TO STATE

FROM STATE	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27
1	*	*	*	*	*	*	*	*	*	*	*	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
2	–	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	–	–	–	–	–	–	–	–
3	–	–	*	*	*	*	–	*	*	*	*	–	*	–	*	*	–	*	–	–	–	–	–	–	–	–	–
4	–	–	–	*	*	–	–	*	*	*	*	–	*	–	*	*	–	*	–	–	–	–	–	–	–	–	–
5	–	–	–	–	*	–	–	–	–	*	*	–	*	–	*	*	–	*	–	–	–	–	–	–	–	–	–
6	–	–	–	–	*	*	–	–	–	*	*	–	*	–	*	*	–	*	–	–	–	–	–	–	–	–	–
7	–	–	–	–	*	*	*	–	–	*	*	*	*	*	*	*	*	*	*	–	–	–	–	–	–	–	–
8	–	*	–	*	*	–	*	–	–	–	–	*	*	*	*	*	*	*	*	–	–	–	–	–	–	–	–
9	–	–	–	–	–	–	–	–	1	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
10	–	–	–	–	–	–	–	–	–	1	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
11	–	–	–	–	*	–	*	–	–	–	–	*	*	*	*	*	*	*	*	–	–	–	–	–	–	–	–
12	–	–	–	–	–	–	–	–	–	–	–	*	–	–	–	–	–	–	–	–	*	*	*	*	*	*	*
13	–	–	–	–	–	–	–	–	–	–	–	–	*	–	–	–	–	–	–	–	*	*	*	*	–	*	*
14	–	–	–	–	–	–	–	–	–	–	–	–	–	*	–	–	–	–	–	*	*	*	*	*	–	*	*
15	–	–	–	–	–	–	–	–	–	–	–	–	–	–	*	–	–	–	–	–	*	*	*	*	–	*	*
16	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	*	–	–	–	–	*	*	*	*	–	*	*
17	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	*	–	–	*	*	*	*	*	–	*	*
18	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	*	–	–	*	*	*	*	–	*	*
19	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	*	–	*	*	*	*	*	*	*
20	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	*	*	*	*	*	*	*	*
21	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	*	*	*	*	–	*	*
22	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	*	*	–	–	*	*
23	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	*	*	–	–	*	*
24	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	*	*	*	*	*	*	*
25	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	*	*	*	*	*	*	*	*
26	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	*	–	*	*	–	*	–	–
27	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	1
28	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
29	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	*	–	*	*	–	*	–	–

KEY

– transition probability = 0.0
1 transition probability = 1.0
* transition probability in the range 0 < P < 1

FIGURE 7 : 'SKELETON' STPM

A COMPARATIVE STUDY OF THE MANAGEMENT EFFECTIVENESS OF TWO TECHNICALLY SIMILAR MAJOR HAZARD SITES *

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This paper describes a study undertaken in order to quantify the effects of organisational, management and human factors in relation to Quantified Risk. The study compared the safety management effectiveness of two technically similar Major Hazard sites, and predicted that one company would represent about twice the major hazard risk of the other. Following the study the companies provided accident data, suggesting that the occupational safety performance of one company was about twice as effective as the other. This finding was broadly in line with the overall prediction regarding the effectiveness of the major hazard safety management systems.

Safety Management, Human Factors, Quantified Risk Assessment

INTRODUCTION

The onshore and offshore major hazard industries already apply comprehensive measures to ensure that the levels of safety and availability achieved are of a high order. However, it is apparent that in the onshore and offshore industries, accidents such as those at Flixborough (Health and Safety Executive, 1975 [1]), Bantry Bay (Stationery Office, Dublin, 1980 [2]), and Grangemouth (Health and Safety Executive, 1989 [3]) can be seen to have had strong components of management failure. In addition, many studies have shown that a large proportion of major accidents are associated with human error. Joscheck (1981) [4], for example, suggests that 80-90% of the chemical industry's incidents and accidents involve the human element, and Singleton (1989) [5], reinforces these estimates by suggesting that between 50-80% of system failures can be ascribed to human error. The strength of the human contribution to system failure and hydrocarbon loss has been confirmed by Instone (1989) [6], who observes that, "It can be argued that virtually all causes of loss excluding natural perils are as a result of Human Error". Studies by Rasmussen (1980) [7], Samanta *et al.* (1981) [8], Ghertman and Griffon-Fouco (1985) [9], Institute of Nuclear Power Operations (1985) [10], and Bellamy *et al.* (1989) [11] suggest that it may be possible not only to identify the causes of human failure, but via safety management measures, find ways to reduce their overall likelihood.

