of catastrophic incidents is low, the number of fatalities and injuries are not reasonable indicators for measurements of safety performance. “The absence of a very unlikely event is not, of itself, a sufficient indicator of good safety management” [1]. Injuries, illnesses, and losses should be measured, but they are only part of the bottom line of safety performance, and are not good as a feedback for safety management.

Previous Work

Most organizations that employ measurements of process safety elements within facilities developed these measurements by a local staff, and some of them involved consulting companies that helped to develop the measurement system to address the facility’s unique characteristics. York [2] reports on a facilitated self-assessment measuring system of North American Rhodia Inc. that is incorporates the Occupational Safety and Health Administration’s (OSHA) Process Safety Management standard (PSM) and the Environmental Protection Agency’s (EPA) Risk Management Program

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This dissertation follows the style and format of *Process Safety Progress*.

(RMP) requirements as well as Responsible Care Process Safety Code elements and additional Rhodia requirements. The measurement system is lacking since it consists primarily of user evaluations.

The Center for Chemical Process Safety (CCPS) developed a measurement system for measurements of PSM elements in facilities. A computerized program version has been launched[1] (Pro-Smart) by CCPS. The program is useful toward measurement of progress of a certain facility. Furthermore, the results are more credible when the same user makes the evaluations over time. The general concept of the measurement system is emphasized in a paper written by CCPS executives and members and published on the web[2].

Benchmarking of process safety elements is mostly conducted among facilities, but neither the questionnaires nor the results are available to the general public. CCPS benchmarks Management of Change program practices among its members. However, the benchmarking report is not available.

Most of the efforts in the development of process safety performance measurements are invested toward measuring the industry as a whole and with some efforts directed toward performance measurements of federal agencies.

OSHA is a federal agency under the authority of the Department of Labor (DOL) and is responsible for the safety and health of employees in the work place. OSHA s incidence rate is a statistical index that measures illnesses and injuries per 100 worker years [3]. The Fatality Accident Rate (FAR) is a European index mostly used by the British and is a statistical index that measures the number of fatalities per 1000 employees working their entire lifetime (50 working years per employee). Indices as FAR and Incidents Rate which represent failure to effectively control risks are called Trailing Indicators. These indices are important, and can be used to measure

[1] The program is a commercial product. A demo is available at http://www.aiche.org/ccps/prosmart/index.htm , (September 2003) but it reveals very little about the features of the program and the concept.

[2] **D. J. Campbell, E.M. Connelly, J. S. Arendt, B. G. Perry, S. Schreiber**, "Performance Measurement of Process Safety Management Systems"**,** www.concordassoc.com/publicayionsSan%20Antonio%20Paper1.html (September 2003).

performance in the process industries (as well as in any other industry). However, fatalities, injuries, and illnesses are only the outcomes of a safety culture. Recognizing that safety management input should be measured as well as outcomes, many entities developed indices that address inputs. Indices that measure the level of risk reduction (inputs) are called Leading Indicators. Travers [4] considered three groups of Indicators:

- Indicators of the degree/frequency of major incidents or those with the potential to escalate to major incidents (mainly trailing indicators)
- Indicators of the effectiveness and future effectiveness of risk control revealed through regulatory interventions (a mixture of leading and trailing indicators)
- Indicators of public assurance in the effectiveness of risk control (mainly leading indicators

Travers work consists of a list of indicators. A few questions arise regarding the proposed measures:

- How comprehensive is his proposal? (Especially in light of trying to address major hazards in all major hazardous industries)
- This work refers to European regulations and standards. Are these standards applicable toward measurements in the US?
- How feasible are the existing data that support the measures proposed in the work?
- What are the characteristics of the indicators and do the proposed indicators fit these characteristics?

Travers work is preliminary and may answer these questions in the future.

Newell [5] (Organization Resources Counselors Inc.) presents a very well developed concept of process safety performance measurements. In his work, Newell analyzes in detail OSHA s database as a sole source of data for performance measurements. Newell recommends using the OSHA rates for measurements only as part of comprehensive balanced assessments that include other key information. Newell calls for use of leading, trailing and financial indicators rather than trailing indicators only. His work is based on the balanced scorecard, which is best emphasized by [1] “Accentuate the positive to eliminate the negative”. This concept has been widely used since the early nineties and is common to many suggestions for performance measurement systems. Newell’s work describes the features of the trailing, and leading indicators, but it does not actually develop the indicators. Although this work does not introduce the indicators, its contribution is significant in the phase where data sources are considered and in the phase of defining the indicators. Similar works to have been done by Ritwik [6] (Kuwait National Petroleum Co.), Walker et al. [7] (ABS Consulting), Morrison [8] (Nova Chemicals, Inc.), and Toellner [9]. All of these works contribute to some of the process safety performance measurement issues but none of them are comprehensive, well defined, and developed.

The European Organization of Economic Co-operation and Development (OECD) launched a project related to the development of Safety Performance Indicators for Chemical Accidents Prevention, Preparedness and Response [10] & [11], six years after publishing guiding principles for chemical accident prevention, preparedness and response that was implemented by 29 countries including Canada. OECD distinguishes between the industry and the public, and [10] discusses the Canadian stakeholder view of accident prevention, emergency preparedness, and response. Its indicators have many similarities to the OSHA VPP program. OECD [10] introduces the general concept for process safety performance indicators. According to this paper the project interim report should have been published in 2002, however, the report is not available.

Many organizations collect data on industrial incidents. These organizations differ from each other in their interests, data collection procedures, definitions, and scope, and each of them is analyzing its data to achieve its goal and to accomplish its mission. There is an increased interest in using data on incidents to improve safety in the last 20 years. In the late 1980s, V. C. Marshal consolidated incident data from sixty or so years and harnessed it toward loss reduction, and loss prevention in his book *Major Chemical Hazards* [12]. Today the interest is bigger than ever, because of the development of information technologies that look promising in their abilities to see what "unarmed human eye" cannot see. Major efforts are being invested toward collection of incident related data. The US Department of Health and Human Services, The Agency for Toxic Substances and Disease Registry (ATSDR) maintains Hazardous Substances Emergency Events Surveillance (HSEES) and publishes annual and cumulative reports [13], and is only one among many other type of data collection projects that is maintained by the Centers for Disease Control and Prevention (CDC). The US Department of Transportation repository consists of a large number of transportation safety related databases, and many reports are available on their website [14]. The last are only two from at least 15 sources of information of incident related data that have been analyzed and incorporated in assessments of industrial safety performance by the Mary Kay O'Connor Process Safety Center, at the Texas A&M University, College Station Texas (MKOPSC). However, the main challenge in using incident related data only begins when the data is available.

Marono et al. suggest use of the European Commission accident-reporting database, MARS, as a support for the definition of a safety performance indicator system [15]. McCray and Mannan are the first to look at several databases to analyze opportunities for risk reduction and loss prevention [16]. Mannan with O'Connor and West established the basis for a continual effort to exhaust the potential that is hidden in incident databases in their paper "Accident History Databases: An Opportunity" [17]. Mannan et al. looked again into EPA RMP Info database in order to determine the most significant chemical releases [18] as part of the efforts described above. Early in 2002 the MKOPSC published a report on the feasibility of using federal incident databases to measure and improve chemical safety [19].

Scope of Dissertation

In this dissertation I developed models for performance measurements of elements of process safety in three levels:

- Within facilities
- Among facilities
- Across industries

Three Disciplines Approach

Three disciplines can be distinguished within the spectrum of process safety performance measurements:

- Measurements of Process Safety Elements within Facilities
- Benchmarking of Process Safety Elements among Facilities
- Assessment of Industrial Safety Performance

Measurements of Process Safety Elements within Facilities

OSHA PSM is a comprehensive standard. PSM element compartmentalization in the standard creates an opportunity to develop measurement models for each of the elements separately. For example, lack of appropriate Management of Change practices is reported to be the cause for a significant number of the incidents in the chemical and petrochemical industries. Therefore, this work presents the development of an index-based model for management of change performance measurements according to guidelines that are listed in Chapter II.

Benchmarking of Process Safety Elements among Facilities

The performance-based nature of the PSM element is apparent from a reading of the regulatory requirements. Thus it is difficult to claim with certainty what is meant by regulatory compliance. Practices often vary and there is a critical need to determine the industry consensus or Recognized and Generally Accepted Good Engineering Practices (RAGAGEP). The effort of benchmarking PSM elements is thus aimed at developing benchmarks of industry practices for various process safety management requirements. Benchmarking of PSM elements is a sequence composed of 4 stages:

1. Decomposition of the element to its basic components
2. Questionnaire development
3. Surveying facilities
4. Results analysis

Emergency Preparedness and Response, Management of Change, and Investigation of Chemical Process Incidents are some of the crucial elements in process safety programs. This work presents the results of benchmarking of practices of the Management of Change, and Emergency Preparedness and Response elements, and a questionnaire for the Incident Investigation element.

Assessment of Industrial Safety Performance

The flow chart in Figure 1-1 is a simplified description of the process of using incident data collection from various sources for industrial safety performance assessment. The primary focus of industrial safety performance assessment, which uses the methodology described herein, is to establish a baseline metrics for the universe under investigation with regard to safety. This requires identification of incident trends, distribution of number of incidents, number of injuries, property damage costs, releases of materials, hospitalizations, and evacuations. These should be analyzed and correlated across the causes of incidents, equipment involved, initiation events, location, and other indicators. Several of the sources of information that are available collect only part or a sample of the information. However, it is possible to estimate the total number of chemical/product related incidents by applying statistical tools on the data. Implementation of indicator-based industrial performance measurement systems helps to determine whether the efforts invested toward safety improvement lead to the desired results. Other benefits are the ability to determine the areas that will lead to major reduction of losses and reduction in the number of incidents.

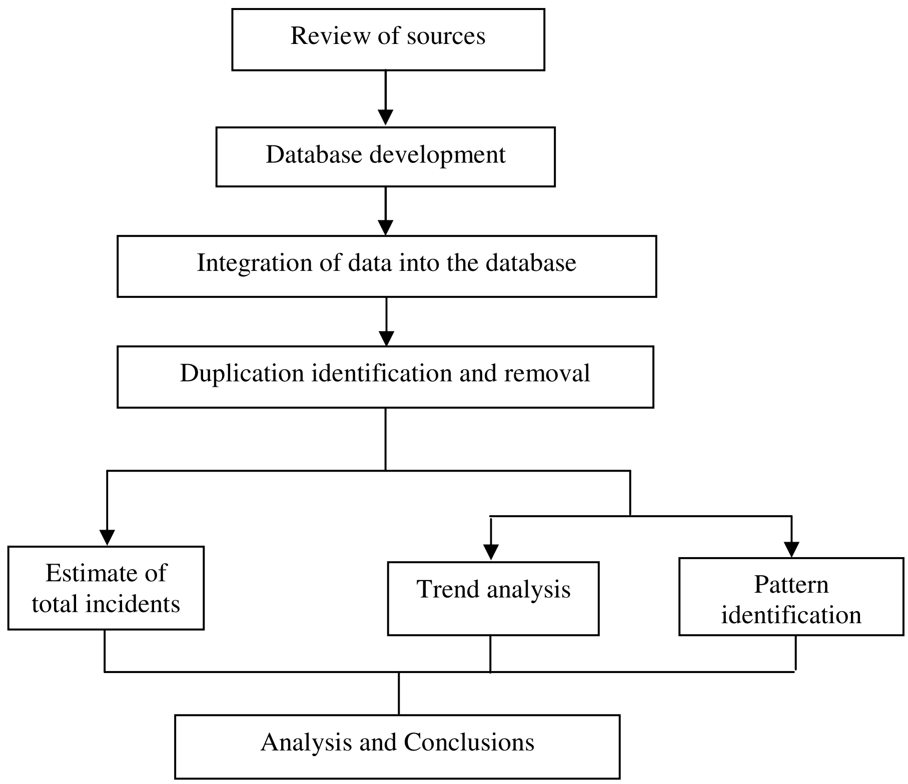

Figure 1-1. Methodology flow chart

The study herein presents the development of a methodology described above and the results of implementation of this methodology to analyze and identify poor safety performance factors in the propane industry.

CHAPTER II

INDEX-AIDED MODEL FOR PROCESS SAFETY PERFORMANCE MEASUREMENTS OF MANAGEMENT OF CHANGE PROGRAM PRACTICES

Guidelines for the Development of an Index-Aided Model

MOC programs are implemented in diverse ways [20]. Because of the performance-based nature of MOC programs, they can be implemented to meet at the minimum OSHA PSM requirements or on the other hand MOC programs can be implemented with the desire to achieve the best practice. This chapter documents the development of an index-aided model for MOC safety performance measurement system.

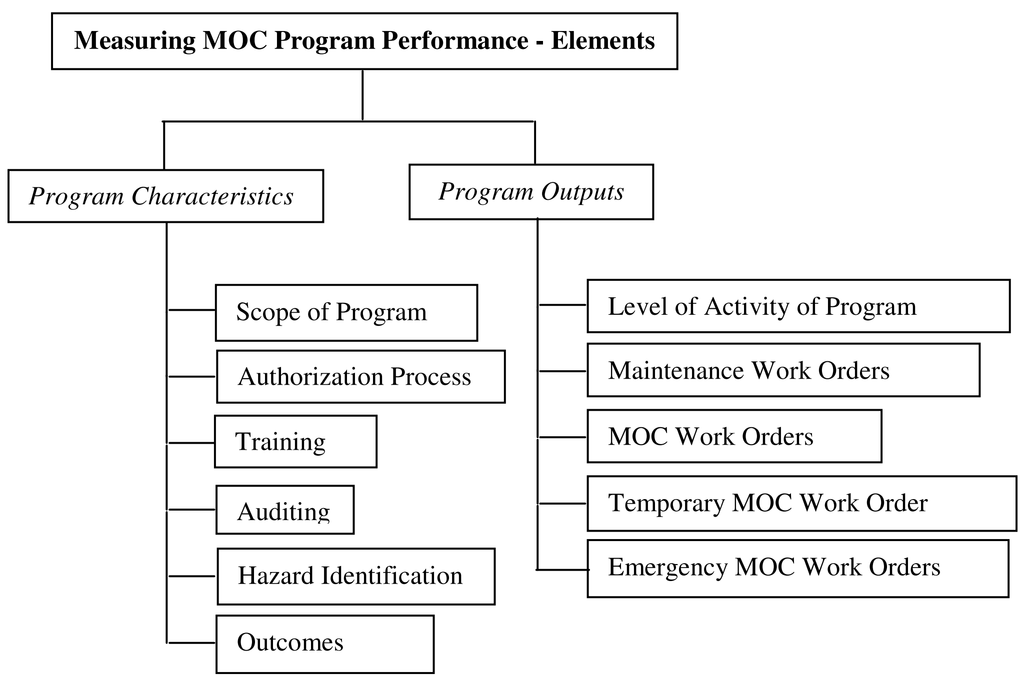

Figure 2-1. Measurement input

Various factors affect the performance of a MOC program. Scope of the program, level of awareness, implementation of temporary and emergency MOC procedures, and usage of risk screening techniques are among these factors. According to the model that is developed in this study, two types of inputs are required for measuring MOC program performance measurements:

1. Periodical measurements, such as the number of Maintenance Work Orders that were miss-classified in the time period under investigation;
2. Characteristics of the program, such as techniques that are available for hazard identification;

Figure 2.2 presents the type of elements that will be considered in the measurement system. As explained previously, existing models of process safety performance measurements within facilities are not getting credit, because the users are required to evaluate elements in the program according to their best judgment. Therefore, measurements that are conducted by different users probably reveal different results.

The major guideline for the development of the model here is to establish a measurement system that is independent of the evaluator. A measurement system that is developed according to this guideline will establish a basis for performance comparisons among facilities. However, to eliminate subjectivity from the evaluators, some elements must be standardized, and this process requires a survey of a panel of experts. Application of the Analytical Hierarchy Process (AHP) technique will be developed to standardize these elements. The following is a brief description of the principle of the AHP methodology.

Analytical Hierarchy Process (AHP) Technique

Several decision making methods were examine in this study: Weighted Sum Model (WSM), Weighted Product Model (WPM), Elimination and Choice Translating

Realty (ELECTRA), Techniques for Order Preference by Similarity to Ideal Solution (TOPSIS), and the Analytical Hierarchy Processing (AHP) [38]. The ability of AHP to incorporate interaction among factors in the model, and to track consistency in judgment, are leading factors in the decision to use AHP in this study. The method and its advantages are described bellow.

Thomas L. Saaty developed the AHP in 1982, and published his book Decision Making for Leaders [21] in 1986. Saaty was employed by the Department of Defense as a mathematician working on an analytical framework for group decisions. Recognizing the limitations of humans to manage complex decisions, the AHP was developed to work with multi-criteria and multi-alternative situations to simplify the decision making process to a level that the human brain can synthesize using a natural intuitive logic. In the safety universe, AHP is used solely and with other predictive methods to predict occupational injuries [22,23] and for several other applications. AHP is a leading decision-making method in transportation because of its power to prioritize high precision processes. Moreover, AHP is widely used for environmental decision-making and prioritization [24]. The AHP methodology can be divided into four major stages:

1. Hierarchical structuring of the problem, which is structured hierarchically similar to a flow chart. The overall objective is placed at the top, the criteria and sub-criteria bellow, and the alternatives at the bottom.
2. Assignment of relative importance weights: In this stage the decision maker determines the relative importance of a set of criteria, a set(s) of sub-criteria, and a set of alternatives. An independent comparison among every combination of couple of elements from a certain level with respect to a relevant element from a higher level in the hierarchy is part of the procedure. This technique of comparisons of a couple of criteria or a couple of elements at a time is known as pairwise comparisons.
3. Inconsistency calculations: The level of inconsistency in decision making can be measured and calculated in comparison to random decision making.

4. Overall priority weight determination: At this stage the priority weights of each of the alternative are calculated.

AHP has several advantages over conventional scoring methods, which could have been used to accomplish the goal in this study:

1. The Pairwise comparisons process increases the accuracy of alternative comparisons, because the methodology uses a set of comparisons to evaluate the alternatives with respect to a single criterion at a time.
2. Pairwise comparisons are used to assign weights to the criteria in the same way it is done for alternatives; however, it is done in a separate stage.
3. The internal inconsistency in the judgment of the criteria and the alternatives is quantified.
4. AHP works with interdependence of elements and is not limited to linear thinking.
5. The AHP does not require consensus. The methodology synthesizes a representative outcome from diverse judgments.

The following is an example of a problem and a Pairwise comparisons question: Assume the following overall objective: selecting the best college. The criteria for judging the alternatives are National Rank, Costs, and Location. The alternatives will be Texas A&M, MIT, and Cal Tech. Figure 2-2 demonstrates the hierarchy of the problem:

The following is an example question that compares the importance of the National Rank criterion and the Cost criterion with respect to the overall goal: How much more important is National Rank than Cost with respect to Selecting the Best College?

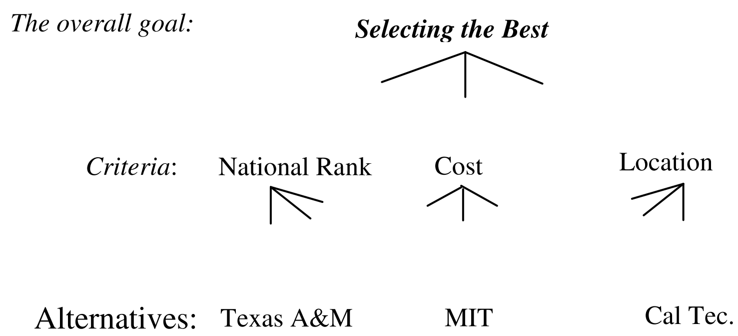

Figure 2-2. The best college problem hierarchy

National Rank is more important than Cost: 1 2 3 4 5 6 7 8 9

Or,

Cost is more important than National Rank: 1 2 3 4 5 6 7 8 9

Where the numeric values are indicating the following:

1 - Equal Importance

2 – Equal to weakly more important

3 - Weakly more important

4 – Weakly to strongly more important

5 - Strongly more important

6 – Strongly to very strongly more important

7 – Very strongly more important

8 - Very strongly to absolutely more important

9 - Absolutely more important

Selecting 7 in the upper row emphasizes that National Rank is very strongly more important than Cost in the process of selecting a college. Selecting 5 in the lower row emphasizes that Cost is strongly more important than National Rank. Similarly, National Rank is compared with Location, and later Cost is compared with Location. It is expected that if National Rank was selected to be twice as important as Cost, and Cost is three times more important than Location, then National Rank is six times more important than Location. Although it seems intuitive in a three element system, it is not so simple for a larger number of elements. The Analytical Hierarchy Process methodology can extract the relative importance of elements in a problem and measure the level of inconsistency as described above. A 10% inconsistency is recommended as a cut-off value for revision of the judgments. The AHP analysis process is described in the following paragraphs.

AHP Analysis

Calculating the Weights

Assume that a_{ij} is the value of comparison of element i with element j. Therefore it represents the ratio between the weight of element i (w_i) and the weight of element j (w_j) as shown by Equation 2-1:

$$a_{ij} = {w_i}/{w_j} \tag{2-1}$$

The a_{ij} is equal to 1 wherever i = j (since the element is compared with itself). Moreover, a_{ji} is the reciprocal of a_{ij}:

$$a_{ji} = \frac{1}{a_{ij}} = {w_j}/{w_i} \tag{2-2}$$

Assigning the comparison of relative weights between elements into a matrix will yield the following form:

$$A = \begin{bmatrix} a_{11} & a_{12} & \cdots & a_{1n} \\ a_{21} & a_{22} & \cdots & a_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ a_{n1} & a_{n2} & \cdots & a_{nn} \end{bmatrix} = \begin{bmatrix} 1 & {w_1}/{w_2} & \cdots & {w_1}/{w_n} \\ {w_2}/{w_1} & 1 & \cdots & {w_2}/{w_n} \\ \vdots & \vdots & \ddots & \vdots \\ {w_n}/{w_1} & {w_n}/{w_2} & \cdots & 1 \end{bmatrix} \tag{2-3}$$

The following step performs normalization of the matrix. The sum of the vectors $\sum_{i=1}^{n} a_{ij}$ are calculated for this purpose, and the values within each vector are divided by this sum. The matrix changes form as follows:

$$B = \begin{bmatrix} 1 \Big/ \sum_{i=1}^{n} a_{i1} & a_{12} \Big/ \sum_{i=1}^{n} a_{i2} & \cdots & a_{1n} \Big/ \sum_{i=1}^{n} a_{in} \\ a_{21} \Big/ \sum_{i=1}^{n} a_{i1} & 1 \Big/ \sum_{i=1}^{n} a_{i2} & \cdots & a_{2n} \Big/ \sum_{i=1}^{n} a_{in} \\ \vdots & \vdots & \ddots & \vdots \\ a_{n1} \Big/ \sum_{i=1}^{n} a_{i1} & a_{n2} \Big/ \sum_{i=1}^{n} a_{i2} & \cdots & 1 \Big/ \sum_{i=1}^{n} a_{in} \end{bmatrix} \tag{2-4}$$

The component of the weight of element i in column j is calculated according to Equation 2-5:

$$w_i^{(j)} = \left(\frac{1}{\sum_{i=1}^{n} a_{ij}} \right) \bullet \begin{bmatrix} a_{1j} \\ a_{2j} \\ \vdots \\ a_{nj} \end{bmatrix} \tag{2-5}$$

Then, the final weight of element i is calculated by averaging the $w_i^{(j)}$ along row i:

$$w_i = \frac{1}{n} \sum_{j=1}^{n} w^{(j)} \tag{2-6}$$

Measuring Inconsistency

If element i is a_{ij} times more important than element j, and element j is a_{jk} times more important than element k, then consistency will require that element i is ($a_{ij} \bullet a_{jk}$) times more important than element k.

Multiplication of matrix A by the weight vector $\vec{w}$ will produce the results in Equation 2-7 only if the judgments are perfectly consistent:

$$A = \begin{bmatrix} 1 & w_1/w_2 & \cdots & w_1/w_n \\ w_2/w_1 & 1 & \cdots & w_2/w_n \\ \vdots & \vdots & \ddots & \vdots \\ w_n/w_1 & w_n/w_2 & \cdots & 1 \end{bmatrix} \begin{bmatrix} w_1 \\ w_2 \\ \vdots \\ w_n \end{bmatrix} = \begin{bmatrix} nw_1 \\ nw_2 \\ \vdots \\ nw_n \end{bmatrix} = n \begin{bmatrix} w_1 \\ w_2 \\ \vdots \\ w_n \end{bmatrix} \tag{2-7}$$

If $A\vec{w} = n\vec{w}$, as demonstrated above, then $\vec{w}$ is an Eigen vector of matrix A, and the Eigen value is $\lambda = n$. However, results are rarely consistent. The AHP methodology calculates a Consistency Index (CI) as follows:

- Multiply matrix A by the weight vector $\vec{w}$ to form vector $\overline{B}$

$$A = \begin{bmatrix} a_{11} & a_{12} & \cdots & a_{1n} \\ a_{21} & a_{22} & \cdots & a_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ a_{n1} & a_{n2} & \cdots & a_{nn} \end{bmatrix} \begin{bmatrix} w_1 \\ w_2 \\ \vdots \\ w_n \end{bmatrix} = \begin{bmatrix} b_1 \\ b_2 \\ \vdots \\ b_n \end{bmatrix} = \vec{B} \tag{2-8}$$

- Divide each component of vector $\overline{B}$ with the corresponding component in the weight vector $\vec{w}$ to form new vector $\overline{C}$:

$$\begin{bmatrix} b_1 \\ b_2 \\ \vdots \\ b_n \end{bmatrix} \div \begin{bmatrix} w_1 \\ w_2 \\ \vdots \\ w_n \end{bmatrix} = \begin{bmatrix} b_1 / w_1 \\ b_2 / w_2 \\ \vdots \\ b_n / w_3 \end{bmatrix} = \begin{bmatrix} c_1 \\ c_2 \\ c_3 \\ c_4 \end{bmatrix} = \vec{C} \tag{2-9}$$

- Average the components of vector $\overline{C}$ to obtain an approximation of $\lambda_{\max}$:

$$\lambda_{\max} = \frac{1}{n} \sum_{i=1}^{n} c_i \tag{2-10}$$

- Finally, the CI for a matrix of size of n is calculated as follows:

$$CI = \frac{\lambda_{\max} - n}{n - 1} \tag{2-11}$$

However, to measure consistency on a familiar scale, it is compared to a consistency of a random assignment of weights. A very large number of simulations with random weights with several sizes for matrix established a Random Consistency Index (RI). Table 2-1 presents the results of these simulations:

Table 2-1. Random consistency for various matrix sizes

Matrix size n	1	2	3	4	5	6	7	8	9	10	11
RI	0.00	0.00	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49	1.51

Finally, the Consistency Ratio (CR) is calculated by comparing the Consistency Index to the random consistency:

$$CR = \frac{CI}{RI} \tag{2-12}$$

A CR value of less than 0.1 is considered to be a reasonable consistency [29].

Presentation of the Problem of This Study

The hierarchy chart of this study is too large to present in a single figure, so the problem is presented in segments. The problem will be introduced and discussed from the overall goal at the top to the elements at the bottom. At the beginning, the relations among the major criteria with respect to the overall goal will be presented. Then the branches of the major criteria will be discussed, and the hierarchies will be developed to the level of elements. A questionnaire that was developed according to the guidelines described previously was distributed among the following six experts:

- Dr. M. Sam Mannan: Professor of Chemical Engineering at Texas A&M University, College Station, Texas, Director of the Mary Kay O Connor Process Safety Center (MKOPSC), at Texas A&M University (TAMU), internationally recognized process safety expert, and a reviewers of several process safety journals.
- Dr. Harry H. West: a member of the Steering Committee and the Technical Advisory Committee of the MKOPSC TAMU, and internationally recognized expert and process safety consultant.
- Mr. Roy E. Sanders: a senior process safety executive, a member of the Technical Advisory Committee at the MKOPSC, TAMU, lecturer of several courses as part of the Continuing Education program of the MKOPSC, TAMU, and lecturer of courses that are offered by the American Institute of Chemical Engineers. Moreover, Mr. Sanders wrote the well-recognized book Management of Change In Chemical Plants; Learning from Case Histories [25].

- Mr. Skip W. Early: process safety consultant, a member of the Technical Advisory Committee at the MKOPSC, TAMU, lecturer of several courses as part of the Continuing Education program of the MKOPSC, TAMU.
- Mr. Adrian L. Sepeda: Served many years as a safety executive at Occidental Chemicals. Upon his retirement, Mr. Sepeda offers his services as a process safety consultant, and is currently consultant to the Center of Chemical Process Safety (CCPS), at the American Institute of Chemical Engineers. Among his duties Mr. Sepeda is a lecturer with the Continuing Education program at the MKOPSC, TAMU.
- Mr. Donald W. Jenkins: worked as a project engineer with Amoco Production for many years, was among the group that defined PSM for Amoco Production in the 1990's. Upon his retirement, Mr. Jenkins returned to BP Amoco as a consultant, and is in charge of MOC in the offshore projects office.

The responses of the experts (the estimations) were geometrically averaged [26]. Then, these averages were rounded to the closest value on the AHP scale (a discrete scale of 9,8,..,2,1,1/2 , 1/3,..,1/9). The rounded values will be referred as the estimations in this chapter. The estimations are then substituted in the matrices, and then analyzed according to Equations 2-1 to 2-12. The hierarchies of the branches with the results are presented below.

Overall Goal: Safety Performance Measurements of MOC Program Practices

The MOC program consists of a variety of performance influencing factors. This study suggests a performance evaluation system of MOC program practices according to six factors that will be used as criteria in the hierarchies in the problem. The following is a description of these factors:

1. Scope of program: areas in the plant that are subject to the MOC program
2. Authorization process: the process of authorization of the various types of MOC

3. MOC training: training frequencies, type of training, and employees that participated in the training program.
4. Internal audit process: content that is addressed by the audit program.
5. Hazard identification: capabilities of the MOC program to detect change-related hazards.
6. Outcomes: measurement of flaws, e.g., the number of failures to miss-classify Maintenance Work Orders (MWOs) as MOCs.

Figure 2-3 demonstrates the hierarchy tree of the overall goal and the major six criteria:

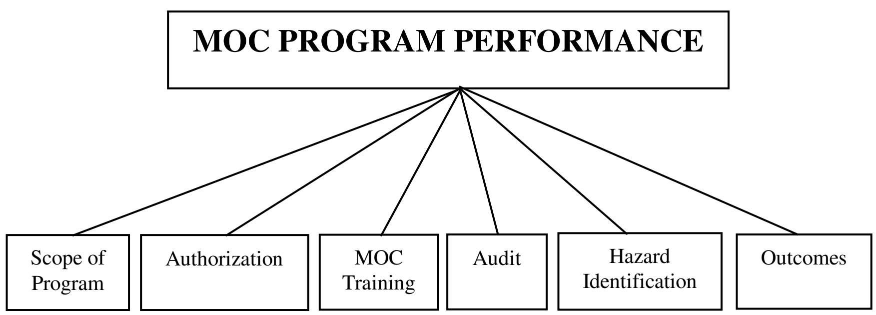

Figure 2-3. Hierarchy of the overall goal

Matrix 2-13 consists of the estimations, and Table 2-2 consists of the relative weights and the consistency ratio:

$$\begin{array}{l} \textit{Scope of Program} \\ \textit{Authorization} \\ \textit{MOC Training} \\ \textit{Audit} \\ \textit{Hazard Identification} \\ \textit{Outcomes} \end{array} \begin{bmatrix} 1 & 2 & 1 & 2 & 1/2 & 1/2 \\ 1/2 & 1 & 1/2 & 2 & 1/2 & 1 \\ 1 & 2 & 1 & 3 & 1 & 2 \\ 1/2 & 1/2 & 1/3 & 1 & 1/3 & 1/2 \\ 1 & 2 & 1 & 3 & 1 & 1 \\ 1 & 1 & 1/2 & 2 & 1 & 1 \end{bmatrix} \quad (2\text{-}13)$$

Table 2-2. Relative weights and C.R. of the overall goal set of criteria

Criterion	**Relative Weight** w_i	
Scope of Program	0.160	C.R.= 0.00
Authorization	0.123	
MOC Training	0.234	
Audit	0.074	
Hazard Identification	0.230	
Outcomes	0.178	

Scope of Program

Paragraph 29 CFR 1910.119(1) of the OSHA PSM standard requires that employers must write and implement procedures to manage changes in processes that are covered under the OSHA PSM. However, Management of Change procedures are implemented in diverse ways. Although the requirements of OSHA PSM are limited to specific systems, other systems that are not covered under OSHA PSM can be crucial to the safe operation of the plant. The result of a study of MOC program practices [20] reveals that implementation of the MOC program varies from a level that is considered a violation of the PSM requirements to a level at which all disciplines in the organizations are subject to MOC programs, including organizational changes.

Facilities in plants can be divided to four major groups:

1. Group A – Critical Areas
2. Group B – Utility Areas
3. Group C – Associated Areas
4. Group D - Organizational Changes

This study distinguishes among four groups of areas, groups A, B, and C consist of sub-areas. Group A, Critical Areas, encompasses process areas such as hazardous chemical storage, other areas that are covered by OSHA PSM, petroleum bulk storage, tank farms, control rooms, main power distribution control board rooms, central fire extinguishing systems, and similar facilities. Utility Areas provide the facilities for the process to take place, and failure in one of these areas will cause uncontrolled shutdown. These areas include facilities such as power plants, cooling towers, and air plants. Associated sub-areas include facilities where failure in their operation have no significant effect on the safe operation of the plant, or at least it will allow a safe shutdown. These include wide range of areas such as laboratories, conveyors, and central office buildings. Figure 2-4 demonstrates the hierarchy of the Scope of Program criterion.

The estimations and relative importance of the groups are shown in Matrix 2-14 and in Table 2-3 respectively:

$$\begin{array}{l} \textit{Critical sub Areas} \\ \textit{Utility sub Areas} \\ \textit{Associated sub Areas} \\ \textit{Organizational Changes} \end{array} \begin{bmatrix} 1 & 3 & 3 & 2 \\ 1/3 & 1 & 2 & 1 \\ 1/3 & 1/2 & 1 & 1/2 \\ 1/2 & 1 & 2 & 1 \end{bmatrix} \qquad (2\text{-}14)$$

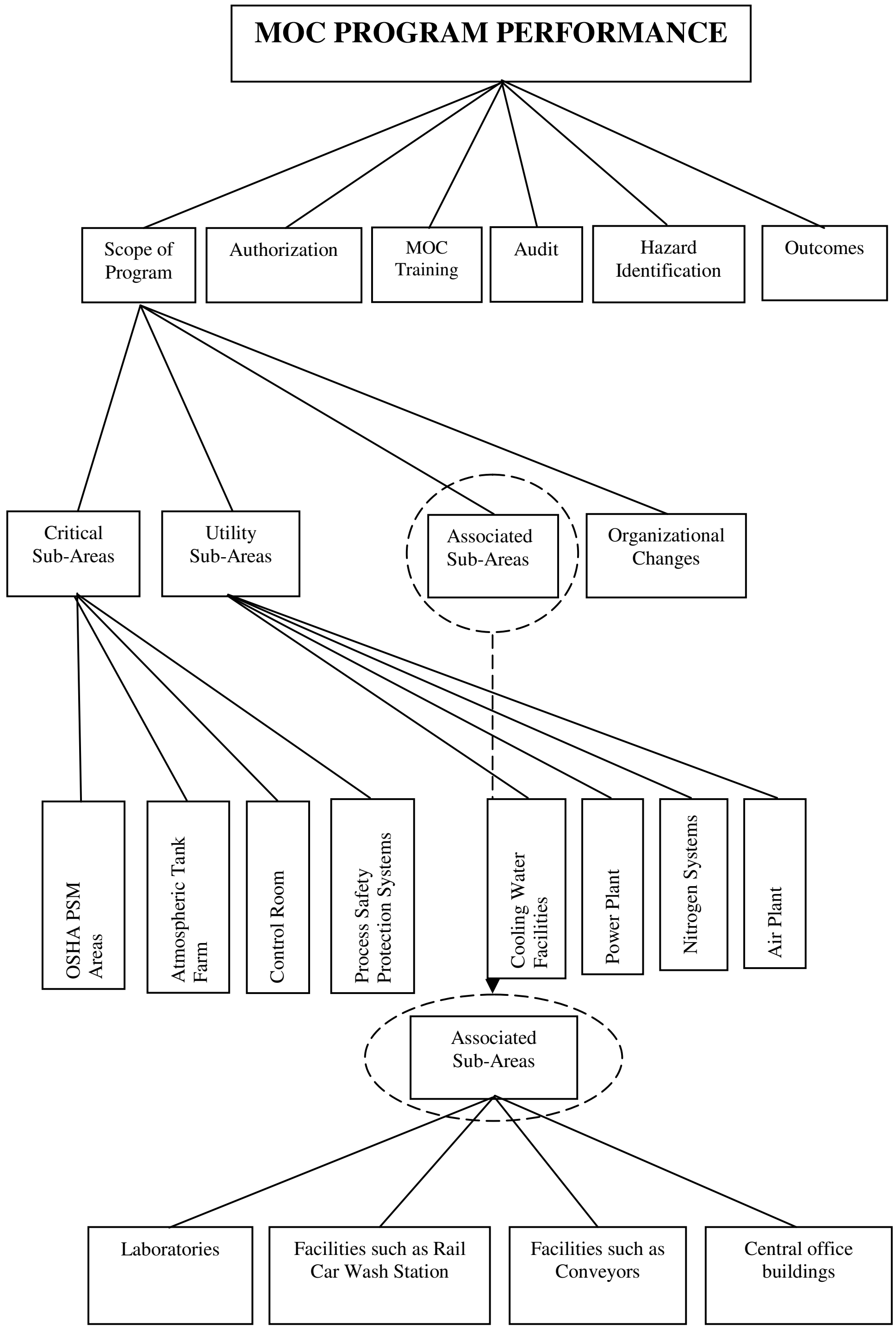

Figure 2-4. Hierarchy of the scope of program criterion

Table 2-3. Relative weights and C.R. of the scope of work set of criteria

Criterion	Relative Weight w_i	
Critical sub Areas	0.457	C.R.= 0.02
Utility sub Areas	0.202	
Associated sub Areas	0.120	
Organizational Changes	0.221	

Critical Sub-areas

As previously explained, critical areas encompass process areas such as hazardous chemical storage, areas that are covered by OSHA PSM, and others. Matrix 2-15 consists of the estimations and table 2-4 consists of the relative weights and the C.R.:

$$\begin{matrix} \textit{OSHA PSM Areas} \\ \textit{Atmospheric Tank Farm} \\ \textit{Control Room} \\ \text{Pr}\textit{ocess Safety } \text{Pr}\textit{otection Systems} \end{matrix} \begin{bmatrix} 1 & 3 & 2 & 1 \\ 1/3 & 1 & 1/2 & 1/3 \\ 1/2 & 1 & 1 & 1 \\ 1 & 3 & 1 & 1 \end{bmatrix} \qquad (2\text{-}15)$$

Table 2-4. Relative weights and C.R. of the critical sub-area set of elements

Criterion	Relative Weight w_i	
OSHA PSM Areas	0.357	C.R.= 0.02
Atmospheric Tank Farm	0.110	
Control Room	0.230	
Process Safety Protection Systems	0.303	

Utility Sub-areas

Utility sub-areas are areas that support the processes and the plant. An undesired event that will cause deviation from the normal operation conditions of these areas will lead to unsafe conditions in the plant. The following sub groups are included in the Utility sub-areas category:

- Facilities such as cooling towers
- Power plant (including steam system)
- Nitrogen supply and regulating system
- Air plant

Matrix 2-16 consists of estimations of the Utility sub-areas, and table 2-5 presents the relative weights and the C. R.:

$$\begin{array}{l} \textit{Facilities such as Cooling Water} \\ \textit{Power Plant} \\ \textit{Nitrogen Supply and Regulation System} \\ \textit{Air Plant} \end{array} \begin{bmatrix} 1 & 1/2 & 1/2 & 1 \\ 2 & 1 & 2 & 2 \\ 1 & 1/2 & 1 & 2 \\ 1 & 1/2 & 1/2 & 1 \end{bmatrix} \quad (2\text{-}16)$$

Table 2-5. Relative weights and C.R. of the utility sub-area set of elements

Criterion	Relative Weight w_i	
Facilities such as Cooling Towers	0.165	C.R.= 0.02
Power plant (including steam system)	0.392	
Nitrogen supply and regulating system	0.279	
Air Plant	0.165	

Associated Sub-areas

Associated sub-areas are areas that supply different services to the plant. Interruption in the operation of these areas will not cause interruption to the safe operation of the plant. The associated sub-areas consists of four major sub-areas:

- Laboratories
- Service facilities such as Rail Car Wash
- Facilities such as conveyors, and central maintenance areas.
- Central administrative areas (human resources changes are not included)

Matrix 2-17 and Table 2-6 consist of the estimations and the relative weights of the associated sub-areas, respectively:

$$\begin{matrix} \textit{Laboratories} \\ \textit{Service Facilities such as Rail Car Wash} \\ \begin{pmatrix} \textit{Facilities such as Conveyors, and} \\ \textit{Central Maintenance Area} \end{pmatrix} \\ \textit{Central Adimistrative Area} \end{matrix} \begin{bmatrix} 1 & 1 & 2 & 2 \\ 1 & 1 & 1 & 1 \\ 1/2 & 1/2 & 1 & 1 \\ 1/2 & 1 & 1 & 1 \end{bmatrix} \quad (2\text{-}17)$$

Table 2-6: Relative weights and C.R. of the associated set of sub-area set of elements

Criterion	**Relative Weight** w_i	
Laboratories	0.346	C.R.= 0.02
Service facilities such as Rail Car Wash	0.246	
Facilities such as conveyors, and central maintenance area.	0.204	
Central administrative areas	0.204	

Training MOC

General

There are many methods for evaluating the effectiveness of a training program. This methods consist of two components: (1) quality and appropriateness of the content, and (2) proper implementation of the program. Elaborate methods have been developed to address the quality and appropriateness of a training program content [27]. However, all of these methods consist of elements that violate the guidelines of this study. Other methods attempt to establish correlation and a statistical relationship between accident rates and training effectiveness [28]. However, a low rate of events and poor accident data jeopardize the validity of the results.

