

AN EVALUATION STUDY OF SAFETY INFORMATION MANAGEMENT IN THE PETROCHEMICAL INDUSTRY

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While industry realises that safety information is a critical building block for creating knowledge, developing skills, and performing safety related activities and tasks, failure to communicate safety related information has been cited as a significant contributing factor to industrial accidents. There are many examples of missed or ignored warning signals of failure to handle safety information in ways that could have prevented catastrophic outcomes.

To improve safety performance, the process industries must ensure Safety Information Management (SIM) is implemented satisfactorily. For the purpose of understanding current practice and industry's view on SIM, a survey using a questionnaire filled out by 177 people working in the petrochemical industry in Taiwan has been carried out. The questionnaire was developed based on the Balanced Scorecard (BSC) concept, an extensive review of the literature in the fields of safety management and performance measurement, and feedback from safety experts.

This paper describes the process and conclusions of the survey. A statistical analysis of the information gathered indicates that the outcome from the questionnaire was both reliable and valid. The results of the survey have been used to identify the perspectives and indicators for evaluating SIM performance and will lead to the development of a SIM performance measurement tool for the process industries.

KEYWORDS: Safety Information Management, Balanced Scorecard, performance measurement

INTRODUCTION

Safety information is a crucial building block in the important process of creating knowledge, developing skills, and performing safety related activities and tasks in accordance with planned occupational health and safety objectives. Ideally, people engaged in health and safety responsibilities, or affected by the activities, need to be provided with specific, accurate and relevant information to assist them to learn and to accomplish their duties[1]. In particular, the process industries have been required to operate at a high-level of safety by the authorities and the public, because there is the potential for the consequences of an industrial incident to be huge, even if the likelihood of the incident is very low[2]. Therefore, the control and management of safety information has become an issue of crucial importance throughout the process industries.

On the other hand, information failures have been cited as a significant contributing factor and precondition in studies of organization disasters and accidents[3,4,5,6]. Examples abound of missed or ignored warning signals of failure to handle safety information in ways that could have prevented catastrophic outcomes[7].

The process industries must ensure that safety information management (SIM) systems are functioning satisfactorily. An integrated approach is needed to evaluate the performance of SIM as well as to locate and identify problem areas. Therefore, the principal aim of this evaluation study is to investigate current SIM system practices, how the performance of SIM is measured, and to identify the key performance indicators that should be adopted.

SAFETY INFORMATION MANAGEMENT

For the process industries, safety information is a set of complete and up-to-date information concerning process chemicals, process technology, and process equipment. There are a variety of descriptions for safety information but all of which are similar. One of the most complete categories of safety information has been proposed by AIChE's Center for Chemical Process Safety[8] and is detailed in Table 1. The compiled information will be a necessary resource to a variety of users including the team that will perform the process hazards analysis; those developing the training programs and the operating procedures; contractors whose employees will be working with the process; those conducting the pre-startup reviews; local emergency preparedness planners; and insurance and enforcement officials.

In Europe, the Seveso II Directive supports the submission of a safety report to a regulating authority by operators of certain types of chemical installations. This is now a requirement throughout many EU member states. The Seveso II Directive is implemented in the UK by the COMAH regulations, requiring the submission of a Safety Case to the Health and Safety Executive (HSE). This information includes sating what is done or predicting what might happen in a major accident. It must be gathered from many disparate sources within an engineering enterprise.

Furthermore, in most developing and developed countries, main safety legislations for the process industries require process plants to employ a Process Safety Management (PSM) system to focus on engineering practices that could prevent process-related accidents. To achieve the ultimate worth of a PSM program, results from the implementation of each individual element of PSM must be documented. This ensures that information is

Table 1. Safety information categories

• Process knowledge	• Management of change	• Incident investigation
• Process hazard analysis	• Operating procedures	• Standards, codes, regulations
• Quantitative risk assessment	• Training	• Contractor issues
• Process equipment integrity	• Emergency response	• Safety work practices
• Human factors	• Auditing	• Control software

available to be communicated to those persons responsible for implementing other PSM elements[8]. In fact, most PSM elements are dependent on the flow of safety information to function properly.

Moreover, for the international market, most process plants adopt international certification standards to demonstrate their safety performance. Standards such as BS 8800 (British Standard: 1996 Guide to occupational health and safety management systems) and OHASA 18001 (Occupation Health and Safety Assessment Series) provide certain guidelines for safety and health documentation and communication. These standards require the certificated organization to establish and maintain procedures for identification, maintenance and dissemination of health and safety records, as well as the results of audits and reviews.

In summary, from process operation, legislation compliance and business competition viewpoints, every process plant is required to maintain an integrated system that optimises the collection, transfer and presentation of safety information, in accordance with defined procedures, whether automated or manual. A SIM system should be treated as the essential framework for supporting safety management practices. Figure 1 illustrates the role of a SIM system in providing a safety framework. The 'Safety Information Management System' considers safety information flows, information technologies and information management activities which support managers and workers in their activities in order to improve safety performance.