Clearly if some techniques can be devised to assess the overall impact of human beings on overall system safety, it should be possible to target resources at the management failures and reduce the

* *The work described in this paper is of an exploratory nature. There is no implication that the findings will have an automatic application for the operational or advice roles of HSE.*

likelihood of major accidents. Reports abound regarding the significance of management to the control of industrial hazards, and it is now generally agreed that the evidence for regarding management reliability as a fundamental issue in risk assessment and management is substantial (Perrow, 1984 [12], Reason, 1991 [13], Whalley and Lihou, 1988 [14], Bellamy and Geyer, 1991 [15], Brearley, 1990 [16]). The "Management at Risk Guide", the work for which was conducted on behalf of the Human Factors in Reliability Group (Jenkins *et al.*, 1991 [17]) also makes it clear that the view that considering management as a separate intractable issue in risk assessment is no longer tenable.

As might be expected, therefore, it is now recognised within the onshore and offshore major hazards industries that safety management systems may be expected to have a major influence on failures and the rate at which they occur. Currently, it is normal to perform Quantified Risk Assessments (QRA) in order to determine what the major components of risk might be for any given installation, and examine these cases for their susceptibility to human failures with respect to the initiation, control, consequence, impact and mitigation of foreseeable accident sequences. As a consequence of these considerations, the impact of Human Factors in relation to QRA is now becoming better established.

It will be clear from the above that there is a substantial human component in the accidents outlined above, which if it could be identified, quantified and accommodated within QRA procedures, might be expected to materially affect any generic risk assessments made. Most QRA studies conducted to date, e.g. Canvey (Health & Safety Executive, 1979 [18]) and Rijnmond (1982) [19] have used deterministic failure rates. These rates are derived from a limited range of data sources, mainly power station and large chemical plant facilities in North America and Europe. This historical accumulation of data is normally referred to as generic data.

A problem with the generic failure rate data used in QRA studies is that it implies the same average value for all sites, regardless of the quality of safety management systems employed. QRA studies need at least to be supported therefore with a reasonable qualitative overview of safety management systems, and preferably some quantitative estimate as well (recognising that this may be a crude estimate only).

One of the normal means of assessing the need for safety improvements is by Auditing or Inspection. This is essentially a means of assessing the ability of a company to manage its affairs with respect to the safety of its employees, its risk loading on members of the public and its impact on the environment. It is complementary to Risk Analysis and much of the information gathered during an audit can form a useful input to a risk study. The aims of an audit are, very much like attending a doctor, to seek out the symptoms which lead to the correct diagnosis of the disease or diseases, so that an appropriate treatment can be found.

Several systems have been developed to assess the quality of safety management or to quantify the human role in risk assessment studies. For example, the International Safety Rating System, ISRS (Bird and Germain, 1985 [20]) has been developed as an audit technique to provide a score on the quality of safety management, and the Instantaneous Fractional Annual Loss, IFAL, technique has been developed to indicate where there may be potential areas of loss that could be attributable to safety management effectiveness (Whitehouse, 1987 [21]). Whenever such techniques are applied, however, a question which is often asked is, "is it possible, using a safety management audit assessment technique to detect accurately the differences between two managements operating

identical equipment, and indicate in which direction, and to what extent, these differences might be quantified?". It was with this concern in mind, that the study outlined in this paper set out to obtain a provisional answer to this important question.

SAFETY MANAGEMENT ASSESSMENT

The objective of the study was to make an unqualified prediction of the computed Management Factor differences that might be observed between two onshore companies who were operating technically similar plant ***without prior knowledge of the safety data of either organisation.*** For the purposes of this study a safety management assessment technique known as the **MANAGER** (**MAN**agement **A**ssessment **G**uidelines in the **E**valuation of **R**isk) Technique (Pitblado *et al.*, 1990 [22]) was used.

MANAGER is a proposed Modification of Risk technique, which tends to be simpler to apply than some Human Reliability Assessment techniques, and which is regarded by some industries as representing a potentially cost effective means for estimating the likely overall contribution of organisational, management, and human factors influences to risk.

