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Integrating Performance Indicators Into the Audit of Process Safety Management Systems

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The development of the audit method has included the identification of possible performance indicators at each level of the sociotechnical pyramid for a range of areas of work in which accidents have been shown to occur most frequently. The measurement of performance indicators is part of a feedback loop which causes safety improvements. Integration of performance indicators into the audit system has been tested at three operating chemical industries in Terengganu and Selangor in Malaysia. A summary of the weaknesses of the similar elements identified in the three audited plants is presented. Analysis on the approach used enables the identification of deficiencies in safety management aspects.

Keywords: Accidents, audit, deficiencies, performance indicators, safety management, *and* sociotechnical pyramid.

INTRODUCTION

Analyzing the occurrence of accidents in some factories shows the existing failure preconditions within the sociotechnical system of a plant. The existing failure preconditions that arose were more on the managerial aspects, hence, highlighting deficiencies in management system. Therefore, it is an objective of this paper to look into means of tackling the root causes within the safety management system.

Integration of performance indicators into the audit system is one of the means used to tackle these root causes. Phang's audit method (1993), which was based on the sociotechnical pyramid shown in Figure 1, was chosen for this integration approach; hence, it seeks for the development of a chain of action in identifying management weaknesses in controlling hazards. In order for this to be carried out, the choice of appropriate performance indicators is clearly important. This could be identified depending on the outcome of an audit.

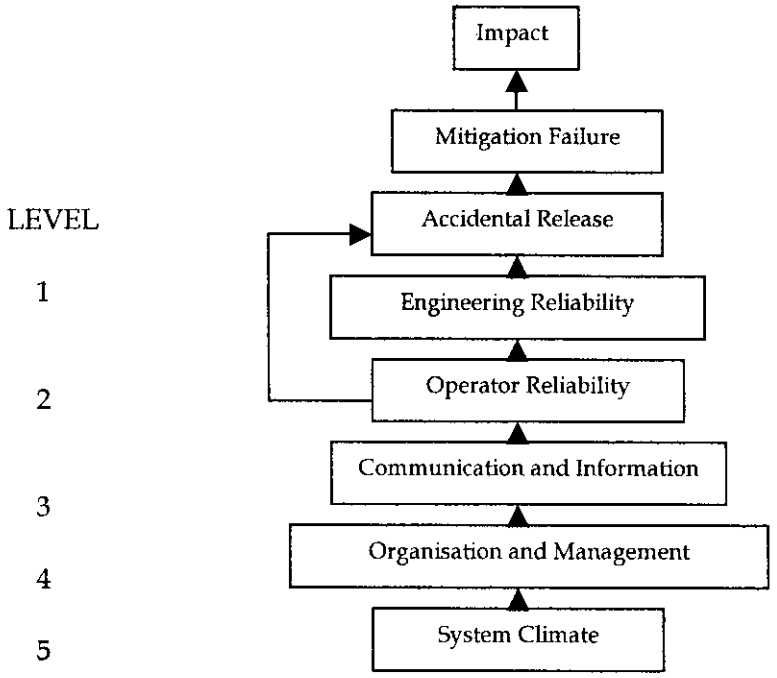

Figure 1. The Sociotechnical Pyramid (Hurst and Ratcliffe 1994)

PERFORMANCE INDICATORS

Lievre and Foraher (1995) described performance indicators as a system which is required for the early identification of the failures in the implementation of the main safety management systems. As the name suggests, performance indicators can indicate how effectively a process is operating or a system set up is implementing. However, Shaw and Blewett (1995) stated that performance indicators are not necessarily perfect measures because they will not always be able to tell the company the complete story, but to guide the company where to start to improve its performance. On their own, the author believes that performance indicators cannot provide adequate information on the elements requiring improvement. Thus, integrating them with an audit system is important.

Based on the definition above, performance indicators can then be derived from any critical plant operating parameters which affect health, safety and the environment.

In order to have closer monitoring and guiding ways for the development of the safety culture, some possible performance indicators are used in correlation with the levels of sociotechnical pyramid. The levels of sociotechnical as seen in Figure 1 have links into several keywords. Wells et al. (1994) developed several keywords from the sociotechnical system which similarly represents the components of sociotechnical pyramid. The application of developed keywords would provide suggestions for appropriate performance indicators to be developed by the author which exist within a particular level as shown in Table 1.