INFORMATION FAILURE AND ACCIDENTS

A number of papers have been presented from a range of industries on the subject of poor safety information flow. These researches cite 'information failure' as a significant contributing factor and precondition of organisations disasters and accidents (Turner, 1978; Reason, 1997; Toft & Reynolds, 1997; Turner & Pidgeon, 1997; Vaughan, 1996; Murray & Choo, 2002). In particular, Turner (1978) writes "Disasters equal energy plus misinformation" and King & Hirst (1998) modify the equation to "Disasters equal energy and/or toxic substances plus misinformation or rejection of information" to emphasise the importance of handling information for preventing disaster.

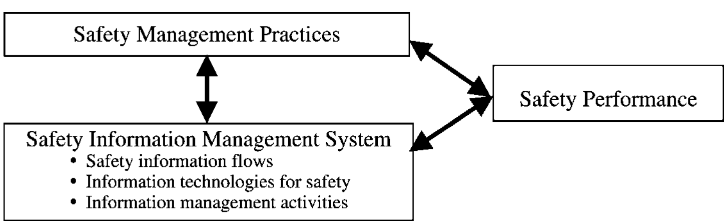

Figure 1. The role of a SIM system in safety management

Turner's insightful observations about the origins of disasters formed the foundations for understanding the important role of safety information failure. He emphasises the significance of individual and organizational cultural beliefs and the social distribution of knowledge related to safety, hazards, and the adequacy of precautions. One of Turner's key observations was that disasters result from a failure of foresight and an absence of some form of knowledge and information among the groups and individuals involved.

Toft and Reynolds[4] identified that 'information' was one of the five main recommendation types after analysing 19 public inquiries into disasters that occurred in the UK between 1965 and 1978. Every one of these 19 inquiries had at least one recommendation of the 'information' type. Moreover, Wells[11] conducted research that provided evidence to prove that inadequate SIM leads to industrial accidents. Similar results from the MARS database[12] and the Chemical Safety Board[13] also proved the correlation between SIM and accidents.

SIM PERFORMANCE MEASUREMENT MODEL

Delone and McLean[14] undertook extensive research that resulted in a summary of management information system evaluation techniques. They argued that there are six major interrelated and independent constructs that, in combination, define information system success. (see Figure 2). Their model is accepted as one of the more complete and has been widely used as a basis of empirical research[15]. However, the principles of the model have been presented without significant discussion of its underlying theory and logic[16].

Marchand et al.[17] describe information orientation as a composite of a company's capabilities to effectively manage and use information. Their model, Information Orientation, is comprised of three categories of practices: information technology; information management; and information behaviours and values. Each of these three practices contains several dimensions (factors) as indicators to represent a useful domain for defining their mother-practice.

The most commonly used performance evaluation tool, The 'Balanced Scorecard' (BSC), developed by Kaplan & Norton[18], has been used extensively in the manufacturing, government, retail and financial services sectors[19]. Kaplan and Norton have defined the BSC as a multi-dimensional framework for describing, implementing and managing

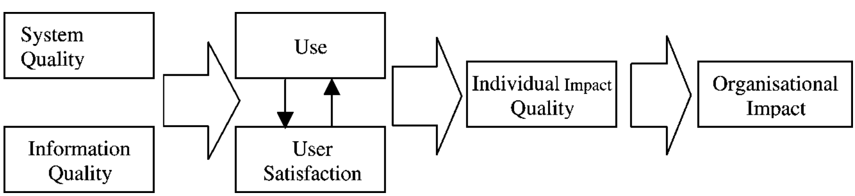

Figure 2. Information system success model (Delone and Mclean, 1992)

strategy at all levels of an enterprise by linking objectives, initiatives and measures to an organisation's strategy. It must be noted that the BSC is not a static list of measures, but rather a framework for implementing and aligning complex programs of change, and, indeed, for managing strategy-focused organisations[20]. The concept of the BSC encourages managers to consider and balance performance measures for different critical areas or perspectives that affect successful mission accomplishment. Following the original BSC framework, researches have been undertaken in applying the BSC to evaluate the performance of Information System (IS), Information Management (IM) and Information Technology (IT) fields[21,22]. Therefore, in this study, the BSC approach was adopted as a conceptual guide to assist the development of a framework of SIM performance.

Kaplan & Norton[22] set forth a hypothesis about the chain of cause and effect that leads to strategic success. Hence, the cause-and-effect hypothesis is fundamental to understanding the metrics used in the BSC method. Figure 3 shows the cause-and-effect hypothesis for this study. Based on the analysis and synthesis of safety information management and its evaluation, the BSC for SIM performance measurement is proposed and detailed in Figure 4. In the proposed BSC, four definable and robust perspectives are:

1. Strategic perspective: Concerned with how SIM contributes to the accomplishment of the organisation's overall safety mission and strategic goals.
2. Operational perspective: Concerned with the complete and up-to-date set of engineering documentation functioning to improve performance of operation as well as all safety related tasks.
3. User orientation perspective: Covers issues associated with usage such as SIM tool utilisation, availability of training and technical support, and satisfaction with the safety information system.
4. Technology perspective: Refers to the hardware, software, application programs, telecommunication networks, and the technical expertise that support the safety information processing and communications activities at all levels of a process plant.