The technique is designed to possess the following properties:

- it is based on a review of the role of safety management to actual accident causation within the chemical process industry
- the question set addresses all areas shown to be important in accident causation (including human factors influences as well as more conventional loss prevention areas)
- it incorporates widely accepted principles of management science in order to address key elements of the safety management system
- the technique attempts to provide both a qualitative overview of site safety management and an indication of quantitative modification to generic failure frequencies
- although ultimately based on the skill of the assessor, it is reasonably repeatable, checkable for quality assurance purposes, and furnishes traceable insights as to the judged effect on risk predictions
- the resources required for application are intended to be commensurate with the needs of other techniques for application within onshore and offshore QRAs.

The current questionnaire used in the method is structured into 12 broad topic areas. These parallel closely the major topic areas in the Center for Chemical Process Safety's Guideline on Technical Management of Process Safety (CCPS, 1989 [23]), and not only incorporates the principles outlined above, but also draws on well established chemical industry loss prevention principles. The areas covered are:

- **written procedures**
  coverage, quality of documentation, updating, distribution, suitability for operators

- **incident and accident reporting**
  criteria, documentation, investigation, reporting requirements, monitoring of statistics

- **safety policy**
  safety culture, safety personnel, safety promotion, safety information

- **formal safety studies**
  hazard identification, personnel involved, implementation of results

- **organisational factors**
  management structure, job descriptions, independence of safety and inspection functions

- **maintenance**
  work permit system, contractors, documentation, maintenance deferment, inspection (routine and non-routine), treatment of safety critical items, procurement quality assurance

- **emergency resources and procedures**
  declaration of emergency, emergency control centre, emergency response manual, exercises, equipment

- **training**
  documented system, coverage (process, safety, other), training resources, who is trained (operators, maintenance, engineers, management), retraining

- **management of change**
  documentation, authorisation and review procedures (e.g. HAZOP, FMEA, etc.)

- **control room instrumentation and alarms**
  ergonomic design, availability of important plant and control variables, emergency shutdown system, alarm system (control vs safety critical), availability of control and emergency documentation, communication

- **other human factor influences** (not covered above)
  site housekeeping, shift system and manning levels, communications channels, log keeping, stress

- **fire protection systems**
  firewater, fire alarm, gas detector systems.

Questions in each section are straightforward and relatively easy to answer and score. Typical examples under **Written Procedures** are:

- Do operating procedures cover: normal operations, start-up and shutdown?
- Are the procedures written in a style suitable for foreman and operators?
- Do procedures cover operational limits, with reasons for these?
- Is the person responsible for issuing the instructions clearly indicated?
- Are the instructions dated and do they show a revision number?
- How are relevant personnel made aware of updates?

The MANAGER Question Set has been in development for a number of years, and has so far been applied in a number of forms to audit more than fifty industrial sites world-wide. At the end of a safety management audit using the technique, assessors are required to make an overall judgement concerning the effectiveness of the Safety Management Systems (SMS) that they have scrutinised. The range of judgement as whether the SMS is working effectively or otherwise is based on the observation that there appears to be a factor of 1000 variation (Rijnmond Study, 1982 [19]), between failure frequencies on many components (pipes, vessels, etc.) which could lead to loss of containment and result in large uncontrolled leaks. As the Bellamy *et al.* (1989) [11] review of pipe and vessel failure causation has demonstrated that over 80% of such failures might have been preventable or safely recovered given better SMS, a non-linear scoring scheme has been designed to cover 3 orders of magnitude of Management Factor (MF).

Using the current scoring scheme a completely average plant has an MF of 1.0, and a completely good plant has an MF of 0.1 (i.e. ten times better than generic). This upper limit reflects the already high level of safety in the high hazard process industries, and the relatively greater effort required to achieve a given level of change in this direction. By way of contrast, a completely bad plant has an MF of 100 (i.e one hundred times worse than generic). This lower limit reflects the ease with which a given level of change in safety performance can occur with falling safety management standards.

THE COMPANIES

The companies each had sizeable inventories of bulk chlorine and sulphur dioxide, operated practically identical plant, were CIMAH (Control of Industrial Major Accident Hazards) regulated, and had recently been privatised. Both companies were enthusiastic about the planned study and offered considerable assistance, both in terms of logistic planning and manpower resources. The companies also agreed to provide accident, incident and operational data at the end of the study, so that a comparison could be made between the predictions, and the observed performance of each company.