The scope of performance measurements of a MOC training program in this study is limited to verification that the program consists of three types of training and that the appropriate employees will be subjected to a suitable training. Curves that measure the appropriateness of the frequency of training will be developed later in this chapter under the Outcome criterion.

Figure 2-5 emphasizes the three dimensions in performance measurements of a MOC training program:

- Topic addressed by the program. A MOC training program is expected to consist of the following elements:
    1. Formal awareness training
    2. Procedure updates
    3. Information transfer practices (e.g. informing new shift on activities that involves MOC during the previous shift, such as notes with regard to night work orders in the logbook, review of logbook when returning from vacation, etc.)

- Type of employees that are subjected to training. It is possible to divide plant employees into several groups and for this study employees are divided into three groups as follows:

    1. Administrative employees
    2. Field operation employees (including maintenance, operators, operation management, engineering, technical staff, and purchasing)
    3. Contractors

- Frequency of training; OSHA PSM requires that training will be conducted at least once every three years. Even though higher training frequency will yield better results, especially in the introductory phase of the program. Therefore, frequency of training will be a function of the program maturity. However, the appropriateness of the training frequency will be considered later.

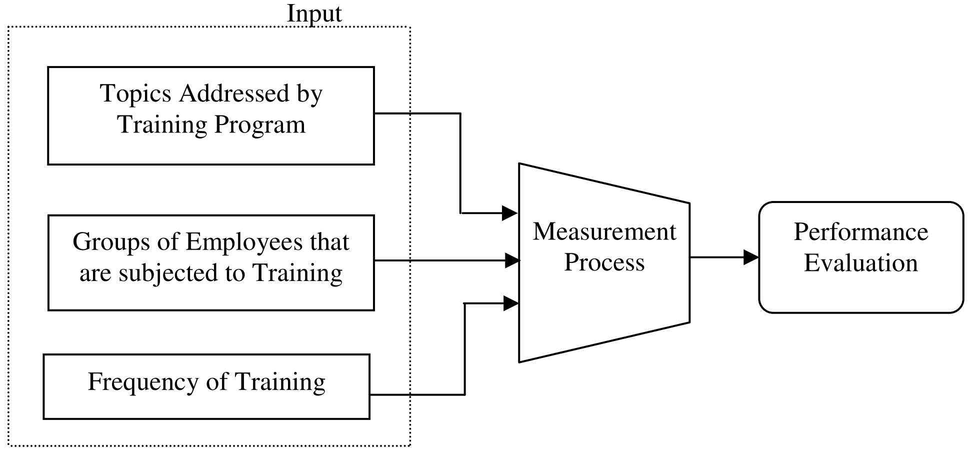

Figure 2-5. Training program performance evaluation process

Figure 2-6 demonstrates the hierarchy of the training component. The estimations and relative effects that awareness training, procedure updates, and information transfer have on the quality of the training are shown in Matrix 2-18 and in Table 2-7, respectively.

$$\begin{matrix} \textit{Awareness Training} \\ \textit{Procedure Updates} \\ \textit{Information Transfer} \end{matrix} \begin{bmatrix} 1 & 2 & 2 \\ 1/2 & 1 & 1 \\ 1/2 & 1 & 1 \end{bmatrix} \quad (2\text{-}18)$$

Table 2-7. Relative weights and C.R. of the training set of sub-criteria

Criterion	**Relative Weight** w_i	
Awareness Training	0.500	C.R.= 0.00
Procedure Update	0.250	
Information Transfer	0.250	

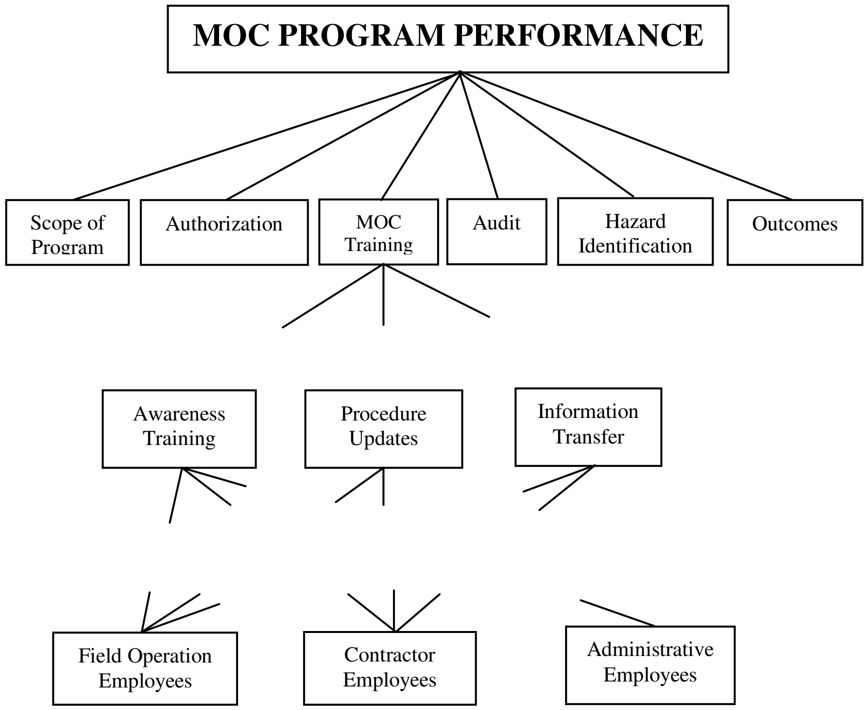

Figure 2-6. Hierarchy of the MOC training criterion

Awareness Training

Matrix 2-19 includes estimations for the importance of training for each of the three employee groups. The relative importance values and the C.R. of the three type of training are presented in Table 2-8:

$$\begin{matrix} \textit{Awareness Training} \\ \text{Pr}\textit{ocedure Updates} \\ \textit{Information Transfer} \end{matrix} \begin{bmatrix} 1 & 2 & 3 \\ 1/2 & 1 & 3 \\ 1/3 & 1/3 & 1 \end{bmatrix} \qquad (2\text{-}19)$$

Table 2-8. Relative weights and C.R. of the training groups of employees in awareness training

Criterion	Relative Weight w_i	
Field Operation Employees	0.525	C.R.= 0.05
Contractor Employees	0.334	
Administrative Employees	0.142	

Procedure Updates and Information Transfer

Only two of the employee groups are exposed to procedure updates and information transfer. Table 2-9 summarizes the relative importance of procedure updates and information transfer with regard to training for field operation employees and contractor employees.

Table 2-9. Relative weights of training groups of employees in procedure updates and information transfer

Criterion	Relative Weight w_i with Regard to Procedure Updates	Relative Weight w_i with Regard to Information Transfer
Field Operation Employees	0.667	0.667
Contractor Employees	0.333	0.333

Hazard Identification

General

The main purpose of the Management of Change program is to verify that safety aspects are addressed appropriately in the design and implementation of changes. MOC program hazard detection capabilities are dependent on the methods that are "offered" by the program (risk screening capabilities). Moreover, these capabilities depend on training to identifying the need for implementation of such techniques (Awareness Training) as well. Figure 2-7 demonstrates the hierarchy of the Hazard Identification criterion. The risk screening capabilities element consists of four major group techniques:

- Safety review
- Checklist, What-if, What-if/Checklist
- Advanced Process Hazard Analysis (PHA) techniques, such as HAZOP, FMEA, FTA, ETA.
- Human reliability analysis techniques

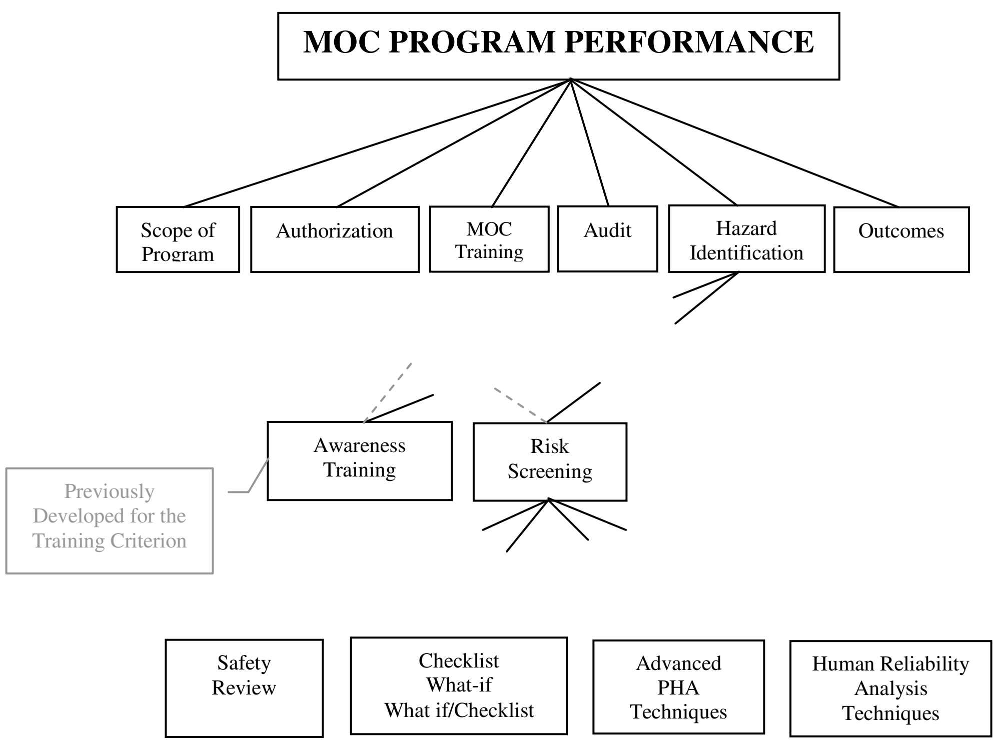

Figure 2-7. Hierarchy of the hazard identification criterion

Table 2-10. Relative weights and C.R. of the hazard identification set of sub criteria

Criterion	**Relative Weight** w_i
Awareness Training	0.500
Risk Screening	0.500

Table 2-10 lists the relative weights of Awareness Training and Risk Screening, with respect to the Hazard Identification Criterion.

Risk Screening

The estimations and the relative importance of employing each group of Risk Screening techniques is presented in Matrix 2-20 and in Table 2-11, respectively.

$$\begin{matrix} \textit{Safety Review} \\ \textit{Checklist, What-if, What-if / Checklist} \\ \textit{Advanced PHA Techniques} \\ \textit{Human Reliability Analysis Techniques} \end{matrix} \begin{bmatrix} 1 & 1/2 & 1/2 & 3 \\ 1 & 1 & 1 & 2 \\ 2 & 1/2 & 1 & 2 \\ 1/3 & 1/2 & 1/2 & 1 \end{bmatrix} \qquad (2\text{-}20)$$

Table 2-11. Relative weights and C.R. of the risk screening set of elements

Criterion	**Relative Weight** w_i	
Safety Review	0.216	C.R.= 0.03
Checklist, What-if, What-is/Checklist	0.321	
Advanced PHA Techniques	0.349	
Human Reliability Analysis Techniques	0.114	

Outcomes

General

"Outcomes" is a complicated criterion. Unlike the other criteria, the outcomes criterion measures the results of MOC program implementation. As Figure 2-8 reveals[3], this criterion consists of six elements, which are analyzed according to three sub-criteria. Although the relative effects on the performance of each element are being developed in this study, further work is required to quantify each of the elements in this criterion. The Outcomes criterion consists of the following sub-criteria:

- Hazard identification failures: This sub-criterion represents elements that are relevant to hazard identification failures.
- Authorization failures: The Authorization sub-criterion represents the relative effects of MOC work orders for which the authorization process was not completed appropriately on the performance of the Outcomes criterion.
- Classification failures: The classification failure criterion represents the effect of the Maintenance Work Orders that should have been identified as MOCs but were miss-classified on the performance of the outcomes criterion.

Information with regard to the six elements is collected during the audit process. The following information is required for the measurement:

- Number of MWOs that were not classified as regular MOCs – [*MWO-MOC miss-classifications* element]
- Number of MWOs that were not classified as Temporary MOCs - [*Failure to Apply Temporary MOCs* element]

---

[3] Gray boxes and gray dashed lines in hierarchies emphasizes that the criteria/sub-criteria/elements are mutually dependent on other criteria/sub-criteria/elements that are not playing direct role in the actual discussion. AHP is not limited to linear pattern of thinking, and is considering mutual dependencies.

- Number of MWOs that were not classified as Emergency MOCs (*Failure to Apply Emergency MOCs* element)
- Number of MOC work orders for which the authorization process was not completed appropriately (*Failure to Appropriately Authorize* element)
- Number of improper hazard evaluation technique applications (*Failure to Apply Appropriate Hazard Evaluation Techniques* element)

The estimations and the weights of the Outcomes sub criteria are presented in Matrix 2-21 and in Table 2-12, respectively:

$$\begin{matrix} \textit{Classification Failure} \\ \textit{Authorization Failures} \\ \textit{Hazard Detection Failures} \end{matrix} \begin{bmatrix} 1 & 1 & 1 \\ 1 & 1 & 1/3 \\ 1 & 3 & 1 \end{bmatrix} \qquad (2\text{-}21)$$

Table 2-12. Relative weights and C.R. of the outcomes sub-criteria

Criterion	**Relative Weight** w_i	
Classification Failure	0.321	C.R.= 0.12
Authorization Failures	0.225	
Hazard Detection Failures	0.454	

The inconsistency ratio of 0.12 requires re-evaluation. To verify that this inconsistency ratio value was not due to inconsistency of judgment, the matrix of comparison was recalculated. However, the resulting values in the matrix were the estimations before rounding them to fit the AHP scale. The inconsistency value when calculated as described above was 0.07. Therefore there was no need to re-evaluate the judgment.

Classification Failures

As Figure 2-8 demonstrates, the Classification Failures sub-criterion is affected by the following:

- MWO-MOC misclassifications
- Failure to apply temporary MOCs
- Failure to apply emergency MOCs

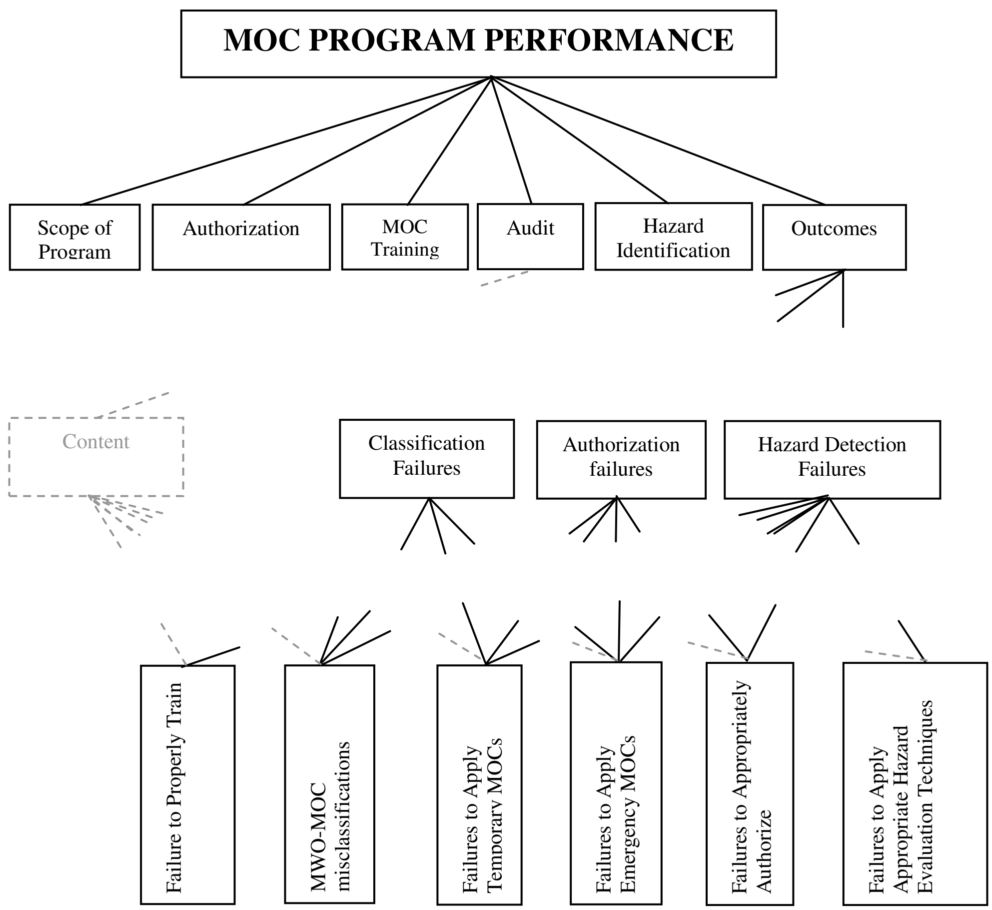

Figure 2-8. Hierarchy of the outcomes criterion

Matrix 2-22 presents the estimations and Table 2-13 presents the relative weights and C.R.:

$$\begin{array}{l} MWO-MOC\ Misclassifications \\ Failure\ to\ Apply\ Temporary\ MOCs \\ Failure\ to\ Apply\ Emergency\ MOCs \end{array}\begin{bmatrix} 1 & 1 & 1 \\ 1 & 1 & 1 \\ 1 & 1 & 1 \end{bmatrix} \quad (2\text{-}22)$$

Table 2-13. Relative weights and C.R. of the classification failures set of elements

Criterion	**Relative Weight** w_i	
MWO-MOC Misclassifications	0.333	C.R.= 0.00
Failure to Apply Temporary MOCs	0.333	
Failure to Apply Emergency MOCs	0.333	

Authorization Failures

Failure to deliver any MOC work order through the MOC path is by definition an authorization failure. Another type of failure is MOC work orders that are tunneled through the MOC program path, but the authorization process was not completed appropriately. The elements that affect the authorization failures are as follows:

- MWO-MOC misclassifications
- Failure to apply temporary MOCs
- Failure to apply Emergency MOCs
- Failure to authorize appropriately

Matrix 2-23 presents of the estimations. The relative weights and the C.R. are listed in Table 2-14:

$$\begin{matrix} \text{MWO – MOC misclassifications} \\ \text{Failure to apply Temporary MOCs} \\ \text{Failure to apply Emergency MOCs} \\ \text{Failure to Appropriately Authorize} \end{matrix} \begin{bmatrix} 1 & 1 & 1 & 2 \\ 1 & 1 & 1 & 2 \\ 1 & 1 & 1 & 2 \\ 1/2 & 1/2 & 1/2 & 1 \end{bmatrix} \quad (2\text{-}23)$$

Table 2-14. Relative weights and C.R. of the authorization failure set of elements

Criterion	Relative Weight w_i	
MWO-MOC misclassifications	0.286	C.R.= 0.00
Failure to apply temporary MOCs	0. 286	
Failure to apply Emergency MOCs	0. 286	
Failure to appropriately authorize	0.143	

Hazard Detection Failures

As Figure 2-8 demonstrates, the Hazard Detection Failures criterion is affected by all six elements. The estimations are presented in Matrix 2-24, and the relative weights and C.R. are presented in Table 2-15:

$$\begin{matrix} \text{Failure to properly train} \\ \text{MWO – MOC misclassifications} \\ \text{Failure to Apply Temporary MOCs} \\ \text{Failure to Apply Emergency MOCs} \\ \text{Failure to Appropriately Authorize} \\ \left(\begin{matrix}\text{Failure to Apply Appropriate Hazard} \\ \text{Evaluation Techniques}\end{matrix}\right) \end{matrix} \begin{bmatrix} 1 & 2 & 2 & 2 & 3 & 2 \\ 1/2 & 1 & 1 & 1 & 2 & 2 \\ 1/2 & 1 & 1 & 1 & 3 & 2 \\ 1/2 & 1 & 1 & 1 & 3 & 1 \\ 1/3 & 1/2 & 1/3 & 1/3 & 1 & 1/2 \\ 1/2 & 1/2 & 1/2 & 1/2 & 2 & 1 \end{bmatrix} \quad (2\text{-}24)$$

Table 2-15. Relative weights and C.R. of the hazard identification failures set of elements

Criterion	Relative Weight	
Failure to Properly Train	0.306	
MWO-MOC Misclassifications	0.168	C.R.= 0.01
Failures to Apply Temporary MOC	0.180	
Failures to Apply Emergency MOC	0.162	
Failure to Appropriately Authorize	0.070	
Failure to Apply Appropriate Hazard Evaluation Techniques	0.113	

Audit

The audit process consists of several components [29]. The hierarchy in Figure 2-9 presents the elements that affect the safety performance of the program. The Audit criterion consists of two sub-criteria: (1) the content that the Audit procedure addresses; and (2) appropriateness of the audit frequency. As for appropriate audit frequency, a curve that considered both the audit frequency as well as the program maturity is developed separately below in this chapter. Table 2-16 presents the relative importance of audit frequency and the content sub-criteria:

Table 2-16. Relative weights of the audit set of sub-criteria

Criterion	Relative Weight
Content of Audit	0.75
Appropriate Audit Frequency	0.25

Matrix 2-25 and Table 2-17 presents the estimations and the relative weights and C.R. of the Audit Content set of elements, respectively:

$$\begin{array}{l} \text{Implementation of MOC Training} \\ \text{Misclassification of MOCs} \\ \text{Temporary MOCs} \\ \text{Emergency MOCs} \\ \text{Authorization Process} \\ \text{Hazard Evaluation} \end{array} \begin{bmatrix} 1 & 3 & 1 & 1 & 2 & 1 \\ 1/3 & 1 & 1 & 1 & 3 & 1 \\ 1 & 1 & 1 & 1 & 1 & 1 \\ 1/2 & 1 & 1 & 1 & 1 & 1 \\ 1/3 & 1/3 & 1 & 1 & 1 & 1 \\ 1/2 & 1 & 1 & 1 & 1 & 1 \end{bmatrix} \quad (2\text{-}25)$$

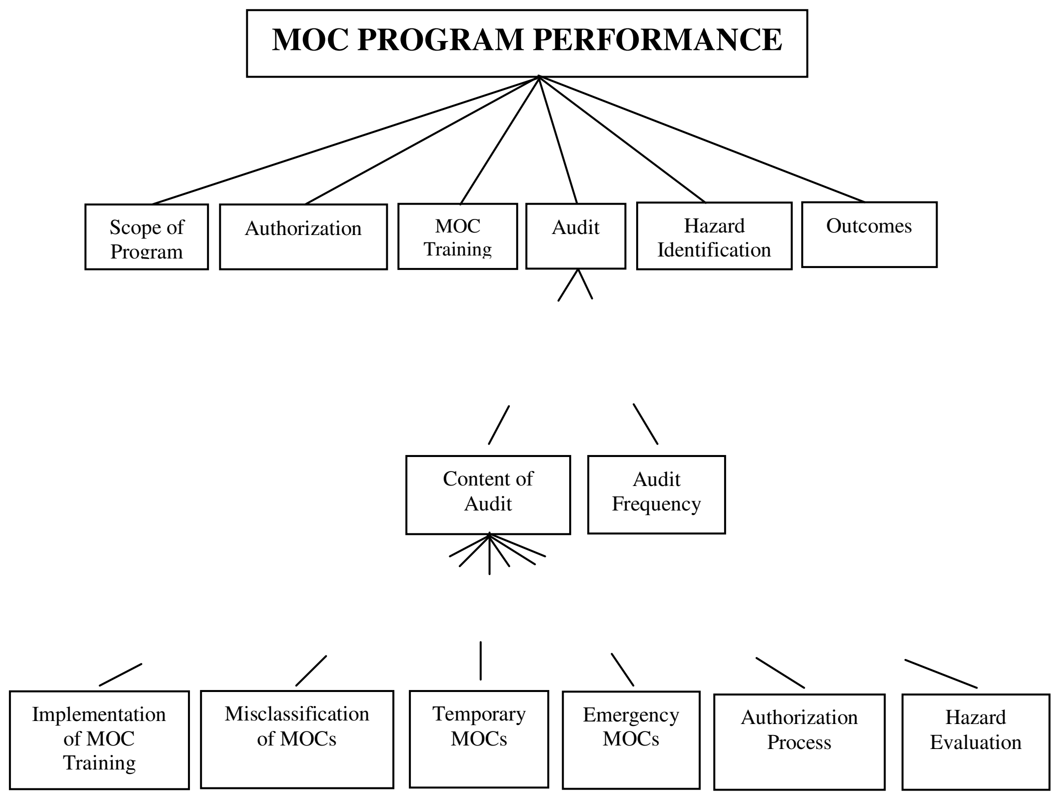

Figure 2-9. Hierarchy of the audit criterion

Table 2-17. Relative weights and C.R. of the content of audit set of elements

Criterion	Relative Weight	
Implementation of MOC Training	0.223	C.R.= 0.03
Misclassification of MOCs	0.173	
Temporary MOCs	0.159	
Emergency MOCs	0.159	
Authorizations	0.127	
Hazard Evaluations	0.159	

Authorization

Several criteria affect the level of MOC authorization. Among these criteria are the financial resources that are required to implement the change, which include human resources requirements. The authorization process integrates these factors. However, the focus of this study is on the effects on the safety performance of the program. Figure 2-10 demostrates the hierarchy of the Authorization criterion with respect to regular MOCs, temporary MOCs, and emergency MOCs, and the positons that are available for the authorization of each type of MOC. Matrix 2-26 presents the relative importance of MOC authorization, and Table 2-18 presents the relative weights with respect to the authorization process.

Table 2-18. Relative weights and C.R. of authorization set of sub-criteria

Criterion	Relative Weight	
Regular MOC	0.333	C.R.= 0.00
Temporary MOCs	0.333	
Emergency MOCs	0.333	

$$\begin{matrix} Regular\ MOC \\ Temporary\ MOC \\ Emergency\ MOC \end{matrix} \begin{bmatrix} 1 & 1 & 1 \\ 1 & 1 & 1 \\ 1 & 1 & 1 \end{bmatrix} \tag{2-26}$$

The estimations of the relative importance of Regular MOCs, Temporary MOC, and Emergency MOC authorization by the various positions in the plant are presented in Matrixes 2-27, 2-28, and 2-29, respectively:

$$\begin{matrix} MOC\ Coordinator \\ (Operation\ Manager\ and/or\ Maintenance\ Manager) \\ Plant\ Manager \\ EH\ \&\ S\ Officer \\ Engineering/Instrumentation \\ Executives \end{matrix} \begin{bmatrix} 1 & 1/3 & 1/2 & 1/2 & 1 & 2 \\ 3 & 1 & 3 & 2 & 3 & 5 \\ 1 & 1/3 & 1 & 1 & 1/2 & 2 \\ 2 & 1/2 & 1 & 1 & 1 & 4 \\ 1 & 1/3 & 2 & 1 & 1 & 3 \\ 1/2 & 1/5 & 1/2 & 1/4 & 1/3 & 1 \end{bmatrix} \tag{2-27}$$

$$\begin{matrix} MOC\ Coordinator \\ (Operation\ Manager\ and/or\ Maintenance\ Manager) \\ Plant\ Manager \\ EH\ \&\ S\ Officer \\ Engineering/Instrumentation \\ Executives \end{matrix} \begin{bmatrix} 1 & 1 & 1 & 1 & 1 & 3 \\ 1 & 1 & 3 & 2 & 2 & 5 \\ 1 & 1/3 & 1 & 1 & 1/2 & 3 \\ 1 & 1/2 & 1 & 1 & 1/2 & 3 \\ 1 & 1/2 & 2 & 1 & 1 & 4 \\ 1/3 & 1/5 & 1/3 & 1/3 & 1/4 & 1 \end{bmatrix} \tag{2-28}$$

$$\begin{matrix} MOC\ Coordinator \\ (Operation\ Manager\ and/or\ Maintenance\ Manager) \\ Plant\ Manager \\ EH\ \&\ S\ Officer \\ Engineering/Instrumentation \\ Executives \end{matrix} \begin{bmatrix} 1 & 1/2 & 1 & 1 & 1 & 3 \\ 2 & 1 & 3 & 2 & 2 & 5 \\ 1/2 & 1/3 & 1 & 1 & 1/2 & 3 \\ 1 & 1/2 & 1 & 1 & 1 & 4 \\ 1 & 1/3 & 1 & 1 & 1 & 4 \\ 1/3 & 1/5 & 1/3 & 1/4 & 1/4 & 1 \end{bmatrix} \tag{2-29}$$

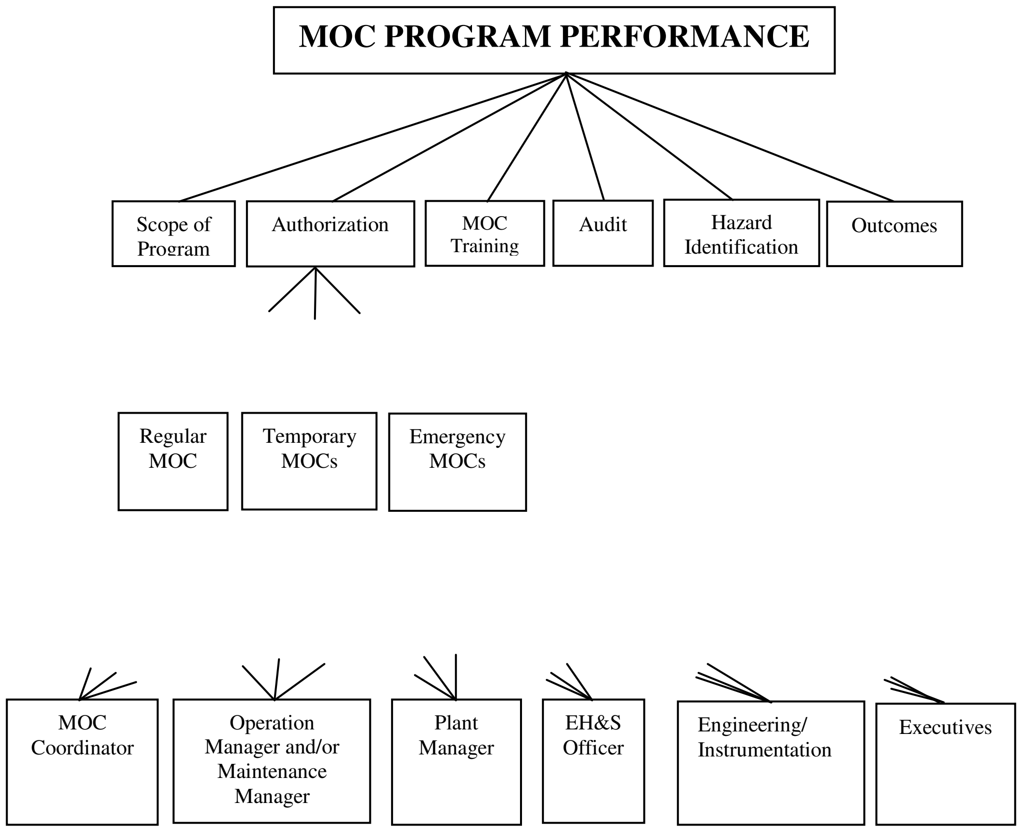

Figure 2-10. Hierarchy of the authorization criterion

Table 2-19 sumarizes the relative importance of the three types of MOC authorizations by the positions in the plant.

Table 2-19. Relative weights and C.R. of the authorization set of elements

Criterion	**Regular MOC**	**Temporary MOC**	**Emergency MOC**	
MOC Coordinator	0.107	0.179	0.179	$C.R._{Reg}$. 0.00 $C.R._{Temp}$= 0.00 $C.R._{Emerg.}$ = 0.00
Operation Manager and/ or Maintenance Manager	0.357	0.291	0.291	
Plant Manager	0.137	0.132	0.133	
EH&S Officer	0.179	0.140	0.164	
Engineering/ Instrumentation	0.163	0.207	0.184	
Executives	0.057	0.051	0.049	

where,

$C.R._{Reg.}$ is the consistency ratio in weighting regular MOCs

$C.R._{Temp.}$ is the consistency ratio in weighting temporary MOCs

$C.R._{Emerg.}$ is the consistency ratio in weighting emergency MOCs

Outcome Curves

General

Pairwise comparison questions were used to establish outcome curves of training and audit frequencies, as well as to reveal relative weights. The experts were asked to estimate the appropriateness of several frequencies of training and auditing (e.g., how much more effective is training policy of once in two years in the third year after launching MOC program than the policy of once in three years?). The estimations were normalized by dividing each of the estimations by the maximum value in its level of maturity. Using the regression models available in Microsoft Excel™ the values were adapted in both dimensions: (1) along the frequencies for each maturity level; and (2) along the maturity levels for each of the frequencies. Finally, the functions of the best-fit curves were calculated.

Training Frequency

The appropriate training frequency is a function of the maturity of the MOC program. It is expected that immature programs (programs that were launched in a period of less than five years) will require more frequent training than mature programs. The relative importance of the various types of training has been addressed previously with regard to the population that is being trained. Because of their nature, procedure updates and practices of information transfer training, unlike awareness training, cannot be formally scheduled. Figure 2-11 presents the awareness training performance curves as a function of training frequency and maturity of the MOC program:

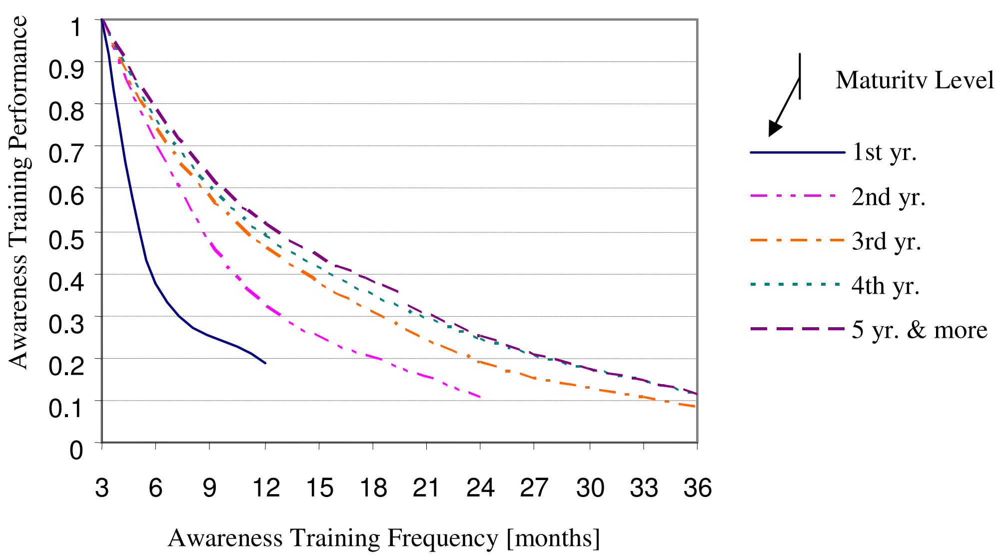

Figure 2-11. Awareness training frequency performance curves

The functions of the curves for each level of maturity are listed in Appendix A. As Figure 2-11 reveals, the higher the frequency of awareness training, the higher the performance level.

Audit Frequency

As with training policy, appropriate frequency of internal audit process is a function of the maturity of the MOC program. The launch of a new program, a new corporate ownership, and recovery from an impropriety program require rapid auditing to identify flaws as early as possible. The Audit Frequency performance curves, are presented in Figure 2-12, revealed an interesting finding. Audit frequency of less than once in 6 months was found to be less appropriate than the frequency of once in 6 months for maturity levels of 4 years and less, and audit frequency of less than once in 12 months was found to be less appropriate than the frequency of once in 12 months for a maturity level of 5 and more years. The audit process is intensive. It requires significant resources, and it commands the attention and time of operation employees during their shift time. The behavior of the curves in the range of less than 12 months for the 5 years maturity level, and the behavior of the curves in the range of less than 6 months for the other levels of maturity, may express the concern of the experts from the effects of high audit frequency on the system.

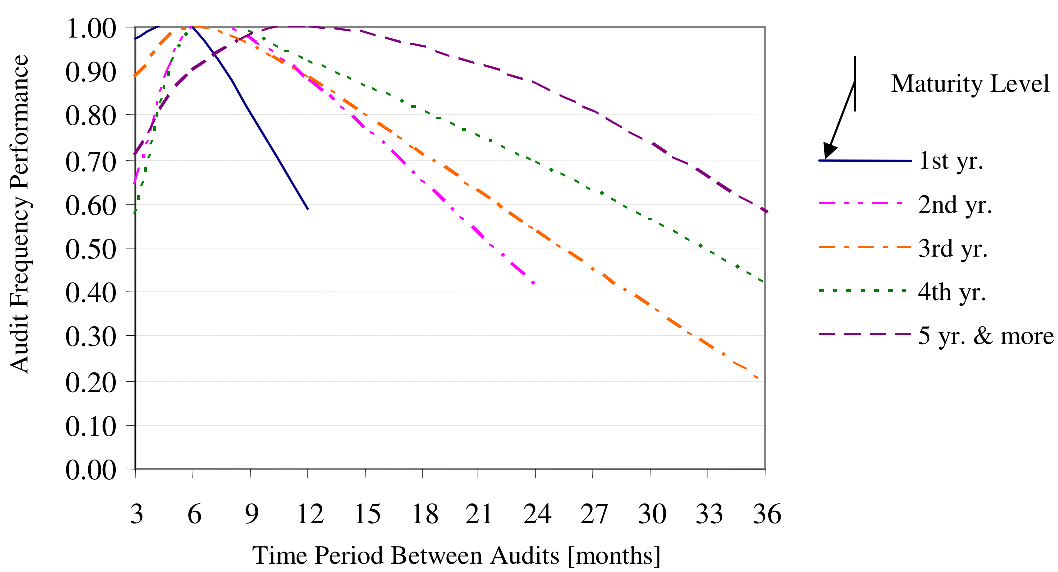

Figure 2-12. Audit frequency performance curves

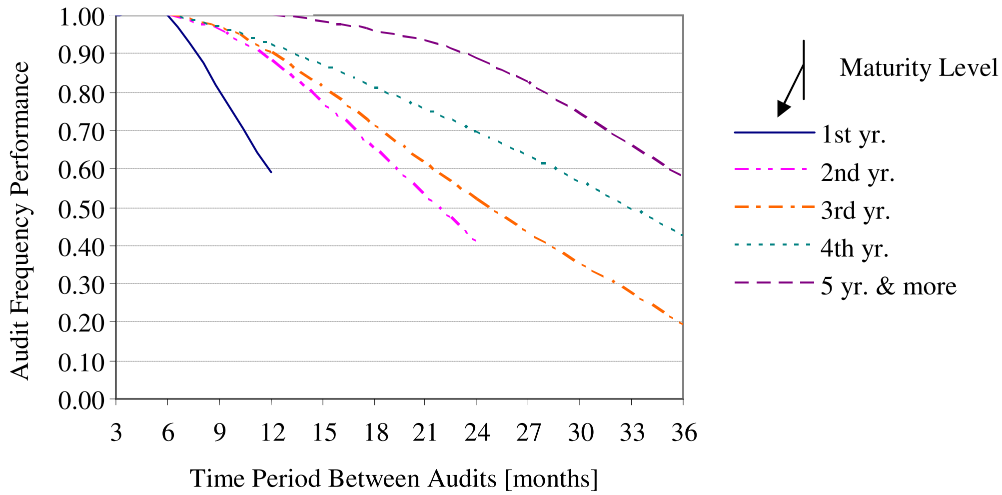

Figure 2-13. Modified audit frequency performance curves

A facility that employs a policy of audit frequency that is shorter than the minimum that is required to gain maximum performance credit, may waste resources and efforts. However, in the domain of process safety performance of the audit frequency, the facility should be scored maximally. Therefore, Figure 2-12 was modified to address this change. The modified curves are presented in Figure 2-13.

Sensitivity Analysis

The Concept

Sensitivity analysis is extremely important when the decision making process is used for selecting from a set of alternatives. If the sensitivity analysis reveals that a small change in the weight of a criterion will change the alternative previously selected, then the decision maker should focus on the weight assignments to ensure that the best alternative is selected. In applications of decision-making for ranking purposes, the importance of a sensitivity analysis is minor and may have an insignificant impact. In a study such as has been conducted in this work, change in rank will cause insignificant change in the scores.

The majority of elements in this model are connected to the overall goal through a single path. However, in the Outcome criterion, the elements are connected to the overall goal through the Audit branch too. Therefore, it is hard to predict how changes in the weights of the criteria will affect the ranking of its elements.

The expression for the minimal change in criteria weights that is required to reverse the selection of the most preferred alternative is available in the literature. The following is a generalization of this expression to calculate the minimal change in criteria weights that is required to reverse the rank of any alternative, and a thorough analysis on the audit branch.

Most Critical Criterion

The most critical criterion can be defined in two ways: (1) the criterion that the smallest change in its weight w_j will cause replacement only of the best top alternative; (2) the criterion that the smallest change in its weight w_j will cause change of rank of any of the alternatives. The first definition is of interest for the processes of selecting the best alternative. However, in decision making methods for evaluation of performance measurements, as is applied in this study, the second definition is of an interest.

The changes in criterion weight can be measured absolutely or relatively (to the value of the weight). Sensitivity analysis may reveal different results when the analysis aims for the smallest absolute change compared to an analysis that aims for the smallest relative change. The smallest absolute change has rarely been studied [30], mainly because this information is useless if it is not compared to the original value, which then turns to be a relative change. The search for the most critical criterion in this study is in the relative change domain.

Several other definitions are required for the study: A_i is the i alternative from a set of m alternatives. For the purpose of this study, the alternatives are ranked in a descending order, i.e., alternative A_1 is the most important alternative with a final preference value (the final value of the weight with respect to the overall goal) of P_1. Hence, the following relation is satisfied P_1• P_2• ….• P_m.