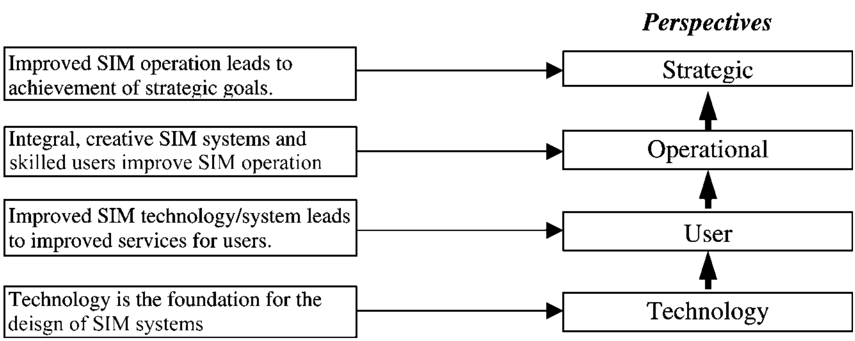

Figure 3. Cause-and-effect hypothesis

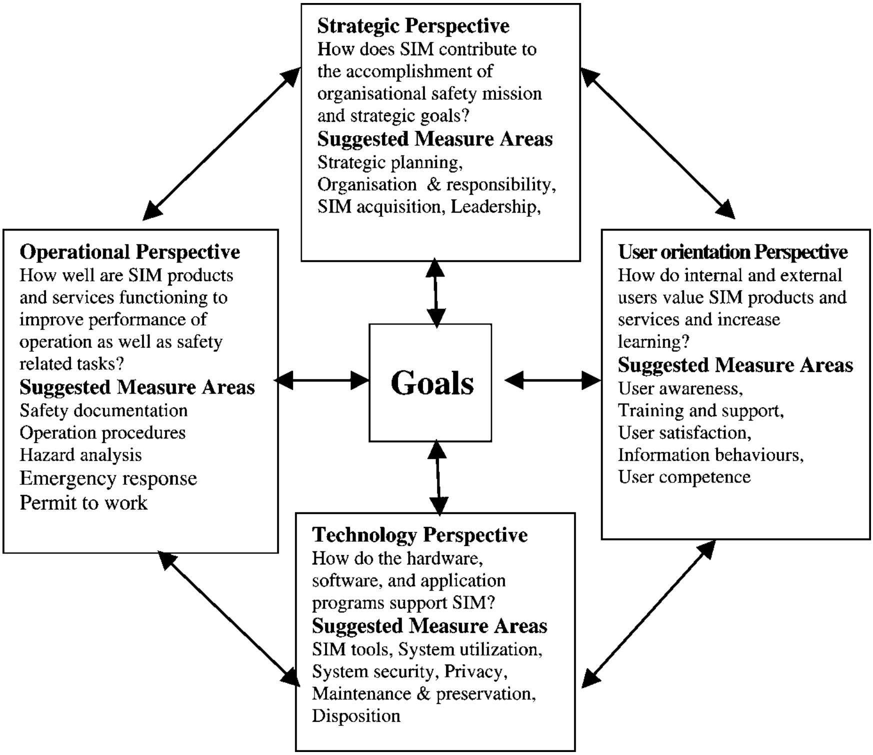

Figure 4. Proposed BSC for SIM performance

SURVEY

Based on the proposed BSC for SIM performance measurement described above, each perspective should have its own set of indicators and each indicator has its own set of measures. After a comprehensive review of the literature in such fields as performance measurement, safety management, safety engineering, strategic management, information technology and information systems, a set of strategic, outcome oriented performance indicators, listed in Table 4, have been developed for SIM in the process industries. These perspectives and indicators were used as the starting point for initial discussions and pilot tests undertaken in the survey of this study. Moreover, in order to establish an understanding of current SIM systems, this survey not only allows the development of the SIM performance perspectives and indicators by providing data for quantitative analysis, but also focuses on an investigation of current SIM practice of the petrochemical industry in Taiwan.

The questionnaire used in the survey was formulated after a comprehensive review of the literature. The questionnaire layout comprised three main sections illustrated below:

- Section A: General information and definition of key words used in the questionnaire followed by questions concerning the backgrounds of the questionnaire respondents and the SIM portfolios of their organisations.
- Section B: Concerned with the current SIM practice in industry, and designed to investigate the respondents views on their organisation's SIM performance.
- Section C: Concerned with obtaining the respondents opinions on the relative importance of the four perspectives by ranking % and on the level of importance of each indicator by ticking a five-point Likert scale.