Day to day management of operations was generally organised from each site. However, corporate resources were necessary for all but the simplest functions, and as each installation was a part of a larger organisation spread over wide geographical areas, interviews were conducted at the two facilities and at their respective management and resource control centres, in order to obtain a comprehensive assessment. For both of these organisations, resources such as training, personnel, maintenance and engineering services (including formal safety studies) were shared between all the sites within the organisation.

At the end of the study, the companies provided accident, incident and operational data, so that an unbiased comparison could be made between the predictions, and the observed performance of each company.

THE SITES

Interviews were conducted at the two facilities and at their respective management and resource control centres. Each of the sites studied contained materials in sufficient quantities to require adherence to CIMAH (top tier) regulations. The primary risk associated with the operation of these sites involved the bulk storage of chlorine, with a secondary risk from bulk Sulphur Dioxide storage. The bulk storage of hazardous chemicals represents a potential risk to members of the public. In both cases, the major hazard facilities were located in flat geographical areas close to both housing and schools.

Each facility was a part of a larger organisation spread over wide geographical areas. Each of the study sites were relatively small facilities with a few people on-site during the day and one person on-site at night. The small number of facility personnel (5-6 daily, 1 at night) and the remoteness of the facilities from corporate facilities provided a very different basis for evaluation when compared to sites that have been reviewed in the past, where the majority of the management infrastructure has been located on the site where the "risk" resides. In the case of the sites reviewed, day to day management of operations was generally organised from the site. However, corporate resources were necessary for all but the simplest functions. For both of these organisations, resources such as training, personnel, maintenance and engineering services (including formal safety studies) are shared between all the sites within the organisation.

The two sites were evaluated from both an operational and a management perspective. Each had similar types of operation; toxic inventories; high daily product throughputs; the need for high quality control and technological sophistication. Both facilities had central control rooms where co-ordination of daily activities could take place. One facility utilised a dedicated control room operator to control and monitor the plant using a variety of means that allowed both control and display of the majority of equipment functions and parameters. At the other facility, by way of contrast, the control room operator was responsible for a variety of sites and gave peripheral attention to the monitoring of the facility under study. This latter operator relied on the setup of equipment onto automatic functioning by other personnel at the plant level. Once the plant was started up, the control room operator could monitor displays of equipment variables and parameters in the control room. Any problems or changes to equipment were undertaken by other personnel at local panels or at the equipment itself.

PRELIMINARY RESULTS AND CONCLUSIONS

The comparative study indicated that there were significant differences between the two companies in the way that they plan, organise, implement and control their respective approaches to the management of safety.

There were also many points of similarity. For example, a factor shared by both facilities with implications for control room operations and the control room operators is that both facilities shared the potential risk for generation of, and exposure to, toxic gas vapour clouds. Neither control room had a ventilation system that could isolate on gas detection. As a result, both control rooms contained breathing apparatus to allow them to be inhabited with gas present. Neither site seemed to have any very well developed approaches to fire detection or fire-fighting (this could have been a consequence of the fact that fire is not viewed as a significant potential threat).

Both facilities were attempting to produce a product stream that was held within tight tolerances, even though their raw materials were somewhat different. Another point of similarity was that having both been privatised recently, the companies were undergoing considerable structural change at the time of the study. The personnel in both companies seemed to feel that communication downward was good, whilst communication upwards was considerably less effective. It was also notable that efforts to produce thorough written procedures appeared to be lacking in both companies, with the exception of the CIMAH regulated side of the operation. Neither company seemed to possess very well developed management of change systems.

Surprisingly, both companies seemed to have experienced some slight difficulty with regard to joint operations and exercises with their local fire brigades, although for somewhat different reasons. Although training was viewed somewhat differently by both companies, the resources available were generally remote, both spiritually and physically from the needs identified by the site managements. Safety was taken seriously in both companies, particularly with respect to occupational safety, but one company seemed by its actions to be noticeably somewhat more attentive to major hazard matters than its counter-part.