C_j is criterion j (from a set of n criteria) with a weight w_j. Let $w_j^{/}$ be the new weight that will cause a change in the ranking of the alternatives. Now the absolute change in the weight of criterion C_j will be as follows:

$$w_j - w_j^{/} \tag{2-30}$$

The following is an expression for the relative change:

$$\frac{w_j - w_j^{/}}{w_j} \bullet 100 \tag{2-31}$$

Let $\delta_{k,i,j}$ (for 1 =< i =< j =< m and 1 =< k =< n) denote the minimum change in the current weight w_k of criterion C_k such that the ranking of alternatives A_i and A_j are reversed. The relative change $\delta_{k,i,j}^{/}$ can be expressed as follows:

$$\delta_{k,i,j}^{/} = \frac{\delta_{k,i,j}}{w_k} \bullet 100 \tag{2-32}$$

The criteria weights, when using AHP, are normalized and add to unity. Therefore, introduction of a new weight for one criterion to reverse the ranko f alternatives A_i and A_j will affect the other weights. The new weight of criterion C_k is as follows:

$$w_k^* = w_k - \delta_{k,i,j} \tag{2-33}$$

The expression 2-34 presents the new normalized weights:

$$
\begin{aligned}
w_1' &= \frac{w_1}{w_1 + w_2 + \Lambda + w_k^* + \Lambda + w_n} \\
w_2' &= \frac{w_2}{w_1 + w_2 + \Lambda + w_k^* + \Lambda + w_n} \\
& \mathrm{M} \\
w_k' &= \frac{w_k^*}{w_1 + w_2 + \Lambda + w_k^* + \Lambda + w_n} \\
& \mathrm{M} \\
w_n' &= \frac{w_n}{w_1 + w_2 + \Lambda + w_k^* + \Lambda + w_n}
\end{aligned}
\tag{2-34}
$$

The interest here concerns the question "What is the change in the weight of criterion C_K so that the final preferences P_i' and P_j' of alternatives A_i and A_j will be reversed and the expression in 2-35 will be valid"?:

$$P_j' > P_i' \tag{2-35}$$

Let a_{iR} denote the preference of alternative A_i with respect to criterion C_R , and a_{jR} the preference of alternative A_j with respect to criterion $C_{R.}$ When using AHP the expression for the final preference is as follows:

$$P_i' = \sum_{R=1}^{n} w_R' \bullet a_{iR} \qquad and \qquad P_j' = \sum_{R=1}^{n} w_R' \bullet a_{jR} \tag{2-36}$$

Substituting expression 2-36 into 2-35 yield the following:

$$P_i' = \sum_{R=1}^{n} w_R' \bullet a_{iR} \quad < \quad P_j' = \sum_{R=1}^{n} w_R' \bullet a_{jR} \tag{2-37}$$

Substituting the expression for the new weights into the expression in 2-37 will give the following:

$$\frac{\sum_{R=1}^{K-1} w_K a_{iR}}{\sum_{R=1}^{K-1} w_K + w_K^* + \sum_{R=K+1}^{n} w_K} + \frac{w_K^* a_{ik}}{\sum_{R=1}^{K-1} w_K + w_K^* + \sum_{R=K+1}^{n} w_K} + \frac{\sum_{R=K+1}^{n} w_K a_{iR}}{\sum_{R=1}^{K-1} w_K + w_K^* + \sum_{R=K+1}^{n} w_K} < \frac{\sum_{R=1}^{K-1} w_K a_{jR}}{\sum_{R=1}^{K-1} w_K + w_K^* + \sum_{R=K+1}^{n} w_K} + \frac{w_K^* a_{jk}}{\sum_{R=1}^{K-1} w_K + w_K^* + \sum_{R=K+1}^{n} w_K} + \frac{\sum_{R=K+1}^{n} w_K a_{jR}}{\sum_{R=1}^{K-1} w_K + w_K^* + \sum_{R=K+1}^{n} w_K} \tag{2-38}$$

The denominator is common and is positive. Therefore, expression 2-38 can be reduced as follows:

$$\sum_{R=1}^{K-1} w_K a_{iR} + w_K^* a_{ik} + \sum_{R=K+1}^{n} w_K a_{iR} \quad < \quad \sum_{R=1}^{K-1} w_K a_{jR} + w_K^* a_{jk} + \sum_{R=K+1}^{n} w_K a_{jR} \tag{2-39}$$

Substituting expression 2-33 into 2-39 yields the following:

$$\sum_{R=1}^{K-1} w_R a_{iR} + w_K a_{ik} - \delta_{Kij} a_{iK} + \sum_{R=K+1}^{n} w_R a_{iR} < \sum_{R=1}^{K-1} w_R a_{jR} + w_K a_{jk} - \delta_{Kij} a_{jK} + \sum_{R=K+1}^{n} w_R a_{jR} \tag{2-40}$$

Rearranging the components in the expression in 2-40 will produce the expression in 2-41:

$$-\delta_{Kij} a_{iK} + \sum_{R=1}^{n} w_R a_{iR} < -\delta_{Kij} a_{jK} + \sum_{R=1}^{n} w_R a_{jR} \tag{2-41}$$

Since $\sum_{R=1}^{n} w_R a_{iR} = P_i \quad and \quad \sum_{R=1}^{n} w_R a_{jR} = P_j$ expression 2-41 is reduced to the following:

$$-\delta_{Kij} a_{iK} + P_i < -\delta_{Kij} a_{jK} + P_j \tag{2-42}$$

Rearranging the components and isolating δ_{Kij} will yield an expression for the change in the weight of criterion K to reverse the preferences of alternatives A_i and A_j:

$$\delta_{Kij} < \frac{(P_j - P_i)}{(a_{jk} - a_{ik})} \quad if \quad (a_{jk} > a_{ik}); or$$

$$\delta_{Kij} > \frac{(P_j - P_i)}{(a_{jk} - a_{ik})} \quad if \quad (a_{jk} < a_{ik}) \tag{2-43}$$

The expression for the relative change is as follows:

$$\delta'_{Kij} < \frac{(P_j - P_i)}{(a_{jk} - a_{ik})} \times \frac{100}{w_k} \quad if \quad (a_{jk} > a_{ik}); or$$

(for 1<=i<= j<=m and 1<=k<= n) (2-44)

$$\delta'_{Kij} > \frac{(P_j - P_i)}{(a_{jk} - a_{ik})} \times \frac{100}{w_k} \quad if \quad (a_{jk} < a_{ik})$$

Since the maximum change that can be applied to the weight w_k of criterion C_k is as large as w_k, it is possible to test if such a change is feasible as follows:

$$\frac{(P_j - P_i)}{(a_{jk} - a_{ik})} \leq w_K \tag{2-45}$$

If this condition is not fulfilled then the change δ'_{Kij} is infeasible. Two major conclusions result from 2-44 and 2-45 are:

1. If alternative A_i dominates alternative A_j (i.e., the preference of alternative A_i is higher than the preference of alternative A_j in each of the criteria) then it is

impossible to make alternative A_j more preferred by applying changes to the weights of the criteria.

2. Criterion C_k is considered a robust criterion if all quantities $\delta_{Kij}^{\prime}$ are infeasible.

Sensitivity Analysis of the Outcome Branch

The elements in Figure 2-8 are connected to the overall goal through four sub-criteria and two criteria. The following notation will be used for the purposes of this analysis:

C_1 - The Outcome criterion

C_1^1 - The Classification Failures sub-criterion

C_1^2 - The Authorization Failures sub-criterion

C_1^3 - The Hazard Detection Failures sub-criterion

C_2 - the Audit criterion

C_2^1 - The Audit Content sub-criterion

A_1 - The Failure to Train Properly element

A_2 - The MWO-MOC misclassification element

A_3 - The Failure to Apply Temporary MOCs element

A_4 - The Failure to Apply Emergency MOCs element

A_5 - The Failure to Authorize Appropriately element

A_6 - The Failure to Apply Appropriate Hazard Detection Techniques element

Table 2-20 summarizes the preferences of the elements with respect to the various criteria, sub-criteria, and the overall goal.

There are 90 combinations of $\delta_{Kij}^{\prime}$ for a system of 6 alternatives and 6 criteria. However alternatives A1, A5, and A6 are not connected to all of the criteria, and therefore only 69 combinations were calculated.

Table 2-20. Preferences of the outcome elements with respect to the various criteria

Elements	C_1^1	C_1^2	C_1^3	C_1	C_2^1	C_2	P_i
A_1	N/A	N/A	0.306	0.107	0.023	0.017	0.020
A_2	0.333	0.286	0.168	0.247	0.173	0.130	0.054
A_3	0.333	0.286	0.180	0.253	0.159	0.119	0.054
A_4	0.333	0.286	0.162	0.245	0.159	0.119	0.054
A_5	N/A	0.143	0.070	0.064	0.127	0.095	0.018
A_6	N/A	N/A	0.113	0.051	0.159	0.119	0.019

The most critical criterion was found to be the Hazard Detection Failures. A reduction of 6.14% of its weight reversed the rank of Element A1 with Element A_6. Since the final preferences of alternatives A_1, A_2, and A_6 are very close to each other, the changes in the criteria weights to cause different rank is not large, especially for criteria with initial low weight.

Summary

By defining the hierarchy of the Management of Change elements, it was possible to apply a Multi Criteria Decision Making method (MCDM) to reveal the relative weights of the MOC components. However, most MCDM methods encounter problems when interdependencies exist among the components. Therefore, the AHP was selected to analyze this problem, because this method works well with interdependencies and it measures the consistency in assignment of weights. A questionnaire survey of 179 questions sent to several experts revealed weights of the criteria and elements of the model. The results were analyzed by AHP, and the judgment of the experts was determined to be consistent. Only a single matrix has a Consistency Index value of 0.12 that was found to be high because of rounding values to fit to the AHP scale and not because of inconsistency among the experts.

Sensitivity analysis has a minor importance when MCDM is applied for measurements of effects and not for selecting from a set of alternatives. However, an expression was developed for the minimum change that is required to reverse the preferences of any element, and sensitivity analysis was conducted for the branch that does not consist of robust criteria. The analysis revealed that Hazard Detection Failures is the critical criterion. A reduction of 6.14% of its weight reversed the rank of element A_1 with element A_6. However, since the final preferences of alternatives A_1, A_2, and A_6 are nearly the same, the changes in the weights of criteria that are required to reverse preferences is not large, especially with criteria of initial low weight.

The curves of training frequency performance and audit frequency performance were developed too. The development of the audit frequency curves revealed an interesting conclusion: An audit frequency of less than 1 in 6 months was found to be less appropriate than the frequency of 1 in 6 months for a maturity level of 4 years and less. An audit frequency of less than 1 in 12 months was found to be less appropriate than the frequency of 1 in 12 months for a maturity level of 5 and more years. The assumption is that the behavior of these curves may express the concern of the experts about effects of imposing too frequent audits on the system.

The results were consolidated to a form that is useful for performance measurements of Management of Change programs. This form is presented in Appendix B.

CHAPTER III

BENCHMARKING OF PROCESS SAFETY ELEMENTS AMONG FACILITIES*

General

Chemical, oil, and gas plants process many potentially hazardous chemicals. Historically, a variety of measures have been used for hazard reduction and risk management. During the last decade, federal regulations have been promulgated in the United States mandating process safety management standards. OSHA's Process Safety Management (PSM) and the EPA's Risk Management Program (RMP) regulations provide the baselines and framework for development of programs and procedures in the industry. Due to the performance-based nature of these regulatory requirements, there is wide variation in these programs and practices. This chapter summarizes the results of benchmarking exercises aimed at identifying the diversity of implementation practices of MOC and Emergency Preparedness and Response programs. A questionnaire for benchmarking of Process Safety Incident Investigation (PSII) procedures in industry is also developed.

Benchmarking of Management of Change Practices in the Process Industries

Background

Changes and modifications in chemical plants are essential for survival in the dynamic process industry. These changes and modifications are needed for a variety of reasons, such as yield improvement, compensation for unavailable equipment, production increases, increases in storage capacity, cost reduction, safety improvements, and pollution prevention. The process changes usually involve changes in operating procedures - changes in piping, equipment, or materials of construction - as well as

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changes in feedstocks, catalysts, fuels, or their method of delivery. However, a number of catastrophic incidents have been attributed to improperly handled process changes [25,31,32,33,34]. OSHA's PSM regulation [35] and EPA's RMP regulation [36] both require regulated facilities to develop and implement MOC programs. Both the regulations are similar and performance-based. The MOC requirements as specified in the OSHA's PSM regulation are produced below in its entirety in Table 3-1[4]. The performance-based nature of the MOC element is apparent from a reading of the regulatory requirements shown in Table 3-1. Practices often vary [37, 38] and there is a critical need to determine the industry consensus or Recognized and Generally Accepted Good Engineering Practices (RAGAGEP).

Table 3-1. Management of change requirements – OSHA PSM regulation

29 CFR 1910.119(l) Management of change. *(l)(1)The employer shall establish and implement written procedures to manage changes (except for "replacements in kind") to process chemicals, technology, equipment, and procedures; and, changes to facilities that affect a covered process.* *(l)(2)The procedures shall assure that the following considerations are addressed prior to any change:* *(l)(2)(i) The technical basis for the proposed change;* *(l)(2)(ii) Impact of change on safety and health;* *(l)(2)(iii) Modifications to operating procedures;* *(l)(2)(iv) Necessary time period for the change; and,* *(l)(2)(v) Authorization requirements for the proposed change.* *(l)(3) Employees involved in operating a process and maintenance and contract employees whose job tasks will be affected by a change in the process shall be informed of, and trained in, the change prior to start-up of the process or affected part of the process.* *(l)(4) If a change covered by this paragraph results in a change in the process safety information required by paragraph (d) of this section, such information shall be updated accordingly.* *(l)(5) If a change covered by this paragraph results in a change in the operating procedures or practices required by paragraph (f) of this section, such procedures or practices shall be updated accordingly.*

[4] The MOC requirements of the EPA RMP regulation are similar to the OSHA PSM requirements.

This is true not only in the case of management of change but also in the case of other elements of the process safety management program. This effort is thus aimed at developing a benchmark of industry practices for different process safety management requirements. Management of change because of the wide variation in application is the first element chosen for analysis. The benchmarking exercises should be repeated on the same elements (e.g., management of change) as practices change. It is important to note that with new technologies and other advances, RAGAGEP will remain a moving target with the need for continual benchmarking and determination of RAGAGEP as they apply to the current time-frame. The MOC benchmarking represented in this chapter was conducted during the months March and April of 2001. A questionnaire was prepared and distributed to more than 50 plants, out of which 27 facilities responded. The questionnaire is reproduced in its entirety in Table 3-2. The plants surveyed had 100 to 1000 employees. Figure 3-1 shows the distribution of facilities based on the number of employees. The facilities averaged between 6-15 separate process areas, however, one facility had 72 processes. The industries represented consisted of chemicals, refineries, petrochemicals, and gas plants.

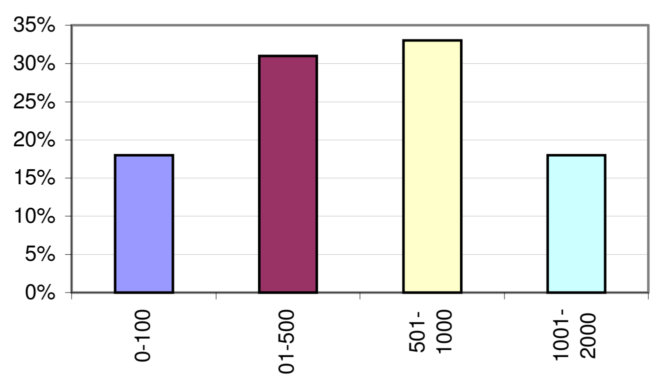

Figure 3-1. Distribution of facilities based on number of employees

Table 3-2. Questionnaire for benchmarking management of change

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Management of Change (MOC) is a relatively recent procedure that was mandated by the OSHA Process Safety Management regulation. The objective of the questions contained herein is to identify the diversity of MOC application within the chemical processing industry. A copy of the report resulting from this project will be provided to all the participants.

This benchmarking questionnaire is targeted towards 24-hour continuous operation single site facilities. Please return the questionnaire with appropriate notations if these assumptions are not correct.

1 Facility Size and Type

1.1. How many employees (including contractors) work at this site? For uniformity, include everyone on the payroll, including the administrative and contract personnel.
____

1.2. How many separate process areas are within the plant complex?
____

1.3. Which of the following best characterizes the process operations at this site? (Check only one)
- π Chemical
- π Refining
- π Petrochemical
- π Pharmaceutical
- π Food
- π Gas Plant
- π Other (please specify__________________________________)

2 Scope

2.1. Is MOC applied plant-wide or only for regulatory "covered" proces s areas? (Check only one)
- π Plant-wide
- π Regulatory "covered" process areas

2.2. Is MOC applied to atmospheric tank farm areas? (Check only one)
- π Yes
- π No

2.3. Is MOC applied to utilities, such as steam generation or waste-water treatment areas? (Check only one)
- π Yes
- π No

2.4. Are there any process areas within your plant that are NOT subjected to formal MOC procedures? (Check only one)
- π Yes Describe_______________________________________
- π No

3 Policy Development

3.1. Was the MOC policy and procedures developed by corporate staff and then introduced to each plant? (Check only one)
- π Yes
- π No

3.2. Was the MOC policy and procedures developed by local plant staff? (Check only one)
- π Yes
- π No

3.3. Were PSM consultants used to initially develop MOC policy and procedures? (Check only one)
- π Yes
- π No

3.4. Are MOC procedures consistent plant-wide or vary somewhat within each area of the plant? (Check only one)

Table 3-2. (continued)

- π Consistent plant-wide
- π Vary somewhat within each area of the plant

3.5. Is there any effort to maintain consistent MOC procedures with other plants within the corporation? (Check only one)
- π Yes
- π No

4 Size of MOC program

4.1. How many maintenance work orders (replacement-in-kind) are initiated annually?

____

4.2. How many MOCs (all MOCs including emergency and temporary MOCs) are initiated annually[1]?

____

4.3. Do you keep records of MOCs that are <u>not</u> approved? (Check only one)
- π Yes
- π No

4.3.1. If answer to 4.3 is yes, how many MOCs were eventually <u>not</u> approved?

____

5. Emergency MOCs

5.1. How many emergency MOCs are initiated annually[1]?

____

5.2. Who approves emergency MOCs?

____

5.3. How long does it take to get approval of an emergency MOC?

____

5.4. Are emergency MOCs audited/checked as soon as practicable? (Check only one)
- π Yes
- π No

How many emergency MOCs require remedial actions or violate the company/site MOC procedures?

6. Temporary MOCs

6.1. How many temporary MOCs are initiated annually[1]?

____

6.2. Who checks to see if the changes affected by the temporary MOCs are restored to their normal conditions after the expiration of the authorized time period?

____

6.3. Are temporary MOCs audited/checked as soon as practicable do determine if the change has been restored to the original condition? (Check only one)
- π Yes
- π No

7. MOC records management

7.1. Are MOC files maintained in a plant central records storage area or within each respective plant area? (Check only one)
- π Plant central records storage area
- π Within each respective plant area

7.2. Are MOC files maintained electronically or does a paper copy exist? (Check only one)
- π MOC files maintained electronically
- π Paper copy
- π Both

7.3. Who is responsible for maintaining MOC files? (Check only one)

Table 3-2. (continued)

π Safety
π Operations
π Maintenance
π Other____________________

8. Audit
  8.1. Have there been additional audits of the MOC program beyond the standard required 3-year PSM audit? (Check only one)
    π Yes
    π No
  8.2. Is the PSM Audit conducted by corporate staff not normally located at the plant? (Check only one)
    π Yes
    π No
  8.3. Were outside consultants involved in the Audit? (Check only one)
    π Yes
    π No
9. Audit Results
  9.1. Did the Audit reveal any MOCs were mis-classified? (Check only one)
    π Yes (if possible indicate approx % of MOCs audited which had issue _____%)
    π No
  9.2. Did the Audit reveal any field changes that were not subjected to MOC procedures? (Check only one)
    π Yes (if possible indicate approx % of MOCs audited which had issue _____%)
    π No
  9.3. Did the Audit reveal any maintenance work orders that should have been classified as MOCs? (Check only one)
    π Yes (if possible indicate approx % of MOCs audited which had issue _____%)
    π No
  9.4. Were there any recommendations for upgrading your MOC program from the latest audit? (Check only one)
    π Yes
    π No
    9.4.1. If so, what were these recommendations?
    ____
    ____
    ____
10. MOC software
  10.1. Do you use any special software to facilitate the MOC procedure? (Check only one)
    π Yes
    π No
  10.2. Was this software developed in-house? (Check only one)
    π Yes
    π No
  10.3. If commercial software is used, is it satisfactory? (Check only one)
    π Yes (List name of software used_______________________)
    π No
11. MOC Program Awareness Training
  11.1. How are new employees and contractor employees made aware of the MOC policy and procedures? (Check all that apply)
    π Formal training classes
    π Provided with policy manual

Table 3-2. (continued)

- π Informal toolbox safety meetings
- π Other________________________

11.2. If training classes are provided, how often are classes scheduled?

____

11.3. Is MOC training separate from PSM program awareness training? (Check only one)

- π Yes
- π No

11.4. Is a video describing the need for MOC used within your MOC awareness training program (such as the video available from Roy Sanders of Lake Charles)? (Check only one)

- π Yes (List name of material used__________________________)
- π No

12. Impact on Risk Management Plan

Section 68.36(b) of the EPA RMP regulation states

> 'If changes in processes, quantities stored or handled, or any other aspect of the stationary source might reasonably be expected to increase or decrease the distance to the endpoint by a factor of two or more, the owner or operator shall complete a revised analysis within six months of the change and submit a revised risk management plan…."

12.1. Who is responsible for checking changes requiring an MOC for impact on the RMP plan? (Check only one)

- π Safety
- π Environmental
- π Corporate Specialist
- π Other_____________________

12.2. Have any change requiring an MOC ever caused an RMP update?

____

13. MOC initiation

13.1. Do **all** work orders require a corresponding MOC authorization number or explanation 'why MOC is not required"? (Check only one)

- π Yes
- π No

13.2. Who is responsible for identifying a work order is NOT a replacement–in–kind, and is therefore work that requires an MOC? (Check only one)

- π Safety
- π Operations
- π Maintenance
- π Other_____________________

13.3 Are DCS software changes documented using the MOC procedure? (Check only one)

- π Yes
- π No

13.3.1 If so, who maintains the DCS software change documentation (Check only one)

- π Operations
- π Engineering (DCS specialists)
- π Other (provide function name ___________)

14. PHA revalidation

14.1. What criteria are used to determine whether or not a PHA must be performed with an MOC?

____

____

____

Table 3-2. (continued)

14.2. Do PHA's performed for MOCs vary in the degree of detailed review and documentation (If yes, please explain)?
- π Yes (____
  ____
  ____
  ____)
- π No

14.3. Did the PHA revalidation team review MOC records? (Check only one)
- π Yes
- π No

14.4. Did the PHA revalidation team find any changes that were not identified in the MOC records? (Check only one)
- π Yes (if possible indicate approx % of MOCs audited which had issue _____%)
- π No

15. Environmental and Quality

15.1. Are environmental staff consulted as part of the MOC review? (Check only one)
- π Yes
- π No

15.2. Is the plant accredited under ISO 9000? (Check only one)
- π Yes
- π No

15.3. Is the PSM MOC program consolidated with the Quality configuration management program? (Check only one)
- π Yes
- π No

15.3.1. If so, are records consolidated? (Check only one)
- π Yes
- π No

16. Risk Screening or Ranking MOC

(The following group of questions is based upon the concept that proposed MOCs should be screened in order to provide the appropriate resources to evaluate the impact on safety of the proposed change.)

16.1. Does your site use Risk Screening or Ranking of MOCs?
- π Yes
- π No

16.2. Who developed the risk screening procedure?
- π Yes
- π Local in-house staff
- π Corporate PSM staff
- π Outside consultants
- π Other______________

16.3. Who conducts the risk screening? (Check only one)
- π MOC initiator
- π MOC Coordinator

16.4. How many risk categories are available?

____

16.5. Are potential consequences and potential event frequency evaluated separately in the determination of the appropriate risk category? (Check only one)
- π Yes
- π No

16.5.1 if yes, how is potential consequences and potential event frequency evaluated? (Check only one)

Table 3-2. (continued)

- π Checklists
- π Staff experience only

17. Safety Review of MOC
    17.1. If risk screening is used, are different safety review techniques applicable to each MOC risk category? (Check only one)
    - π Yes
    - π No

    17.2. Are checklists available for low risk MOC? (Check only one)
    - π Yes
    - π No

    17.3. Are high-risk MOC categories evaluated within the plant or required to be submitted to corporate safety staff? (Check only one)
    - π Evaluated within the plant
    - π Submitted to corporate safety staff

18. Authorization
    18.1. How many authorizations are required on a MOC request to proceed with the change?
    ____

    18.2. If risk screening is used, are different authorization levels applicable to each MOC risk category? (Such as authorization at the process unit area or plant manager level.) (Check only one)
    - π Yes
    - π No

    18.3. If risk screening is used, are different number of authorizations applicable to each MOC risk category? (Check only one)
    - π Yes
    - π No

19. Training in the MOC
    19.1. Who is responsible for conducting training regarding the impact of the MOC? (Check only one)
    - π MOC coordinator
    - π Operations
    - π Training department
    - π Other (list function ______________________________)

    19.2. If risk screening is used, are different types of training requirements applicable to each MOC risk categories? (Check only one)
    - π Yes
    - π No

    19.3. Are night orders or logbook notation used for informing staff of low risk MOC changes? (Check only one)
    - π Yes
    - π No

20. Pre-Startup Safety Review
    20.1. Is the PSSR program considered closure of the MOC program? (Check only one)
    - π Yes
    - π No

    20.2. Who is responsible for conducting the PSSR? (Check only one)
    - π Operations
    - π MOC coordinator
    - π Other_______________

    20.3. Is startup safety review following turnaround handled separately than PSSR? (Check only one)
    - π Yes
    - π No

Table 3-2. (continued)

21. Metrics
    21.1. Have you developed a program to measure MOC effectiveness? (Check only one)
        π Yes
        π No
    21.2. Did you develop your own metrics or adapted it from other sources? (Check only one)
        π Developed own metrics
        π Adapted metrics from other sources
22. Does your MOC program include management of organizational changes? (Check only one)
        π Yes
        π No
    22.1. If answer to question (22) is yes, what is the highest level in your organization that requires a management of organizational change?
    ____
23. Would you be willing to submit a redacted version (deleting all specific references to your organization) of your MOC policy and procedures manual to the Mary Kay O'Connor Process Safety Center for sharing with other companies? (Check only one)
        π Yes
        π No
24. Please describe any general impressions of the MOC program at your plant, such as plans to extend the MOC program to other areas, portions of the MOC program that are causing difficulty, suggestion to improve the efficiency of MOC program, etc.

[1] *Please provide an estimate for 2000 if complete records are available. If complete records for 2000 are not available, please provide an annual average for the most recent year for which complete records are available*

The distribution of facilities based on type of industry is presented in Figure 3-2.

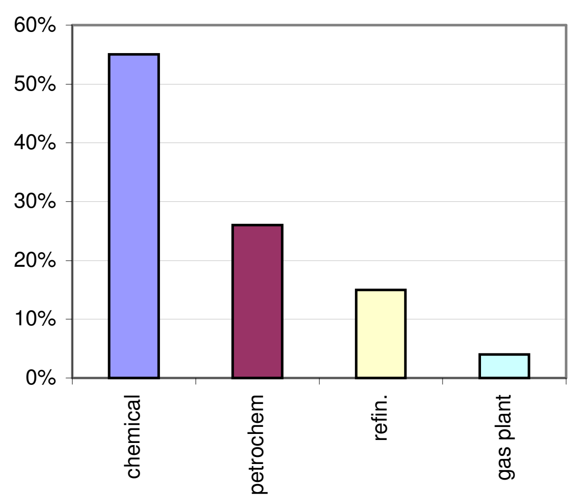


Figure 3-2. Distribution of facilities based on type of plant

Scope

A majority of the respondents reported that management of change programs had been implemented ‘plant -wide”. Only 11% of the respondents reported narrow implementation based on determination of regulatory coverage. However, almost all of the respondents reported that the MOC program was covering atmospheric tank farms and other utilities. Respondents were asked about MOC exceptions based on the following two groups:

Group A	Group B
Utilities area	Central office building
Portable water station	Q.A laboratories
Nitrogen station	Railcar wash station
Air plant	Environmental areas
Cooling water facilities	

Facilities that responded that MOC was implemented plant-wide included Group A in the MOC implementation. Group B areas were almost always excluded from MOC implementation. An interesting point made by one of the respondents is that while all areas are subject to MOC procedures, the level of execution and effort varies from area to area.

Policy Development

MOC procedures are almost always developed by local plant staff without external PSM consultant assistance, and without assistance from corporate staff. However, significant efforts are made to maintain consistent MOC procedures with other plants within the corporation. Other ways of developing and implementing MOC procedures that had been reported are:

- Corporate staff provides guidelines and the plant develops plant-specific MOC procedures.
- The use of standard plant-wide implementation procedures with varying degrees of compliance.
- The use of MOC procedures from other plant's as guidelines to develop a plant-specific procedure.

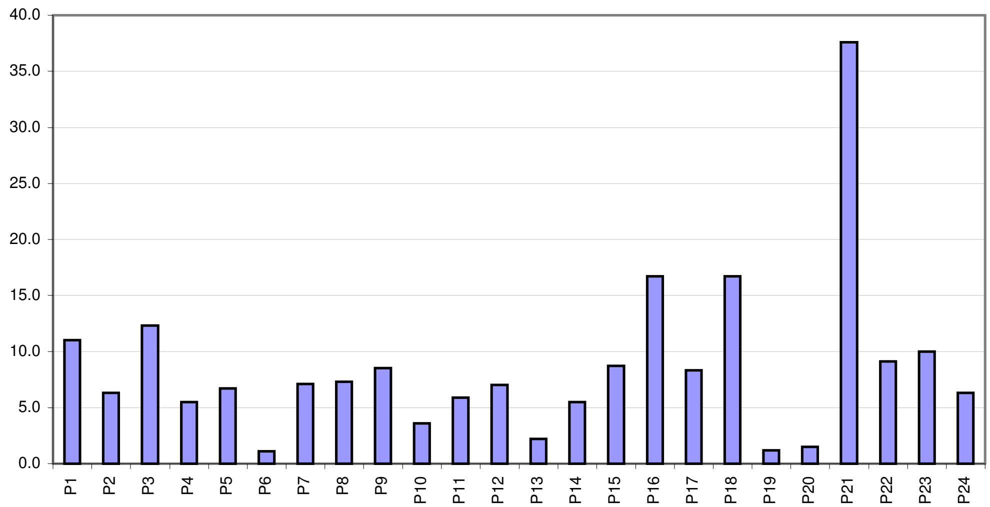


Figure 3-3. Total number of annual MOCs per 10 employees per year

Size of MOC Programs

A significant fact revealed by the study was that 25% of the participants could not obtain the number of Maintenance Work Orders (MWO) initiated annually. In addition, another 11% could not estimate the number of MOC orders initiated annually. Several thousand MWOs are initiated annually in the majority of the plants, but 17,000 and 20,000 MWOs were also reported, though, not by the biggest facilities. On the average, each facility initiated several hundred MOCs annually. The number of annual MOCs was normalized in order to obtain typical values independent of facility size. The results are plotted in Figure 3-3 (three of the respondents did not share this information). The average number of MOCs per 10 employees for all the respondents is nine annually. Most of the values vary in the range 5 to 20 MOCs per 10 employees per year. A relatively high value of 37 MOCs per 10 employees was obtained from a small (about 150 employees) facility. An examination of the facility records reveals that it also reports the highest value of annual MWOs per 10 employees. The ratio between the number of annual MWOs initiated and the annual MOCs initiated varies in the range of 10 to 40, with two exception values of 58 and 170 which probably indicates poor MOC implementation. More than half of the respondents indicated that they do not keep records of unapproved MOCs.

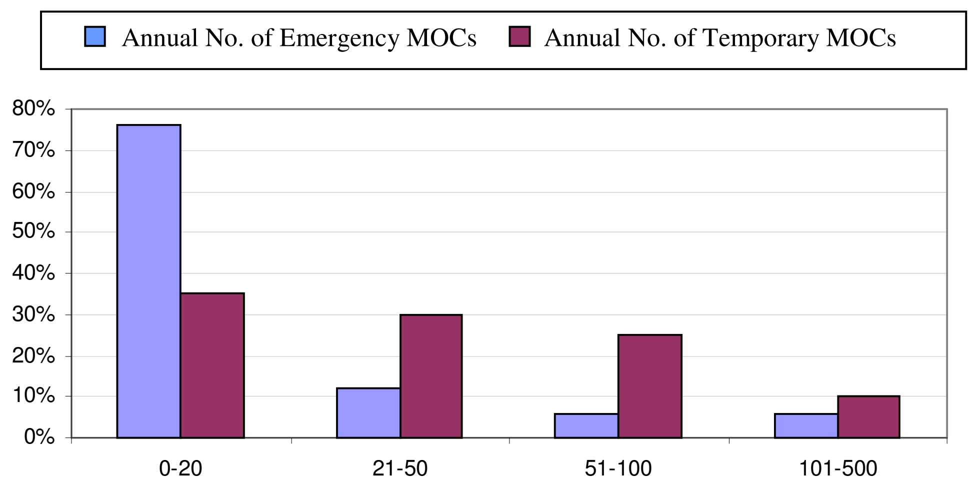


Figure 3-4. Distribution of annual number of emergency and temporary MOCs

Emergency and Temporary Changes

Emergency MOC procedures should be developed for emergency process changes that cannot be postponed. The procedure needs to address the effects caused by the changes assuming that they will be taken in consideration, and confirm that all documentation will be completed.

35% of the respondent could not recall any emergency MOCs. One of the respondents remarked that there is no need for emergency changes in their facility. In most cases, a few hours were needed to approve emergency MOCs. Figure 3-4 shows the distribution of emergency and temporary MOCs. 75% of the respondents reported 20 or fewer emergency MOCs annually and 35% of the respondents reported 20 as fewer temporary MOCs. As indicated by the data in Figure 3-4, one or two facilities reported large number of emergency as well as temporary MOCs. The individuals responsible for authorizing emergency MOCs varied from plant to plant. The responses revealed that emergency MOCs were authorized by shift superintendent, operations manager, plant manager, and others. In most cases there were multiple authorization requirements. It should be noted that the data revealed a few cases in which a clear division was made between day and off-shift authorization personnel. From the responses, we deduce that there is a high consistency of auditing the emergency changes as soon as practicable. We also deduce that there is high consistency of auditing of temporary changes, so as to restore them to their previous condition. Further analysis of the data provides additional insights. For example, that there was no consistency as to who was responsible for restoration of temporary changes to previous conditions. The MOC coordinator, the MOC initiator, area leaders, as well as engineering and safety personnel carried out this task.

MOC Record Management

Figure 3-5 shows the distribution of media used for MOC records management. The responses indicate the preference for storing MOC documentation does not lie within the plant's central area. Further analysis shows that approximately only 40% keep both hard copies and electronic copies of their MOC records, and only about half use electronic files. The most common group responsible for records maintenance is the PSM group, engineering, or operation.

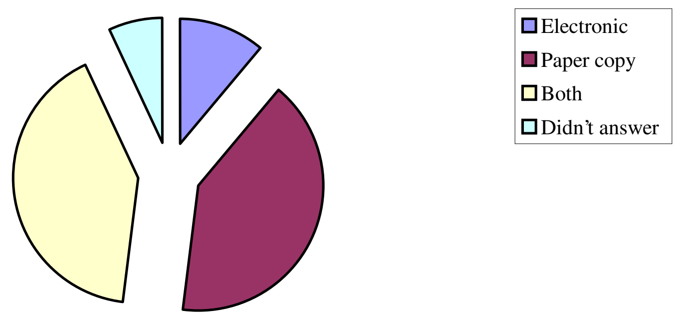


Figure 3-5. Distribution of media used for MOC record management

Audit

More than 40% of the respondents apply the minimum standard required by the PSM regulations for audits (i.e., 3-year PSM audit) for auditing MOC programs. About 60% of the participants reported that the audits were conducted by corporate staff and 50% involved external consultants as well. The results from the audits revealed that there was only a small number of miss-classified MWOs that should not have been classified as MOCs. About 74% of the respondents also indicated that their audits identified the need for MOC program upgrades. This finding emphasizes the need for frequent auditing of MOC programs, principally for new PSM management systems. A screening of audit recommendations identified some common 'weak links":

- Lack of training
- Demand to apply MOC to organizational changes
- In some cases, revising of the MOC program
- Ambiguity regarding temporary changes

Lack of training was noted quite often and this may point to the need for developing guidelines for MOC training programs or at a minimum, developing requirements for auditing the training programs separately from the PSM training programs.

MOC Software

MOC software products are not commonly used. Two-thirds of the participants do not use software for implementation of Management of Change programs. Of the remaining 33%, only two facilities use commercial software products, while the others use 'in-house" software.

MOC Program Awareness Training

56% of the respondents indicated that formal training classes for MOC program awareness are provided for new employees. Some of the same 56% respondents stated that additional MOC program awareness training was provided at other occasions, such as informal safety meetings. Other facilities reported that they offered on-the-job training and/or informal training only. A few facilities reported no training at all, and one facility reported computer-based training only. Formal training classes, wherever provided, were scheduled on a 'need-only" basis, while a few respondents reported regular annual training. In general, half of the respondents stated that they provide MOC program awareness training apart from other PSM awareness training. There is no consistency regarding the entity that is responsible for conducting the training - it is uniformly distributed between MOC coordinators, operations, and others.

Impact on Risk Management Plan

The EPA Risk Management Program regulation requires re-submittal of the risk management plan (RMP) within six months of certain changes (e.g., changes which cause the worst-case scenario to increase or decrease by a factor of two). Almost half of the respondents stated that the safety department was responsible for checking whether a change will result in revising the RMP. Only two facilities indicated process changes that resulted in update and re-submittal of the RMP. One of these was as a result of introduction of a chemical in the process. The other one reported changes in their Off-site Consequence Analysis (OCA). The same facility reported another significant change that resulted in a review of its OCA, but it was decided later that the change did not required the re-submittal of the RMP within six months.

PHA Revalidation

The questionnaire asked for the criteria used by the respondents for making decisions regarding the need for a PHA associated with MOCs. The common criteria for determination of the need for performing PHA are:

- All check points of Change Hazard Review are not satisfied
- Complexity
- New materials
- Changes in the process chemistry
- Changes with a major safety impact

56% of the respondents stated that the level of detail of PHA's varied according to the complexity of the change. Most of the respondents indicated that they used What-If for simple cases and HAZOP for more complex cases.

Risk Screening or MOC Ranking

The MOC questionnaire contained a series of questions that are based upon the concept that proposed MOCs should be screened to provide the appropriate resources in order to evaluate the impact on safety from the proposed change. About 44% of the respondents stated that they were using risk screening of MOCs. Local in-house staff developed most of the screening procedures with some input from corporate PSM groups. There was no consistency regarding who would conduct the risk screening procedure. There were responses that indicated both the MOC initiator and the MOC coordinator as individuals responsible for MOC screening.

Risk screening procedure should determine categories of risk in order to classify the screening results. The number of categories varied between 3 to 7, however, in one case 20 categories was also reported.

Five (19%) facilities reported that potential consequences and potential events were evaluated separately in the determination of risk categories. Checklists were noted to be the preferred evaluation methods over experienced staff evaluation.

Safety Review of MOC

Both OSHA and EPA regulations mandate safety review of MOCs. The optimal stage to initiate a safety review is when preliminary engineering of the change has been completed. Thus, the safety review should take place before the detailed design stage. The survey revealed that most of the facilities that used risk screening of MOCs, used different safety review techniques for different categories of risk. A checklist is most commonly used for low risk MOCs. None of the facilities submit their safety reviews to corporate safety staff for evaluation.

Authorization

As indicated in Figure 3-6, the number of authorizations for MOC approval varied widely with 76% of the respondents requiring four or fewer authorizations. However, some respondents indicated higher number of authorizations with one indicating a maximum of 10 authorizations. A few of the respondents indicated that those are the maximum but the actual number of authorizations is determined on a case-by-case basis according to the risk level. Most of the facilities use the same number of authorizations for levels of risk screening as well as for all MOC risk categories.

As revealed from the survey, at most facilities Pre-Startup Safety Review (PSSR) is identified as the closure of MOC procedure. PSSR is conducted by both operations and MOC coordinators; but mainly by operations. Some 63% of the participants reported that PSSR following the turnarounds were handled separately from other PSSR's.

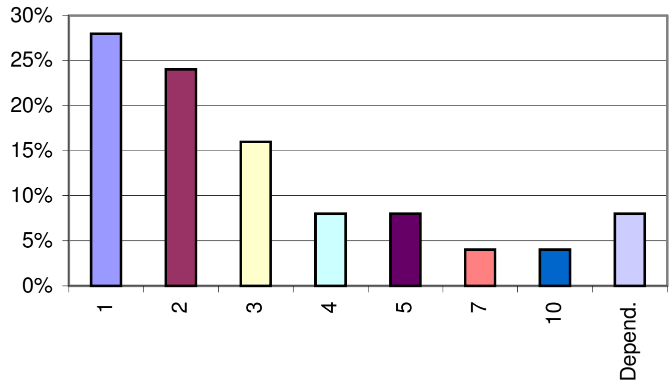


Figure 3-6. Distribution of number of authorizations required for MOC approval

Applying MOC to Organizational Changes

Only 44% of the respondents reported applying MOC programs to organizational changes. Some of the respondents indicated that some of the audits recommended the inclusion of organizational changes in the MOC programs.

Summary and Conclusions

In general, MOC programs are implemented plant-wide. Only half of the respondents in this survey apply MOC procedures to organizational changes. MOC policies and procedures are developed almost entirely by the local plant personnel without external assistance except in a few cases. There is a high degree of consistency with regard to restoring changes related to temporary MOCs to their previous conditions, although audit results pointed to some level of ambiguity regarding temporary MOC issues. Majority of the respondents reported difficulties in recalling elementary emergency MOC data. Lack of training was most noted in audit recommendations and may raise the question of the need to develop guidelines for training for MOC programs. Half of the respondents indicated that they do not use risk-screening procedures.