A draft of the questionnaire was sent to three members of the academic staff of the authors' department and four safety managers within petrochemical factories in Taiwan. This pilot test helped to refine the wording, ordering, structure and layout of the questionnaire.

The questionnaire was targeted at all the petrochemical factories in Taiwan. According to information from Taiwan's Labour Department, there were about 90 petrochemical factories operating in Taiwan at the time the survey was carried out. Each factory was asked to complete three questionnaires, one by its safety manager, one by a site supervisor and one by an operator. In total, 270 questionnaires were sent out in November 2003. A total of 177 questionnaires were returned, representing an average response rate of 65.6%. Fifteen returned questionnaires were eliminated due to missing data or invalid answers, leaving a final sample size of 162. So, the valid response rate was 60%. After collecting all the returned questionnaires, the SPSS 11.0 (Statistic Package for the Social Science) was adopted for analysing the data. The results of the survey are described below in sections 5.1 to 5.4 below, namely, General information, Current SIM practices, Perspectives and indicators, and Weight determination, respectively.

GENERAL INFORMATION

The basic data of the respondents and surveyed factories was as follows:

- The valid number of respondents involved in the survey was 162. Respondents were categorised into three groups, namely: safety manager (SM), site supervisor (SS) and operator (OP). There were 79 safety manager respondents, 44 site supervisor respondents and 39 operator respondents.
- The majority of the respondents were very experienced personnel with 66% of the respondents having over 10 years of experience.
- The majority of the respondents from the petrochemical industry in Taiwan was petrochemical manufacturing (59%), followed by polymers manufacturing (35%) and petroleum refineries (6%).
- The majority of the factories were large with 27% the factories having over 500 employees, and 49% of the factories having between 100 to 499 employees.

- Of the factories surveyed, 80% had at least one hazardous site. A hazardous site can only operate after obtaining a formal permit from the authority.
- Most surveyed factories follow the ISO Standards on Quality Management and Environmental management. 92% of factories receive ISO 9000 certification and 71% of receive ISO 14000 certification. However, only 23% of factories receive the OHASA 18001 (Occupational Health and Safety Assessment Series 18001) certification.

CURRENT SIM PRACTICES

The main observations on current SIM practices are as follows:

- 83% of the surveyed factories have adopted a 'part computerised' SIM system. Only 8% of surveyed factories use a completely 'manual' system, and only 9% use a 'fully computerised' system.
- Over 51% of factories developed their own SIM systems. Only 27% of them used software contractors to develop their systems and 25% purchased a commercial package.
- 52% of factories evaluated their SIM performance resulting in 48% undertaking no evaluation.
- In the methods adopted to evaluate SIM, the most popular is the checklist being used by 71% of the factories undertaking evaluation. The second most popular method is internal audit being used by 63%. These were followed by document review and external audit, used by 57% and 51%, respectively. However, over 65.7% of the factories reflected that the methods adopted for evaluating SIM performance are only slightly reliable or are, indeed, unreliable.
- The respondents were required to consider each of 25 'Performance Factors' on a five-point Likert scale, from 'strongly disagree' at the lower end to 'strongly agree' at the upper end. These Performance factors were derived from extensive literature review. Table 2 shows the survey results of this part. In the table, both the mean and ranking for each group and overall respondents have been calculated. For all 162 valid responses, the average score of all 'Performance Factors' is 3.31, revealing a positive view on the current SIM practices. However, the score 3.31 is close to '3.00-slightly agree' which indicates that respondents do not think that the current SIM practices are adequate or effective.
- The top five ranked performance factors with their means are listed as follows:
  - P9-it provides most operation procedures required (3.77)
  - P4-it is highly supported by head quarters (3.75)
  - P14-it helps the work to be done more safely (3.72)
  - P3-it complies with the company's safety policy (3.70)
  - P18-it improves safety learning and innovation (3.62)

  These high ranked performance factors reveal the truly positive performance of the current practices. It shows most respondents agree that: most operation procedures have been provided by SIM systems; SIM activities have been well supported by Head Quarters; SIM systems can improve safety at work; SIM systems comply with

Table 2. Mean and ranking of performance factors (current practice)