EXPERIMENTAL AUDIT

An experimental safety management system (SMS) audit was carried out at three chemical plants in Terengganu and Selangor in Malaysia. Audit questions concentrated on the following areas which have been identified as common contributors to accidents (Hurst and Ratcliffe 1994), namely:

1. Identification of hazards in design,
2. Identification of hazards in operations,
3. Checking of operations work,
4. Human factors in operations,
5. Checking of maintenance work, and
6. Human factors in maintenance.

The audit involved conducting a sampling technique to look at 'horizontal' and 'vertical'

Table 1. Integration of Performance Indicators with the Components of the Sociotechnical Pyramid

SOCIOTECHNICAL LEVELS	KEYWORDS	POSSIBLE PERFORMANCE INDICATORS
System Climate (Level 5)	Technical adsorption Legislation Political climate/pressure group Economic climate/business factors	- Improved process know-how - Improved competence - Improved compliance record - Reduced bounded impact and legal actions brought against the company - Decrease in business interruptions - Increased marketing - Staff turnover per category - Increased profits - Increased production zone
Organisation and Management (Level 4)	Decision-making hierarchy Commitment to safety Resource provision Production resources	- Cleared lines of responsibilities in safety - Improved reputation - Reduced legal actions brought against the company - Improved regulatory relations - Improved motivation - Reduced ambiguities - Decrease in business interruptions - Function of product recycled - Availability for production of plant
Management Processes (Level 3)	Monitoring, quality control and appraisal Safety responsibilities Incident reporting Working practices and procedures	- Reduced legal actions brought against the company - Improved compliance record - Reduced insurance rates - Frequency of accidents/incidents - Number of injury per category - Number of unsafe acts reported - Number of safety audit scored - Number of injuries and damage - Lost workday injuries - Number of corrective actions taken - Reduced number of short-cuts - Reduced volume of environmental hazards - Increased worker productivity from reduced environmental risks
Operator Reliability (Level 2)	Recruitment of training Personnel capabilities Safety culture Immediate supervision and support	- Level of staff competence - Knowledge of job performance measures - Number of failures in annual assessment - Increased safety individual awareness - Level of motivation achieved - Reduced work pressure - Number of conflicts per category
Engineering Reliability (Level 1)	Availability Detailed engineering Maintenance	- Shutdown frequency - Cost of distruption to operation - Safety systems out of operation - Conformed the standards - Passed periodic testing - Percent of equipment breakdown - Proportion of repair time to outage time

Table 2. Performance Indicators Gathered for Each Audit Area

Identification of Hazards in Design • Number of quality problems identified as being caused by design faults • Number of incidents not identified by hazard identification procedures
Identification of Hazards in Operation • Number of unsafe acts reported per category • Results of plant inspection/audit • %Compliance to the standard • Number of injuries per year
Human Factors in Operation • Number of operational failures per year • Number of failures reported due to unaware to the compliance of working procedures and standards • Number of injuries per year
Checking of Operation Work • Number of failures identified during operation work • Frequency of operation tasks checked based on PTW maintenance systems • Number of corrective actions taken on identified deficiencies in checking operation work
Checking of Maintenance Work • Number of corrective actions taken related to maintenance work per year • Percent of equipment breakdown during operational work
Human Factors in Maintenance • Percent permit-to-work compliance • Number of injuries per year • Number of human error recorded per year

slices of the system. During the audit some information on performance indicators were gathered for each audit area as shown in Table 2.

RESULTS

All the information and data obtained were assembled according to the six areas considered. Weaknesses in each area identified by the audit are listed below.

Identification of hazards in design

- Absence of formal codes of practice to carry out Hazop
- Inadequate means for resolving potential conflicts due to economics and production pressures
- No written policy regarding modification review procedure
- Inadequate job descriptions and clear allocation of responsibilities for design team members

Checking of operation work

- No means allocated for routine task checking
- Inadequate clarification of roles and responsibilities
- Inadequate work plan
- Inadequate arrangements for adherence to standard working procedures
- Inadequate means to periodically carry out the hazard studies for operational work
- Inadequate experience in carrying out hazard related works

Human factors in operations

- Inadequate levels of supervision allocated
- Inadequate training operators
- Inadequate formal specification of roles and responsibilities of line management
- Inadequate periodic work observation carried out on new operators
- Inadequate means to ensure a two way communication is fully implemented
- Inadequate enforcement to ensure all people are fully compliant with the permit-to-work procedures