The well-known phrase "You can't manage what you don't measure" illustrates the need to measure the effectiveness of Management of Change programs. Unfortunately, only about a third of the participants measure MOC effectiveness. An interesting piece of information was the opinion of the respondents regarding the level of implementation of the MOC program at their sites. Of the 50% that responded to this question, 38% indicated that the program needed improvement while the remaining 12% were satisfied with their program.

Benchmarking of Emergency Preparedness and Response Practices in the Process Industry

Background

Process safety of a chemical plant encompasses several layers of protection. Control measures, shutdown systems, release absorption, accumulation of releases by dikes, and protection by barriers, are layers of protection that are intended to prevent the development of an event because of deviations from normal operation conditions. Emergency Response is the next layer of protection that is intended to control an event if possible, or to reduce consequences in cases of loss of control. However, a reliable response to an emergency event requires planning. This section presents results of a benchmarking study of practices of emergency preparedness and response of 15 facilities in the process industry.

Unanticipated circumstances may yield emergency events. Emergency Planning adds additional layer of protection to circumstances where all of the other layers of protection failed to prevent the incident. Figure 3-7 demonstrates the three major components of emergency planning:

Ten chemical plants, three petrochemical facilities, a single gas plant, and a single pharmaceutical facility, participated in the survey study (the Plants). The number of processes in the Plants varies from a single process gas plant to a 160 processes site. The range of number of employees varies between 27 to 25,000 employees.

OSHA PSM and EPA RMP requirements with regard to emergency planning are briefly summarized by Dennison [39].

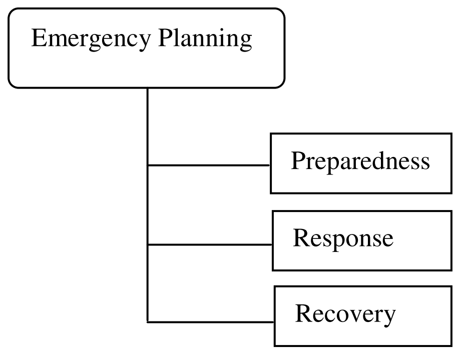


Figure 3-7. Components of emergency planning

Emergency preparedness requires a multi-domain deployment. Preparedness process begins with identification of credible scenarios based on which consequence analyses are conducted, and appropriate response strategies are developed. The analysis of resources and capabilities that are required for response to the emergency scenarios is part of the Preparedness stage. This analysis examines the resources and the capabilities at the facilities, at neighboring sites, and the resources that are available at the local community. The development of resources is conducted according to the resource assessment and the level of corporation amongst these parties and other emergency support organizations. Figure 3-8 presents a flow chart of the emergency preparedness stage.

Since at least two parties are involved in emergency situations, in addition to the network within the facility, communication system becomes crucial element to a successful execution of emergency plans in real time situations as well as in drills.

The complex nature of emergency events requires a very clear hierarchy of command, and a procedure that should be clear of ambiguities. Training and assessments of the potential collaboration among the parties that are involved in the response to emergency events are extremely important. Quite often, preparedness programs are reestablished due to assessments of drills.

The development of physical infrastructure for emergency events consists of the following:

- Development of shelters and safe heavens
- Establishment of Emergency Operation Center (EOC)
- Development of emergency communication capabilities, and
- Development of appropriate medical support infrastructure

Emergency systems are developed parallel to the development of physical facilities. Following is a typical list of emergency systems:

- Emrgency power supply
- Emergency water supply
- Communication systems
- Emergency management support computer system
- Site and community allert systems
- Adequate incident command transportaion
- Appropriate control room protection measures

The objective of this is the benchmarking of Emergency Planning practices among the facilities in the process industries. The ‘Guidelines for Technical Planning for On-Site Emergencies” [40] was one of the references consulted in the development of a questionnaire for this study. The questionnaire was distributed to more than 50 plants, out of which 15 facilities responded. The questionnaire is reproduced in its entirety in Table 3-3.

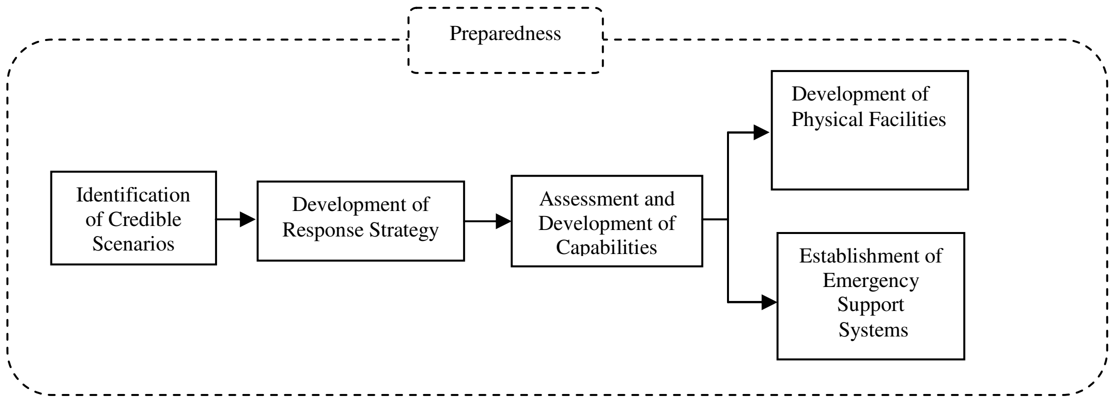


Figure 3-8. Block diagram of the emergency preparedness stage

The effects of September 11th, 2001 events on the security of facilities in the process industries are still not completely understood, and there is no consensus agreeament with regard to the way that emergency planning should address similar events. Thus, this work did not incorporate elements such as vulnerability assessments.

Table 3-3. Benchmarking emergency preparedness programs questionnaire

---

1. Facility Size and Type

1.1 How many employees (including contractors) work at this site? For uniformity, include everyone on the payroll, including the administrative and contract personnel.

____

1.2 How many separate process areas are inside the plant complex?

____

1.3 Which of the following best characterizes the process operations at this site? (Check only one)

Chemical
Refining
Petrochemical
Pharmaceutical
Food
Gas Plan
Other (please specify______________________________)

2. Identifying credible incidents

2.1 A lot of efforts are invested in order to define 'worst credible incidents' in order to plan an emergency program. In some cases, worst possible incidents (incidents with sever consequences, but with very poor likelihood) are taken into consideration during emergency planning. Were worst possible incidents taken into consideration in your facility's emergency planning?

Yes
No

2.2 Our emergency program covers incidents with the following magnitude:
(Check all that are applicable.)

Local incidents
Moderate incidents
Catastrophic incidents

2.3 Which of the following best describes the process of identifying credible incidents in your facility's emergency planning:

Using intuition and rules of thumb
Unstructured expert brainstorming
Applying quantitative risk analysis methods
Investigation of the Process Hazard Analysis to identify credible incidents

Table 3-3. (Continued)

2.4 Incident prioritizing is also necessary for emergency planning. The likelihood of initiation of incident is fundamental to the prioritizing process. However, estimation of the likelihood of failure of the protecting system can contribute to this process and change priorities. Does your emergency planning consider protecting systems failures in the prioritizing process?

Yes, consider incident events and protection systems failure for prioritization
No, consider only incident events for prioritization
Don't know

2.5 Commercial incident modeling software is available to evaluate incidents consequences. How did your emergency planner evaluates these consequences?

Simple calculations.
Homemade software.
Commercial software (specify____________________________).

2.6 Incidents can have long-term effects on the environment. These effects are not simple to estimate. Has your emergency program considered long-term environmental effects?

Yes
No

2.7 Has a catastrophic scenario due to terrorist attack been considered in your emergency planning?

Yes
No

3. Capabilities and resources assessments

3.1 A variety of facilities may be used to support emergency operations. Below is a representational list of facilities [40]). Check all that is available in your plant:

Short-term shelters
Save havens (Shelter with alternative air breathing source)
Incident command post
Emergency Operation Center (EOC)
Media information Center (MIC)
Medical support facility (other the first aid room)
Alternate water supply
Community and facility alerting systems
Real-time modeling system
Emergency management computing system
Emergency power system
Meteorological instruments

3.2 If a medical facility other then first aid room is available, briefly describe its capabilities and limitations:

____

3.3 Preparedness of the nearest hospital may be crucial to the consequences of incidents. Is the nearest hospital capable of handling massive casualties?

Table 3-3. (Continued)

Yes
No
The hospital is not involved in our emergency program

3.4 if yes, is it aware regarding the chemicals used in your facility?
Yes
They have general idea
No

3.5 Is other medical center(s) part from your facility's emergency net?
Yes
No

3.6 Are medical airlift resources available and prepared?
Yes
No

3.7 Are local emergency agencies familiar with the plant layout and hazards?
Yes
No

3.8 Are neighboring sites aware of and prepared for your facility emergencies (and Vice Versa)?
No
They have a general idea
EH&S officers coordinate the mutual emergency preparedness and responses
Corporate committee established and mutual periodical drills are operated

3.9 Are contractors a part of the plant emergency response program?
Yes
No
If yes, are they trained to their jobs?
Yes
No

3.10 Do personnel structure changes cause emergency program re-evaluation?
Yes
No

3.11 Does Management of Change procedure address changes to your emergency program?
Yes
No

3.12 Check the box that applies in your site:
The site consists of a fire brigade
The site depends on local fire department

Table 3-3. (Continued)

3.12 Are fire brigade personnel available outside of daytime shift?

Yes.

No.

3.14 Does the local community fire brigades participating in the site drills?

Yes

No

3.15 Using neighboring sites' emergen cy equipment is efficient in terms of cost-benefit, and can be justified for certain types of equipment. If this case applies to your plant, list the shared type of equipment: ______________________________________

4. Physical facilities and systems

4.1. From reference [40]:

'Shelters - provide passive protection for inhabitants when ventilation is off and all windows and other openings are closed.

Safe havens – Provide protection by providing alternative source of breathing air supply."

Mostly, control rooms are used as shelters or safe havens.

Control rooms in your facility are designed as:

Shelters

Shelters, but other buildings are serving as safe havens

Safe havens

4.2. Which of the following has been assigned to be used as Emergency Operation Center (EOC)?

No EOC in the plant

Control Room

Selecting arbitrary office/room.

Conference room

Specially designed building (or part of a building)

Other (specify____)

4.3. How many employees are required to be in the EOC in emergency?

1-10

10-20

20-50

Higher

4.4. What is the distance between the EOC and the nearest process?

Less than 50 yards

50 –100 yards

100 – 300 yards

300 – 1000 yards

More then a mile

4.5. Is an alternative EOC available?

Yes

No

Table 3-3. (Continued)

4.6. The EOC is designed as a (see 4.1 for explanation of terms):
Shelter
Safe haven

4.7. Is an emergency power supply available to the EOC?
Yes
No

4.8. Which of the following best describes your medical support facility (MSF)?
First aid room
Day to day emergency clinic
A large room equipped to become MSF
Designated building (or part of building) to serve as MSF

4.9. An industrial fire truck is a powerful piece of equipment in certain scenarios. Does your plant employ one?
Yes
No

5. Communication

5.1. Do local, off-site agencies hold open emergency open channel(s) to the plant?
Yes
No

5.2 who are the local community representatives that your plant is coordinating and communicating with?
Emergency Management agency
Fire department officers
County emergency service director
City manager officers
Mayor
Other (specify____)

5.3 Is a tone alert system installed in your plant?
Yes
No (if other systems then tone alert, specify)

____

5.4 List the tone alert system codes and their meanings:

____

5.5 What type of alert system(s) is being used to inform the local community regarding emergencies?

Table 3-3. (Continued)

Tone alert system
Cable television override system
Computer telephone dialing system
Other:

5.6 How often are on-site and off-site alarm systems tested?

On-site	**Off-site**
Not tested at all	not tested at all
Weekly	Weekly
Monthly	Monthly
Quarterly	Quarterly
Every six months	every six months
Annually	Annually
Not applicable	Not applicable

5.7 An emergency program may be supported by variety of agencies and organizations. Check those that are applicable in your plant 's emergency program:

Fire department
Police department
Emergency medical center
Office of emergency service
Emergency preparedness organization
Civil defense agency
Local emergency planning committee
Department of health
Highway department
Public and private hospitals
Red Cross
Salvation Army

6. Metrics

6.1 Have you developed procedures to measure your emergency program effectiveness?

Yes
No

6.2 Did you develop your own metrics or adapted from other sources?

Developed own metrics
Adapted from other sources
Not applicable

6.3 Is your metric procedure designed to measure the adequacy of existing emergency facilities, supplies, and equipment?

Yes
No
Not applicable

Table 3-3. (Continued)

6.4 Is your metric procedure designed to measure your level of coordination with off-site emergency response agencies?

Yes
No
Not applicable

6.5 How frequently is your emergency program reviewed:

Annually
Minimally, as required by OSHA PSM regulation
Minimally, plus after major changes applied
Other:

7 Positions

7.1 Who is designated to serve as Incident Commander (IC)?

Relevant production manager
Relevant plant manager
EH&S officer
Vice president
CEO
Other: ______________________

7.2 Who is responsible for determining the severity of an incident (Local, moderate, catastrophic)?

Production manager
Plant manager
EH&S officer
IC

7.3 Who is responsible for updating the equipment and supply inventory lists?

Operation personnel
EH&S personnel
Contractor
Other: ______________________

7.4 Who makes the evacuation decision?

Production manager
Plant manager
EH&S officer
IC
Other: ______________________

Table 3-3. (Continued)

8. Training

8.1 Employees, regardless of their responsibilities during emergencies, are required to be trained for emergency awareness and response. Below is a list of subjects that can be covered by non-emergency team employee training. Check all the subjects that are applicable in your facility:

- Identification of hazardous situations
- Identification of physical warning signs (smoke, smell,..)
- Evacuation routes and shelter locations
- Emergency reporting procedures
- Usage of PPE
- Identification of types of fire
- Usage of proper fire extinguishing equipment
- Drills on usage of PPE and fire extinguishing

8.2 Are contractor employees trained like other employees?

- Yes
- No

8.3 Who is responsible for coordinating the emergency training program?

- Plant manager
- EH&S officer
- PSM team
- Human resources
- Other: ____

8.4 Is simulated crisis communication drilled?

- Yes
- No

8.5 Are training records kept in your plant?

- Yes
- No

The Process of Identification of Credible Scenarios

The process of identifying credible scenarios reveals events that emergency planning should address. A process hazard evaluation will lead to a large list of potential incidents. This list should be assessed to determine likelihood and consequences of each of the incidents and then prioritized according to the risk associated with them.

For each incident it is possible to determine the worst-case scenario. Loss of containment, where all the material is being released instantaneously is a worst-case scenario. However, the likelihood of development of such a scenario is extremely low.

Preparedness for emergencies that consist of worst-case scenarios requires enormous resources and may overwhelm the business operability of the facility. For each scenario, the outcomes should be listed, and the consequences and probabilities should be evaluated, while considering the facility's management control. Events such as instantaneous loss of containment are of major concern in the process industries, however, measures, such as control systems, overpressure relief, alarms, mechanical as well as non-destructive tests reduce the likelihood of development of such as scenario.

93% of the plants considered worst-case scenarios in the development of their emergency plans. These plans cover all three levels of magnitudes of events: local, moderate, and catastrophic.

Identification of Process Areas with High Hazards

The majority of the facilities in the process industries have a large inventory of hazardous chemical in many areas in the facility. The large number of chemicals along with the large number of equipment and the variety of potential incidents that can occur from the combinations of chemicals-equipment lead to an enormous number of possible scenarios. As noted earlier, it is impractical to plan for all emergencies. Therefore, it is neccesary to analyze and prioritize the scenarios. This process is presented in Figure 3-9. Large number of techniques and available for the identification of areas of major hazards. The results of examination of the plant with these techniques leads to a list of ranked areas that are analyzed to identify credible scenarios. However, the results of the analysis may vary if the analysis does not consider protection system failure. Only three of the plants took into consideration failure of protection systems in the process of ranking scenarios for emergency planning.

Techniques for Identification of Credible Scenarios

As with identification of areas with major hazards, variety of techniques are available to identify Credible Scenarios. The depth of analysis can vary from an informal review that involves intuition to a full Process Hazard Analysis session. Results from a

Process Hazard Analysis (PHA) can be extremely helpful if the analysis is done thoroughly, since identification of credible scenarios is one of the purposes of conducting PHAs.

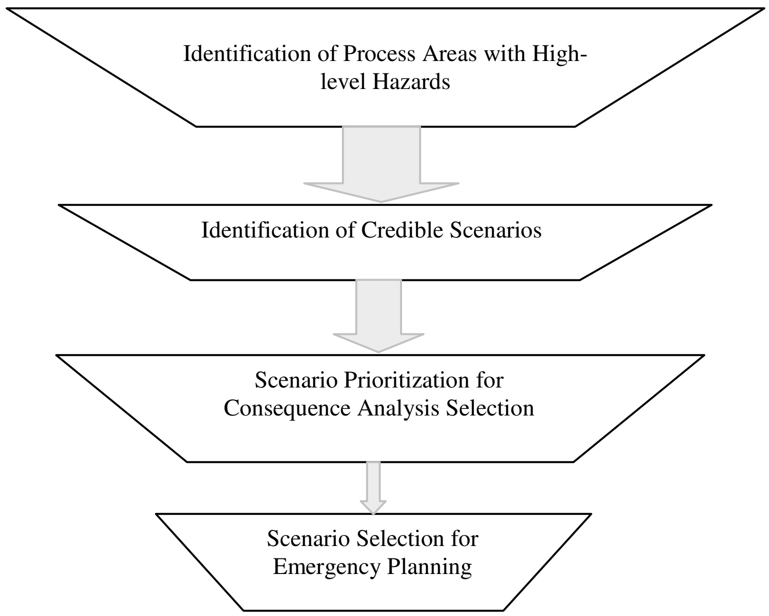


Figure 3-9. Process of scenario selection for emergency planning

The participants in the survey were asked to check which of the following four best describes the process of identifying credible scenarios in their plants:

- Using intuition and rules of thumbs
- Unstructured expert brainstorming
- Application of Quantitative Risk Analysis methods
- Use of the Process Hazard Analysis (PHA) to identify credible scenarios

As Figure 3-10 reveals, the majority of the facilities used PHA results for the process of identifying credible scenarios. 20% of the plants conducted quantitative risk analysis, and only one of these 20% used quantitative risk analysis as the only tool for credible incident identification. The only plant that used intuition and rules of thumbs used quantitative risk analysis and PHA results as well.

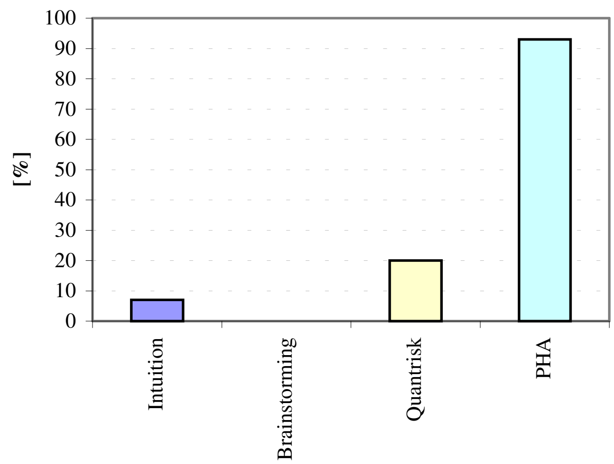


Figure 3-10. Methods to identify credible scenarios

Consequence analysis is a thorough procedure that requires major efforts. Therefore, several commercial software were developed in the early to mid 90's to support this procedure. EPA, as an example, offers free downloadable software on its website, that can be useful in consequence analysis. However, other organizations have used commercial software as well as tailored software in order to be able to respond to EPA RMP, and OSHA PSM requirements. The survey reveals that currently none of the plants are using tailored software for consequence analysis. However, 27% are using simple calculations to assess the consequences of the various scenarios. Only 20% of the plants use programs that are available (free) on the website of the Environmental Protection Agency. Long-term as well as short-term effects on the environment are being considered in the plans of 60% of the plants.

As noted earlier, the effects of 9/11/2001 events are not addressed in this study. However, the plants were asked whether their emergency program considered catastrophic scenario due to terrorist attack. 73% responded positively.

Assessment of Capabilities and Resources

The magnitude of incident that the credible scenarios will cause is the input to the process of assessment of resources and capabilities.

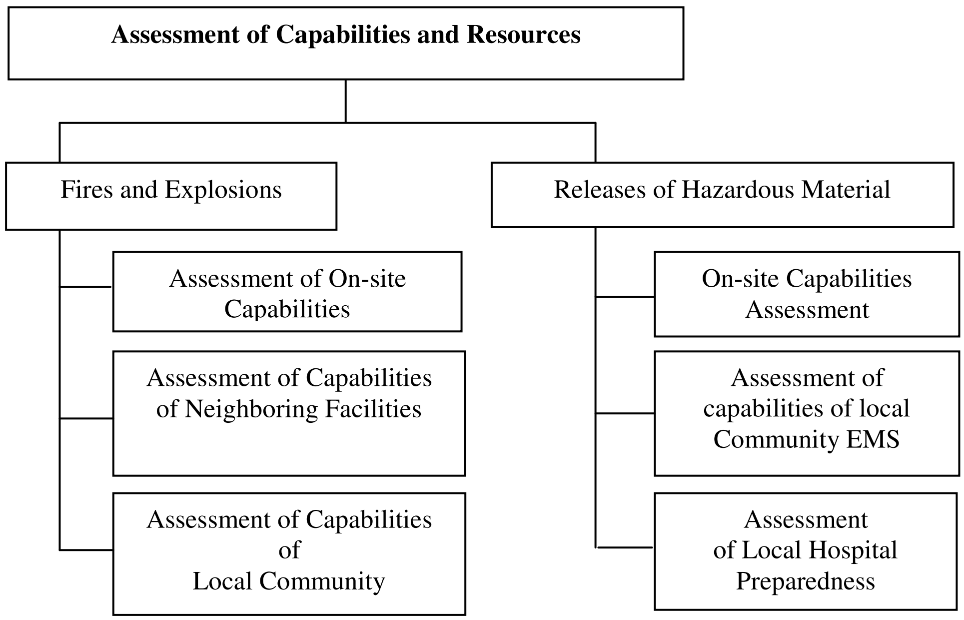


Figure 3-11. Assessment of resources and capabilities

As Figure 3-11reveals, the resources that are required to deal with emergencies are based on assessments in three domains:

- On-site
- Neighboring facilities
- Local community

Emergency Support Facilities

Following is a list of emergency support facilities that are useful in emergency scenarios:

- Short-term shelters [StS]
- Safe havens (Shelter with alternative air breathing source) [SH]
- Incident command post [ICP]
- Emergency Operation Center [EOC]
- Media information Center [MIC]
- Medical support facility (other than first aid room) [MSF]
- Alternate water supply [AWS]
- Community and facility alert systems [ALERT]
- Real-time modeling system [RtMS]
- Emergency management computing system [EMCS]
- Emergency power system [EPS]
- Meteorological instruments [MI]

Figure 3-12 demonstrates the level of availability of these facilities among the plants. Safe Havens are available at 40% of the plants, alternate water supply is available at 33% of the plants only, and emergency management computing system is part of the emergency support systems at 20% only. Other supporting facilities are quite common among the plants in the survey.

Medical Facilities

As for medical facility other than first aid room, three of the plants have capabilities of a medical department. These facilities consist of medical doctors, nurses, and variety of equipment to support emergency situations as well as day-to-day needs. Common to these plants is that they consist of more than 5,000 employees. Third of the participants do not employ medical support facility that is more than a first aid room. The medical capability of the other 7 plants are better than that of a first-aid room and can be used for stabilization of the patients until they are evacuated to the nearest local community medical facility.

The capability of the nearest hospital to handle massive casualties is an important parameter in emergency planning. Furthermore, awareness of the hospital with regard to the chemicals that are being used in the plant could be crucial to the ability to handle casualties in incidents that involves release of hazardous materials. 93% of the plants indicated that hospitals in their area can handle massive casualties. Hospitals near 80% of the plants are aware about chemicals in the facilities, and hospitals near the other 20% have a general idea only.

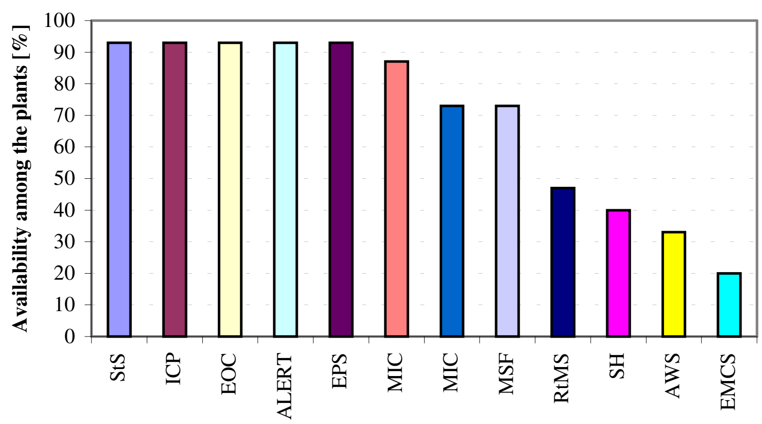


Figure 3-12. Availability of emergency support facilities

However, 87% of the plants increased their emergency net to medical facilities other than the nearest one, and have a medical airlift available and ready at all time.

Fire Fighting

On-site fire brigade are available at 93% of the plants, and their fire fighters are available outside of daytime shift. Local community fire brigades participate in site drills of all the plants. Only 40% of the plants have some form of mutual assistance and equipment sharing. However, 80% of the plants have equipment with at least a single fire truck. One of the plants noted that all their equipment is listed on a master database and is available from/to 17 industries, 25 fire departments, 11 law enforcement agencies, and 22 public safety agencies under a master mutual aid agreement.

Physical Facilities and Systems

Shelters: -CCPS [41] defines the following:

- 'Shelters - provide passive protection for inhabitants when ventilation is off and all windows and other openings are closed".
- 'Safe havens – Provide protection by providing alternative source of breathing air supply".

Control rooms are used as shelters or safe havens. Control rooms are used as shelters at 53% of the plants, and safe havens are not available. At 27% of the plants control rooms are used as safe havens in emergencies, and in the remaining 20%, control rooms are shelters, however, other facility is used as safe haven.

Emergency Operation Center (EOC): - Assessments, development of response strategy, communication and control of activities in emergency event are conducted from the EOC. The EOC allows the emergency management and staff to effectively supervise the activities and to make decisions with regard to development of events in the area. Factors such as the facility that is being used as EOC, distance of the EOC from processes, and the design of EOC have an enormous effect on the effectiveness of emergency operation and management.

Following is a list of facilities that can be used as EOC:

- Control Room
- Arbitrary office/room
- Conference room
- Specially designed building

Specially designed buildings are being used by 80% of the plants as EOC. 13% are using conference room, and one of the plants uses facility other than these in the list.

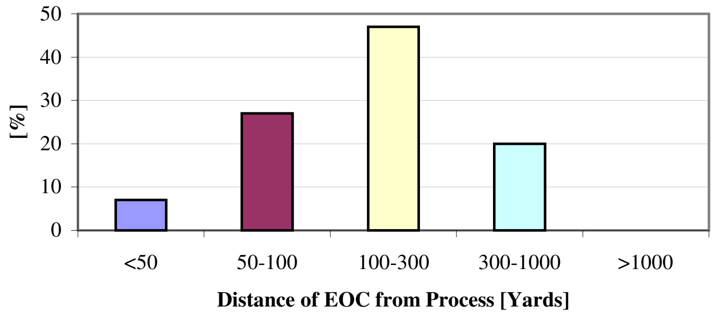


Figure 3-13. Distribution of distances of EOC from process areas

Eighty percents of the plants reported having an alternative EOC. Two of the plants indicated that the alternative EOC is located off-site. The EOCs are designed as shelters at 80% of the plants and as safe havens in the others.

The distance between the EOC and the processes is one of the factors that determines the EOC sensitivity to the intensity of the events. Figure 3-13 shows the range of distances of EOCs from the nearest process in the plant.

Alternative power supply is crucial in emergencies. Only one of the plants reported a lack of alternative power supply for their EOC.

Communication

Several elements in emergency planning are extremely crucial to appropriate execution of emergency response. An effective communication net is one of these elements. The net is required to allow communication between the following: EOC and on-site responders, EOC and off-site responders, EOC and local agencies, EOC and corporate management, EOC and local medical facilities, EOC and employees, Incident Commander and responders, EOC and employees' families, and EOC and media. A convenient way to maintain communication is by maintaining an open channel between the local off-site agencies and the plant, as indicated by 93% of the respondents. The majority of the plants coordinate and communicate their emergency planning with the Emergency Management Agency, and with the fire departments. Half of the plants involved the County Emergency Service Directors in their plans, and 20% involve the City Management Officials and the mayor as well.

As for alert systems, tone alert system is available at all the Plants. Although tone alert system codes vary, the majority consists of at least three codes: weather-related, major emergency, and evacuation.

Local communities can be informed about emergency situations in several ways. Tone alert systems and computerized telephone dialing systems are commonly used by half of the plants. Cable TV override system is an alert measure too, however, it is being used by only 27% of the plants. The local authority is identified as another way to communicate the emergency to the local community by 27% of the plants. Common to these plants is that this type of alerting system is the only measure to warn the community a developing emergency event.

On-site alarm system is tested weekly by all of the plants. Off-site alarm systems are tested weekly or monthly by 60%, and annually by one of the plants. The other 33% do not test the alert system or an off-site alert system is not part of their emergency system.

An emergency program may be supported by variety of organizations. Figure 3-14 emphasizes the level of involvement of these organizations in emergency planning among the plants.

As can be expected, fire and police departments support most of the programs. 75% of the plants involve the Local Emergency Planning Committees (LEPCs) in their plans.

Metrics

Only 60% of the plants have procedures in place to measure the effectiveness of their emergency program. The procedure is being used to measure the adequacy of existing emergency facilities, supplies, and equipment in all 60% of these plants. Moreover, at all of these plants, but one, the procedure examines the effectiveness of coordination with off-site emergency response agencies.

Ninety percents of the plants review their program annually. One of these plants reported a semi-annual management review as well, and that any incident and potential incident generates a discussion of response planning and contingencies in investigation and safety meeting.

Positions

Table 3-4 presents the distribution of the variety of positions in the plants who assume the role of an Incident Commander (IC) during an emergency. Determination of the severity of an event, decision with regard to the level of escalation, and timing of this decision has tremendous effect on the consequences. Misinterpretation of magnitude as local instead of moderate, or as moderate instead of catastrophic can cause significant loss and many casualties. Therefore, the personnel that are assigned to make this decision carry a heavy burden. At 87% of the plants IC is responsible for this decision. EH&S officers are responsible for this decision at the other 13%. At 93% of the plants the decision on evacuation is in the hands of the Incident Commander. Only one of the plants nominates EH&S officers to make this decision. In two of the plants the decision is in the hands of two positions: (1) plant manager as well as Incident Commander; (2) Incident Commander as well as lead operator.

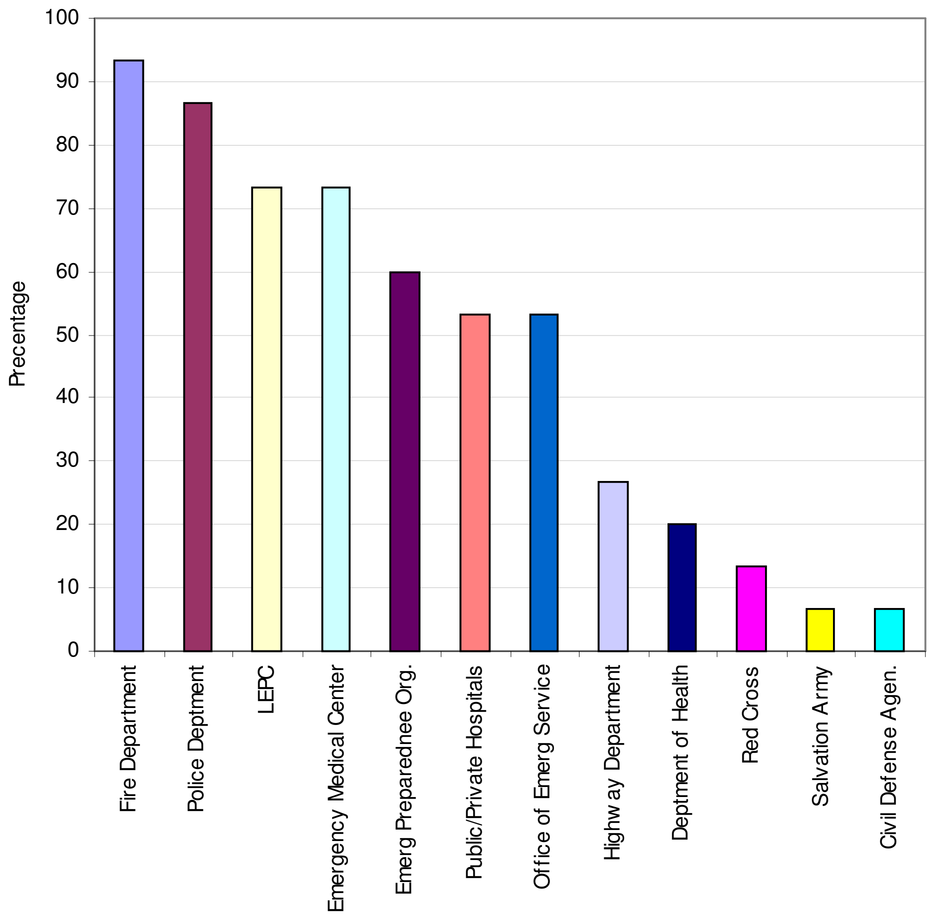


Figure 3-14. Level of involvement of organizations in emergency planning

The responsibility of equipment updating and supply inventory is distributed as follows:

- EH&S officers at 67% of the plants
- Emergency Response Personnel at 33% of the plants, and
- Production Manager at 7% of the plants

Training

Employees are required to be trained for emergency awareness and response, regardless of their responsibilities during emergencies. The "Guidelines for Process Safety Fundamentals in General Plant Operations" [41] provides descriptions of these types of training. Table 3-5 consists of a summary list of training subjects and distribution of its implementation in the plants.

Table 3-4. Distribution of variety of positions in the plant as IC

Position	Distribution [%]
Emergency Response Officer	40
Production Managers	27
Plant Superintendent	13
EH&S Officer	13
Plant Manager	7
Executives	0

Table3-5. Distribution of implementation of training subjects

Training Subject	Distribution of Implementation [%]
Identification of hazardous situations	100
Identification of physical warning signs (smoke; smell;..)	87
Evacuation routes and shelter locations	100
Emergency reporting procedures	100
Usage of PPE	100
Identification of types of fire	93
Usage of proper fire extinguishing equipment	100
Drills on usage of PPE and fire extinguishing	80

The survey reveals that contract employees are provided the same training as other employees at 60% of the plants only. The responsibility to coordinate training for emergency preparedness is mainly in the hands of EH&S officers and personnel in similar positions. As for training records, only one of the plants reported that these records are not kept. 80% of the plants simulate crisis communication in their drills.

Summary and Conclusions

The study reveals several interesting findings. Only 20% of the plants consider protection systems failure in the process of ranking scenarios for emergency planning. This process is sensitive to the presence of these systems. The results of PHA session are used as an input for the process of identification of credible scenarios widely. Although EPA's website offers free softwa re to support consequence analysis, only 20% of the plants take advantage of the free software.

The analysis of resources and capabilities revealed that safe havens are available at 40% of the plants, and that alternative water supply is available at 33% only. Plants that consist of more than 5,000 employees employ medical facility with the capabilities of a medical department. 80% of the plants are equipped with at least one fire truck. Although alert systems that directly warn the public with regard to emergencies is a convenient measure in terms of early notification, 27% of the plants in the survey depend on the local authorities for the notification of the public.

Procedures that evaluate the effectiveness of emergency program have been developed by 60% of the plants. However, 93% of the plants review their program annually.

The survey revealed that contract employees are provided the same training as other employees by 60% of the plants.

Benchmarking of Incident Investigation Practices Questionnaire

General

Facilitating a well-developed Incident Investigation procedure is a crucial component in Process Safety Programs. OSHA requires that regulated facilities develop a procedure to investigate incidents. The regulations specify a timeframe for the initiation of an investigation and basic requirements for an investigation team. Incident Investigation is a through process and is implemented in various ways. Incident investigations may vary in the major approach to the investigation, the type of techniques that are used, the way evidence is treated, and other characteristics.

The "Guidelines for Investigating Chemical Process Incidents" [42] was one of the references consulted in the development of a questionnaire for benchmarking Process Safety Incident Investigation (PSII) practices. The development of the following questionnaire is aimed at identifying the diversity of implementation of these practices in the industry.

Definitions

The definitions of several of the major parameters in incident investigations may vary slightly in the literature. The following definitions were used in this document:

- *Root Cause*: - an underlying prime reason why an incident occurred
- *Deductive Approach:* - Deductive logic progresses from the general to the specific. A major event is placed in the top of the problem and the logic progress backward in time and examines possible scenarios that can develop a path to the top
- *Inductive Approach:* - In Inductive Approach, the logic progress from a selected event or set of facts, and moves forward in time, examining possible effect, results, and consequences

- *Multiple Root Cause Analysis*: - A deductive search for all credible scenarios in which an event could occur.

The Questionnaire

Table 3-6 consists of the questionnaire for benchmarking PSII.

Table 3-6. Benchmarking process safety incident investigation programs questionnaire

1. **General Approach**

1.1 There are three major approaches to conduct PSII. Check the one that best describes the approach in your plant:

☐ Informal investigation performed by immediate supervisors

☐ Committee-based investigations using expert judgment to find a credible solution of cause and remedy

☐ Multiple-cause, systems oriented investigation that focuses on root cause determination, integrated with an overall process safety management program

2. **PSII Techniques**

2.1 Which of the following types of analysis are mainly used for PSII in your plant?

☐ Deductive

☐ Inductive

2.2 The following list consist of large number of techniques for PSII. Please check all the techniques that are being used in your plant for PSII:

☐ Fault Tree Analysis (FTA)

☐ Causal Tree Method (CTM)

☐ Management Oversight and Risk Tree (MORT)

☐ Multiple-cause, systems-oriented Incident Investigation Technique (MCSOII)

☐ Accident Anatomy Method (AAM)

☐ Action Error Analysis (AEA)

Table 3-6. (continued)

- ☐Cause-Effect Logic Diagram (CELD)
- ☐ Hazard and Operability Analysis (HAZOP)
- ☐ Accident Evolution and Barrier (AEB)
- ☐ Work Safety Analysis (WSA)
- ☐ Change Evaluation/Analysis (CEA)
- ☐ Human Performance Enhancement System (HPES)
- ☐ Human Reliability Analysis (HRA)
- ☐ Multi-linear Event Sequencing (MES)
- ☐ Sequentially Timed Event Plot (STEP)
- ☐ Systematic Cause Analysis Techniques (SCAT)
- ☐ TapRoot™ Incident Investigation System
- ☐Technique of Operations Review (TOR)

2.3 Several of the techniques listed above were originally developed as computer-based techniques. Are computer-based PSII techniques implemented in your plant?

- ☐ Yes
- ☐ No

The validity of PSII techniques consists of many parameters. Several of these parameters are listed in the questions bellow.

2.4 PSII techniques in your plant are effective in supporting the following (Check all that apply):

- ☐ Near-misses
- ☐ Minor Incidents
- ☐ Major Incidents

2.5 The extent of acknowledging standards and industrial guidelines in the implementation of PSII techniques in your plant is as follows:

- ☐ Weak
- ☐ Moderate
- ☐Strong

2.6 PSII is not an exact science. The degree of freedom in judgment during implementation of PSII techniques may vary widely. Implementation of PSII techniques in one plant may be very prescriptive and may reduce user

Table 3-6. (continued)

subjectivity to minimum, while implementation of the same technique in other plant can be strongly dependent on user identity.

Implementation of PSII techniques in your plant is:

☐ Prescriptive, the user is required to maintain a minimal level of judgment

☐ Moderately dependent on the user - certain degree of judgment is required from the user, however his/her degree of freedom is limited

☐ Strongly user dependent – it is likely that two different users will arrive at different conclusions

3. Databases

Incident related databases could be helpful in learning from the experience of others, sharing information with others, and identifying areas of weaknesses, benchmarking performance, and more. The following questions aim to reveal the level of incorporation of databases in the process of PSII.

3.1 Is equipment reliability performance recorded in your plant?

☐ Yes

☐ No

3.2 Are these records submitted to a database?

☐ Yes

☐ No

If yes, are these records submitted to a central reliability database (similar to the equipment reliability database that the Center for Chemical Process Safety maintains)?

☐ Yes (Please specify: ______________________________)

☐ No

3.3 Does the PSII procedure in your plant use historical information from incident databases such as EPA ARIP (Accident Release Information program), EPA Risk Management Program (RMP), etc.?

☐ Yes

☐ No

(If yes please specify:___________________________________)

Table 3-6. (continued)

4. Management Commitment

4.1 Which of the following best describes the characteristics of implementation of PSII procedure in your plant?

☐ Focus on finding causes

☐ Focus on assigning blame

4.2 In your opinion, is the resource of PSII sufficient to sustain the investigation?

☐ Yes

☐ No

4.3 The level of implementation of recommendations from PSII is among the indicators of the commitment of the management system to process safety. Which of the following best describes the level of effort invested in implementation of PSII recommendations?

☐ Low

☐ Moderate

☐ High

4.4 As with level of implementation of recommendations, the level of communication of "lessons learned" is among the indicators of management commitment to process safety. Which of the following best describes the situation in your plant?

☐ The value of learning lessons from incidents is strongly emphasized

☐ Lessons learned from previous incidents are discussed in formal occasions such as safety trainings and meetings

☐ Lessons learned are rarely communicated

4.5 The investigation of near-misses may have the same benefits as PSII. However, these investigations are not as common as PSII. Are near misses investigated in your plant?