Performance Factors	SM mean	SM Ranking	SS mean	SS Ranking	OP mean	OP Ranking	Overall mean	Overall Ranking
P1-planning	3.61	6	3.50	11.5	3.31	10.5	3.51	8
P2-organisation & responsibility	3.43	11	3.66	8.5	3.41	6	3.49	9
P3-comply safety policy	3.70	4	3.80	4.5	3.59	2	3.70	4
P4-HQ support	3.75	2	4.05	1	3.41	6	3.75	2
P5-audit SIM	2.82	24	2.77	24	2.72	22	2.78	23
P6-good ex-relationship	2.85	23	2.80	23	2.54	25	2.76	24
P7-process knowledge	3.32	14	3.66	8.5	3.33	9	3.41	12
P8-process hazard analysis	3.47	9.5	3.75	6	3.38	8	3.52	7
P9-operation procedures	3.80	1	3.84	3	3.64	1	3.77	1
P10-internal/external incident	3.23	17	3.43	13	2.97	18	3.22	16
P11-unnecessary information	3.23	17	3.02	21	3.03	16.5	3.12	18
P12-up-to-date information	3.29	15	3.11	19.5	2.67	24	3.09	20
P13-external message	3.23	17	3.11	19.5	2.82	20	3.10	19
P14-more safely	3.73	3	3.89	2	3.51	3	3.72	3
P15-trained to use	3.59	7	3.80	4.5	3.31	10.5	3.58	6
P16-reduced information load	3.49	8	3.55	10	3.28	12	3.46	10.5
P17-on time safety information	3.42	12	3.34	15	3.03	16.5	3.30	13.5
P18-Learning & innovation	3.68	5	3.68	7	3.44	4	3.62	5
P19-Unsatisfied*	3.05	21	3.18	17	2.77	21	2.98	21
P20-easy to use	3.47	9.5	3.50	11.5	3.41	6	3.46	10.5
P21-exchanging channels	2.91	22	2.98	22	2.85	19	2.91	22
P22-generate reports	2.63	25	2.75	25	2.69	23	2.68	25
P23-security	3.18	19.5	3.34	15	3.21	13	3.23	15
P24-disposition	3.18	19.5	3.16	18	3.18	14	3.17	17
P25-support person	3.34	13	3.34	15	3.15	15	3.30	13.5
TOTAL	3.34	NA	3.40	NA	3.15	NA	3.31	NA

*These factors were designed as reverse items. Here, their scores have been revised.

safety policy; and SIM can help employees acquire safety knowledge and improve safety learning.

- The last five ranked performance factors with their means are listed as follows:
  - P22-it can help generate related report (2.68)
  - P6-it improves external relationships (2.76)
  - P5-it is audited frequently (2.78)
  - P21-it provides good communication channels for exchanging information (2.91)
  - P19-most employees are satisfied with the SIM system (2.98)

  Each of these low ranked performance factors has a mean value under 3.0, which indicates negative performance situations from the respondents' viewpoint. It shows most respondents agreed that currently used SIM systems: do not provide a good function with regard to generating safety related reports; do not help in improving the relationship with the public and authorities; have not been audited frequently; do not much satisfy the employees. These low ranked factors indicate that from the users' viewpoint there are concerns and dissatisfactions, and they provide good directions for a review of currently used SIM systems.

Kendall's coefficient (τ), a widely used measure of association for ordinal variables, and Pearson's Product-Moment Correlation coefficient (r), the most widely used measure of association for examining relationships between interval and ratio variables[23], have been calculated to identify correlation between groups of respondents. All the values of τ and r are more than 0.7, except the τ value for SM vs. OP which is 0.676. This indicates great agreement between groups on their opinions of the current SIM practise in Taiwan's petrochemical industry.

The reliability of the survey for assessing current SIM practices was established in two ways. The first was the split-half technique where a person's responses to one half of the survey (randomly selected) was correlated against their responses to the other half. Results here found reliability coefficients of about 0.8, indicating a high degree of reliability. The second used Cronbach's alpha (α) value, which is a numerical coefficient of reliability to test for a model or survey's internal consistency[24]. Taking into account the all 'Performance Factors', the α value is 0.92, indicating again a high degree of reliability.

PERSPECTIVES AND INDICATORS

The most important component of the survey was to gauge the opinion of industry professionals concerning the importance of the various SIM performance perspectives and their associated indicators. To facilitate understanding of the performance evaluation concepts and the proposed BSC for SIM, questions were asked to determine the weighting of perspectives, the importance of indicators. The responses to these questions were used to validate the developed framework of SIM performance through statistical analysis.

Respondents were required to rate the importance of the four SIM performance measurement perspectives of the BSC for SIM. It was essential that the sum of the four perspective's weight was 100% (see Table 3). For all respondents, the mean weighting

Table 3. Perspective weight from direct survey

	Perspective weight (%) from each group			
Perspective	SM	SS	OP	Overall
Strategic	27.0	27.5	23.5	26.3
Operational	29.2	29.9	29.3	29.4
User	23.5	23.1	27.6	24.4
Technology	20.3	19.5	19.6	19.9
Total	100.0	100.0	100.0	100.0

of the four perspectives, in descending order, was, (1) operational (2) strategic (3) user (4) technology. The results indicate that respondents place most importance on the operational perspective. However, the other three perspectives have a weighting between 19–27%, indicating that all four perspectives are essential for proper SIM performance evaluation.