Checking of maintenance work

- Inadequate clarification of task relationships

- No policy to carry out inspection and monitoring of equipment
- Inadequate standard checklist for maintenance activities and inspection
- Inadequate time for maintenance tasks take place
- Inadequate arrangements to familiarize staff with new equipment

Human factors in maintenance

- Inadequate means to control pressure on maintenance staff
- Inadequate means to identify training needs amongst workers
- Inadequate communication
- Inadequate arrangements to ensure the level of task is compatible to the level of competence of staff
- Inadequate means to resolve conflicts between maintenance staff and production schedule

Identification of hazards in operations

- Inadequate means to carry out periodic hazard studies for operational work
- Inadequate detailed inspection in each process area
- Inadequate enforcement of monitoring procedures set up
- Inadequate communication
- Inadequate means to carry out periodic revision of operating procedures

Table 3 shows a list of the identified performance indicators gathered from the audited plants. Due to the difficulties in obtaining the data, not every performance indicator in the list was measured at each of the plants. Detailed plant records for each of these performance indicators were obtained during the audit.

Table 4, 5, and 6 below represent the examples of possible performance indicators gathered in some areas of work obtained from the oil and gas industries and were integrated into the audit method used.

Table 4 shows the monthly percentage of compliance with work standards. This is summed up from the weekly inspection carried out in all sections in the workplace by the work representatives. The objective of carrying out this inspection by the company is to identify all facilities, equipment parts, and activities where substandard practices and conditions could occur. The inspection is carried out using a standard inspection checklist provided for each area of work.

From the table, it shows that the average percentage of compliance to the standard set up at workplace has sharply decreased from 52.7% to 38.5%. This is surprisingly low and worrying that it is getting worse. This is reflected by some identified deficiencies in safety management aspects.

Identified Deficiencies in Safety Management Aspects

- Inadequate checking that work is being carried to the standard set
- Inadequate clarification of safety line management functions
- Inadequate level of supervision
- Inadequate communication in the levels of management
- Inadequate specification of roles and responsibility

Table 3. The Identified Performance Indicators at Audited Plants

Performance Indicators
%Equipment breakdown during operation work
Number of corrective actions taken on safe work practice
Number of corrective actions taken related to maintenance work
Number of unsafe acts reported in the workplace
%Permit-to-work compliance
Number of breaches of safety rules
Accident frequency rates
Incident frequency rates
%Compliance to work standards

Table 4. Percent of Compliance to the Standard Set at Workplace

Month/Year	Year 1 % Compliance	Year 2 % Compliance
January	33.0	37.5
February	60.0	45.0
March	72.0	45.0
April	57.2	23.0
May	79.5	34.0
June	51.2	41.0
July	51.3	27.0
August	56.6	41.0
September	37.7	53.0
October	40.5	38.0
November	48.5	39.0
December	45.3	39.0
AVERAGE	52.7	38.5

N.B. % Compliance = (Total point/total weighted) x 100

- Inadequate work plan
- Inadequate safety awareness in the workplace

Table 5 shows the number of unsafe acts of commission caught during the daily inspection carried out by the safety personnel in the workplace. The company defined these unsafe *acts of commission* as acts that deviate from a specified or generally accepted safe way of performing a task, such as taking up unsafe positions, riding on hazardous equipment, smoking in prohibited areas, operating machinery and equipment at unsafe speeds, or overloading.

From the table, it can be seen that the number of unsafe acts of commission reported (in Year 1 and Year 2) in the workplace is still high and not much improvement is seen. However, the fact that unsafe acts are being reported suggests a feedback loop in place.

Identified Deficiencies in Safety Management Aspects

- Insufficiently thorough inspection carried out on unsafe acts
- Inadequate level of supervision while handling tasks
- No attitude survey carried out on workers in the workplace
- Inadequate adherence to safety regulations outlined

Table 6 represents the percentage of all site injury frequency rates which covered both plant personnel and contractors working on site for Year 1 and Year 2. These figures are based on the reports of reportable injuries made by the supervisor in charge using the standard accident form available at the workplace.