The general levels of competence, commitment, and enthusiasm for improvement were strong in both companies. However there were some important differences. In a qualitative sense, the principal differences observed were:-

- one company had a safety policy that appeared to resolve apparent conflicts between safety and production, whereas in the other company it was much less clear
- whilst both companies appeared to possess strong directed leadership, one company's personnel seemed somewhat unimpressed by their leadership, whilst the other one's personnel had considerable confidence in the senior management
- whilst both companies were aware of the need to move towards a total quality approach, only one of them appeared to be making any headway towards this objective
- housekeeping in one company seemed somewhat better than in the other

- budget availability, and control processes were considerably different from one company to the other; for example in one company necessary expenditure would simply be incurred, and met, whereas in the other company, considerable end of financial year back-fitting would be undertaken
- one company had comprehensive job descriptions, whilst the other did not - this did not seem to affect the quality of staff recruited, and if anything, the company that appeared to lack such comprehensive documentation, actually seemed to fare better in this regard

In a quantitative sense the assessments made using the current MANAGER scoring philosophy suggested that one of the companies was slightly better than the industrial average, whereas the other was judged to be somewhat worse than the industrial average. The difference that is indicated is as follows:-

- Company A was found to have a computed Management Factor of about 0.9
- Company B was found to have a computed Management Factor of about 1.7

Thus an overall difference by about a factor of two in relation to safety management performance indicators was predicted.

The RIDDOR (Reporting of Injuries, Diseases and Dangerous Occurrences Regulations) injury rates per 1000 employees for the two companies concerned are shown in Table 1.

TABLE 1

	PERIOD		
	April 86 - March 87	April 87 - March 88	January 91 - March 91
Company A	8.7	7.3	5.9
Company B	12.5	10.3	8.0

Other performance measures tend to confirm these indications, and it seems that the prediction is largely borne out by the available evidence. As already mentioned, of the order of 50 audits of this and a similar nature have now been performed, and show promise in the evaluation of risk and its impact on risk management decision making. The range of Management Factor scores obtained so far has been from 0.5 (indicating better than average) to 8.0 (considerably worse than average), a range of 16. The Management Factor is a generic prediction about the overall likelihood of the relative difference in initiating failure frequencies, and is not a measure of the personal competence of individual site managers. The score results have in virtually all cases reflected the qualitative assessments of those familiar with the plants, both managers and assessors. The objective of the MF scoring technique is to provide a repeatable quantitative score suitable for use in QRA studies, and there seems to be a strong basis for believing that it is discriminating between safety management systems in a constructive, insightful and repeatable way.

Using techniques such as the HSE's Risk Assessment Technique **RISKAT** and DNV Technica's **SAFETI**, it is possible to make quantified risk assessments of major hazard plant in order to determine the implications for risk management in connection with land use planning. A paper published by Hurst *et al.* (1992) [24] outlines the possible use of the safety management data produced in this study within the context and shows that although the individual risk at the two plants is comparable in a purely technical sense, when the assessed management impacts are taken into account, a clear difference can be seen between the plants. The paper also considers if such a finding might change the conclusions that would otherwise be drawn regarding the use of land surrounding both sites. No firm conclusions are reached due to the early research nature of the work.

An Individual Risk of 1 x 10^{-5} per year at the better managed plant is computed to be at a distance of 290m, whereas the same risk is found at a distance of 400m for the other, somewhat less well-managed plant. Clearly as there is evidence that the management assessments are plausible, the difference in applicable distance for the same risk could have important implications for Risk Managers and decision makers. It also has a profound effect on the areas of land sterilised by land-use planning constraints, and the extent and cost of emergency planning and preparedness. However, because of the exploratory nature of these findings, there can be no implication that the results will have an automatic application for the operational or advice roles of HSE.

DISCUSSION

It must be borne in mind that this experiment has only been undertaken once, and for complete confidence, it would be necessary to have strong evidence of repeatability. Nevertheless the evidence is compelling. Another issue that needs to be considered is the fact that the study has examined the difference between the occupational safety data of the two organisations and not the major hazard data for both sites. Unfortunately from the point of view of the study, although mercifully from the point of the view of the public, the major hazard data are few and far between. As this was the case it was not possible to compare the major hazard data in any meaningful way. However, it could be argued on the basis of the Heinrich Triangle notions, that the occupational accident data may well be in some way representative of other classes of safety performance data.

CONCLUSIONS

An overall difference by about a factor of two in relation to safety management performance indicators was predicted (Company A having been assessed as being roughly twice as safe as Company B), and comparison with the data has shown that the direction of the prediction and its strength are highly compatible with observed safety performance. This suggests that it may be possible in future to discriminate between the safety management effects of individual organisations in relation to the control, operation, and assessment of major hazards both onshore and offshore.

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