Respondents were also required to rate the importance of each performance indicator associated with each perspective by indicating the level of importance, on a five-point Likert scale. The scale used was: (1) Little Important; (2) Slightly Important; (3) Important; (4) Very Important; (5) Absolutely Important. The mean value and standard deviation of each performance indicator are detailed in Table 4 for each group of respondents. The mean values ranged from 2.91 for Disposition, to 4.59 for Leadership. The mean value for all indicators was 3.90, indicating that the respondents rated the indicators, on average, as very important. Only one value had a mean of less than 3 (i.e. Disposition). The main results of this part are as follows:

- Leadership (4.59) is considered to be the most important indicator for SIM. This is not a surprise, because leadership has been cited as a crucial element not only in safety programs but also in most management practices. Leadership can be exhibited by senior management in setting clear policy and guidelines for performance, and for enhancing the value of the SIM ethic within the organisation.
- Operation procedures (4.38) has the second highest rank of the indicators. Operation procedures are designated to cover all aspects of operation and ensure reliable, efficient and safe operation of the plant. There is no question that operation procedures are necessary for the various modes of process operation to assure continuous, efficient, and safe operation of a facility.
- Incident reporting/investigation (4.15) is also placed as a highly important indicator. Proper procedure and documentation of incident investigation provides the basis for corrective actions leading to improvements in the organisation's safety management program and, accordingly, should enhance plant safety.
- Permit to work (4.15) has same mean with incident reporting/investigation. A permit system ensures that affected parties are made aware that nonroutine work is being

Table 4. Survey results of the importance of indicators

Indicator	SM mean	Ranking by SM	SS mean	Ranking by SS	OP mean	Ranking by OP	Overall mean	Ranking by overall
SP1-Strategic planning	4.08	8	4.09	11.5	3.87	12.5	4.03	10
SP2-Organisation & responsibilities	4.11	6.5	4.16	7	3.92	9	4.08	6
SP3-Acquisition	3.96	16.5	4.11	10	3.82	16.5	3.97	14.5
SP4-Leadership	4.70	1	4.59	1	4.36	1	4.59	1
SP5-Evaluation	4.11	6.5	4.16	7	3.82	16.5	4.06	8
SP6-Standardisation	4.01	13	4.02	13	3.77	19.5	3.96	16.5
SP7-External relationship	3.41	27	3.64	25	3.26	27	3.43	27
OP1-Process knowledge	4.01	13	4.20	5	3.92	9	4.04	9
OP2-Process Hazard Analysis	4.15	5	4.25	3	3.97	6.5	4.14	5
OP3-Operation procedures	4.38	2	4.45	2	4.31	2	4.38	2
OP4-Incidents reporting	4.22	3	4.14	9	4.03	4	4.15	3.5
OP5-Permit to work	4.19	4	4.23	4	3.97	6.5	4.15	3.5
OP6-Management of change	4.06	9	4.00	14	3.90	11	4.01	12
OP7-Emergency response	4.00	15	4.09	11.5	4.00	5	4.02	11
OP8-Safety work practices	3.72	20.5	3.70	23.5	3.85	14.5	3.75	21
UP1-User awareness	3.96	16.5	3.82	21	3.85	14.5	3.90	18
UP2-User training & support	3.87	18	3.93	17	3.87	12.5	3.89	19
UP3-User competence	3.76	19	3.98	15	3.77	19.5	3.82	20
UP4-Information behaviours	4.01	13	4.16	7	4.10	3	4.07	7
UP5-System utilisation	3.72	20.5	3.70	23.5	3.56	23	3.68	13
UP6-User satisfaction	3.63	24	3.77	22	3.58	21.5	3.66	24
TP1-SIM tools	4.03	11	3.91	18.5	3.92	9	3.97	14.5
TP2-Technology integration	4.04	10	3.95	16	3.79	18	3.96	16.5
TP3-Security	3.67	23	3.86	20	3.54	24.5	3.69	23
TP4-Privacy	3.57	25	3.61	26	3.59	21.5	3.59	25
TP5-Work continuity	3.71	22	3.91	18.5	3.54	24.5	3.72	22
TP6-Maintenance and preservation	3.53	26	3.48	27	3.49	26	3.51	26
TP7-Disposition	2.94	28	2.89	28	2.90	28	2.91	28
Average	3.91	NA	3.96	NA	3.80	NA	3.90	NA

performed and ensures that appropriate safety precautions are taken prior this work. There are many examples where inadequate permit to work systems have failed to prevent accidents. Safety standards and regulations require the adoption of safety work permit systems. Comprehensive and clear documentation is necessary to ensure that such systems are in place and effective.

- Disposition has the lowest mean, 2.91. This indicates that it is considered relatively less important to deal with safety information, though 'Disposition' is one of the information life cycle elements to ensure the availability of still-useful safety information. The main reason is that it is believed that modern IT tools can provide huge storage capacity with low costs. Therefore, respondents are less concerned with this indicator.
- Although 'External relationship' is the second least indicator, the mean value (3.43) shows that, relatively, it is still important. The survey data shows that some respondents are not comfortable on providing plant information to the public. However, the right to know of the public and authorities with regard to safety and health issues is the trend of new safety legislation. Good SIM performance must consider a mechanism to share information and facilitate partnership with external organizations.