The table shows that the average percentage of all injuries reported in the company from Year 1 to Year 2 increased by 0.03%. However, analysing the mean using a two-sample *t* statistic shows that there is no significant difference between those two data. Looking at the table as well it is hard to believe that the company has zero percent injury frequency rates recorded for 7 months from January to July. It was unclear to say whether these were due to under-reporting factor. However, the company could minimize the number of injuries very significantly if all the identified deficiencies in safety management aspects are properly tackled.

Identified Deficiencies in Safety Management Aspects

- Inadequate independent checks carried out on modification sections
- Inadequate adherence to operating procedures
- Inadequate amount of supervision allocated in operation section
- Inadequate communication amongst the management level
- Inadequate adherence to the PTW system

Table 5. Number of Unsafe Acts of Commission Reported in the Work Area

Month/Year	Year 1 No. of unsafe acts	Year 2 No. of unsafe acts	Year 3 No. of unsafe acts
January	4	0	6
February	4	0	2
March	11	5	5
April	0	2	2
May	2	4	0
June	6	3	0
July	3	12	0
August	3	14	0
September	0	0	6
October	0	2	1
November	3	11	*
December	1	2	9
AVERAGE	37	55	31

N.B. * Major plant shutdown, thus no inspection on unsafe acts carried out.

- Existence of pressure due to inadequate time allocated for the work to be completed
- Inadequate specification of roles and responsibility
- Inadequate competency in carrying out work
- Inadequate maintenance training
- Inadequate safety awareness

DISCUSSION

Integrating the existing performance indicators within a management loop produces a chain of action in which the deficiencies in the safety management aspects are identified. This illustrates the relationships between Safety Management Audit (SMS) and performance indicators (PIs).

These deficiencies are regarded as root causes which can form sequences of management failure in which the readily measureable performance indicators identified would be at the top of a tree. This illustrates that a hierarchy of accident causation as in Figure 1 (sociotechnical pyramid) exists. The immediate causes of an incident which is due to inadequate adherence to operating procedures (Level 2) was enhanced by the involvement of lack supervision or because the operator was not properly trained (Level 3). These causes can be traced to more remote causes which are connected to management (Level 4) such as inadequate roles and resposibility, which in turn brought by severe production pressures (Level 5) (Phang 1993).

For the monitoring purposes the choice of performance indicators is important. A few of those in use in the companies audited were less than ideal, for example, the number of unsafe acts reported and the number of breach of safety rules. It is difficult to say any reduction recorded, for example, is due to an improvement in safety rules, whereas no detailed inspection in each process area was carried out as identified by the audit. However, the percentage of compliance to the work standard seems to be a good performance indicator. It was adequately measured using a standard checklist,hence no 'under-reporting' factor can occur because all the elements specified in the checklist were thoroughly checked and analyzed. Accidents are very infrequent (Heinrich 1980), so that accident frequency rate makes a poor performance indicator.

CONCLUSIONS

The audit approach used enables commenting on areas where management control is found paticularly blurred or not demonstrated in the safety management system control loop and leading to some recommendations. The outstanding outcomes from this audit approach used are:

1. Audits can be used to identify safety management system problems which are affecting particular performance indicators.

2. Well-chosen performance indicators can give a measure (as a function of time) of the

improvement in those areas shown by the audit to be deficient.

3. Integration approach used leads to an identification of criteria for selecting the ideal performance indicators to be used to upgrade safety management system at the workplace following an audit as follows:

   - Occur frequently,
   - Not be liable to under-reporting, and
   - Be easy to measure.

REFERENCES

Heinrich, H.W. (1980). *Industrial accident prevention*, 5th ed., McGraw-Hill, New York (1980).

Hurst, N. W., and Ratcliffe, K. (1994). "Development and application of a structured audit technique for the assessment of safety management systems (STATAS)," *Hazards XII European Advances in Process Safety*, IChemE, Rugby, U.K., 315–328.

Lievre, T., and Foraher, F. (1995). "Safety performance monitoring for drilling: A more comprehensive system," Proceedings of the SPE/IAD Drilling Conference in Armsterdam, 28 February–2 March. 357–360.

Phang, C. M. C. (1993). *Tackling the root causes of process failures*. Ph.D. Thesis. Department of Mechanical and Process Engineering, University of Sheffield, U.K.

Wells, G., Phang, C., and Wardman, M. (1994). "Improvements in process safety reviews prior to Hazop," *Hazards XII European Advances in Process Safety,* IChemE, Rugby, U.K.