☐ No

☐ Yes

Table 3-6. (continued)

If yes, are there any parameters governing the decision to investigate near-misses?

☐ No. All near-misses are investigated

☐ All near-misses are investigated, however, the extent of the investigation varies

☐ Yes, the parameters are as follows: ________________________

____

____

4.6 Does the system in your plant establish a positive and comfortable environment that encourages reporting incidents and near-misses?

☐ Yes

☐ No

4.7 Briefly describe the way lessons learned are being communicated in your plant: ____

____

____

4.8 Organizations use periodic publications of incident abstracts to communicate lessons learned. Does your organization use periodic publications for that purpose?

☐ Yes

☐ No

5. Investigation Team

5.1 The extent of incidents and near-misses varies, and affects the need, size and structure of the investigation team. Please specify the way incidents and near-misses are classified in your plant, and the way it affects the structure of the team:

____

____

____

____

____

Table 3-6. (continued)

5.2 Are off-site members included in your investigation team?

☐ Yes

☐ No

5.3 Are representatives of the local community and of regulatory agencies involved in the investigations of near-misses and incidents that might effect the population in this community?

☐ No

☐ Yes

If yes, please specify: ____

____

____

____

5.4 There are several major objectives of PSII. Please check those that are the responsibility of the investigation team:

☐ Identify system related multiple root causes

☐ Determine recommendations and actions to be taken to prevent recurrence of incidents and similar events

☐ Implement the recommendations

☐ Follow up on the recommendations

5.5 Are PSII training and refresher training conducted on a regular basis?

☐ No

☐ Yes

If yes, which of the following groups are subjected to this training:

- ☐ Senior management
- ☐ Mid-level management,
- ☐ First line supervisors, etc.

5.6 Specify who are mainly appointed as team leaders in PSII:

____

____

____

Table 3-6. (continued)

5.7 Are recommendations on disciplinary actions in the scope of the PSII team?

☐ Yes

☐ No

6. Evidence

6.1 Physical evidence is required for two distinct phases: the immediate and the long-term. Does the PSII procedure in your plant address storage for evidence:

☐ No

☐ One central storage area is dedicated for short and long-term evidence storage

☐ Long-term evidence is storage appropriately if required

6.2 Among the early stages of the implementation of a PSII procedure is the establishment of a protocol of systematic identification of all the expected evidence, and a coding system for this evidence. Does the PSII procedure in your plant develop such a protocol and coding system?

☐ No

☐ Develop a protocol for identification of evidence only

☐ Develop a coding system only

☐ Yes, both

6.3 Does the PSII procedure in your plant consist of a procedure for document Control?

☐ No

☐ Yes

if yes, does the size and scope of investigation mandate the extent of the documentation?

☐ No

☐ Yes

Table 3-6. (continued)

6.4 Does the PSII procedure in your plant call for simulations and re-creations in cases of gaps or contradictions of information?

☐ Yes

☐ No

7. Recommendations

7.1. In this stage preventive action is developed and examined for each of the root causes. Evaluation of the selected preventive actions for Management of Change (MOC) at this stage can save time and effort if the preventive action under investigation does not satisfy the MOC program criteria. Which of the following applies in your plant?

☐ Evaluation for MOC is conducted at this stage

☐ Evaluation for MOC is conducted only at the last stage before implementation of the preventive actions

☐ The PSII procedure does not address MOC.

☐ Other: ____

____

7.2 Does the PSII procedure in your plant require establishing criteria for restart and operations following an incident investigation?

☐ Yes

☐ No

7.3 Does the PSII procedure in your plant call for improvement that aims for inherently safe design?

☐ Yes

☐ No

7.4 Do regulatory agencies have jurisdiction and authority over restarts following incidents in your plant?

☐ Yes

☐ No

If yes, please specify: ____

____

____

____

Table 3-6. (continued)

7.5 Presentation and review of the recommendations with the area management responsible for the operation of the line that experienced the incident can be extremely beneficial. Is such a session required by the PSII procedure in your plant?

☐ Yes

☐ No

7.6 Does the PSII procedure in your plant aim to examine the validity of your emergency plan?

☐ Yes

☐ No

7.7 Please describe the incident classification criteria employed in your plant:

____

____

____

____

____

____

8. Metrics

8.1 Have you developed a program to measure PSII effectiveness?

☐ Yes

☐ No

8.2 Did you develop your own metrics or adapted them from other sources?

☐ Developed own metrics

☐ Adapted metrics from other sources

8.3 Please describe any general impressions of the PSII procedure at your plant, portions of this program that are causing difficulty, suggestion to improve the efficiency of the PSII program, etc.

____

____

____

____

____

____

Summary

The Benchmarking of Process Safety Incident Investigation questionnaire addresses the general approach to PSII, PSII techniques, use of databases, management commitment to PSII, investigation team, evidence, recommendations following the investigation, overall perception, and quality control. The questionnaire is designed to identify how major themes are addressed in the implementation PSII procedures.

CHAPTER IV

USE OF INCIDENT DATA COLLECTION FROM VARIOUS SOURCES FOR INDUSTRIAL SAFETY PERFORMANCE ASSESSMENT

Introduction

A large amount of information exists about industrial incidents. Many federal and local agencies maintain data collection systems; however, databases have no value without development of data analysis systems. Data mining is the most convenient way to explore databases. Unlike data mining applications for marketing purposes, in process safety management it is extremely important to verify the correlation between the variable and the target variable, since the cost of error is often human life. Indicators have been found to be the most convenient way to explore incident databases. Indicators, if developed correctly, allow tracking of single variables along the time axis and identifying trends. Using indicators creates the opportunity to identify the effects of introduction of new technologies, new standards, regulation changes, and policy changes on safety performance.

Although the literature specifies large number and types of indicators [4,5,6,7,8,9,10,11], these indicators can be grouped as follows:

- **Leading indicators** - Leading indicators are upstream measures indicating whether a process is in control. In the safety universe leading indicators measure activities to diagnose problems and indicate corrective action. The Management of Change index in chapter II is an example of a leading indicator.
- **Trailing indicators -** Trailing measures result from events in the working environment, and usually have a negative connotation. Number of incidents, number of injuries, number of fatalities, number of hospitalizations, number

of evacuations, property loss, and production down times are typical trailing indicators.

The assessment in this study is based on incidents-related databases, which are downstream records (i.e., trailing indicators). This chapter presents a methodology of integrating and harnessing various sources of incident data collection to assess industrial safety performance. The methodology was applied to data on the propane industry in 1998. A comparison of the contribution of using this methodology to the contribution of using the 'best" single source of data is being conducted as well. This study was conducted in two phases:

First phase, an establishment of Criteria: the framework for the study is established in this phase. The phase consists of several sections as follows:

- Determining the scope of products
- Definitions regarding what type of incidents should be excluded
- Definitions regarding the indicators that will be used
- Analysis of usefulness of incident data sources
- Development of a data integration procedure for each one of the sources
- Establishment of database structure
- Development of a procedure for identification of duplicates
- Development of a procedure for estimation of the total number of propane incidents nationwide

Second phase, an assessment of data for 1998: This phase begins with initial identification and assessment of all databases that contain propane incident information. The data from 1998 were filtered, vetted, analyzed, and incorporated into a consolidated database. The propane incident data from the consolidated database was then analyzed to identify patterns and distribution of incidents. A survey that was originally designed to extrapolate NFIRS numbers in order to help estimate the total number of propane incidents nationwide revealed several interesting findings which are presented later in the report.

Definitions

Incidents

In order to accomplish the objectives of this study, many databases were reviewed to establish criteria for database analysis. In order to conduct a meaningful review of the existing databases, it is needed to establish specific criteria and definitions. This section provides the definitions, reasoning, and limitations for analysis of the databases to assess propane safety in the United States and create a baseline from which to measure performance of other years in the future.

The following definition of incident was used for the Propane Incident Data Collection study: "An incident is an unplanned or unintentional event or exposure to propane, liquefied petroleum gas, LPG, propylene, normal butane, isobutene, or butylenes[5] that caused or reasonably could have caused a release, death, injury, evacuation, sheltering in place, environmental damage or property damage". The definition requires several sub-definitions as follows:

- Death: Incident resulting in a fatality
- Injury: Incident resulting in medical treatment beyond simple first aid, loss of consciousness, or diagnosis of a condition or illness by a physician to either a company employee or to the general public
- Evacuation: Incident resulting in a recommendation to vacate the area issued by the emergency authority having jurisdiction
- Environmental Damage: Incident resulting in acute or chronic effects to sensitive ecosystems, migration routes, vulnerable natural areas, or critical habitats of threatened or endangered species

[5] Products in this definition will be referred to as propane in this document

- Property Damage: Incident resulting in either onsite or offsite physical damage to property

The database consists of a large number of fields. These fields are divided into two groups: (1) major fields- parameters that are used in the study; and (2) auxiliary fields – parameters required for integration of databases and other procedures. These fields are not parameters in the study (The zip codes field is an example of an auxiliary field.) A list of the major fields is given in Appendix C. The following is a list of indicators that are used in the analysis stage:

- Number of incidents
- Number of fatalities
- Number of injuries
- Number of fires
- Number of explosions
- Number of evacuations, and
- Property damage

The values of these indicators were measured in several domains:

- Equipment involved
- Vehicle involved
- Structure involved, and
- Cause of incidents.

A major advantage in using indicators is the opportunity to identify trends through several years. However, the advantage of this process could not be implemented because data required for implementation of the methodology was available for only 1998.

Near-Misses

The scope of Phases I and II does not include the collection of near-misses. It is difficult to conduct investigations on past incidents with severe consequences, and nearly impossible to conduct such investigations for near-misses.

Inclusion of Incidents

For the purposes of this study, incidents that are included are as follows:

- Incidents where one or more of the following products were involved:
    1. Propane
    2. Liquefied Petroleum Gas
    3. Propylene
    4. Butane
    5. Butene
    6. Butylene

- Incidents where one of the above products was present even if not released or ignited
- Incidents where one of the above products was involved even if it was not the first material ignited
- Railroad incidents
- Pipeline incidents
- Propane-related incidents, where carbon monoxide was involved
- Incidents where propane was used as a propellant
- Intentional inhalation of product (i.e., huffing)

Sources of Information and Data Integration

Review of Sources of Data

A thorough analysis of existing databases that collect information on industrial incidents was conducted. As shown in Table 4-1, fifteen databases from ten sources were integrated. These databases were selected because they contain information that could be used to establish metrics for the propane industry.

Table 4-1. Sources of information and databases

Source	Database	Usefulness
Federal Emergency Management Agency (FEMA)	National Fire Information Reporting System (NFIRS)	Very
U.S. Consumer Product Safety Commission (CPSC)	• National Electronic Injury Surveillance System (NEISS) • Death Certificates • Investigation Summary • Incident Summary	Very
Mary Kay O'Connor Process Safety Center (MKOPSC)	News Clipping Database	Very
Propane Gas Associations	State of Iowa State of Florida	Marginal
State Agencies	State of Texas	Very
National Response Center (NRC)	Incident Reporting Information System (IRIS)	Marginal

Table 4-1. (continued)

Source	**Database**	**Usefulness**
US Department of Health and Human Services, The Agency for Toxic Substances and Disease Registry	Hazardous Substances Emergency Events Surveillance (HSEES)	Marginal
U.S. Department of Transportation (DOT)	• Hazardous Material Incident • Reporting System (HMIRS) Integrated Pipeline Information • System (IPIS) also known as Hazardous Liquid Accident Data (HLAD).	Moderate
U.S. Environmental Protection Agency (EPA)	Risk Management Program (RMP) 5-year Accident History	Marginal
U.S. Department of Labor, Occupational Safety and Health Administration (OSHA)	Accident Investigation System	Marginal

The following tables provide an overview of the sources and the databases. The overview includes:

- Information on the covered universe, which explains what type of facilities must report and what regulation mandates the gathering of the data;
- Collection method, which explains how the agency gathers the required information;
- Principal data elements of the database that provide a brief description of the type of data found in the database;
- Strengths of the database; and
- Weaknesses of the database.

Table 4-2 consists of an overview of the US Fire Administration database, the National Fire Information Reporting System (NFIRS):

Table 4-2. An overview of NFIRS

Covered Universe	In 1974 the USFA was authorized to gather data on US fire incidents. About 2 million incidents are collected annually from about 14,000 fire and emergency departments. The National Directory of Fire Chiefs and Emergency Department is the most updated list of fire departments in the US. This list consists of about 29,000 fire departments and about 6,900 emergency departments. About 39% of these departments are currently reporting to NFIRS from 42 states. This source consists of a large number of propane related incidents (~2,800 for 1998)

Table 4-2. (continued)

Collection Method	Fire and emergency departments report on events that required their involvement. Some of the departments report directly to the system, others report to the state fire marshal, and his office submits the information to NFIRS.
Principal Data Elements	Data collected on incidents for this database include the following: • Time and date • Address • Consequences • Damage estimation • Material involved • Fire/emergency department details • Location categories • Number of emergency personnel in the site • Equipment involved • Causes
Strengths	NFIRS is a very extensive data collection source for propane incidents. It is able to capture a large amount of data, and includes a very detailed location code. The damage estimation is quite unique.
Weaknesses	Even though NFIRS consists of a large number of incidents, it fails to capture many of the most significant incidents, and therefore is not as comprehensive as it might seem.

Table 4-3 consists of an overview of the U.S. Consumer Product Safety Commission (CPSC) database, the National Electronic Injuries Surveillance System (NEISS):

Table 4-3. An overview of NEISS

Covered Universe	For nearly 30 years the U.S. Consumer Product Safety Commission (CPSC) has operated a statistically valid injury surveillance and follow-up system known as the National Electronic Injury Surveillance System (NEISS). The primary purpose of NEISS has been to provide timely data on consumer product-related injuries occurring in the U.S.
Collection Method	The data collection process begins when a patient is admitted to the emergency department (ED) of a NEISS hospital. An ED staff member elicits critical information as to how the injury occurred and enters that information in the patient' s medical record. At the end of each day, a NEISS hospital coordinator reviews all ED records for the day, selecting those that meet the (current) criteria for inclusion in NEISS. The NEISS coordinator abstracts pertinent data from the selected ED record and transcribes it in coded form to a NEISS coding sheet using rules described in a NEISS Coding Manual.
Principal Data Elements	The database consists of date, product, and text description of the incidents and consequences.
Strengths	The strength of the NEISS database is the fact that a text is available. Also it is statistically valid and can be extrapolated. The quality of the data can be partly attributed to the fact that trained professionals gather data.

Table 4-3. (continued)

Weaknesses	The major weakness of the NEISS database is that neither location of the incident nor time of day is available. These facts make the identification of duplicates between NEISS and other sources virtually impossible.

Through the courtesy of CPSC, we received pre-selected data from three additional databases:

- Incident File: This is a collection of incidents gathered by CPSC on an informal basis from news sources and from reports by individuals, health care workers, agencies, and others.
- Death Certificate File: State health departments provide these death certificate files to CPSC where consumer products are found to be involved in the deaths. The Clearinghouse provides summaries of the death certificates with victim information removed.
- In-Depth Investigations (INDP) File: The INDP file contains summaries of reports of investigations into events surrounding product-related injuries or incidents. Based on victim/witness interviews, the reports provide details about incident sequence, human behavior, and product involvement.

However, information on the databases is poor, and therefore these sources could not be reviewed completely.

Table 4-4 consists of an overview of the MKOPSC news clippings database:

Table 4-4. An overview of the MKOPSC news clippings database

Covered Universe	The MKOPSC news clipping database is a collection of incidents from newspaper databases. These databases are a survey of large number of newspapers nationwide. Following is a list of sources: • "Pay -Per-View" Archival Services: 1. NewsLibrary.com 2. NorthernLight.com • Free – Real Time sources: 1. Google 2. AltaVista
Collection Method	Collection methods vary somewhat among the sources. The archival sources present a short description of the clipping. Cases that are of interest are purchased/downloaded. Information was extracted from the sources and entered into the News Clipping database. The free real-time sources gather articles from a much larger number of sources but only retain information for about 30 days. Google searches more than 4,000 sources.
Principal Data Elements	The news-clipping database consists of several fields as well as an area for text descriptions. The information that is extracted is input to the following fields: • Name and address of facility, company or dealer • Date of incident • Fatalities, injuries, hospitalizations, evacuations, and sheltering • Distribution of the above among employees, contractors and general public

Table 4-4. (continued)

Principal Data Elements (continued)	• Number of response units in the incident site • Release location • Nature of release • Cause • Material involved, and • State of material released
Strengths	The news clipping procedure has several strengths: • News clipping provides real-time information that can be used to follow up on incidents. However, this option is applicable to real-time data collection and not for 1998. • Quite often the name of the local responder, investigator, or reporter is available. • Allows direct contact to gain or confirm information, obtain investigative reports, etc. (Again, valid only for real-time incident data collection and not for 1998) *Gives text description of what happened* • Focuses on notable incidents • Not just fires and explosions, but includes some near-misses as well • Internet search getting better with time

Table 4-4. (continued)

Weaknesses	• Information can be inaccurate or ambiguous • Some of the sources retain the information for a short period of time • Converting news clipping to electronic form requires extensive human resources

Table 4-5 consists of an overview of the Department of Transportation - the Hazardous Material Incidents Reporting System (HMIRS):

Table 4-5. An overview of HMIRS

Covered Universe	The Hazardous Materials Incident Reporting System (HMIRS) of the Research and Special Programs Administration (RSPA) was established in 1971 to fulfill the requirements of the federal hazardous materials transportation law. The law requires incident reporting of carriers of hazardous materials. All spills meeting the following criteria are reported to the RSPA: As a direct result of hazardous materials a person is killed or receives injuries requiring hospitalization, or estimated property damage exceeds $50,0 00, or an evacuation of the general public lasts for one or more hours, or a major transportation artery or facility is closed for one or more hours, or the operational flight pattern or routing of an aircraft is altered.

Table 4-5. (continued)

Covered Universe (continued)	1. Fire, breakage, spillage, or suspected contamination occurs involving shipment of radioactive materials or infectious substances 2. There is a release of a marine pollutant exceeding 450 L or 400 kg, or 3. Any hazardous material is unintentionally released from a package or any quantity of hazardous waste is discharged during transportation. All modes of transportation are included except pipeline and bulk marine transportation.
Collection Method	Reported by carriers' owner.
Principal Data Elements	HMIRS database consists of 114 fields. The followings are some of the fields that are relevant to the Propane Incident Data Collection Project: • Carriers' information • Carriers' Damage • Cause • Product • Decontamination costs • Destination • Fires, explosions • Consequences • Loss of Product costs

Table 4-5. (continued)

Strengths	Information is detailed and generally of good quality since the carriers are required to report within 30 days and they are knowledgeable of their business
Weaknesses	No data is provided for incidents where the consequences are below the thresholds.

Table 4-6 consists of an overview of the Department of Transportation – the integrated Pipeline Information System (IPIS) or (Hazardous Liquid Accident Data):

Table 4-6. An overview of IPIS

Covered Universe	Data includes releases of natural gas or petroleum/petroleum by-products that meet reporting requirements as outlined in 49 CFR Parts 191, 192, and 195. The Hazardous Liquid Accident Data is the database that reports all incidents except the ones involving natural gas.
Collection Method	Reports on incidents are required to be submitted to the Office of Pipeline Safety by the responsible operators within 30 days of the incident to avoid penalties.

Table 4-6. (continued)

Principal Data Elements	IPIS database consists of 62 fields. The following is part of the information that is being collected: • Information on operator • Date and time of incident • Location • Origin of release (valve, scraper, trap, pump, welding, girth…) • Pipeline production year • Cause • Fatalities and injuries of employees as well as non-employees • Property damage • Commodity classification • Fire/explosions involved • Operating information • Corrosion information • Several text fields
Strengths	• Most of the incidents that meet the reporting requirement are submitted. • People that report are from the industry, which helps improve data accuracy.
Weaknesses	Incidents under the reporting thresholds are not captured.

Table 4-7 consists of an overview of the National Response Center (NRC), the Incident Reporting Information System (IRIS) Database.

Table 4-7. An overview of IRIS

Covered Universe	IRIS contains data on reported releases from fixed facilities, marine, offshore facilities, pipelines, and transportation vehicles. Many federal statutes require reporting of releases to the National Response Center (NRC). Pipeline spills are reported under the Hazardous Liquid Pipeline Safety Act. Air releases are reported under: • Clean Air Act; • Toxic Substances Control Act; • Federal Hazardous Materials Transportation Laws; and • Resource Conservation and Recovery Act.
Collection Method	This database is used primarily for emergency response notification and is operated 24 hours a day, 7 days a week. The initial notification of a release is usually by telephone. These reports are comprised of mostly short answer questions.
Principal Data Elements	The database contains data on oil, chemical, biological, and etiological discharges into the environment anywhere in the United States or its territories. The NRC collects information nationally on reports of hazardous material releases as well as releases of hazardous substances and oil from fixed facility and transportation incidents. The information consists of location of the release, owner's details, a short description of the incident, and the information related to the consequences (affected medium, fatalities, injuries, evacuations, cost of damages) of the incident.

Table 4-7. (continued)

Strengths	NRC handles approximately 30,000 telephone calls each year, of which approximately 25,000 are unique incidents.
Weaknesses	Because this system contains initial reports, the information is preliminary and therefore in many cases inaccurate or incomplete. There also is duplicate reporting of incidents. Propane incidents at residents and small businesses are seldom reported.

Table 4-8 consists of an overview of the Environmental Protection Agency (EPA) – the RMP 5-year Accident History Database.

Table 4-8. An overview of EPA RMP

Covered Universe	Risk Management Program covered facilities that have released a listed substance, which is stored above a threshold quantity and results in fatalities, injuries, or significant environmental or property damage, are required to report 5-year accident histories. It covers about 15,000 facilities from 1994 to 1999. Propane stored for use as a fuel is generally excluded.
Collection Method	5-year Accident History Report

Table 4-8. (continued)

Principal Data Elements	RMP facility must provide EPA with the following information for each incident: • Date, time, and approximate duration of the release; • Chemical(s) released; • Estimated quantity released in pounds; • Type of release event and its source; • Weather conditions, if known; • Onsite impacts; • Known off-site impacts; • Initiating event and contributing factors, if known; • Whether off-site responders were notified, if known; and • Operational or process changes that resulted from investigation of the release.
Strengths	The reports do address such items as the causes and consequences of the release and steps taken to prevent or mitigate future incidents. Reporters are trained in incident investigation, and therefore records are quite accurate.
Weaknesses	Most of the incidents are probably not odorized propane but propane mixtures in chemical processes.

Table 4-9 consists of an overview of the Agency for Toxic Substances and Disease Registry (ATSDR), the Hazardous Substances Emergency Events Surveillance (HSEES) Database.

Table 4-9. An overview of HSEES

Covered Universe	Sixteen state health departments currently have cooperative agreements with ATSDR to participate in HSEES. The state health departments report an "event" if it meets the HSEES definition, which is "any release(s) or threatened release(s) of at least one hazardous substance". A substance is considered hazardous if it might reasonably be expected to cause adverse human health effects. Releases of petroleum products (including propane) are excluded from this system unless mixed with another chemical.
Collection Method	Data are entered by participating state health departments into a Web-based application that enables ATSDR to access data instantly for analysis.
Principal Data Elements	Data collected on incidents for this database include the following: • Time, date, and day of the week; • Geographical location within the facility where the event occurred; • Event type (fixed-facility or transportation-related event); • Factors contributing to the release; • Environmental sampling and follow-up health activities; • Specific information on injured persons: age, sex, type and extent of injuries, distance from spill, population group (employee, general public, responder, student), and type of protective equipment used; • Information about decontaminations, evacuation, or shelter-in-place;

Table 4-9. (continued)

Principal Data Elements (continued)	Land use and population information to estimate the number of persons at home or work who were potentially exposed; and whether a contingency plan was followed and which plan was used. Participating States: Alabama, Colorado, Iowa, Louisiana, Minnesota, Mississippi, Missouri, New Jersey, New York, North Carolina, Oregon, Rhode Island, Texas, Utah, Washington, Wisconsin
Strengths	ATSDR has a proactive approach to incident collection that facilitates more complete and accurate reporting. This source consists of more details on type of injury and personal protective equipment than many other sources.
Weaknesses	The ATSDR HSEES program covers only 16 states, and excludes petroleum products unless other products (non-petroleum) are involved.

Table 4-10 consists of an overview of the propane associations and State Agencies:

Table 4-10. An overview of Propane Gas Associations and State Agencies

Covered Universe	State Propane Gas Associations were established in order to conduct business in a safe and ethical manner, and to encourage professionalism and excellence.

Table 4-10. (continued)

Collection Method	There is no common procedure for data collection among the states. The Texas Propane Gas Association does not collect incident report. However, the Railroad Commission requests the propane companies and dealers to submit incident investigation reports. The Texas Railroad Commission keeps hard copies (only) of its reports. The information was converted to electronic form by TAMU. Iowa Propane Gas Association does not perform incident investigations. Iowa's d atabase consists of data that is collected from newspapers. Florida's Propane Gas association procedure is similar to that of Texas.
Principal Data Elements	Texas Railroad Commission database is the most detailed database among the three. The database consists of several fields. Following is the information that is collected: • Company details and license number • Location • Fatalities and injuries • Information on installation and equipment involved • Container details • Causes, and • Text field for incident summary Florida and Iowa databases consist of fewer details compared to Texas.

Table 4-10. (continued)

Strengths	States that conduct investigations provide a very detailed description on the incidents and are very useful toward incorporation in the propane incident database. Information from three state associations contains more than a hundred incidents. The potential of extracting information from the majority of the state associations could significantly contribute to the comprehensiveness of the database. Texas data provides a good means for assessing incidents directly associated with propane industry facilities.
Weaknesses	States that are collecting information from diverse sources are hard to assess. The fact that associations from different states are collecting information in diverse ways requires development and implementation of several procedures in order to incorporate the data in the database.

Summary of Usefulness of the Sources

Data sources were analyzed in several dimensions in order to consolidate the propane incident data into a single database. Table 4-11 ranks the sources as a function of the contribution a source of information makes with regard to the relevant dimension. The range of potential contribution has been divided to three sub regimes: Low, Reasonable (Reas.), and High.

Table 4-11. Summary of usefulness of sources

NFIRS:	Low	Reas.	High
Number of incidents			ν
Comprehensiveness of data		ν	
Opportunity for information validation	ν		
Significance of data	ν		
Data accuracy		ν	
Opportunity for nationwide estimation			ν
CPSC Databases:	**Low**	**Reas.**	**High**
Number of incidents		ν	
Comprehensiveness of data			ν
Opportunity for information validation	ν		
Significance of data			ν
Data accuracy		ν	
Opportunity for nationwide estimation	ν		
MKOPSC News Clipping Database:	**Low**	**Reas.**	**High**
Number of incidents		ν	
Comprehensiveness of data		ν	
Opportunity for information validation			ν
Significance of data			ν
Data accuracy		ν	
Opportunity for nationwide estimation	ν		

Table 4-11. (continued)

HMIRS:	Low	Reas.	High
Number of incidents		ν	
Comprehensiveness of data		ν	
Opportunity for information validation	ν		
Significance of data		ν	
Data accuracy		ν	
Opportunity for nationwide estimation	ν		
IPIS:	**Low**	**Reas.**	**High**
Number of incidents	ν		
Comprehensiveness of data			ν
Opportunity for information validation	ν		
Significance of data		ν	
Data accuracy			ν
Opportunity for nationwide estimation			ν
IRIS:	**Low**	**Reas.**	**High**
Number of incidents			ν
Comprehensiveness of data		ν	
Opportunity for information validation	ν		
Significance of data	ν		
Data accuracy	ν		
Opportunity for nationwide estimation	ν		

Table 4-11. (continued)

	Low	Reas.	High
EPA RMP:	Low	Reas.	High
Number of incidents	ν		
Comprehensiveness of data			ν
Opportunity for information validation	ν		
Significance of data		ν	
Data accuracy			ν
Opportunity for nationwide estimation	ν		
HSEES:	Low	Reas.	High
Number of incidents	ν		
Comprehensiveness of data		ν	
Opportunity for information validation	ν		
Significant of data	ν		
Data accuracy			ν
Opportunity for nationwide estimation	ν		
Associations and State Agencies	Low	Reas.	High
Number of incidents		ν	
Comprehensiveness of data		ν	
Opportunity for information validation	ν		
Significance of data			ν
Data accuracy			ν
Opportunity for nationwide estimation			ν

Table 4-11. (continued)

NEISS:	Low	Reas.	High
Number of incidents	ν		
Comprehensiveness of data		ν	
Opportunity for information validation	ν		
Significant of data	ν		
Data accuracy			ν
Opportunity for nationwide estimation			ν

Table 4-11 ranks the databases according to several dimensions. The table distinguishes between masses of data and significance of data. Finally, this table presents the opportunities and limitations that exist in the different data collection procedures, with regard to the assessment of safety performance of the propane industry by collecting incident data from various sources. The information flows from the reporters / agencies / newspapers etc. as illustrated in Figure 4-1:

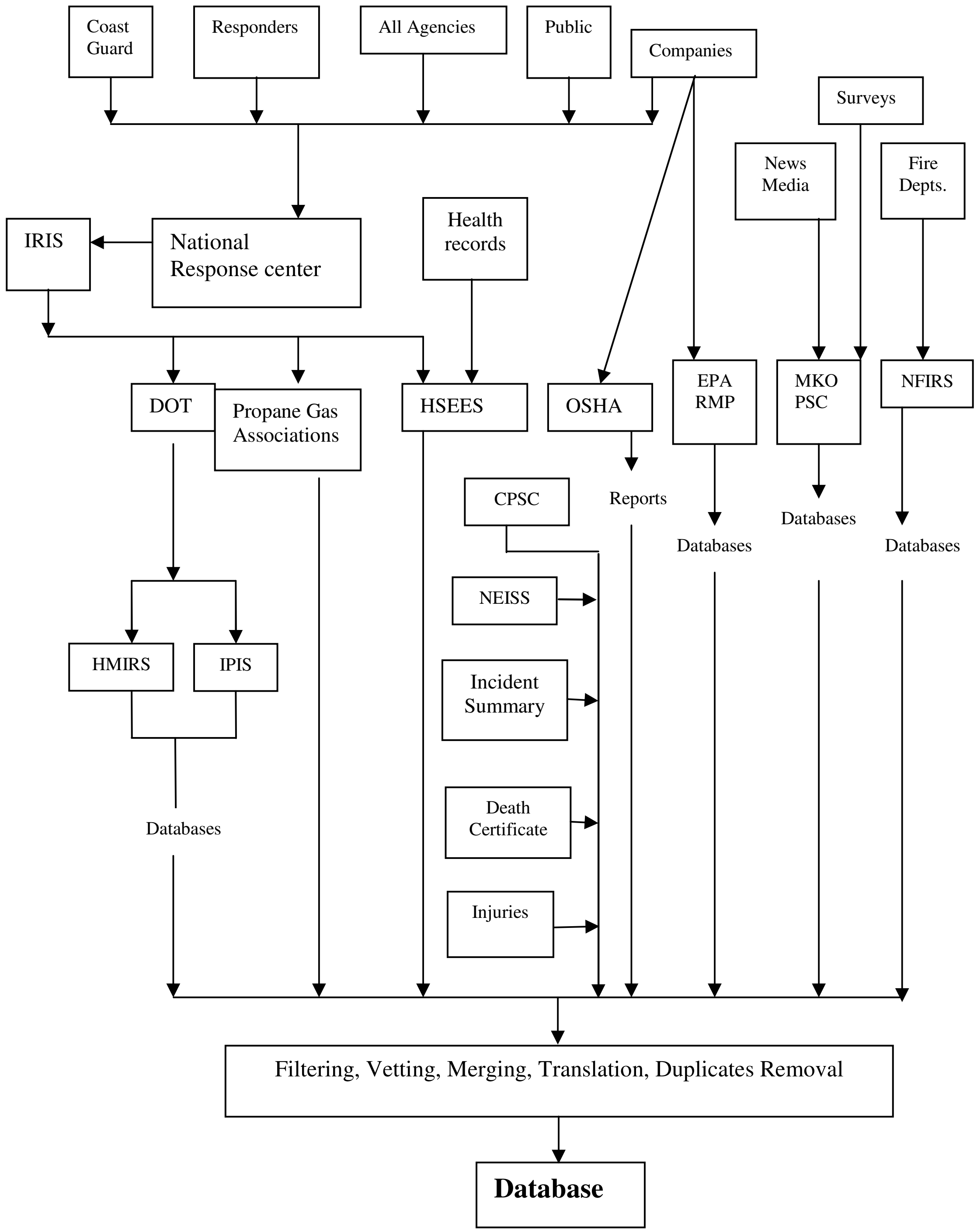


Figure 4-1. Information flow chart

Method of Duplication Identification and Removal

There are two categories of duplications that is encountered during the consolidation of propane incident information from a variety of sources:

- Duplications within the sources
- Duplications among different sources

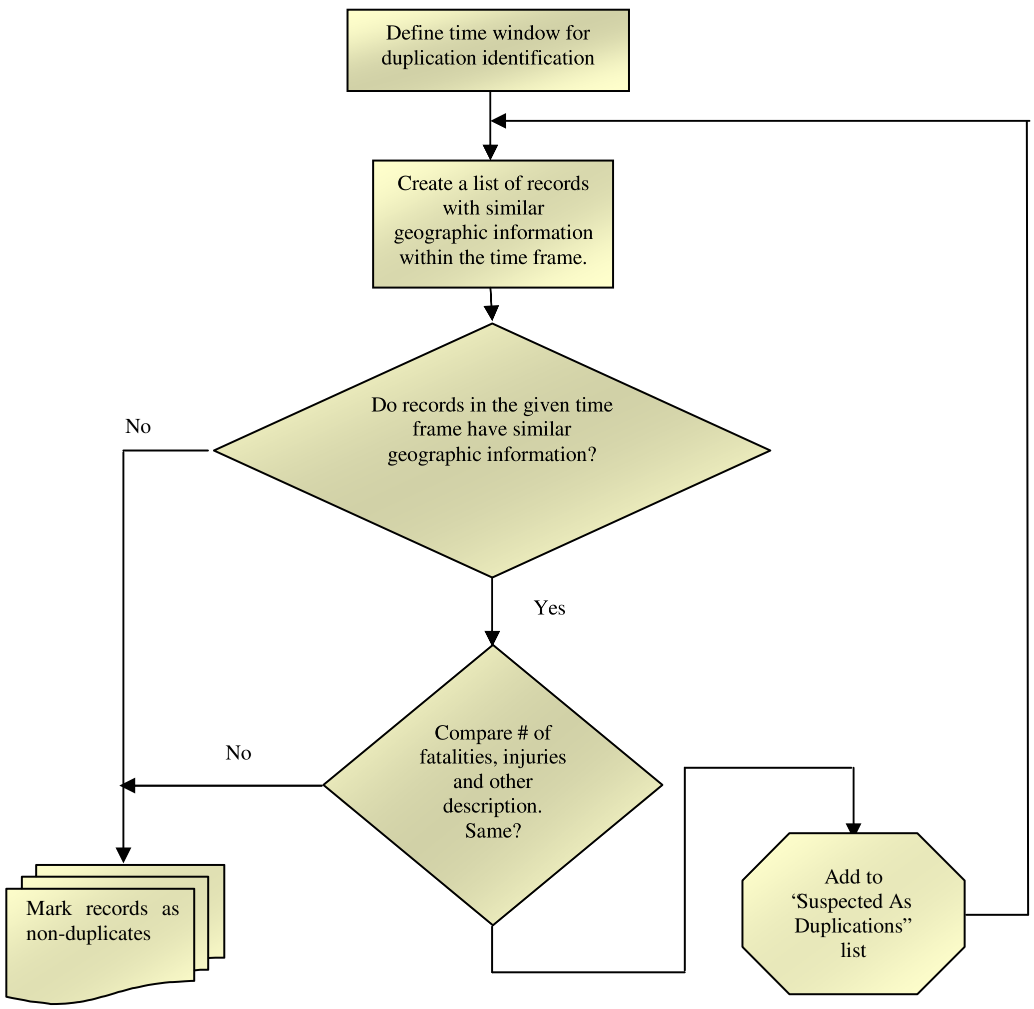


Figure 4-2. Procedure for identification of duplication

In general, it is much easier to identify duplications within the sources as compared to identifying duplications amongst different sources. However, the process of identification of duplications is similar in both cases. Duplication within the same source has the same type of information and is much easier to identify. The duplication identification process is illustrated in Figure 4-2.

The number of records in the list of 'Suspected as Duplications' is sensitive to the time frame that is employed. However, in order to verify that the time frame used is not arbitrary, the sensitivity of duplication number to the time frame was studied.

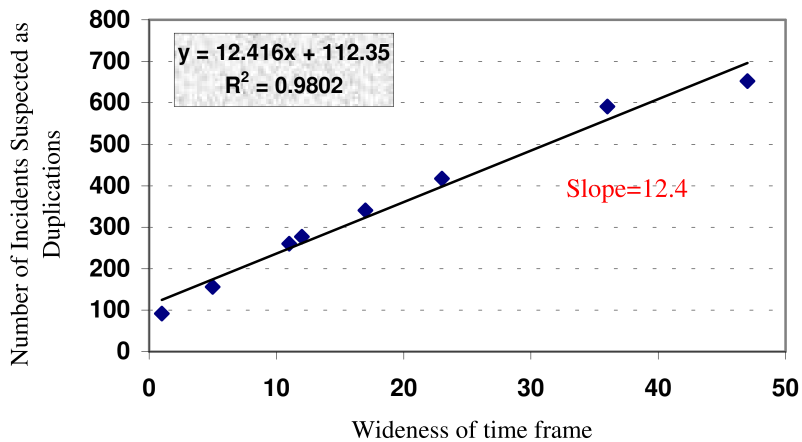


Figure 4-3. Sensitivity to time frame study

Figure 4-3 demonstrates the number of records in the 'Suspected as Duplications' list for various time frames. As Figure 4-3 reveals, the number of incidents that are suspected as duplications is highly correlated with the width of the time frame (root mean square value of more then 0.98). The slope of the correlated line may serve as a qualitative relative indicator for the comprehensiveness of the database. Under the estimation that the probability of an incident to occur is not time dependent, the number of suspected duplication in a given time frame would increase as the portion of the universe of incidents increases.

Once the system creates a list of records that are suspected as duplications, they are eliminated from the consolidated database. Identification of duplicates becomes quite difficult in cases where time of incident is not given.

As for duplicate identification within the databases, the process of verification of whether incidents are duplications varies according to characteristics of the incidents. NFIRS for an example consists of two types of duplications:

1) Fire department that reported the incident more than once.
2) Incidents that were suspected as duplicates, because more than a single fire department entered reports.

In the first case, the verification process was not complicated. In the second case, however, it was required to search the Internet for county maps in order to determine if it is reasonable that a fire department from an adjacent county would assist another fire department and also report to NFIRS. In all of the cases the distance between the counties was too far to assume that the reports are duplicates.

An important criterion for identifying duplications is the number of injuries and fatalities. If two incidents that have other similar characteristics also show exactly the same number of fatalities and injuries, there is a high likelihood that one of these incidents is a duplicate. The system ignored incidents that have different number of injuries or fatalities. A manual check and quality control procedure to ensure that duplicates were identified accurately and that non-duplicates were not eliminated inadvertently was applied. A thorough examination of incidents with fatalities revealed that the automated procedure for duplication identification was able to capture approximately 75% of the duplications among these incidents. Several of the incidents had the same values in all fields (including textual description of the incidents), however, several months gap in the time field prevented these duplications from being revealed. The procedure for duplication identification should be improved further, to increase its capabilities.

As for duplications amongst different databases, the process required relatively more extensive efforts, and each of the cases needed to be treated separately, in addition to using the procedure. Table 4-12 summarizes the number of duplications identified in the 1998 database:

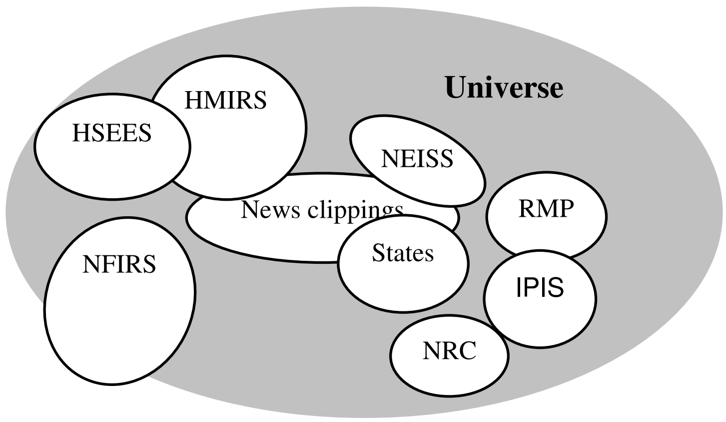


Figure 4-4. Illustration of current situation

Methodology for Estimation of Total Number of Propane Incidents in the United States

Background

The process for estimating the total number of propane incidents in the Unites States can be explained by the theory of sets. Figure 4-4 illustrates the current situation. The gray area represents the total number of propane-related incidents in the US. The white areas represent the actual number of incidents in each of the respective databases.

Table 4-12. Duplications amongst different sources

	NFIRS	Florida	HMIRS	NRC	News	Iowa	Death Cert.	Incident CPSC	IPIS	Texas	Investigation CPSC	NEISS
NFIRS		2	2		1	1	2	17		4	1	
Florida				1				2				
HMIRS				18	2	1						
NRC					1				5			
News							1	4			1	
Iowa												
Death CPSC								3			5	
Incident CPSC											21	
IPIS												
Texas												
Investigation CPSC												2
NEISS												

The number of incidents from each of the databases is a subset of the total number of incidents that this database could consists of (the set), e.g., NFIRS consists of records from about 14,000 emergency departments from 42 states. The records in NFIRS are a subset of a set, which is the number of records that NFIRS would consist of if all 29,000 fire departments as well 6,900 emergency departments from the 50 states reported every propane incident to NFIRS. Figure 4-5 is an illustration of the relation between set and a subset.