These 28 indicators were then subjected to Item Analysis. Prior to Item Analysis, analysis of variance (ANOVA) was performed to test whether the mean values of each indicator were equal for each group of respondents. This helped to clarify whether or not the opinions of these three groups were the same for the 28 indicators in the survey. The results suggest a consensus between the three groups in relation to all indicators covered in the survey. Furthermore, within the mean and ranking for the three groups of respondents and for the respondents overall, the Kendall's coefficient (τ) and the Pearson's Product-Moment Correlation coefficient (r) have been calculated for each pairing of the groups of respondents. All the values of τ and r are greater than 0.7, except the value of τ for SS vs. OP which is 0.66. These correlation coefficients indicate the great agreement among the groups on the importance of indicators.

For the purpose of increasing the internal consistency of the survey (raise the reliability), Item Analysis was carried out to determine which indicators ought to be kept and which should be removed. This study used two approaches to carry out the Item Analysis. The first was 'corrected item-total correlation', in which the correlation is determined between the respective indicator and the total score for all the other indicators. If the correlation is low, it means that the indicator isn't really assisting in the measurement of what is trying to be measured. If the correlation is lower than 0.3, indicating little or no association[23], the indicator should be removed. The results show no correlation values bellow 0.3. The second approach was 'Alpha if indicator deleted'. In this approach, a measure of the reliability of a respective indicator was obtained by determining the Cronbach's alpha (α) of the indicator set if the indicator under examination was deleted. Since the 'Alpha if indicator deleted' values vary among the seven indicators by only 0.05, and since the reliability remained strong in each instance, no indicator should be deleted from the set. Cronbach's alpha (α) analysis was also performed on the total data set to provide a measure of reliability. The total alpha for the indicators is 0.93, demonstrating consistency in the survey responses.

In order to establish the truth concerning the degree of importance placed on each perspective and indicator, and to decide the weight of each perspective and indicator, the fuzzy linguistic majority introduced by L.A. Zadeh was adopted. Fuzzy majority is a soft majority concept, which is manipulated via a fuzzy logic based calculus of linguistically quantified propositions[25]. Kacpryzk[25] specified the fuzzy majority rule by means of a linguistic quantifier to derive various solution concepts for group decision making problems. A full description of the fuzzy linguistic majority and calculation process can be found in reference 25 and 26. Using this approach the degree of importance (I) of each indicator is calculated through its frequency of ranking given by all of the respondents. The values of linguistically quantified propositions ($\mu_{\text{`}most\text{'}}(r)$) and weight of each perspective can be determined as shown in Table 5. Here, $\mu_{\text{`}most\text{'}}(r)$ represents the degree of truth of membership in a linguistic fuzzy set. For example, the degree that 'most' indicators are important to their parent-factor, Strategic perspective, is 80% (see Table 5). In other words, for Strategic perspective, 80% was obtained for the linguistic quantifier 'most'.

WEIGHT DETERMINATION

The relative weight of SIM performance perspectives is the mean weight established from the Survey. From the results of last section, the weight of each perspective has been calculated using two methods, namely, direct survey and fuzzy majority. The results show the same ranking order and have a high correlation coefficient value (Pearson's product-moment coefficient r = 0.95) indicating that the two sets of perspective weights are in good agreement (see Table 6). However, the two sets of perspective weights are slightly different, the weights calculated from the fuzzy majority approach are adopted in this paper, because in the fuzzy majority approach it is only the importance of the perspective that is measured.

The perspective weights derived adopting the fuzzy majority approach were then used to derive the relative weights of the indicators (see Table 7). The relative weights of the indicators were calculated from the product of truth importance (I) value. For example for the indicator SP1, Strategic planning, its relative weight was calculated by

Table 5. Linguistically quantified propositions and weight of perspective

Perspective	$\mu_{\text{`}most\text{'}}(r)$	weight
Strategic	0.80	27.6%
Operational	0.84	29.0%
User	0.74	25.5%
Technology	0.52	17.9%
Sum	2.90	100%

Table 6. Perspective weights

	Section B (direct survey)		Section C (fuzzy majority)	
Perspective	Weight (%)	Rank	Weight (%)	Rank
Strategic	26.3%	2	27.6%	2
Operational	29.4%	1	29.0%	1
User	24.4%	3	25.5%	3
Technology	19.9%	4	17.9%	4

dividing its mean score (I) value from the survey by the summed value, i.e. $0.71/4.92 = 0.143$, the same process was adopted for the remaining indicators. Finally, the Weight (w) of each indicator was calculated from the product of the relative weight of indicator and the weight of its perspective to which it belong. For example for the indicator SP1, the product of $0.143 \times 0.276 = 0.039$.