The Universe is a collection of all incidents that have the potential to be reported. Therefore, Universe is a composition of sets. The translation of the above to the theory of set language is as follows:

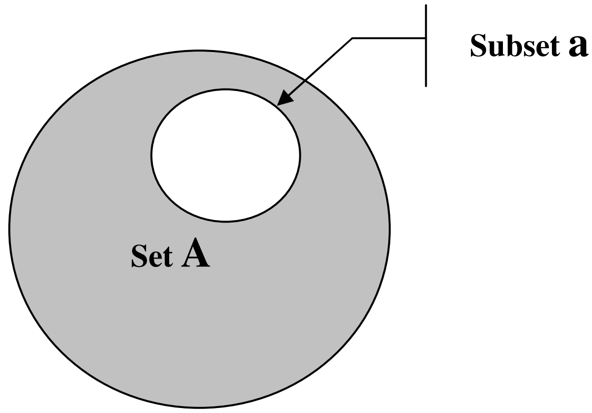


Figure 4-5. Relation between a set and a subset

a_1 **-** is current records in database DB1

A_1 **-** is the potential number of record in the database DB1, if all incidents targeted by this database were reported.

a_1 is a subset of A_1 ⎝ $a_1 \subset A_1$

a_2 - is current number of records in database DB2

A_2 - is the potential number of record in the database DB2, if all incidents targeted by this database were reported.

a_2 is a subset of A_2 ⎝ $a_2 \subset A_2$

The same principles applies to a_3, a_4,......, a_n or all the databases.

The Universe S is a composition of all the sets. However, there are overlaps among the sets, and therefore U is a union of the sets, as Figure 4-6 illustrates.

$$S = (\bigcup_{i=1}^{n} A_i) = A_1 \cup A_2 \cup A_3 \cup \ldots \cup A_n = \qquad (4\text{-}1)$$

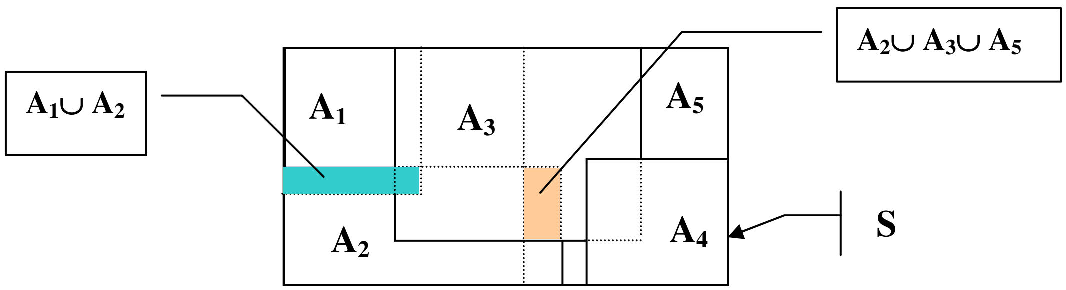
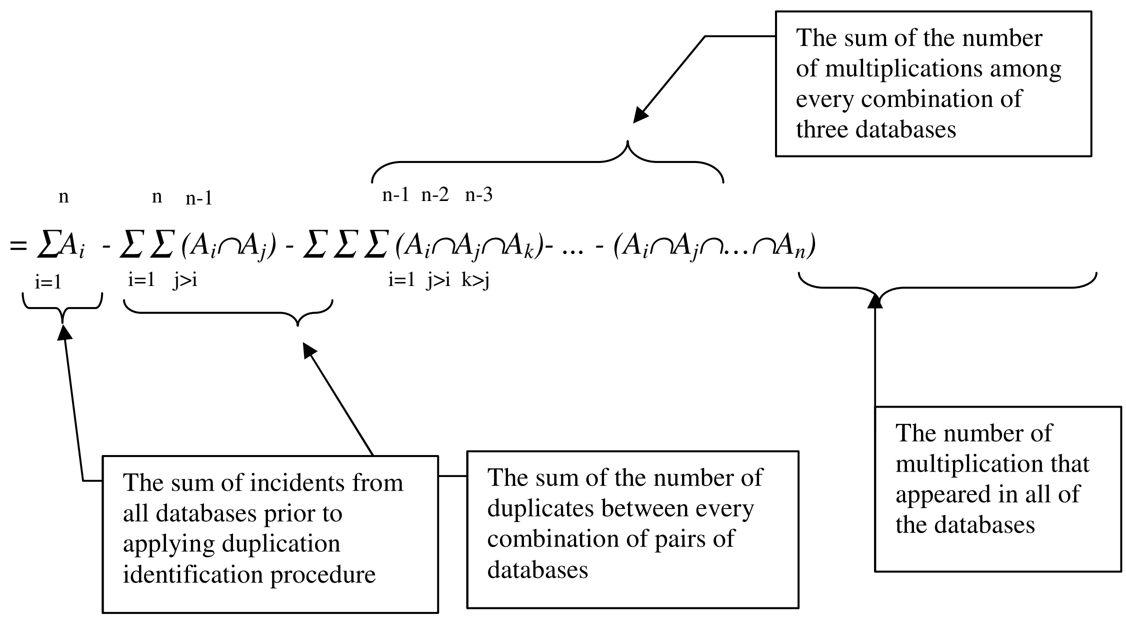


Figure 4-6. Our universe is defined to be a union of the sets (Venn Diagram)



$$= \sum_{i=1}^{n} A_i - \sum_{i=1}^{n}\sum_{j>i}^{n-1} (A_i \cap A_j) - \sum_{i=1}^{n-1}\sum_{j>i}^{n-2}\sum_{k>j}^{n-3} (A_i \cap A_j \cap A_k) - \ldots - (A_i \cap A_j \cap \ldots \cap A_n)$$

No duplications found between more than two sources. Therefore, only the first two parts of equation 4-1 will be employed for the estimation purposes. These two parts are extended and are presented in equation 4-2.

$$S= A_1+ A_2+ A_3+ \quad .+ \quad A_n - [(A_1 \cap A_2 + A_1 \cap A_3 + \quad +A_1 \cap A_n) + \qquad (4\text{-}2)$$
$$+ (A_2 \cap A_3+ A_2 \cap A_4 +\ldots+A_2 \cap A_n)] +\ldots+ (A_{(n-1)} \cap A_n)]$$

The sequence of estimating the universe S is now simplified. The information that is available currently is the subsets a_i and the intersection between these subsets. Figure 4-7 presents the sequence of obtaining the information required to solve equation 4-2.

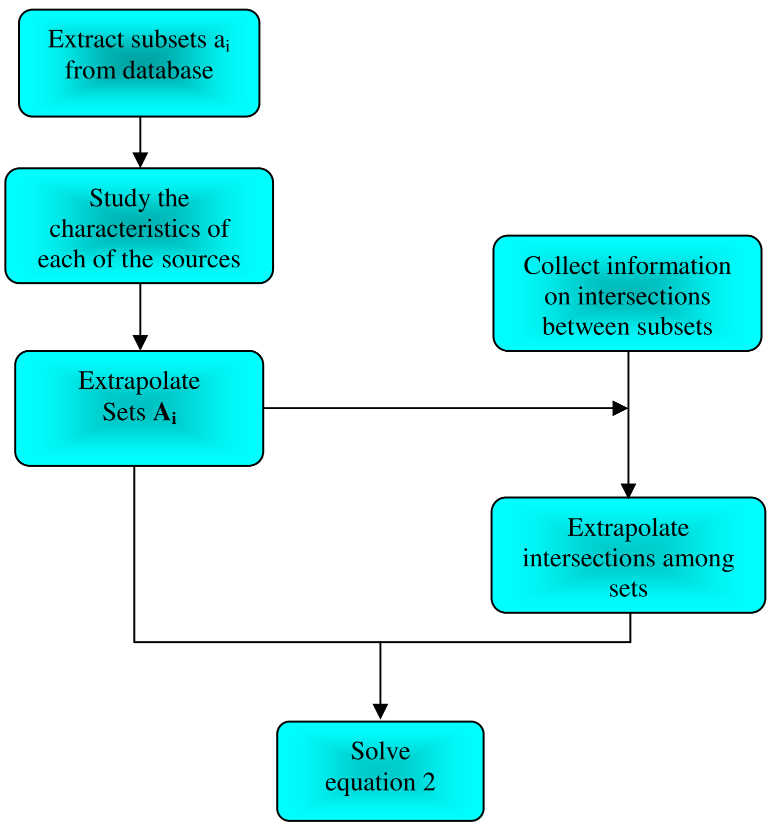


Figure 4-7. Sequence of estimation of universe S

Following are descriptions of the processes of extrapolating the sets A_i according to the characteristics of each of the sources. The assumptions that were required in order to extrapolate the intersections between the sets will be presented later, as well as the results from substituting the information in equation 2.

Extrapolations of Sets A_i

The purpose of collection of information is not the same for all the sources, and therefore the characteristics of each of these sources should be incorporated in order to calculate the number of incidents that the source database would consist of if it were to capture all the incidents that belong in its category. The considerations, as well as the methods for extrapolating the information of the sets, A_i, are as follows. Table 4-13 consists of the number of incidents that each of the sources contributed to the consolidated database.

Table 4-13. Number of incidents from the various sources

Source	Number of Incidents
RMP	32
NFIRS	2,805
Florida	58
HMIRS	96
NRC	146
News	99
Iowa	8
Death - CPSC	31
Incident - CPSC	190
IPIS	12
Texas	55
HSEES	35
Investigation - CPSC	70
NEISS	184
OSHA Excerpt	1

CPSC - National Electronic Incidents Surveillance System

" For[6] nearly 30 years the U.S. Consumer Product Safety Commission (CPSC) has operated a statistically valid injury surveillance and follow-back system known as the National Electronic Injury Surveillance System (NEISS). The primary purpose of NEISS has been to provide timely data on consumer product-related injuries occurring in the U.S. In the year 2000, CPSC initiated an expansion of the system to collect data on all injuries. With the expansion, NEISS becomes an important public health research tool, not just for CPSC, but also for users throughout the U.S. and around the world. The NEISS injury data are gathered from the emergency departments of 100 hospitals selected as a probability sample of all 5,300 U.S. hospitals with emergency departments. The system's foundation rests on emergency department surveillance data, but the system also has the flexibility to gather additional data at either the surveillance or the investigation level.

The data collection process begins when a patient is admitted to the emergency department (ED) of a NEISS hospital. An ED staff member elicits critical information as to how the injury occurred and enters that information in the patient's medical record.

At the end of each day, a NEISS hospital coordinator reviews all ED records for the day, selecting those that meet the (current) criteria for inclusion in NEISS. The NEISS coordinator abstracts pertinent data from the selected ED record and transcribes it in coded form to a NEISS coding sheet using rules described in a NEISS Coding Manual.

Identifying the consumer product(s) related to the injury is crucial for CPSC. The NEISS coordinator assigns a product code from an alphabetical listing of hundreds of products and recreational activities, being as specific as the data allow. For example, if a lawn mower were involved in an injury, the coordinator would use a different product code for a walk-behind mower than for a riding mower. If the ED record contains additional product detail, the coordinator includes that in a line or two of narrative text (e.g., gasoline-powered rotary mower made by XYZ Company). The victim's age,

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[6] Cited from CPSC Website http://www.cpsc.gov/cpscpub/pubs/3002.html (September 2003).

gender, injury diagnosis, body parts affected, and incident locale are among other data variables coded. A brief narrative description of the incident is also included. Once the abstracting and coding are completed, the NEISS coordinator enters the data for the day's NEISS injury cases into a personal computer provided by CPSC. As the coordinator keys in data, CPSC-designed software interactively edit the data, requiring that all fields be filled and allowing only acceptable entries".

Since NEISS surveys sample of hospitals that represent all ethnic groups and concentrations of population, it is statistically valid to extrapolate by multiplying the number of propane-related incidents from NEISS by the ratio between the number of hospitals in the U.S. (estimated as 5,300) and the number of hospitals in the survey (100). The set of NEISS consists of the following number of incidents:

$$N_{\substack{incidents \\ nationwide}} = \frac{N_{\substack{hospitals \\ in\ the\ US}}}{N_{\substack{hospitals \\ in\ the\ survey}}} \bullet N_{\substack{incidents \\ in\ the \\ database}} = \frac{5{,}300}{100} \bullet 184 = 9{,}572_{\substack{incidents \\ nationwide}} \qquad (4\text{-}3)$$

Though NEISS has a potential of capturing large amount of data, it is not additive to the rest of the numbers. The reason for that is that NEISS records do not include location and time, and there is no way to estimate the number of duplicates among other sources and NEISS. However, the estimation using the NEISS database reveals that there were about 10,000 injuries from propane-related incidents.

Florida Propane Gas Association and Texas Railroad Commission

There is no common procedure for data collection among the states. However, the Texas Railroad Commission requests the companies and dealers to submit incident investigation reports. The Commission keeps hard copies (only) of its reports, which was converted to electronic form for this study. The Iowa Propane Gas Association does not perform incident investigations; its database consists of data that is collected from newspapers, and therefore was not used in this estimation. Florida's' Propane Gas Association procedures are similar to those of Texas.

Since these incident collections are mainly from companies and dealers, it seems that normalization to the non-industrial propane consumption rate will be representative. The estimation procedure is shown in Figure 4-8.

The consumption data did not include the industrial consumption. Using industrial consumption as well, would distort the results, e.g., Texas consumes[7] about 406,539 barrels. However, 393,652 barrels are used for industrial purpose, and only 12,900 barrels for other uses. Florida consumes 7,386 barrels total, but only 2,087 barrels for industrial needs and 5,299 barrels for all other needs. The estimation is that collection of incidents from all propane gas associations/Railroad Commissions add up to 1,168 incidents associated with propane dealers.

NFIRS

The NFPA established a project for estimation of incidents in the United States. NFIRS is a collection of reports from 35%-50% of fire departments from 42 states in the US. The following should be kept in mind with regard to NFIRS and fire departments reporting to NFIRS:

1. Large fire departments are usually staffed by paid full-time employees
2. Small (rural) fire departments are usually staffed by part-time volunteers
3. The probability of fire departments with paid employees reporting to NFIRS is much greater than the probability of fire departments with volunteer employees reporting to NFIRS.
4. Majority of propane incidents in relation to population size occurs in rural areas.

[7] Consumption rates are available in the US Department of Energy Website: http://www.eia.doe.gov/emeu/states/sep_fuel/html/fuel_lg.html

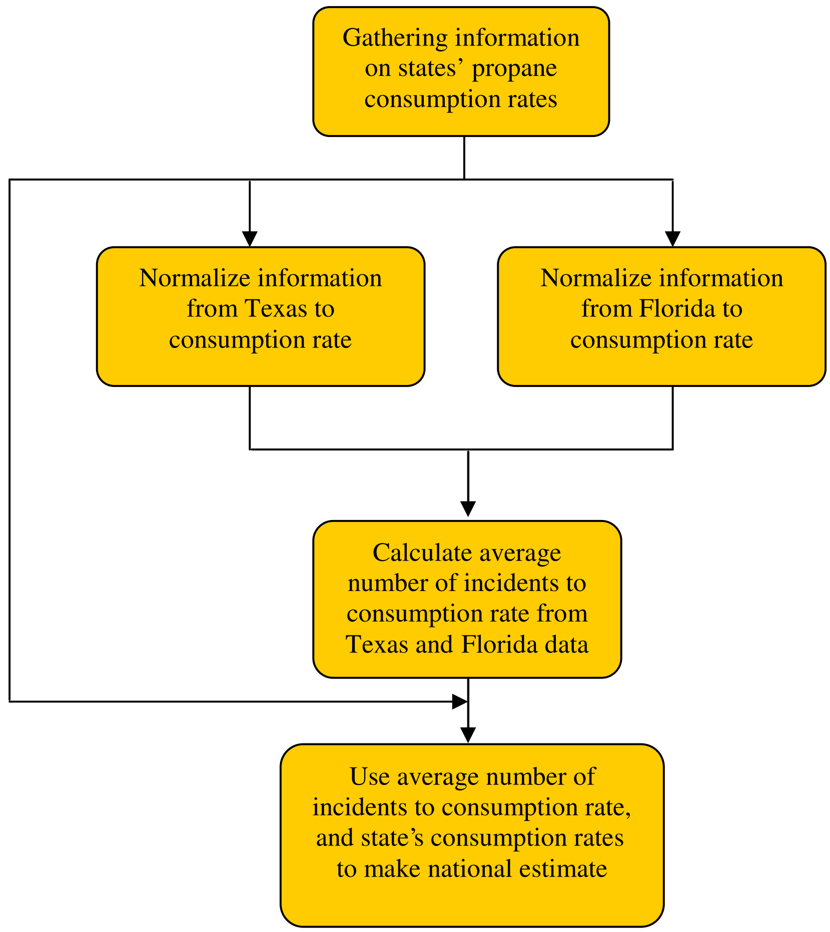

Figure 4-8. Extrapolating data from state agencies

NFPA conducted a survey of about 3,000 (~10% of the fire departments in the US), in order to balance the data in NFIRS. The survey targeted rural areas mainly since the reporting from these fire departments is low. By applying statistical analysis on NFIRS information and the survey results, NFPA calculated the total number of propane incidents in the United States. 10,780 LP Gas related incidents occurred in 1998 in the US according to NFPA.

The estimations as well as number of incidents that cannot be estimated are summarized in Table 4-14.

Table 4-14. Summary of estimations

Source	Number of Incidents	National Estimation
RMP	32	32
NFIRS	2,805	10,780
HMIRS	96	96
NRC	146	146
News	99	700
States	121	1,168
Death - CPSC	31	31
Incident - CPSC	190	190
IPIS	12	12
HSEES	35	96
Investigation - CPSC	70	70
OSHA	1	Lack of information
Total		13,321

Extrapolation of Duplicates

The ideal way to extrapolate the number of duplications is to sample several sample size of sub-sets and to identify number of duplicates for combination of sizes. By using this methodology it is possible to study how the number of duplications increases with increase of the size of subsets. However, the database consists of relatively low number of duplicates. Therefore, the extrapolation of the number of duplicates will be a multiplication of the number of duplicates between sources by the ratio of the sum of the extrapolated number of the incidents in the set and the sum of the actual number of incidents in the database, as was demonstrated in equation 4-3 for NEISS. It should be noted that in case of duplicates between NFIRS and CPSC incident reports, the extrapolated number is greater then the number of incidents in CPSC incident reports

The total number of duplicates is 215 incidents. Substituting the extrapolated number of incidents and extrapolated number of duplicates (NEISS numbers are excluded) leads to a total number of 13,106 propane incidents in the United States in 1998.

Data Analysis and Pattern Identification

Overview

The database consists of 3,721 incidents that have been collected from a variety of sources. There are records of 137 fatalities, and 1,012 injuries in the database. Distribution of fatalities and injuries among the victim categories is given in Table 4-15.

Table 4-15. Distribution of fatalities and injuries

Victim Category	Number of Fatalities	Number of Injuries
General Public	122	740
Worker/ Contractors	8	95
Fire Fighters and Public responders	2	126
Unknown	5	51

As Table 4-15 reveals, the general public is the most vulnerable population for propane incidents. Figure 4-9 illustrates the distribution of fatalities as a function of the cause of death. The fatality data consist of several types of causes. Explosions and explosions that caused fatal burns are among these categories. It is hard to determine the cause of death among the fatalities of explosions. Therefore these categories were lumped together under explosions. In many cases, the description noted that fire was involved. However, there was no way to figure out whether the victims died from burns, carbon monoxide poisoning, or smoke inhalation. In these cases, the cause of death was assumed to be fire.

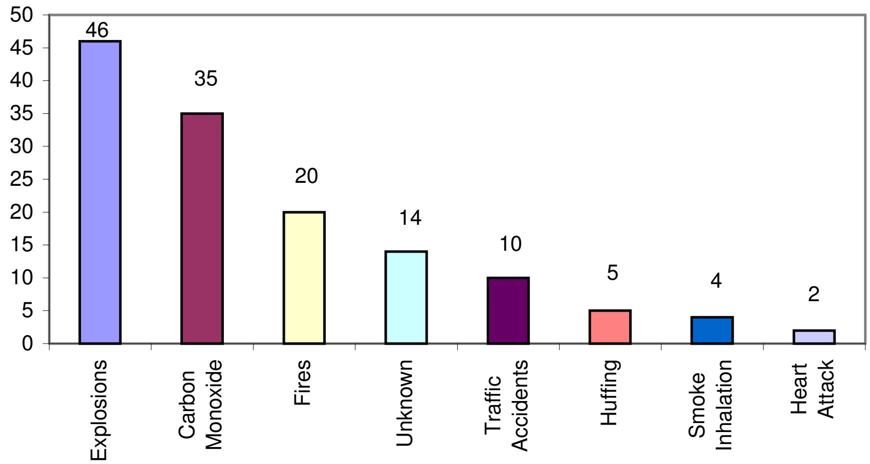

Figure 4-9. Fatalities by causes of death

Explosions caused the highest number fatalities. Carbon monoxide poisoning is the second leading cause of fatalities. The impression from the descriptions is that there is a lack of awareness of what is to been done in order to reduce the hazard of carbon monoxide poisoning while using propane for space heating. None of the reports mentioned the existence of carbon monoxide detectors in the residences. Since incidents in mobile homes are quite common (the database includes 161 incidents in mobile homes and 69 incidents in recreational vehicles), standardizing installation of carbon monoxide detectors may lead to the reduction of number of fatalities from carbon monoxide poisoning. Number of fires and explosions in mobile homes is high, and leak detectors, as well as shut-off valves might also lead to the reduction of these incidents.

Discussion of fatalities requires identification of whether there is certain age range that is more vulnerable than other range of ages. Figure 4-10 demonstrates the distribution of number of fatalities according to the ranges of age.

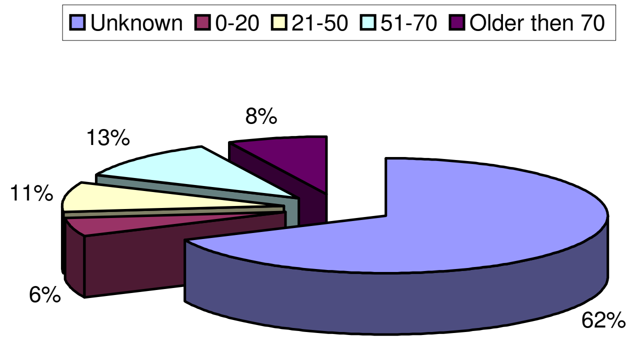

Figure 4-10. Distribution of number of fatalities by age range

In 62% of the fatalities it was difficult or impossible to determine the age of the victims. Although, in several of the cases the age could be assumed (like the huffing cases, where the victims used plastic bags on their heads, which is more likely to indicate that the victims were teenagers), if the ages of the victim were not clear in the data, it was classified as unknown. With age unknown in 62% of cases no conclusions could be drawn. We believe that this type of information may be available if real-time data collection procedures are implemented, because it creates opportunities to investigate the incidents.

Following are patterns and distributions of incidents and consequences with regard to causes, equipment involved, vehicles, and structures. It is important to emphasize that the values in the figures are actual values from the database, and are not extrapolated.

Cause Analysis

Cause analysis is a difficult task even for experienced incident investigators. Concerns arise with regard to causes that are reported by the general public (such as NRC) and others who lack the tools that are required to correctly determine the cause.

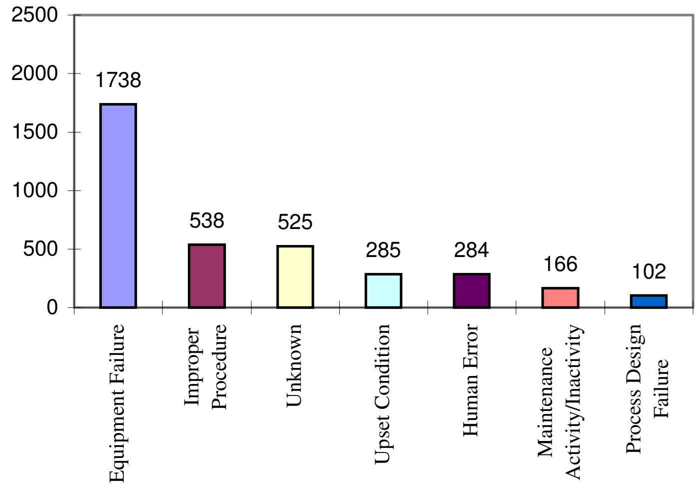

Figure 4-11. Incidents by cause category

In many cases the incident reports consist of description of situation, and it was required to determine the cause from the textual description, which in several cases could be interpreted to more than a single cause. Good practice and judgment were applied in order to reduce the uncertainty. As shown in Figure 4-11, the leading cause is "equipment failure." The frequency of equipment failure is more than 3 times higher than "improper procedures," the next leading cause.

Surprisingly, "human error" and "maintenance activity/inactivi ty" are among the low frequency causes in term of number of incidents.

Among the incidents, equipment failure is the leading cause of fires, and of explosions, as can be seen in Figure 4-12 and in Figure 4-13. Improper procedure is the next major cause for fire and explosions. Human error, which is a major cause of incidents in other industries, is found to be relatively insignificant as a cause of propane incident. It must be noted though, the definition of equipment failure, human error, and other causes is quite subjective and varies quite widely.

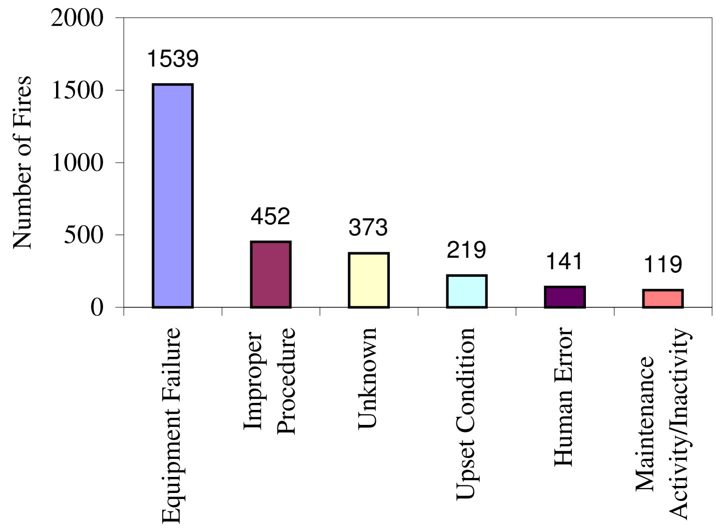

Figure 4-12. Fires vs. cause

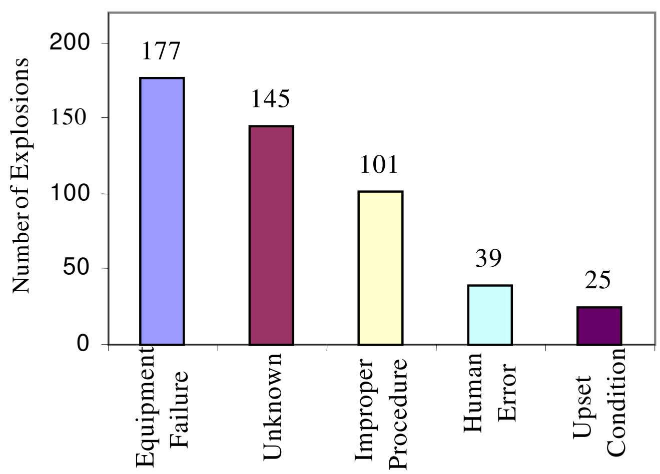

Figure 4-13. Explosions vs. cause

While frequency of incidents is an important indicator, it is also essential to analyze the consequences of incidents. As Figure 4-14 reveals, human error, which was insignificant in terms of frequency of incidents, is a major concern as a cause of fatalities. The large number of fatalities with unknown causes reflects the level of ambiguity or lack of information that exists with regard to about one third of the fatalities.

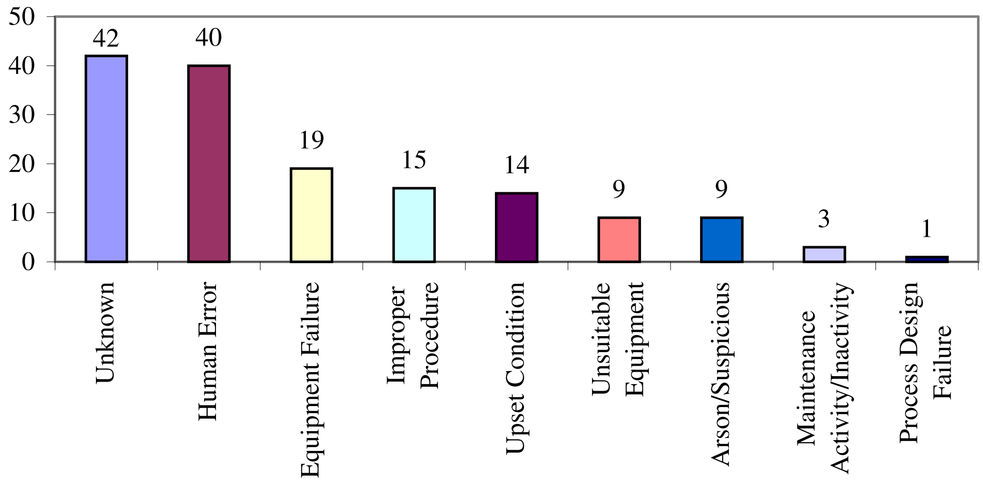

Figure 4-14. Fatalities by cause

There is no single data source that mainly contributes to the 'Unknown". Following are four examples of text descriptions that were difficult to use in determining the cause of the incidents[8]:

- Attempting to light propane stove which then exploded-sequlae (?) of extensive burns
- Subject was burned in a propane explosion at home – sepsis; Severe burns; Exploding propane tank
- Lighting propane tank – Respiratory failure; Inhalation burns; Exploding propane tank
- Victim of propane stove explosion (camper trailer) – Thermal and physical injuries; Explosion of propane tank

[8] The source of these examples is CPSC death certificates database

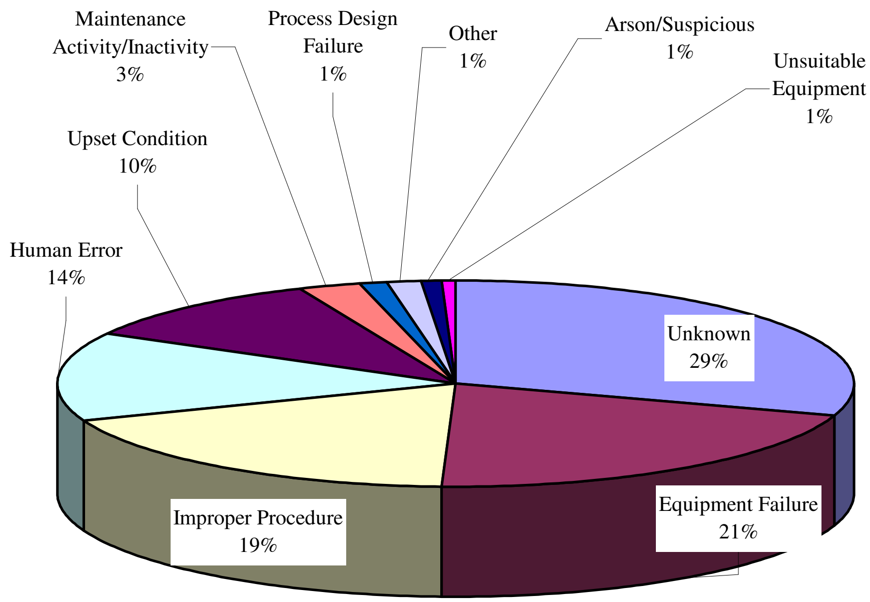

Figure 4-15. Injuries by cause

As Figure 4-15 reveals, Equipment Failure and Improper Procedure are also the leading causes for injuries. Human error is extremely significant as a cause for fatalities; however, equipment failures and improper procedure contribute more to the number of injuries in comparison to human error. It seems that maintenance activity/inactivity is pretty much consistent, with regard to other causes, as a cause for incidents, fires, fatalities and injuries.

As for damage costs, as Figure 4-16 demonstrates, equipment failures caused about $25 million of the property damage. It is important to point out that property damage in EPA RMP facilities is about $26 million, $15 million of which was caused by equipment failure (in several of the incidents, equipment failure was not a single cause).

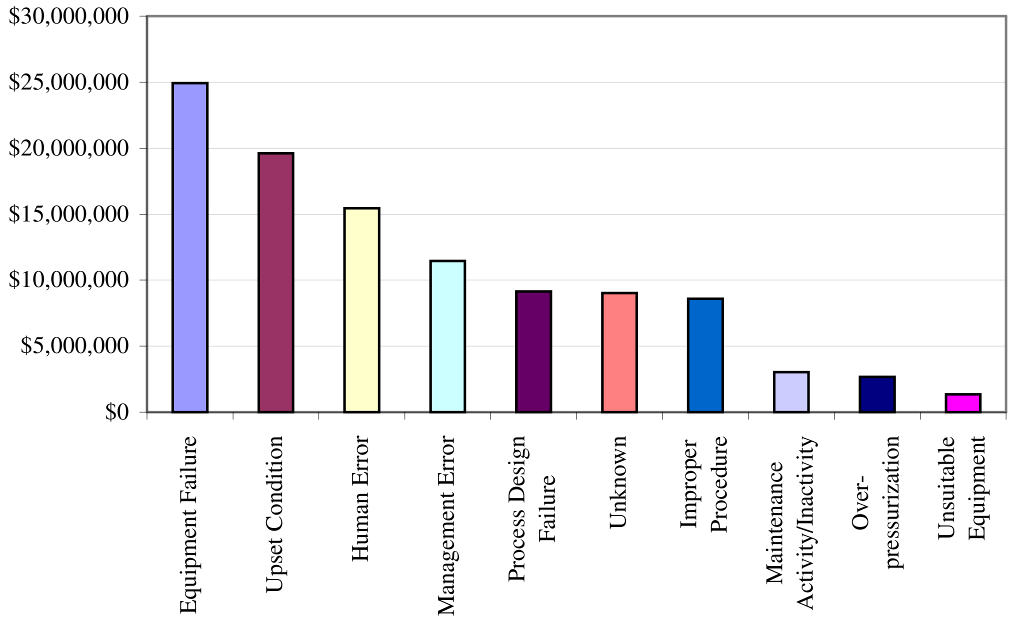

Figure 4-16. Property damage by cause

The intensity of equipment failure as leading cause for property damage would be dramatically reduced, if RMP facilities (facilities that are covered under the EPA RMP regulations) were not considered, as Figure 4-17 reveals. However, equipment failure is still leading as a cause for property damage. Second to equipment failure as leading cause is "upset conditions," which caused about $20 million in property damages. As with equipment failure, upset conditions caused about $11 million only in EPA RMP facilities. Human error resulted in total damage costs of about $16 million, of which $13 million was reported by RMP.

Figure 4-17 presents property damage costs where the property damage reported by RMP facilities have been taken out. Equipment failure and upset conditions are still leading as causes for property damage. Upset condition is followed very closely by process design failure and improper procedures. Human error resulted in about $2 million dollars in damages for these non-RMP facilities.

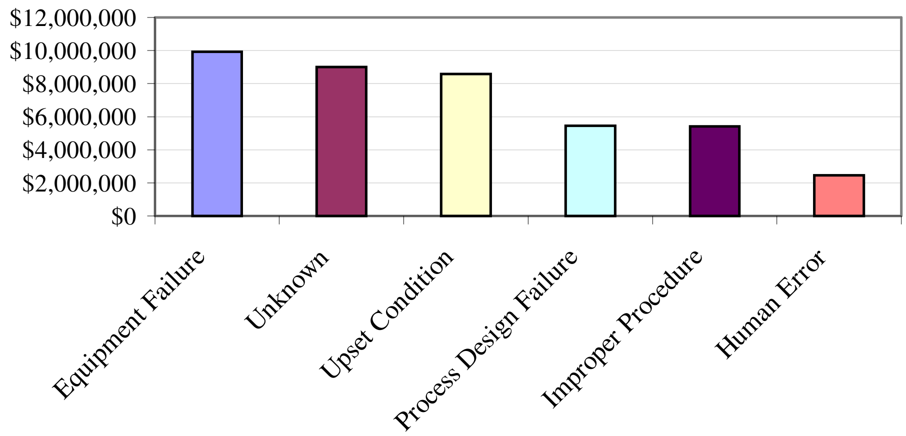

Figure 4-17. Property damage by cause (excluding RMP facilities)

As shown in Figure 4-18, if we disregard "unknown" as a cause, equipment failure caused the highest number of population evacuations. One may suspect that EPA RMP facilities have significant effect on evacuations as well; however, equipment failures in RMP facilities caused fewer evacuations (127 employees) because of a release of 8,500 pounds of butane at a petroleum refinery in Oregon (city), Ohio. Unusual weather conditions in Milwaukee, Wisconsin, with high velocity winds caused a tree branch to fall and puncture a hole in a tank containing 45,000 pounds of propane gas. As a result, 2,000 residents in the neighborhood were evacuated. Evacuations that were caused by upset conditions are mainly evacuations because of incidents where trucks and trains are involved. It is recommended that traffic incidents be separated from upset condistions in future studies.

The majority of evacuations, where equipment failure was the cause, occurred during connecting/disconnecting of hoses from delivery trucks.

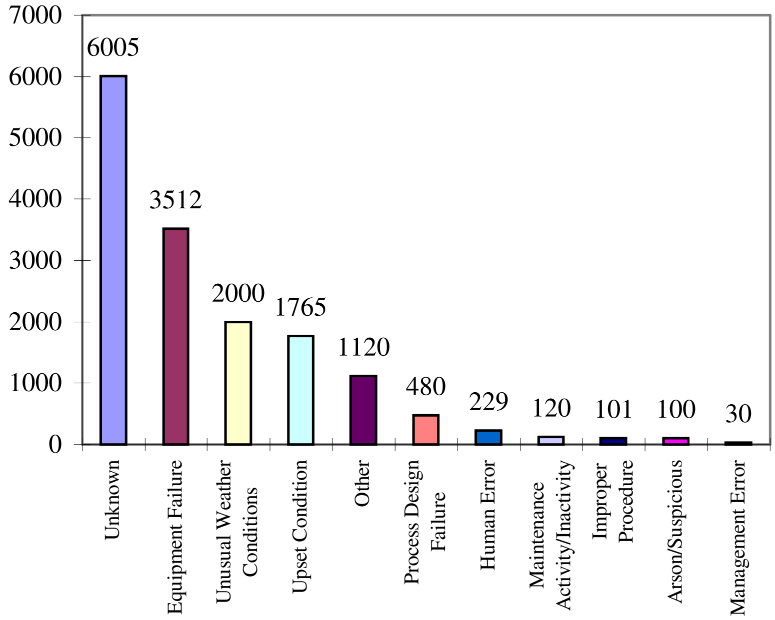

Figure 4-18. Evacuations by causes

Summary of Cause Analysis

Incident consequences have several dimensions. Number of incidents versus injuries, fatalities, damage costs, is a combination of frequency-severity that is being used for prioritization process, risk assessments, and more.

Table 4-16. Severity levels

Severity Level	Number of Fatalities	Number of Injuries	Number of Incidents	Damage Costs Millions
Level 1	No Fatalities	Less than 50	Less than 500	Less than $5
Level 2	1- 10	51 – 100	501 – 1,000	$5 - $10
Level 3	11 – 20	101 – 150	1,001 – 1,500	$10 - $15
Level 4	21 – 30	151 – 200	1,501 – 2,000	$15 - $20
Level 5	More than 30	More than 200	More than 2,000	More than $20

Following is a process of organizing the information in a way that helps in visualizing the "contribution" of the variety of causes to the frequency and severity of consequences. Table 4-16 assigns five levels of severity to the dimensions.

A level has been assigned to the cause categories for each one of the ranges detailed in Table 4-16. Later the cause categories were ranked and arranged according to the severity of their consequences. The results are presented in Table 4-17. As the figures reveal, equipment failure and human error are the causes that led to the most severe consequences. Equipment failure led to more injuries, incidents, and property damage.

Human error however, led to more than twice as many fatalities as equipment failure and therefore should be ranked as the cause that led to the most severe consequences. Improper procedure and upset conditions are responsible for severe consequences as well, but less severe than the consequences of human error and equipment failure. Other cause categories such as management error, process design failure, maintenance activity/inactivity, unsuitable equipment, and arson/suspicious have significant severe consequences as well but relatively fewer in number.

Table 4-17. Consequence severity of cause categories

Cause Category	**Number of Incidents**	**Number of Fatalities**	**Number of Injuries**	**Property Damage**
Equipment Failure	4	3	5	5
Human Error	1	5	4	4
Improper Procedure	2	3	5	2
Upset Condition	1	3	3	4
Management Error	1	1	1	3
Process Design Failure	1	2	1	2
Maintenance Activity/Inactivity	1	2	1	1
Unsuitable Equipment	1	3	1	1
Arson/Suspicious	1	2	1	1

Analysis of Incidents Involving Structures

About 500 categories of structures and locations exist in the database. The structures and locations were adopted from NFIRS, and were grouped into 54 new groups of categories in order to be able to analyze the data. Meaningful data is found with regard to 15 of these groups. Charts in this chapter do not necessarily consist of all groups, but only these that contribute more to the issue under discussion. Following is a list of those 15 categories:

- Residences
- Recreational facilities
- General Areas, Street, Properties, and Roads
- Agricultural Facilities and Storage Areas
- Transportation Maintenance, Repair Shops, Manufacturing and Storage areas
- Distribution Systems for Gas, Water, Steam, and Electricity
- Highways
- Commercial Properties
- Entertainment Facilities
- Chemical Industry and Related Properties
- General Warehouses and other Unclassified Storage Areas
- Parking Areas
- LP Gas Bulk Plant
- Child Care and Aged Nursing
- Food Processing and Storage Areas

The distribution of fires and explosions according to the structure categories is given in Figure 4-19 (note the logarithmic scale). As Figure 4-19 reveals, residences are the most vulnerable locations for fires and explosions. About 62% of the fires, and 58% of the explosions occurs in residences. About 13% of the fires and 6% of the explosions occurred in General areas, which consist of the following:

- Idle properties, vacant lots
- Unclassified construction and unoccupied property
- Open land, fields
- Dump, sanitary landfill
- Public mailbox
- Cemetery
- Unclassified outdoor properties
- Paved private streets, ways, roads and unpaved public streets.