The ranking of the 28 indicators is detailed in Table 7. The highest ranked indicators are SP4, Leadership, and UP4, Information behaviours, and the lowest ranked indicator is TP7, Disposition. It is important to note that, even though User perspective had six of the ten highest ranked indictors, it was the second lowest ranked perspective. It is also important to note that Technology perspective was the lowest ranked perspective. These suggest that the respondents see these perspectives as key enablers to achieving SIM performance improvement. However, their overall perception is that the majority of value generated from SIM is derived from the 'results driven' Operational perspective and Strategic perspective.

CONCLUSION

Managing safety related information inadequately has been cited as a significant factor to industrial accidents. Accidents can occur even where PSM systems exist and the probability of such occurrences increase if documentation is deficient. There are many examples of accidents that might have been avoided if satisfactory PSM documentation had existed and had been effectively used. Many accident investigations also identify inadequate SIM as a critical factor contributing to these accidents.

The usefulness of safety information is dependent on the accuracy and reliability of the information. It must be confirmed that there are mechanisms for capturing information throughout the various stages of process development, design, construction, operation, maintenance, and decommissioning. Also a single standard measurement technique of SIM performance is needed for the process industries to help prevent, control and reduce the risk of inadequate SIM.

Following the information derived from the literature review, a conceptual SIM performance framework has been developed by adopting the BSC approach. The

Table 7. Weight of perspectives and indicators

Perspective with weight	Indicator	Mean	I	Relative weight	Weight (w)	Rank
Strategic perspective (0.276)	SP1-Strategic planning	4.03	0.71	0.143	0.039	9
	SP2-Organisation and responsibilities	4.08	0.72	0.145	0.040	6
	SP3-Acquisition	3.97	0.69	0.141	0.039	9
	SP4-Leadership	4.59	0.82	0.166	0.046	1
	SP5-Evaluation	4.06	0.71	0.144	0.040	6
	SP6-Standardisation	3.97	0.69	0.140	0.039	9
	SP7-External relationship	3.43	0.59	0.119	0.033	20
	SUM	NA	4.92	1.000	0.275	NA
Operational perspective (0.290)	OP1-Process knowledge	4.04	0.71	0.124	0.036	17
	OP2-Process hazard Analysis	4.14	0.73	0.127	0.037	14
	OP3-Operation procedures	4.38	0.78	0.136	0.039	9
	OP4-Incidents reporting	4.15	0.73	0.127	0.037	14
	OP5-Permit to work	4.15	0.73	0.127	0.037	14
	OP6-Management of change	4.01	0.70	0.122	0.035	19
	OP7-Emergency response	4.02	0.71	0.123	0.036	17
	OP8-Safety work practices	3.75	0.65	0.113	0.033	21
	SUM	NA	5.73	1.000	0.290	NA
User perspective (0.255)	UP1-User awareness	3.90	0.68	0.169	0.043	3
	UP2-User training & support	3.89	0.68	0.169	0.043	3
	UP3-User competence	3.82	0.66	0.165	0.042	5
	UP4-Information behaviours	4.07	0.73	0.182	0.046	1
	UP5-System utilisation	3.68	0.64	0.158	0.040	6
	UP6-User satisfaction	3.66	0.63	0.157	0.040	6
	SUM	NA	4.02	1.000	0.255	NA

Technology perspective (0.179)	TP1-SIM tools	3.97	0.69	0.158	0.028	22
	YP2-Technology integration	3.96	0.69	0.158	0.028	22
	TP3-Security	3.69	0.64	0.147	0.026	24
	TP4-Privacy	3.59	0.62	0.142	0.025	26
	TP5-Work continuity	3.72	0.64	0.147	0.026	24
	TP6-Maintenance and preservation	3.51	0.60	0.138	0.025	26
	TP7-Disposition	2.91	0.48	0.110	0.020	28
	SUM	NA	4.36	1.000	0.179	NA

proposed conceptual framework examines the SIM implementation of 4 different, but inter-connected, perspectives: strategic, operational, user and technology. Under these 4 perspectives, 28 indicators have been developed.

The questionnaire survey has been undertaken to investigate SIM current practice and identify the important indicators for inclusion into the SIM performance measurement tool. The responses of the survey were positive and the results helped to select appropriate indicators. The survey also helped to calculate the relative weight of perspectives and indicators, and these can be adopted to develop a scoring system for SIM performance measurement. In summary, the Operational perspective received the highest weighting (29.0%), followed by Strategic perspective (27.6%), User perspective (25.5%), and Technology perspective (17.9%).

After identifying perspectives and indicators and determining their relative weights from the survey, the next challenge is to develop a tool for SIM performance measurement using these perspectives and indicators. The proposed programme of work is as follows:

1. Refining indicators and measures
2. Developing the implementation of SIM performance measurement
3. Developing an interactive computer-aid tool
4. Testing and validation the tool through case studies

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