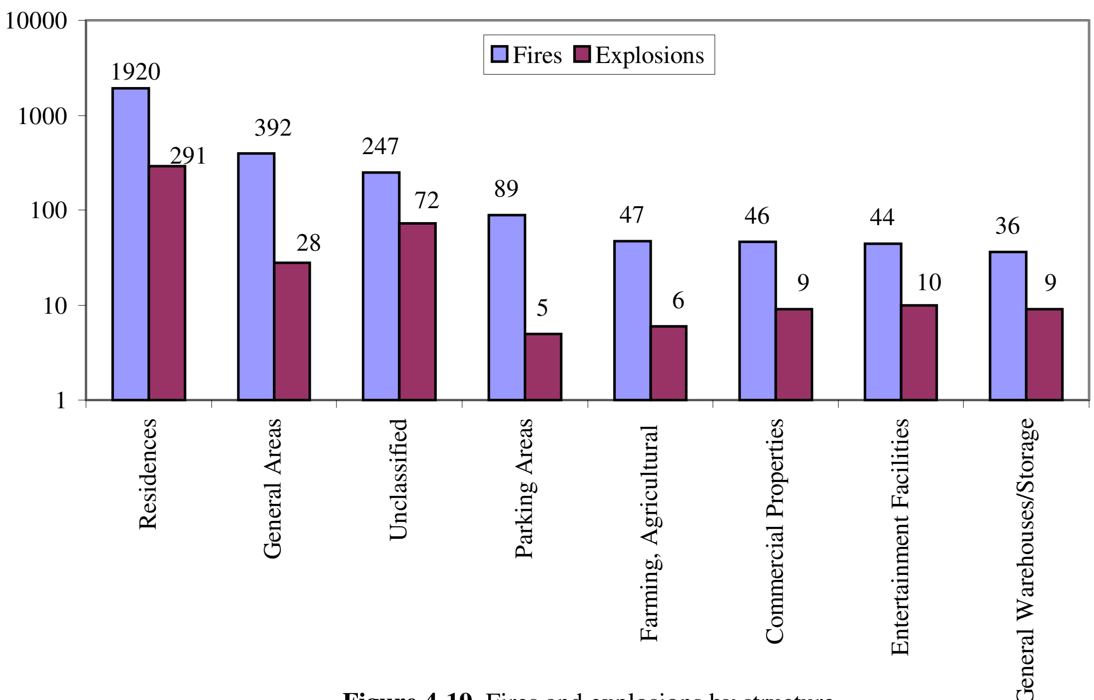

Figure 4-19. Fires and explosions by structure

In most of these incidents stove, heaters and lanterns within the recreational vehicles or trailers initiated the incidents. It should be noted that trailers incidents are counted among the recreational facilities, and mobile homes are counted among residencies.

In Recreational facilities, although the number of fires and explosions in these facilities is low, these incidents had severe consequences. 23 fires and 18 explosions that were captured by the database (In the majority of the explosions, fires were involved too) resulted in 19 fatalities, as Figure 4-20 reveals. Most of the incidents occurred in trailers while camping.

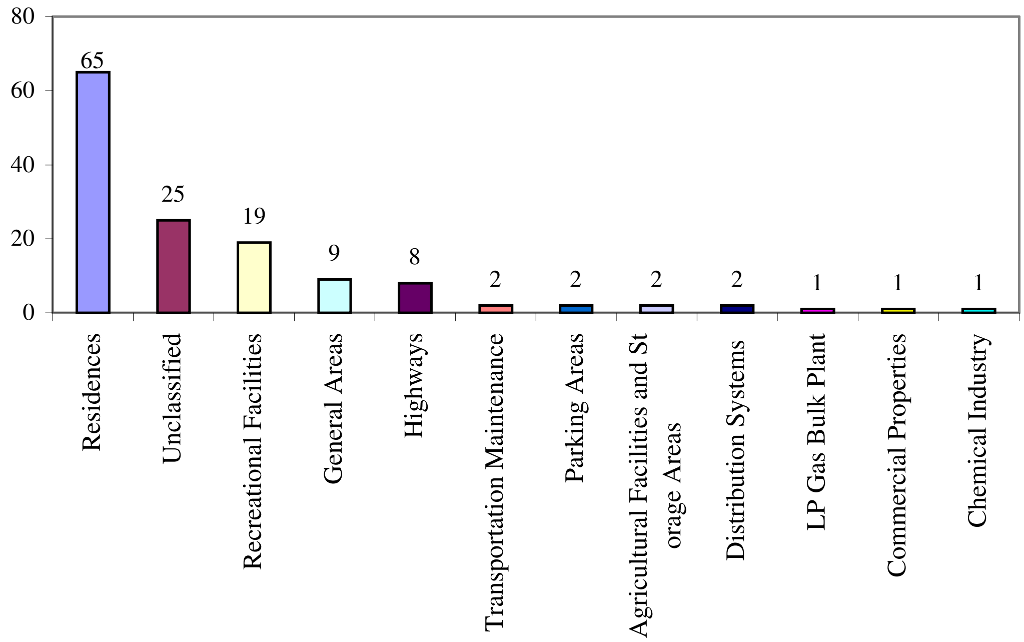

Figure 4-20. Fatalities by structure

As for injuries, Residences outnumber all other structure categories. Commercial Properties is a category that consists of many types of stores, and several other properties such as laundries, home maintenance services, studios, and more. In a broad category such as Commercial properties, as well as in Residences, large numbers of incidents, injuries and fatalities could be expected. Commercial Properties had a large number of injuries but a low number of fatalities. Since Commercial Properties are mainly operated during daily hours, a developing incident may be noticed early enough and therefore the severity of the consequences are reduced.

Figure 4-21 reveals significant number of injuries in Child Care and Old Age Nursing structures. The majority of these injuries were exposure to carbon monoxide, and in several cases, inhalation of propane.

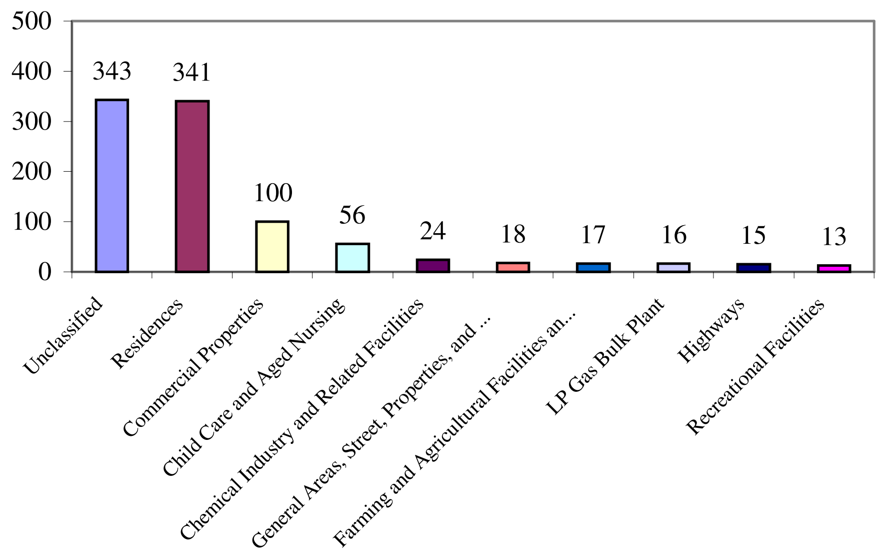

Figure 4-21. Injuries by structure

The chemical and petrochemical sector are capital intensive industries. Thus, incidents that involve fires and explosions cause significant damage costs, especially in cases that shutdown time is long and loss of production costs are enormous. The large number of fires and explosions in residences obviously led to extensive damage. Distribution of damage costs by incidents in structures is shown in Figure 4-22.

Summary of Structure Analysis

Residences is the structure category that suffers the most severe consequences, probably because there are enomous number of residences in comparison to other structures. Many fires and explosions occurred in general areas (which is a broad category) however, the consequences are not as severe in comparison to other categories such as Recreational Facilities, Commercial Properties, Food processing and Storage,

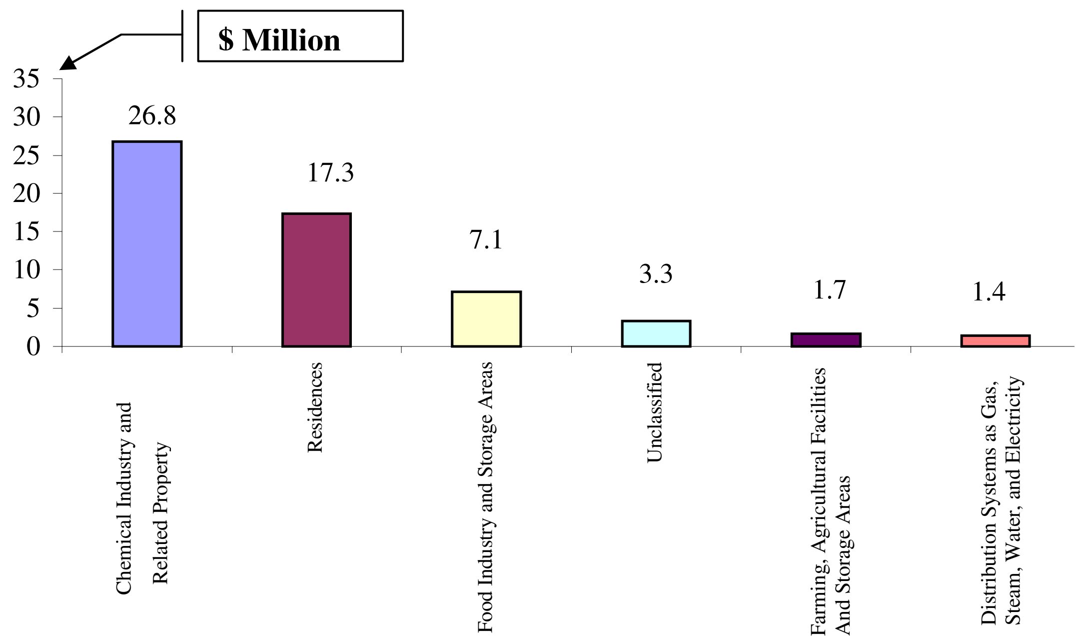

Figure 4-22. Damage costs by structure

and Chemical Industry Facilities. Damage cost of Chemical industry are high, however, most of the damage in this category have been reported, and the cost are quite well evaluated. The food processing and storage areas suffers from a large property damage however, the number of fatalities and injuries are low. This might be explained by the fact these areas consist of capital intensive equipment and goods, but are not highly occupied by people.

Analysis of Equipment Items Involved in Incidents

The equipment categories found in the databases consist of about 80 categories. It is possible to group many of these categories. Following is a list of equipment groups that have been used to analyze and identify patterns of incident according to equipment:

- Cooking
- Heating
- Industrial
- Cooling
- Piping
- Other

Figure 4-23 illustrates the distribution of incidents according to the groups above. The number of incidents where cooking equipment was involved is extremely high and so is the number of incidents where heating equipment is involved. The distribution of incidents of cooking equipment and heating equipment are presented in Figure 4-24 and Figure 4-25 respectively.

The number of incidents where cooking equipment involved is extremely high mainly because of incidents in which open fired grills were involved. The open fired grill incidents outnumber portable cooking unit incidents (which has the next largest number of incidents) by four times.

The number of heating equipment incidents is not as large as that of cooking equipment. The majority of cooking equipment incidents involved fires and explosions. However, many of the heating equipment incidents are carbon monoxide poisoning.

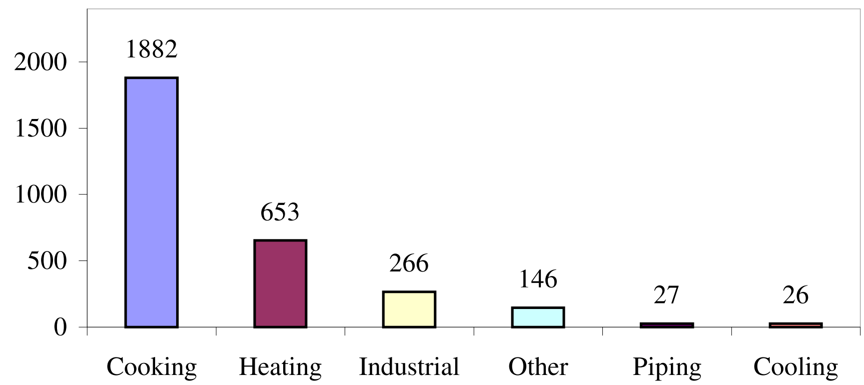

Figure 4-23. Incidents by equipment category

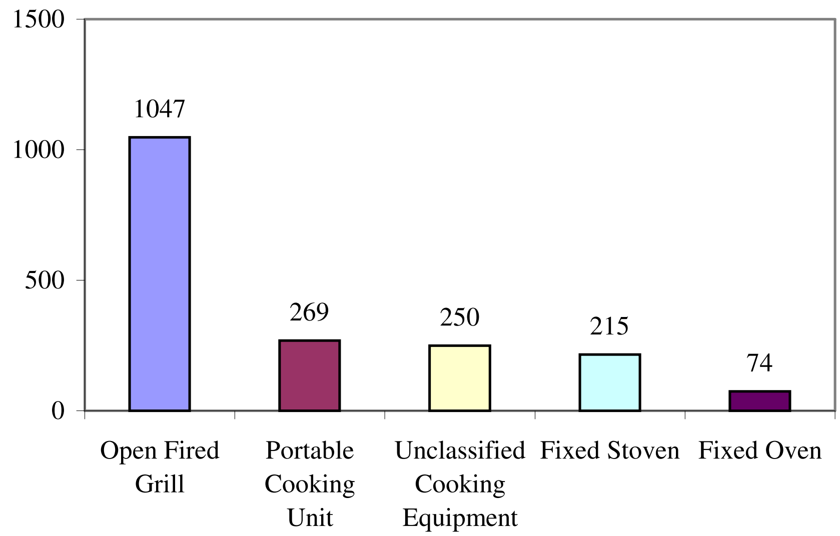

Figure 4-24. Incidents by type of cooking equipment

As for fatalities, the problematic issue of carbon monoxide poisoning, is carbon monoxide's ability to be attached to blood cells is about 200 times stronger than that of oxygen. Moreover, carbon monoxide is colorless, has no smell, and usually claims its victims while they are asleep, i.e.; the probability of severe consequences in carbon monoxide incidents is higher.

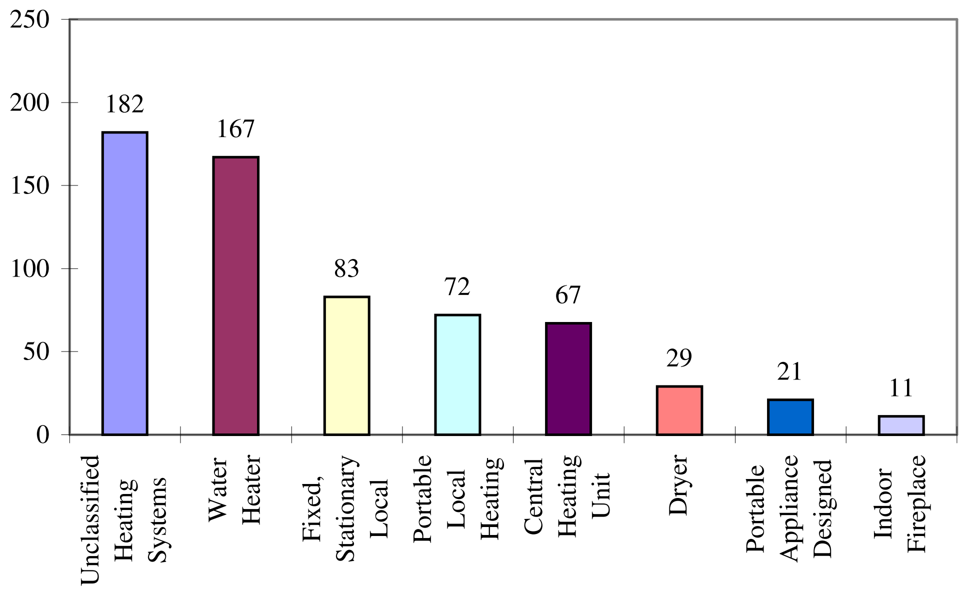

Figure 4-25. Incidents by type of heating equipment

These relationships are demonstrated in Figure 4-26 that presents the distribution of fatalities versus group of equipment. As this figure reveals, incidents where heating equipment was involved caused about three times as many fatalities compared to cooking equipment incidents, although the number of cooking equipment incidents is about three times larger than the number of heating equipment incidents. Figures 4-27 and Figure 4-28 consists of the distribution of fatalities by cooking equipment and heating equipment respectively.

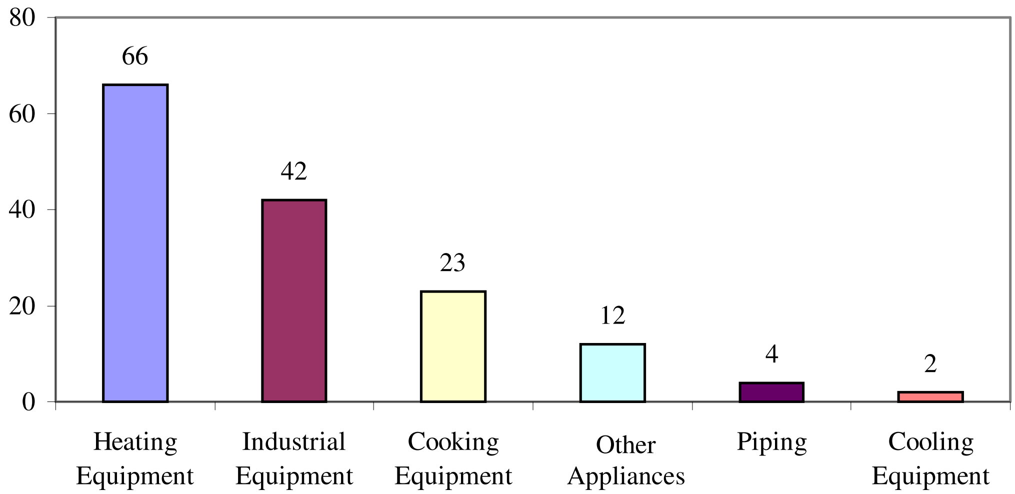

Figure 4-26. Fatalities by equipment categories

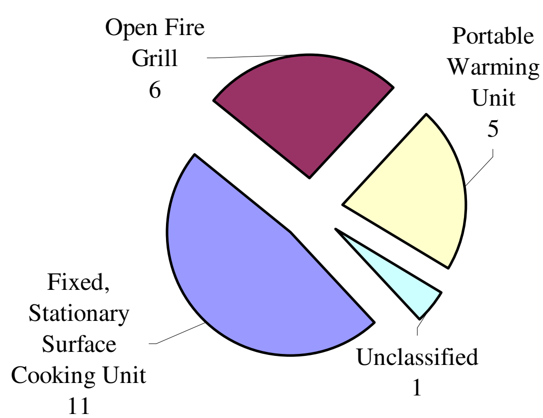

Figure 4-27. Fatalities by type of cooking equipment

Among the cooking equipment, stoves are the leading equipment category that cause fatalities. Among the heating equipment, portable space heaters are the deadliest equipment, mainly because of carbon monoxide poisoning.

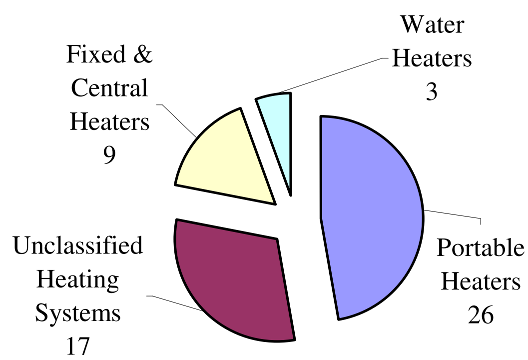

Figure 4-28. Fatalities by type of heating equipment

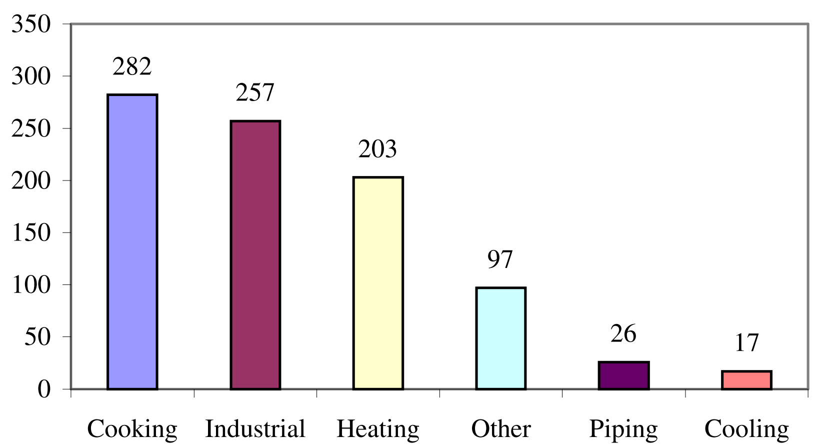

Figure 4-29. Injuries by type of equipment

Figure 4-29 shows the distribution of injuries according to the type of equipment involved in the incident. As for injuries, industrial equipment is a significant factor in causing injuries. Storage and process vessels, pumps, generators, compressors, casting, molding, and forging equipment are including in this category. Figure 4-30 and Figure

4-31 present injury distribution by type of cooking and heating equipment respectively. Although open fire grills are involved in more than a thousand incidents in the database, these incidents caused less than 100 injuries.

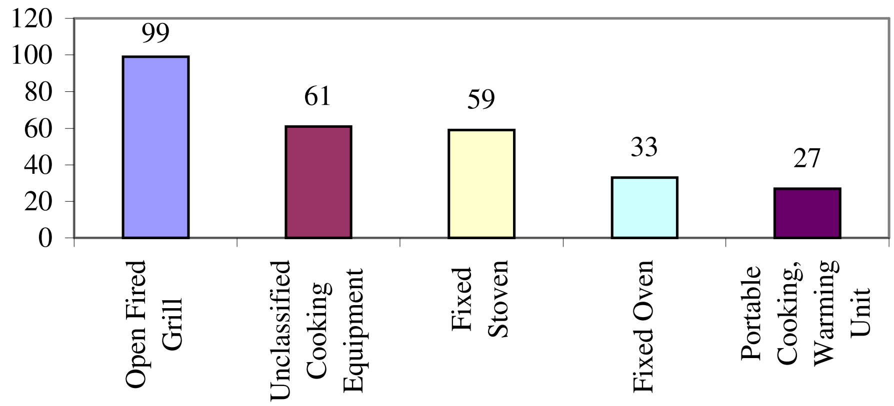

Figure 4-30. Injuries by type of cooking equipment

Heating equipment is a major concern in terms of severity of consequences. In both fatalities and injuries, heating equipment claimed a significant number of victims. In many of the fatalities where heating equipment was involved, the cause of death was carbon monoxide poisoning, while heating equipment-related injuries are mainly because of fires and explosions.

Figure 4-32 reveals the distribution of fires and explosions according to the type of equipment. The correlation between the fires and explosions for each of the categories is quite consistent; e.g., equipment category with the largest number of fires is the category with the large number of explosions. However, among the cooking equipment incidents, about 12% are explosions, while 23% of the heating equipment incidents are explosions, i.e., heating equipment causes more explosions than fires compared to cooking. Since industrial equipment incidents are mainly propane tank incidents, the majority of these incidents are explosions as well.

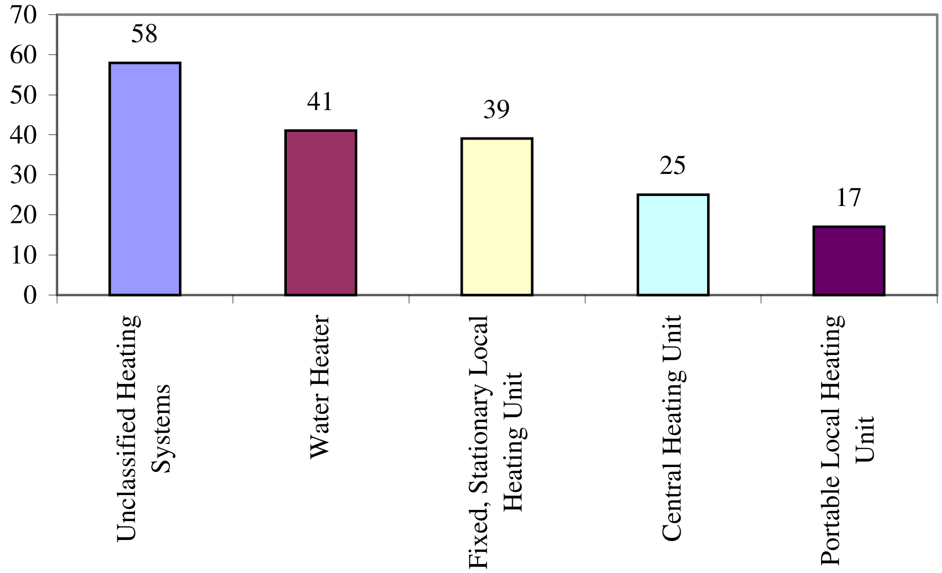

Figure 4-31. Injuries by type of heating equipment

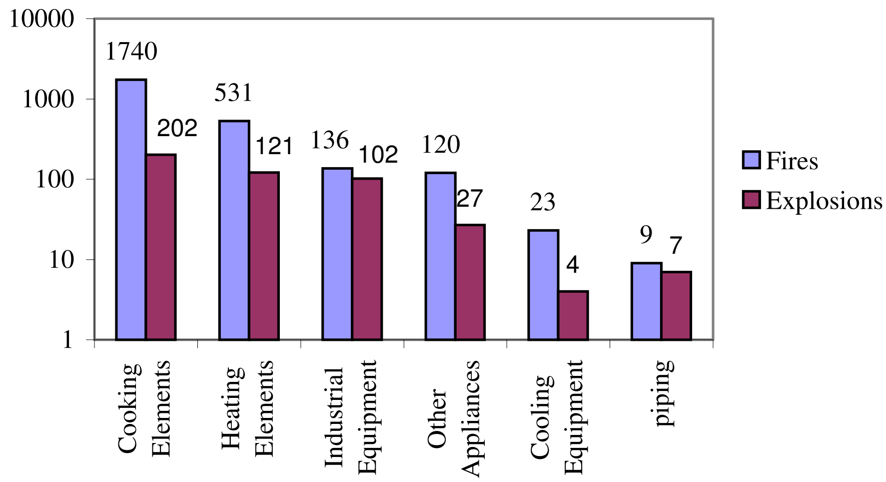

Figure 4-32. Fires and explosions by equipment category

As for property damage, in a single incident in a refinery in Baytown, Texas, a pipe ruptured and caused $9,000,000 property damage. In another incident in Oklahoma, failure of a process vessel caused $10,000,000 damage. Several other incidents caused property damage of several million dollars as well. The common thread to all of these incidents is that they are RMP facilities. Incorporating data on RMP facilities distorts the picture of property damage and therefore Figure 4-33 excludes damage to RMP facilities. Figure 4-34 and Figure 4-35 demonstrate property damage by cooking and heating equipment respectively.

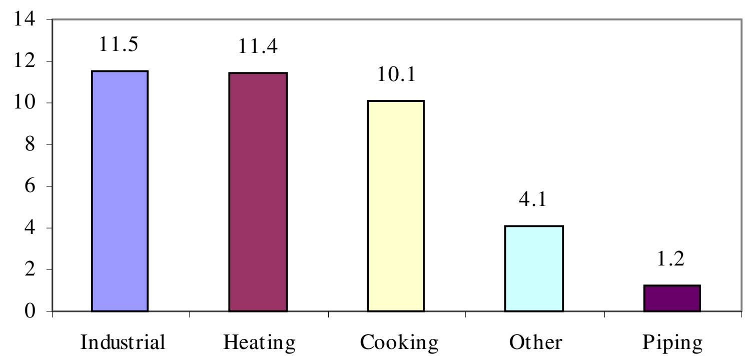

Figure 4-33. Property damage by equipment category. (Excluding RMP facilities) [$ million]

Figure 4-34. Property damage by cooking equipment [$ million]

The major property damage cost because of cooking equipment incidents is damage that was caused by explosions and fires of open fired grills.

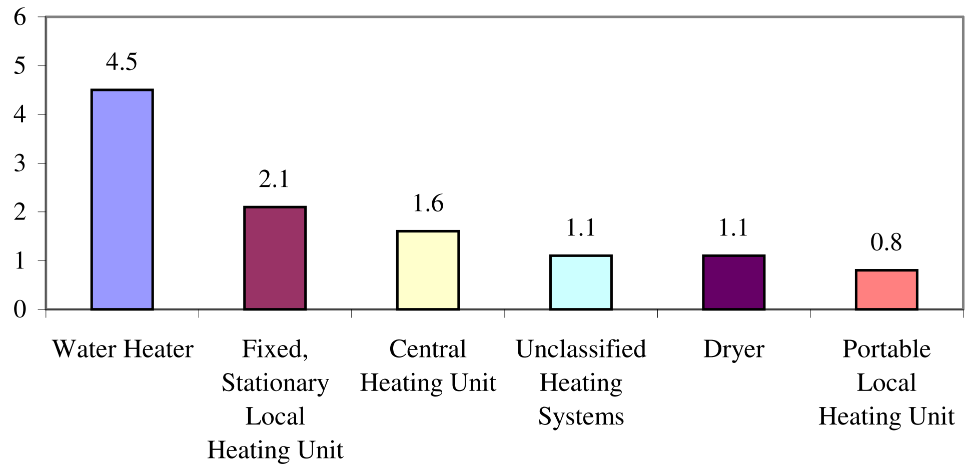

Figure 4-35. Property damage by type of heating equipment [$ million]

Property damage because of unclassified cooking equipment and other cooking categories are quite low in comparison to the damage of grill incidents. Water heaters are responsible for the highest property damage costs in the heating equipment category.

Propane is a combustible product and in cases of releases of large quantity near population concentration, the population is required to be evacuated. The largest population evacuation resulted because of industrial equipment. Among the types of equipment, storage tank incidents led to evacuation of the majority of the population under this category.

Three major incidents with very large LPG incidents caused the evacuation of more than 8,700 people. A single piping rupture in a refinery in Ohio required the evacuation of 131 persons. The distribution of number of people evacuated by type of equipment is shown in Figure 4-36.

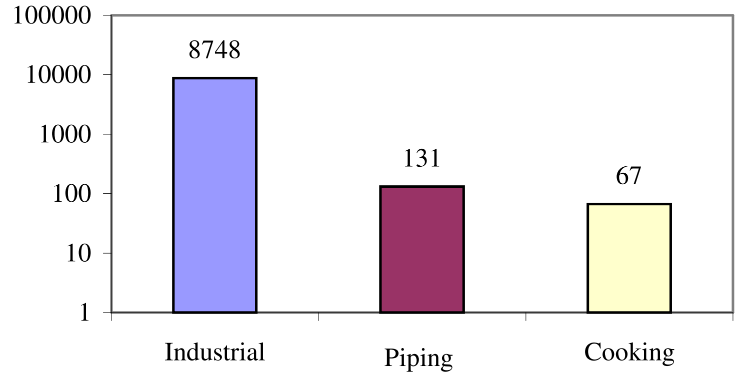

Figure 4-36. Evacuations by type of equipment

Summary of Equipment Items Involved in Incidents

The severity of the categories can be evaluated by assigning severity level listed in Table 4-16. Heating equipment, industrial equipment, other appliances, cooking equipment, piping, and cooling equipment are the most significant categories in this discussion. Table 4-18 presents theses categories after assignment of severity level to each of the consequence dimensions, ranking the categories and organizing the data.

Table 4-18. Consequences severity of equipment categories

Equipment Category	Number of Incidents	Number of Injuries	Number of Fatalities	Property Damage
Heating Elements	2	5	5	3
Cooking Equipment	4	5	3	3
Industrial Equipment	1	5	2	5
Piping	1	2	2	3
Other Appliances	1	2	2	1
Cooling Equipment	1	1	1	1

As table 4-18 reveals, the category with the most severe combination of consequences is heating equipment. The number of fatalities because of heating equipment is about three times higher than the number of fatalities in cooking equipment incidents. However, the number of injuries in cooking equipment incidents is much larger than that of heating equipment incidents.

In terms of property damage (excluding damage to RMP facilities), storage tank (which is represented by the industrial equipment category) incident damage to property is much larger then all other categories.

Analysis of Incidents Involving Vehicles

Several dozens of vehicle types exist in the database. For analysis purposes the number is reduced by grouping them into 11 categories as follows:

- Recreational
- Propane delivery trucks
- Automobiles
- Mobile homes
- General use trucks
- Railroad
- Road transport vehicles (including public transportation)
- Heavy equipment (earth moving equipment, construction equipment, material handling equipment, and other unclassified heavy equipment)
- Agricultural and gardening equipment
- Water vehicles
- Unclassified vehicle

Figure 4-37 illustrates incident distribution according to vehicle categories. As Figure 4-37 reveals, mobile homes are by far the leading category. In many of the mobile home incidents, the equipment involved was space heaters. Figure 4-38 presents the distribution of the number of fires and explosions according to vehicle categories. The largest number of fires and explosions occurred in incidents where the vehicle categories were mobile homes and recreational vehicles. Mobile home fire incidents outnumber all the other categories.

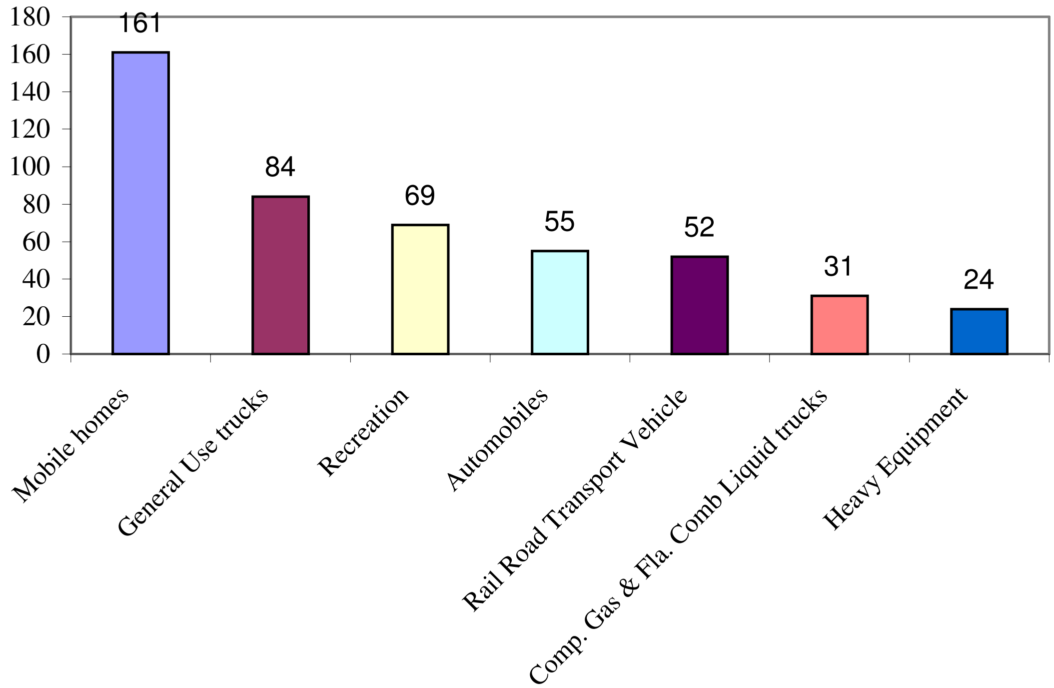

Figure 4-37. Incidents by type of vehicle

The number of incidents of recreational vehicles, automobiles, and in railroad vehicles is similar. The number of incidents of general use trucks is a little higher than the rate of the last three categories. However, this rate is not exceptional, so general use trucks incidents is excluded from this pattern. The number of incidents in compressed gas and combustible liquefied trucks is not large in comparison to the other vehicles. However, it is reasonable to believe that if these numbers were normalized by the number of vehicles in each of the categories, these numbers would be larger than the other vehicle categories. It is also important to remember that the probability that incidents where compressed gas and combustible liquefied trucks are involved will be reported is higher in comparison to the other categories.

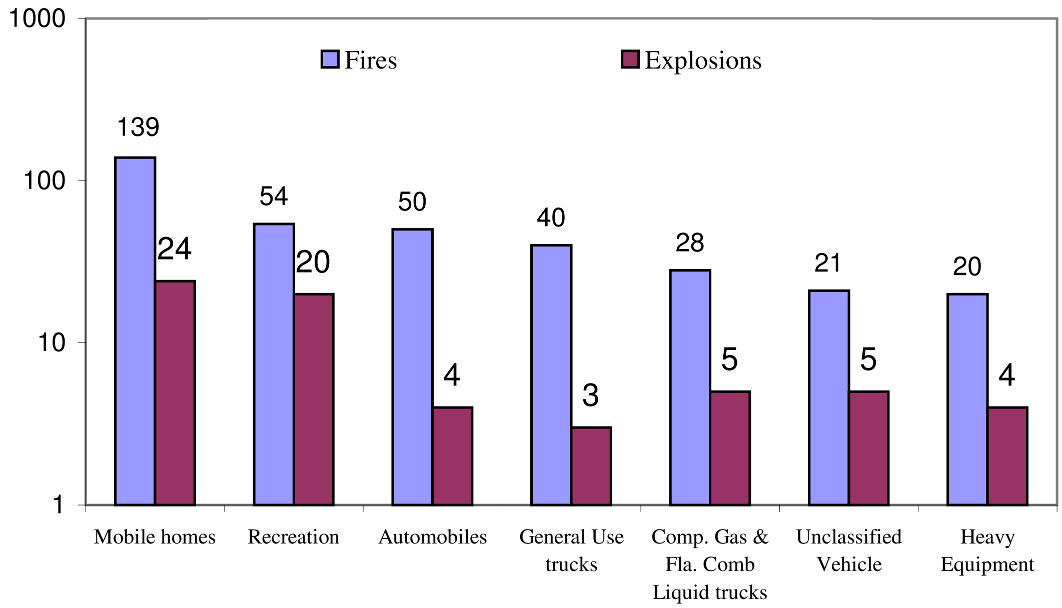

Figure 4-38. Fires and explosions by vehicle

This is because not only do these incidents have the same probability to be reported to NFIRS like any other incidents, but also in several states, it is compulsory to report on commercial propane related incidents. For example, in Texas, the Railroad Commission conducts incident investigations and develops a report in these cases. Moreover, HMIRS, which is a collection of vehicular transportation incidents, might capture these incidents as well. This may explain the high ratio between the number of incidents of compressed gas and combustible liquefied trucks and the other categories.

As Figure 4-39 reveals, recreational properties incidents led to the largest number of fatalities. 75% of these victims died from carbon monoxide poisoning.

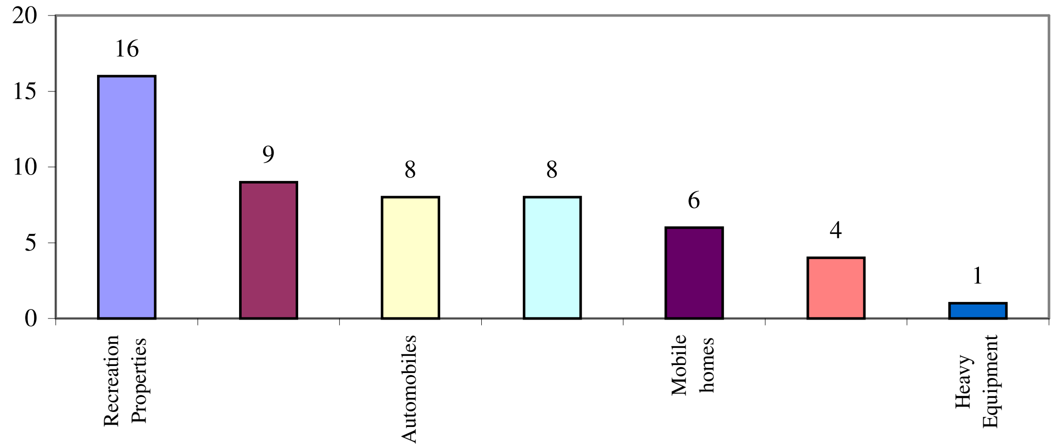

Figure 4-39. Fatalities by type of vehicle

These do not include carbon monoxide fatalities in tents and horse trailers, which are not classified as recreational vehicles. Most of the fatalities in compressed gas and combustible liquefied trucks incidents occurred during traffic incidents. The data lacks the cause of deaths in these cases.

Carbon monoxide poisoning is the cause of death of four of the fatalities in the automobile incidents. It is not clear what was the cause of deaths for three of the fatalities. The report indicates criminal activity since a body was found in the trunk of a car, and additional two people died in the explosion of the car. There is no information with regard to why this incident was classified as a propane incident. For future work, there need to be a resolution of how such incidents should be treated in the database. As from injuries in propane-related incidents where a vehicle was involved, 80 of the injuries in the heavy equipment category are from one incident in Ohio. There is no additional information on this incident.

As would be expected, vehicle incidents create less property damage than incidents in structures. Figure 4-40 demonstrates the distribution of injuries by vehicle type. Figure 4-41 consists of distribution of property damage by vehicle categories.

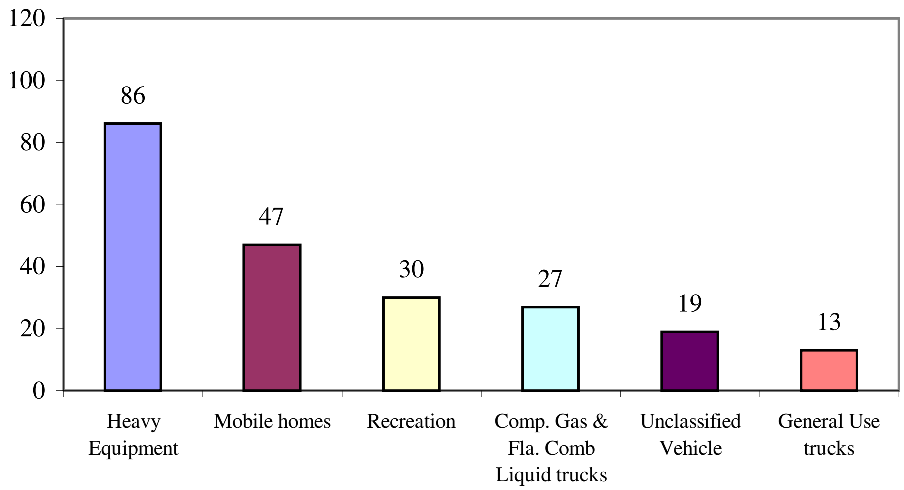

Figure 4-40. Injuries by type of vehicle

The large damage where compressed gas and combustible liquefied trucks is the type of vehicle involved, can be explained by the fact that these are large vehicles with expensive equipments, and the damage in these incidents involves the total damage to

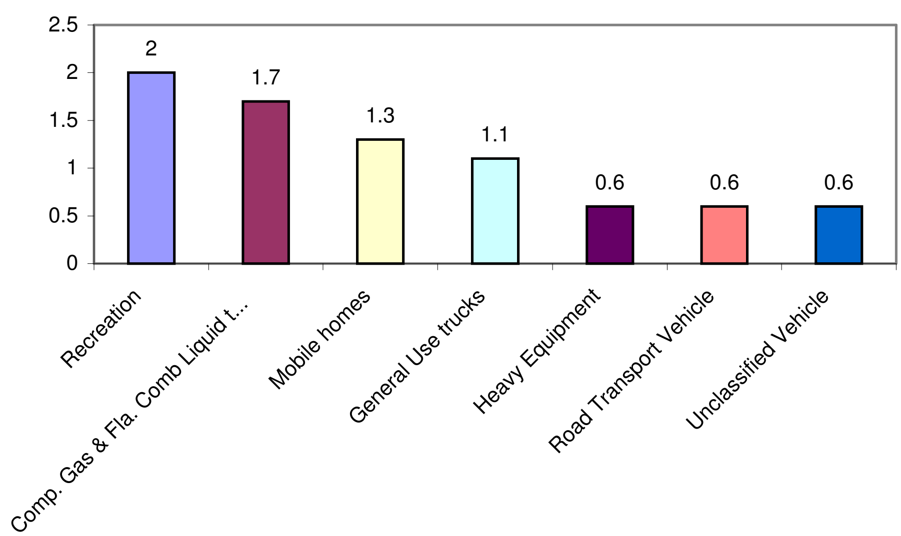

Figure 4-41. Property damage by vehicle categories [$ million]

the trucks as well as the damage to properties involved in the incident. The damage in mobile home incidents consists of many incidents with damage in the range of a few thousands of dollars in each of the incidents.

As for evacuations, Compressed gas and flammable combustible liquid trucks incident forced evacuation of several hundreds of people in each of the incidents, as Figure 4-42 demonstrates.

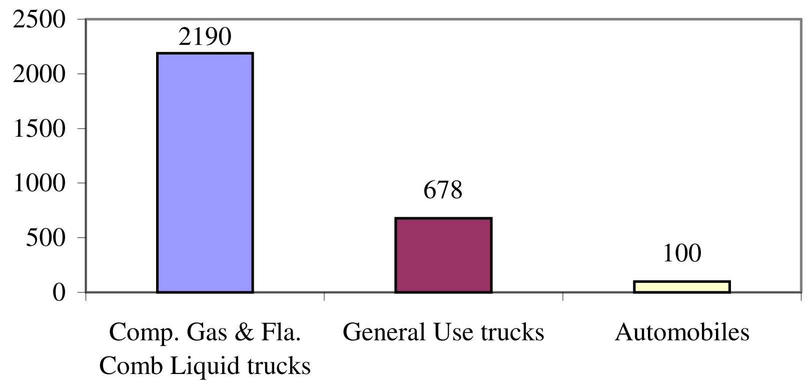

Figure 4-42. Number of evacuated by type of vehicle

Summary

General

Many entities are collecting data on incidents. These entities differ from each other in their interests, data collection procedures, definitions, and scope. Extensive efforts are required in order to integrate information from the data sources as well as to identify the effects of the individual aspects of data collection procedures on the quality and completeness of the data.

Phase I of this study consists of development of criteria, refining definitions and taxonomy, development of procedures, and review of data sources to determine which of these sources are useful for the project. Phase II consists of implementation of Phase I on data from 1998, integration of the data into a new database, data analysis, and assessment of propane incidents nationwide.

In implementing Phases I and II, the performance of the propane industry was assessed and revealed weaknesses, and factors that contribute to the areas of poor performance. The results of this study allows to improve safety in the propane industry by implementing changes in design, standardization of protection equipment and sensors, and to tailor training programs that will address the weak spots that this study reveals. An important aspect in assessing industrial safety performance is measurements along time period of several years, to identify trends. However, the data that is required to conduct this phase of the study is not available.

Estimation of Number of Propane-Related Incidents

The database developed in this study consists of 3,733 incidents. Statistical methods were used to estimate the total number of incidents nationwide. These methods resulted in an estimate of a total 13,000 propane related incidents in 1998. A separate estimate indicates that in 1998 propane incidents resulted in 10,000 injuries involving treatment in an emergency room. This latter source is a survey of emergency room and includes only incidents with injuries. Another estimation indicates that 1,200 incidents were directly related to propane industry facilities and operations.

Duplication Identification

Analysis of the data identified a relatively low number of duplications. The majority of the duplications were found within the sources and not between them, i.e., the duplications are mainly because operators reported some incidents twice (or more). The assumption is that significant improvements can be made by real-time data collection. This is especially true for high consequence events that are more likely to be reported by the news media.

Statistical Summary

The following list is a statistical summary of the analysis:

- 4% of the incidents resulted in 137 fatalities
- 35 fatalities were due to carbon monoxide and 66 were due to fires and explosions
- 15% of the incidents resulted in 1,012 injuries
- 82% of the incidents involved fires
- 14% of the incidents involved explosions
- About 1% of the incidents required evacuations

This study includes incident pattern identification as a function of equipment involved in incidents, types of vehicles, types of structures, and causes. In 50% of the incidents, cooking equipment was involved, and within the cooking equipment, open fire grills are responsible for 55% of the incidents resulting in property damage of more then 6 million dollars.

Among the incidents involving vehicles, fires and explosions are primarily reported at unclassified mobile properties and at mobile homes. Railroad transport vehicles are responsible for about one-third of the fatalities involving vehicles. Heavy equipment caused more than one-third of the vehicle-related injuries in one major incident. Mobile home incidents are responsible for 18% of the injuries and 11% of the fatalities in vehicle incidents. 12% of the injuries and one-third of the fatalities involved recreational vehicles.

Root Causes

Root cause analysis is a complex task for incidents that have just occurred. For incidents that have occurred years earlier it is even more difficult to determine root causes. In many cases, the cause shown in the database was derived from a textual description or was supplied by the reporting entity. It is thus important to point out that the descriptions could be interpreted in more than one way and the causes shown may actually be contributing causes or the initiating event.

The number of incidents where equipment failure' was the cause outnumbered by three times the incidents caused by upset conditions, and makes up about one-third of the causes of the propane-related incidents. Though the frequency of incidents where equipment failure is the cause is extremely high, incidents that were caused by upset conditions and human error, resulted in consequences equal to or worse than those resulting from equipment failures. Equipment failure caused about 23% of the property damage.

Structures

Most of the fatalities and injuries occurred within residences. The structure category with the second highest number of fatalities and injuries is unclassified structures. Recreational facility incidents have a high number of fatalities, although a low number of injuries are reported. Ignoring the damage within chemical industry facilities, incidents in residences caused the most property damage (about 17% of the sum of all property damage reported).

Future Improvement of Data Collection

The development of indicator-based industrial performance measurement systems was explored in this study. However, this study lacks the identification of trends that are helpful in determining whether the efforts invested toward safety improvement lead to the desired results. In order to complete this phase of the study, this methodology should be applied over a reasonable period of time in order to gain valid results. The results herein provide an excellent baseline for performance measurement by using the methodology as described above. However, it is important to point out that in most cases, there is a two to three year delay in getting access to incident data from existing data collection processes (e.g., NFIRS data collection of 1999 became available in late 2002), and it takes three years to complete the data collection for a certain year. A systematic collection of news-clipping data for propane incidents is currently ongoing. The data is being collected since the introduction of the Google news search engine in September 2002. This source has proven to provide far more data than was available previously and perhaps five times as much as in 1998. Thus in order to overcome the time lag involved in using incident data from publicly available sources, the lack of root cause information, and lack of reporting of all incidents; it is recommended to use a real-time incident data collection.

Conclusion

This study demonstrates that propane incident data collection and consolidation from a variety of sources is worthwhile, and that much can be learned from the consolidated database. However a real-time incident data collection procedure must be implemented in order to maximize the methodology.

There is an enormous potential in employing data collection from a variety of information sources. This technique not only increases the amount of data captured by individual sources but also the ability to capture more diverse and significant incidents. The methodology used in this study resulted in the identification of one thousand incidents beyond the 2,800 reported in NFIRS. The methodology also captured ten times more fatalities than NFIRS.

The news-clippings search was applied as a data collection methodology. This methodology was applied and made a significant contribution to the results. However, this methodology is maximized only when applied in real-time because the data sources are available for limited periods of time, and it is possible to solicit additional information only during the period shortly after the incidents occur.

CHAPTER V

SUMMARY AND CONCLUSIONS

Measurements of Process Safety Elements Within Facilities

The models currently in use for measurement of process safety performance of leading as well as trailing indicators has the major disadvantage of being dependent on the evaluators' judgment. Therefore, the guideline in the development of the model in this study was to establish a measurement system that is independent of the evaluator. However, to eliminate subjectivity from the evaluators, several items in the model needed to be standardized. This process required a survey of a panel of experts. The Analytical Hierarchy Process technique has been developed to standardize the Management of Change element of the OSHA PSM standard. Similarly, this method can be applied to other elements in this standard.

Although sensitivity analysis has minor importance when a MCDM method is applied to measure effects and not for selecting from a set of alternatives, this analysis was conducted on the single branch that does not consist of robust criteria. This analysis revealed the critical criterion. However, since the final preferences of the alternatives that are to be reversed are nearly the same, the changes in the weights of criteria that are required to reverse preferences is not large, especially with criteria of initial low weight.

The results of this study are consolidated to a form that is useful for process safety performance measurements of Management of Change programs. This form is presented in Appendix B.

Benchmarking of Process Safety Elements Among Facilities

OSHA PSM is a comprehensive standard. PSM element compartmentalization in the standard creates an opportunity to develop measurement models for each of the elements separately. The performance-based nature of the MOC element is apparent from a reading of the regulatory requirements. Practices of OSHA PSM elements often vary and there is a need to determine an industrial consensus or Recognized and

Generally Accepted Good Engineering Practices (RAGAGEP). The efforts in this study aimed to develop a benchmark of industry practices for three of the process safety management requirements. The benchmarking of PSM elements is a sequence composed of 4 stages:

1. Decomposition of the element to its basic components
2. Questionnaire development
3. Surveying facilities
4. Results analysis

Emergency Preparedness and Response, Management of Change, and Investigation of Chemical Process Incidents are three elements in process safety programs. This study presents the results of implementing the four stages above on the Management of Change and Emergency Planning elements, and the development of questionnaire for the Process Safety Incident Investigation requirement.

Assessment of Industrial Safety Performance

Assessment based on a methodology of incident data collection from various sources is a thorough process that has to be done carefully and in several stages. The primary focus of industrial safety performance assessment, which uses the methodology employed in this study, is to establish baseline metrics for the universe under investigation with regard to safety. This requires definitions of indicators as the distribution of number of incidents, number of injuries, property damage costs, releases of materials, hospitalizations, and evacuations and identification of incident trends of these indicators. The consolidated database is then analyzed and correlated across the causes of incidents, equipment involved, initiation events, location, and other domains. Several of the sources that are available collect only part or a sample of the information. However, it is possible to estimate the total number of incidents by applying statistical tools on the data. Implementation of indicator-based industrial performance measurement systems along several years helps to determine whether the efforts invested toward safety improvement lead to the desired results. Other benefits are the ability to determine the areas that will lead to major reduction of losses and reduction in the number of incidents.

Among the major conclusions from applying the methodology on the propane industry is to not be "misled" by the amount of data that a certain source may contain. In this study, a single source of information (NFIRS) provided about two-third of the data; however, it failed to collect significant data (e.g., failed to collect data with severe consequences). This conclusion justified the efforts that were required to broaden the search and combination of sources of information. Among the sources is a database that was established by a collection methodology that is based on News Clips. This method uses search engines to query newspapers according to a predetermined set of keywords. This method has several advantages including the ability to further investigate the incident or to verify the information if required, if data is being collected in real time.

As noted earlier, this study lacks the identification of trends that are helpful in determining whether the efforts invested toward safety improvement lead to the desired results. In order to complete this phase of the study, this methodology should be applied on a reasonable period of time in order to gain valid results. The results herein provide a baseline for performance measurement by using the methodology as described above. However, it is important to point out that in most cases, there is a two to three year delay in getting access to incident data from existing data collection processes (e.g., NFIRS data collection of 1999 became available in late 2002), and it takes three years to complete the data collection for a certain year. A timetable of real-time data collection is presented in figure 4-43.

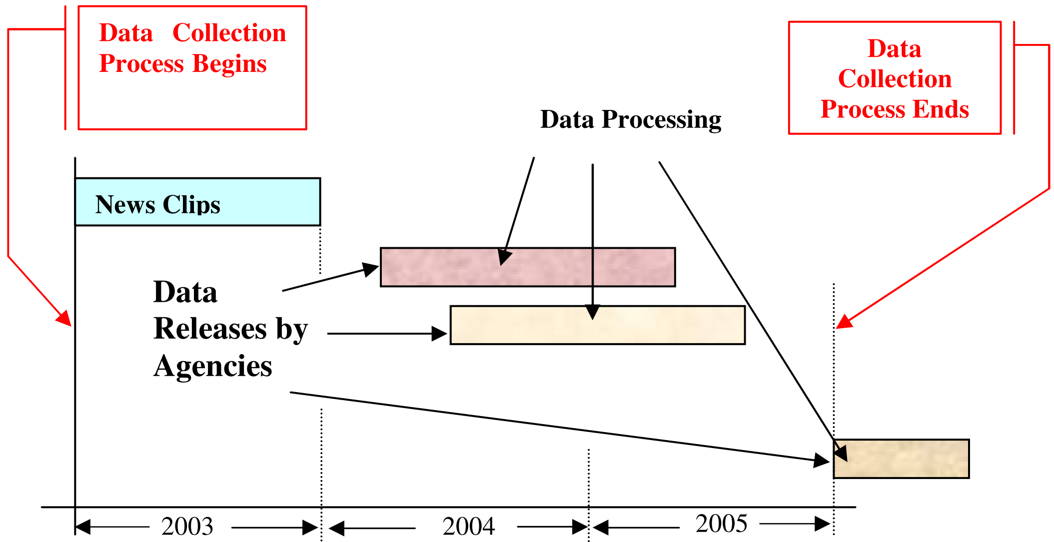

Figure 4-43. Timetable of real-time data collection and analysis

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APPENDIX A

AWARENESS TRAINING AND AUDIT FREQUENCY CURVES

Awareness Training

First year:

$$\begin{cases} y = \dfrac{3.5918}{X^{1.2075}} \quad R^2 = 0.9903 \\ \text{in the range 3-12 months.} \end{cases} \tag{A-1}$$

Second Year:

$$\begin{cases} y = -7 \bullet 10^{-5} \bullet X^3 + 5.3 \bullet 10^{-3} \bullet X^2 - 0.143 \bullet X + 1.383 \quad R^2 = 1.0000 \\ \text{in the range of 3-24 months.} \end{cases} \tag{A-2}$$

Third year:

$$\begin{cases} y = -4 \bullet 10^{-5} \bullet X^3 + 3.5 \bullet 10^{-3} \bullet X^2 - 0.1046 \bullet X + 1.2735 \quad R^2 = 0.9989 \\ \text{in the range of 3-36 months.} \end{cases} \tag{A-3}$$

Fourth year:

$$\begin{cases} y = 2 \bullet 10^{-6} \bullet X^4 - 2 \bullet 10^{-4} \bullet X^3 + 7.2 \bullet 10^{-3} \bullet X^2 \\ \quad - 0.1319 \bullet X + 1.3363 \quad R^2 = 1 \\ \text{in the range of 3-36 months.} \end{cases} \tag{A-4}$$

Fifth year and on:

$$\begin{cases} y = 1 \bullet 10^{-6} \bullet X^4 - 1 \bullet 10^{-4} \bullet X^3 + 5.5 \bullet 10^{-3} \bullet X^2 \\ \quad - 0.11132 \bullet X + 1.2939 \quad R^2 = 1 \\ \text{in the range of 3-36 months.} \end{cases} \tag{A-5}$$

Audit Frequency

First year:

$$\begin{cases} Y=1 \\ \text{In the range of 3-6 months} \end{cases} \qquad \text{(A-6)}$$

$$\begin{cases} y = -6.84 \bullet 10^{-2} \bullet X + 1.4103 \quad R^2 = 1 \\ \text{in the range 6-12 months.} \end{cases} \qquad \text{(A-7)}$$

Second Year:

$$\begin{cases} Y=1 \\ \text{In the range of 3-6 months} \end{cases} \qquad \text{(A-8)}$$

$$\begin{cases} y = 5 \bullet 10^{-5} \bullet X^3 - 3.3 \bullet 10^{-3} \bullet X^2 + 2.61 \bullet 10^{-2} \bullet X \\ \quad + 0.9496 \quad R^2 = 1.0000 \\ \text{in the range of 3-24 months.} \end{cases} \qquad \text{(A-9)}$$

Third year:

$$\begin{cases} Y=1 \\ \text{In the range of 3-6 months} \end{cases} \qquad \text{(A-10)}$$

$$\begin{cases} y = 4 \bullet 10^{-5} \bullet X^3 - 2.5 \bullet 10^{-3} \bullet X^2 + 0.02 \bullet X \\ \quad + 1.2735 \quad R^2 = 1 \\ \text{in the range of 3-36 months.} \end{cases} \qquad \text{(A-11)}$$

Fourth year:

Y=1 (A-12)

In the range of 3-6 months

$$\begin{cases} y = -1 \bullet 10^{-6} \bullet X^{4} = 1 \bullet 10^{-3} \bullet X^{3} - 3.3 \bullet 10^{-3} \bullet X^{2} \\ \quad + 2.35 \bullet 10^{-2} \bullet X + 0.9565 \quad R^{2} = 1 \\ \text{in the range of 3-36 months.} \end{cases} \tag{A-13}$$

Fifth year and on:

$$\begin{cases} \text{Y=1} \\ \text{In the range of 3-12 months} \end{cases} \tag{A-14}$$

$$\begin{cases} y = 6 \bullet 10^{-7} \bullet X^{4} - 5 \bullet 10^{-5} \bullet X^{3} + 9 \bullet 10^{-4} \bullet X^{2} \\ \quad - 5.3 \bullet 10^{-3} \bullet X + 1.0088 \quad R^{2} = 1 \\ \text{in the range of 12-36 months.} \end{cases} \tag{A-15}$$

APPENDIX B
MOC PERFORMANCE CALCULATION FORM

Scope of Program

Check all the facilities to which your plant's MOC program is applied to:

1. Critical sub-Areas (F_1^1):

a. OSHA PSM Areas	0.357	☐
b. Atmospheric Tank Farm	0.110	☐
c. Control Room	0.230	☐
d. Process Safety Protection Systems	0.303	☐

Sum of the values of the checked boxes: $F_1^1 =$ __________________

2. Utility Sub Areas (F_2^1 **):**

e. Cooling Water Facilities	0.165	☐
f. Power Plant	0.392	☐
g. Nitrogen System	0.279	☐
h. Air Plant	0.165	☐

Sum of the values of the checked boxes (e. to f. only): $F_2^1 =$ ________________

3. Associated Sub Areas (F_3^1 **):**

i. Laboratories	0.346	☐
j. Facilities as Rail Car Wash Station	0.241	☐
k. Facilities as Conveyors	0.204	☐
l. Central Office Buildings	0.204	☐

Sum of the values of the checked boxes (i. to l. only): $F_3^1 =$ ________________

4. If Organizational Changes apply, then F_4^1=1.00

W_1^1 is the relative weight of the Critical sub-Areas	$W_1^1 =$ 0.457
W_2^1 is the relative weight of the Utility sub-Areas	$W_2^1 =$ 0.202
W_3^1 is the relative weight of the Associated sub-Areas	$W_3^1 =$ 0.120
W_4^1 is the relative weight of Organizational Changes	$W_4^1 =$ 0.221

The performance of the MOC program in terms of comprehensiveness of the Scope of Program is calculated as follow:

$$F^{Scope\ of\ Program} = W_1^1 \bullet F_1^1 + W_2^1 \bullet F_2^1 + W_3^1 \bullet F_3^1 + W_4^1 \bullet F_4^1 = \_\_\_\_\_\_\_\_\_\_ \quad \text{(B-1)}$$

Authorization

5. Check the positions that should approve each type of MOCs in the list below:

	Regular MOC	Temporary MOC	Emergency MOC
MOC Coordinator	0.107 ☐	0.179 ☐	0.179 ☐
Operation Manager/Maintenance Manager	0.357 ☐	0.291 ☐	0.291 ☐
Plant Manager	0.137 ☐	0.132 ☐	0.133 ☐
EH&S Officer	0.179 ☐	0.140 ☐	0.164 ☐
Engineering / Instrumentation	0.163 ☐	0.207 ☐	0.184 ☐
Executives	0.057 ☐	0.051 ☐	0.049 ☐
Sum of the checked box values in each of columns:	$F_1^2 =$______	$F_2^2 =$______	$F_3^2 =$______

W_1^2 is the relative weight of authorizing Regular MOC. $W_1^2 =$ 0.334

W_2^2 is the relative weight of authorizing Temporary MOC. $W_2^2 =$ 0.333

W_3^2 is the relative weight of authorizing Emergency MOC. $W_3^2 =$ 0.333

The performance of the MOC program with respect to the authorization process is calculated as follows:

$$F^{Authorization} = W_1^2 \bullet F_1^2 + W_2^2 \bullet F_2^2 + W_3^2 \bullet F_3^2 = \_\_\_\_\_\_\_\_\_\_\_\_ \quad \text{(B-2)}$$

Training

Check the group of employees that are subjected to the following MOC Training:

6. Awareness Training (F_1^3):

   a. Field Operation Employees 0.525 ☐

   b. Contractor Employees 0.334 ☐

   c. Administrative Employees 0.142 ☐

Sum of the values of the checked boxes: F_1^3 =________________

7. Procedure Updates (F_2^3):

   d. Field Operation Employees 0.667 ☐

   e. Contractor Employees 0.333 ☐

Sum of the values of the checked boxes: F_2^3 = ________________

8. Informal Information Transfer (F_3^3):

   g. Field Operation Employees 0.667 ☐

   h. Contractor Employees 0.333 ☐

Sum of the values of the checked boxes: $F_3^3 =$ ________________

W_1^3 is the relative importance of MOC Awareness Training. $W_1^3 = 0.500$

W_2^3 is the relative importance of MOC Procedure Updates. $W_2^3 = 0.250$

W_3^3 is the relative importance of Informal Information Transfer. $W_3^3 = 0.250$

The performance of the MOC program in with respect to training employees is calculated as follow:

$$F^{Training} = W_1^3 \bullet F_1^3 + W_2^3 \bullet F_2^3 + W_3^3 \bullet F_3^3 = \_\_\_\_\_\_\_\_\_\_\_\_ \quad \text{(B-3)}$$

Audit

9. Check all items that the Audit process addresses (F_1^4):

a. Proper implementation of training program	0.223	☐
b. Misclassification of MOCs	0.173	☐
c. Temporary MOCs	0.159	☐
d. Emergency MOCs	0.159	☐
e. Authorizations	0.127	☐
d. Proper selection and implementation of hazard evaluation techniques	0.159	☐

Sum of the values of the checked boxes: $F_1^4 =$ ________________

10. Figure A-1 consists of 5 curves for five maturity levels of MOC programs. Match your plant's frequency performance value from Figure B -1 with the current audit frequency, and the maturity level of the MOC program.

$F_2^4 =$ ___________

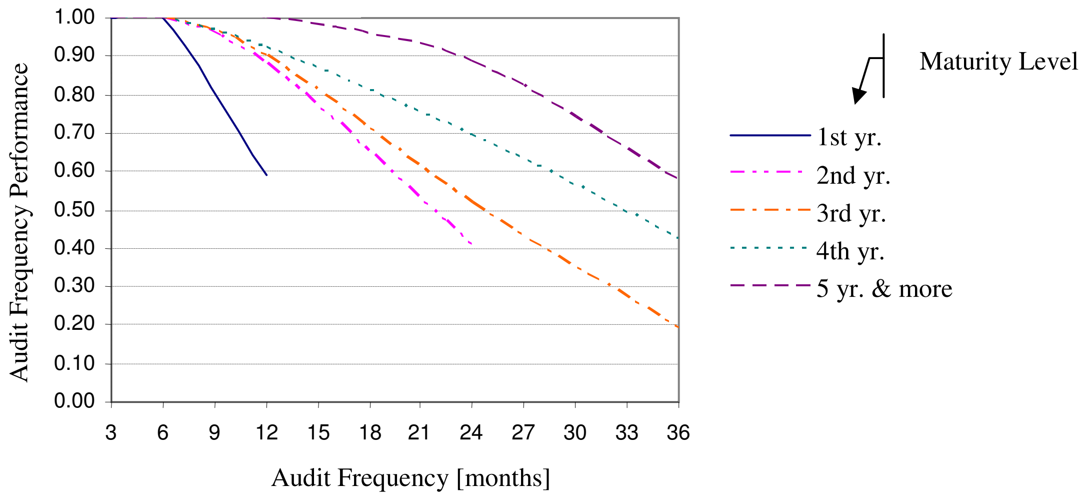

Figure B-1. Audit frequency performance

W_1^4 is the relative importance of Audit Content. $W_1^4 = 0.750$

W_2^4 is the relative importance of appropriate Audit frequency. $W_2^4 = 0.250$

The performance of the MOC program with respect to the Audit process is calculated as follows:

$$F^{Audit} = W_1^4 \bullet F_1^4 + W_2^4 \bullet F_2^4 = \underline{\hspace{4cm}} \quad \text{(B-4)}$$

Hazard Identification

11. Check all hazard evaluation techniques that are employed in hazard identification in the MOC program (F_1^5):

a. Safety Review 0.216 ☐

b. What-if, Checklist What-if/Checklist 0.321 ☐

c. Advanced PHA techniques 0.349 ☐

d. Human Reliability Analysis Techniques 0.114 ☐

Sum of the values of the checked boxes: F_1^5 = ________________

12. Obtain the Awareness Training performance value that was calculated previously: F_1^3 =________________

W_1^5 is the relative importance of hazard evaluation techniques. $W_1^5 = 0.500$

W_2^5 is the relative importance of MOC Awareness Training with respect to the Hazard Identification . $W_2^5 = 0.500$

The performance of the MOC program in with respect to Hazard Identification is calculated as follows:

$$F^{Hazard\ Identification} = W_1^5 \bullet F_1^5 + W_2^5 \bullet F_1^3 = \_\_\_\_\_\_\_\_\_\_\_\_ \qquad \text{(B-5)}$$

Outcomes

13. Classification Failures (F_1^6)

a. MWO-MOC Misclassifications

The following information is required to calculate the performance of MWO-MOC misclassification:

- Number of Maintenance Work Orders (MWO) that were issued during the period under investigation N^{MWO}
- Number of Management of Change Work Orders that were issued during the period under investigation N^{MOC}
- Number of MWO that should be treated as MOCs but were misclassified $N_{MOC}^{misclassified}$

The dynamic factor of the MOC program (represent the level of activity of the MOC program) should be calculated as follows:

$$F^{Dynamic} = \frac{N^{MWO} - N^{MOC}}{N^{MWO}} = \_\_\_\_\_\_\_\_\_\_ \quad \text{(B-6)}$$

The performance of MWO-MOC misclassification with respect to the classification failures should calculated as follow:

$$F^{MWO-MOC} = F^{Dynamic} * \frac{N^{MOC} - N^{misclassified}_{MOC}}{N^{MOC}} = \_\_\_\_\_\_\_\_\_\_ \quad \text{(B-7)}$$

b. Failures to Apply Temporary MOCs

The following information is required to calculate the value that will represent the performance of failures to apply Temporary MOCs:

- Number of Temporary MOC Work Orders (Temp MOCs) that were issued during the period under investigation N^{Temp} (this number should include $N^{misclassified}_{Temp}$ that is described bellow)
- Total number of Work Orders that should be treated as Temporary MOCs but were miss-classified $N^{misclassified}_{Temp}$

The dynamic factor of the Temporary MOC section of the program should be calculated as follows:

$$F^{Dynamic}_{Temp\ MOC} = \frac{N^{MOC} - N^{Temp}}{N_{MOC}} = \_\_\_\_\_\_\_\_\_\_ \quad \text{(B-8)}$$

The performance value that represent failures to apply Temporary MOCs are calculated as follows:

$$F^{Temp\ Failures} = F^{Dynamic}_{Temp\ MOC} \bullet \frac{N^{Temp} - N^{misclassified}_{Temp}}{N^{Temp}} = \underline{\hspace{3cm}} \quad \text{(B-9)}$$

c. Failure to Apply Emergency MOCs

The following information is required in order to calculate the value representing the performance of failures to apply Emergency MOCs:

- Number of Emergency MOC work Orders (Emergency MOCs) that were issued during the period under investigation $N^{Emergency}$ (this number should include $N^{misclassified}_{Emergency}$ which is described below)
- Total number of Work Orders that should be treated as Emergency MOCs but were misclassified $N^{misclassified}_{Emergency}$

The dynamic factor of the Temporary MOC section of the program (which represent the level of activity of Emergency MOCs with respect to the activity of the MOC program) should be calculated as follows:

$$F^{Dynamic}_{Emergency\ MOC} = \frac{N^{MOC} - N^{Emergency}}{N_{MOC}} = \underline{\hspace{3cm}} \quad \text{(B-10)}$$

The performance value that represent failures to apply Emergency MOCs should calculated as follow:

$$F^{Emergency\ Failures} = F^{Dynamic}_{Emergency\ MOC} \bullet \frac{N^{Emergency} - N^{misclassified}_{Emergency}}{N^{Emergency}} = \underline{\hspace{2cm}} \quad \text{(B-11)}$$

$W^{MWO-MOC}_{Classification\ Failures}$ is the relative importance of MWO-MOC misclassifications with respect to the Classification Failures sub-criterion. $W^{MWO-MOC}_{Classification\ Failures} = 0.334$

$W^{Temp\ MOC}_{Classification\ Failures}$ is the relative importance of failures to apply Temporary MOCs with respect to the Classification Failures sub-criterion. $W^{Temp\ MOC}_{Classification\ Failures} = 0.333$

$W^{Emergency\ MOC}_{Classification\ Failures}$ is the relative importance of failures to apply Emergency MOCs with respect to the Classification Failures sub-criterion. $W^{Emergency\ MOC}_{Classification\ Failures} = 0.333$

The performance of the Classification Failures with respect to the Outcomes is calculated as follows:

$$F_1^6 = W^{MWO-MOC}_{ClassificationFailures} \bullet F^{MWO-MOC} + W^{Temp\ MOC}_{ClassificationFailures} \bullet F^{Temp\ Failures} + W^{Emergency\ MOC}_{ClassificationFailures} \bullet F^{EmergencyFailures} = \_\_\_\_\_\_\_\_\_\_ \qquad \text{(B-12)}$$

14. Authorization Failures (F_2^6)
    a. Failures to Appropriately Authorize
    The information that is required to calculate the affect of Authorization Failures is the number of MOCs whose authorization failure was not completed $N^{Authorization}$. The performance value of MOCs that were not authorized properly should be calculated as follows:

$$F^{Authorization} = \frac{N^{MOC} - N^{Authorization}}{N^{MOC}} = \_\_\_\_\_\_\_\_\_\_ \qquad \text{(B-13)}$$

$W^{MWO-MOC}_{Authorization\ Failures}$ is the relative importance of MWO-MOC misclassifications with respect to the Authorization Failures sub-criterion. $W^{MWO-MOC}_{Authorization\ Failures} = 0.286$

$W^{Temp\ MOC}_{Authorization\ Failures}$ is the relative importance of failures to apply Temporary MOCs with respect to the Authorization sub-criterion. $W^{Temp\ MOC}_{Authorization\ Failures} = 0.286$

$W^{Emergency\ MOC}_{Authorization\ Failures}$ is the relative importance of failures to apply Emergency MOCs with respect to the Authorization Failures sub-criterion. $W^{Emergency\ MOC}_{Authorization\ Failures} = 0.286$

$W^{Authorization}_{Authorization\ Failures}$ is the relative importance of failures to authorize MOCs with respect to the Authorization Failures sub-criterion. $W^{Authorization}_{Authorization\ Failures} = 0.143$

The performance of the Authorization Failures with respect to the Outcomes is calculated as follows:

$$F_2^6 = W^{MWO-MOC}_{Authorization\ Failures} \bullet F^{MWO-MOC} + W^{Temp\ MOC}_{Authorization\ Failures} \bullet F^{Temp\ Failures} + W^{Emergency\ MOC}_{Authorization\ Failures} \bullet F^{EmergencyFailures} + W^{Authorization}_{Authorization\ Failures} \bullet F^{Authorization} \quad \text{(B-14)}$$

$F_2^6 =$ __________

15. Hazard Detection Failures (F_3^6)

a. Failures to Apply Appropriate Hazard Evaluation Techniques
The information required to calculate the affect of failures to apply appropriate hazard evaluation techniques is the number of MOCs with an incomplete hazard evaluation $N^{Haz\ Technique}$. The performance should be calculated as follows:

$$F^{Haz\ Failures} = \frac{N^{MOC} - N^{Haz\ Technique}}{N^{MOC}} = \_\_\_\_\_\_\_\_\_\_ \quad \text{(B-15)}$$

b. Awareness Training Frequency

The Failure to Properly Train measures the appropriateness of the Awareness Training frequency. Figure B-2 (below) consists of 5 curves for five maturity levels of MOC. With the current Awareness Training frequency, and the maturity level of the MOC program, obtain the frequency performance value ($F^{Training}$).

$W_{Haz\ Failures}^{MWO-MOC}$ is the relative importance of MWO-MOC misclassifications with respect to the Hazard Detection Failures sub-criterion. $W_{Haz\ Failures}^{MWO-MOC} = 0.168$

$W_{Haz\ Failures}^{Temp\ MOC}$ is the relative importance of failures to apply Temporary MOCs with respect to the Hazard Detection Failures sub-criterion. $W_{Haz\ Failures}^{Temp\ MOC} = 0.180$

$W_{Haz\ Failures}^{Emergency\ MOC}$ is the relative importance of failures to apply Emergency MOCs with respect to the Hazard Detection Failures sub-criterion. $W_{Haz\ Failures}^{Emergency\ MOC} = 0.162$

$W_{Haz\ Failures}^{Authorization}$ is the relative importance of failures to authorize MOCs with respect to the Hazard Detection Failures sub-criterion. $W_{Haz\ Failures}^{Authorization} = 0.070$

$W_{Haz\ Failures}^{Haz\ Techniques}$ is the relative importance of properly applying hazard evaluation techniques with respect to the Hazard Detection Failures sub-criterion. $W_{Haz\ Failures}^{Haz\ Techniques} = 0.113$

$W_{Haz\ Failures}^{\Pr operly\ Train}$ is the relative importance of proper training frequency with respect to the Hazard Detection Failures sub-criterion. $W_{Haz\ Failures}^{\Pr operly\ Train} = 0.306$

Figure A-2 consists of 5 curves for five maturity levels of MOC programs. Match the frequency performance value from Figure B-2 with the current Awareness Training frequency, and the maturity level of the MOC program:

$F^{Training}$ = ____________

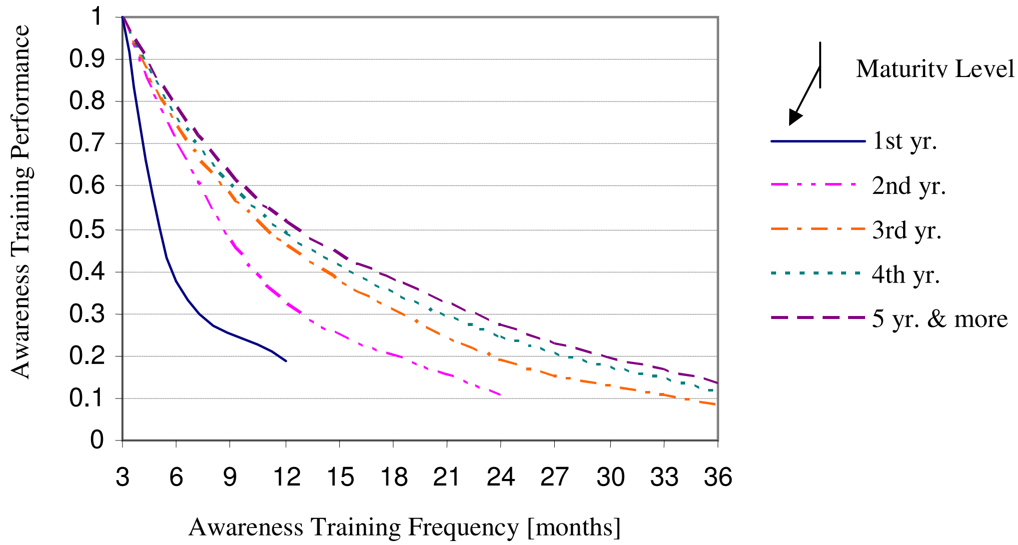

Figure B-2. Awareness training frequency performance

The performance of the Authorization Failures with respect to the Outcomes is calculated as follows:

$$F_3^6 = W_{Haz\ Failures}^{MWO-MOC} \bullet F^{MWO-MOC} + W_{Haz\ Failures}^{Temp\ MOC} \bullet F^{Temp\ Failures}$$

$$+ W_{Haz\ Failures}^{Emergency\ MOC} \bullet F^{EmergencyFailures} + W_{Haz\ Failures}^{Authorization} \bullet F^{Authorization} \qquad \text{(B-16)}$$

$$+ W_{Haz\ Failures}^{Haz\ Technique} \bullet F^{Haz\ Failure} + W_{Haz\ Failure}^{Training} \bullet F^{Training}$$

$F_3^6 =$ ______________

Summary of the Outcomes Criteria:

W_1^6 is the relative weight of the Classification failures sub-criterion. W_1^6 =0.321

W_2^6 is the relative weight of the Authorization Failures sub-criterion. W_2^6 =0.225

W_3^6 is the relative weight of the Hazard Detection Failures sub-criterion. W_3^6 =0.454

The performance of the Outcomes criterion with respect to the MOC Program performance is given as follows:

$$F^6 = W_1^6 \bullet F_1^6 + W_2^6 \bullet F_2^6 + W_3^6 \bullet F_3^6 = \_\_\_\_\_\_\_\_\_\_\_\_ \quad \text{(B-17)}$$

Calculating the OVERALL Program Performance

The relative weight of each of the major criteria is as follows:

W^1 is the relative weight of the Scope of Program. W^1 = 160

W^2 is the relative weight of the Authorization process W^3 = 0.123

W^3 is the relative importance of the MOC Training program. W^1 = 0.234

W^4 is the relative importance of the Audit Process. W^4 = 0.074

W^5 is the relative importance of the Hazard Identification process. W^5 = 0.230

W^6 is the relative importance of the Outcomes. W^6 = 0.178

The final value of the program performance $F^{Performance}$ should be calculated as follows:

$$F^{Performance} = W^1 \bullet F^1 + W^2 \bullet F^2 + W^3 \bullet F^3 + W^4 \bullet F^4 + W^5 \bullet F^5 + W^6 \bullet F^6 \quad \text{(B-18)}$$

$F^{Performance}$ =__________

APPENDIX C

LIST OF DATA FIELDS

1. accident_causes
2. accident_corrective_actions
3. accident_deaths
4. accident_environmental_impacts
5. accident_evacuations
6. accident_explosions
7. accident_fires
8. accident_flammable_mixtures
9. accident_hospitalizations
10. accident_injuries
11. accident_property_damage
12. accident_release_sources
13. accident_released_chemicals
14. accident_releases
15. accident_shelterings
16. accident_treatments
17. accident_unique_causes
18. accident_unique_corrective_actions
19. accident_unique_environmental_impacts
20. accident_unique_release_sources
21. chemical_categories_involved
22. chemicals_involved
23. chemicals_involved_flammable_mixtures
24. event_equipment
25. event_facilities

26. event_locations
27. event_naics
28. event_vehicles
29. events
30. facilities
31. facility_employee_count
32. facility_processes
33. process_chemicals
34. process_flammable_mixtures
35. process_naics
36. safety_inspections

VITA

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1996 – 1998	M.S., Management and Safety Engineering Department at the Ben-Gurion University of the Negev, Israel (graduated magna cum laude).
1986 – 1990	B.S., Mechanical Engineering Department at the Ben Gurion University of the Negev, Israel.

Experience

1999 – 2000	Maintenance Manager at a sulfuric acid plant, Rotem Amfert Group (Subsidiary of Israel Chemicals) Negev, Israel.
1998 – 1999	Maintenance Manager at the Fine Chemical Divition, Dead Sea Bromine Compounds Group (Subsidiary of Israel Chemicals), Israel.
1995 – 1997	Project Manager and departmental safety engineer, N.R.C.N. – Israel.
1992 – 1995	Maintenance Manager, N.R.C.N – Israel.
1990 – 1992	Maintenance Engineer, N.R.C.N – Israel.