Research Models of Safety Management of OnShore Major Hazards and their possible Application to OffShore Safety

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Synopsis

The work described in this paper is of an exploratory nature. The paper briefly reviews the current state of research work which is underway to consider the feasibility of including an assessment of the quality of a safety management system into land-use planning considerations. The paper then goes on to consider possible applications of the research work to the offshore industry.

Keywords

Human Factors, Management, Safety, Risk Assessment, Major Hazard.

1. BACKGROUND

When a local planning authority considers planning applications for new buildings (such as housing, schools, shops etc) around existing major hazard sites it will ask for advice from the Health and Safety Executive (HSE) concerning the safety of the proposed development. The essential question is whether the correct balance has been struck between the separation of the development from the major hazard and the area of land rendered 'unuseable' by an excessive exclusion zone. In giving its advice, HSE may carry out a risk assessment of the plant and calculate the risk to individuals of receiving a certain dose of toxic gas, overpressure or thermal radiation. The advice is then based on the type of development and its location relative to certain criteria risk levels. HSE has published a consultative document "Risk Criteria for land-use Planning in the Vicinity of Major Hazards" which describes this function in detail [1]. The risk assessment for these purposes is carried out using the HSE Risk Assessment Tool 'RISKAT' which has been described in detail elsewhere [1-5].

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[1] 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.

The RISKAT method makes use of generic failure rate data as the basis for estimating the likelihood of the various loss-of-containment accidents that could affect members of the public. These generic data include in a non-specific way contributions to failure from a variety of sources such as construction, maintenance, operations, human and management factors. Research is being carried out to consider whether it is possible to be more specific, in a quantitative sense, about the contribution that these management, organisational and human factors make to the predicted risk levels. In addition HSE may consider any effects that variation in these factors might have on the advice HSE gives concerning the siting of new developments [6].
The approach which is being developed involves a quantitative audit of the safety management system [SMS] at a plant, and the use of the results of the audit to provide a numerical input into the risk assessment procedure. Clearly, the methods may also be relevant to other areas of HSE activity including the inspection of plant and the consideration of CIMAH Safety Reports.

The purpose of this paper is to briefly review the current stage of development of this work and to consider possible applications in the offshore industry. The recent publication by HSE for consultation of draft offshore installations Regulations which include a risk criterion for the survival of a Temporary Safety Refuge [TSR] raises the question as to how the quality of a safety management system is included in the risk assessment for the TSR. It is not the criterion which is dependent on the quality of a safety management system, but the question of whether the procedure used to assess the risk should include an assessment of the quality of the SMS. This is a parallel problem to the one under consideration in the land planning area, which will be discussed in Section 6 of this paper.

2. INCLUDING A QUANTITIVE ASSESSMENT OF THE SAFETY MANAGEMENT SYSTEM IN RISK ASSESSMENT FOR LAND-USE PLANNING. CURRENT STATUS OF DEVELOPMENT.

The safety management system research work has been carried out by a multi-disciplinary group of people representing various organisations. The work is mainly funded by HSE and VROM (The Dutch Ministry of Housing) with some industry contributions. Scientific consultants include Four Elements Ltd and DNV Technica while attitude studies have been carried out by Surrey University, Dept of Psychology.

Fig 1 summarises the progress of the research.

With reference to Fig 1, a database of audit questions has been produced by bringing together information from a range of sources. These include:

- an analysis of industry data describing failures of pipework (7-12);

- an analysis of similar data for failures of vessels (11-13);
- a consideration of authoritative texts on chemical plant risk management, conventional organisational and management theory and management of quality (7, 13, 14);
- a consideration of major accident studies (systems failures) (8);

and

- studies of the attitudes of the workforce and management to safety at chemical plants [15].

Combining these sources of information has produced a comprehensive question set which covers the main areas of underlying causes of plant failure and failures of management control systems i.e. those systems which have the potential to prevent loss - of - containment accidents.

The statistical analysis of failures which has been carried out provides an empirical basis for the question set and has enabled weightings of importance to be placed on each area of the question set. The intention is to carry out a site audit of the SMS and to score each of these areas in its entirety according to the quality of the SMS evaluated. The overall score for the audit is then determined by aggregating the weighted scores for each area.

This methodology of site auditing will look for completeness and feedback in systems designed to ensure safety (for example permit to work systems) and will not include the completion of a checklist of questions. Rather the question set guides the auditor to examine the evidence regarding the effectiveness of these systems. The actual questions asked may vary depending on the needs of the audit. The philosophy here, expanded below, is to ensure firstly that the expertise of auditors and safety professionals is used to the full, secondly to ensure that including additional questions in a particular area of the audit does not affect the weight which is attached to that area and thirdly that the auditor acquires sufficient evidence to accurately judge an area. The weight is determined by the statistics of the underlying causes of failures and failures of preventive mechanisms.

It is intended to gain initial site experience in the UK with the application of this method in 1992 and to produce anchor points for auditors judgements. A submission of a Research Proposal to the CEC Environment Programme will hopefully enable the method to be further developed in a European context. The aim of this proposal is to validate the audit and to compare the practice of land-use planning in various European countries and to consider the application of the audit results to that process. However, because this work is at an exploratory stage there is no automatic implication that the results will affect HSE operational or advisory roles.

Validation of the method is a critical stage which involves the collection of site data, such as Lost Time Injury rates. This process will be carried out in parallel with the auditing and the completion of attitude studies.

The results of the audit will provide a prioritised list of areas for risk reduction, and a management factor or factors for possible use in modifying the data inputs to risk assessment. Decision makers can use the information to consider implications for land-use planning and investment decisions to reduce risk.

3. A BRIEF REVIEW OF THEORETICAL MODELS

Fig 2 illustrates the accident causation model which has been developed by this research work and which is fully described elsewhere (8).

Direct causes of failures such as corrosion are considered to be failures of engineering hardware components and human failures which directly cause loss of containment. These direct causes are often the result of other failures which lie 'deeper' in the system, and are more remote from the direct cause. Thus when an operator incorrectly opens a valve and this causes a release, the opening of the valve and the release are directly connected. However, the event may have occurred because the operator lacked competence because he was not provided with an appropriate procedure, or because there had been a failure in communication, or the operator was not adequately trained, etc. These causes are more remote. Even more remote, for example, is where management may not have allocated sufficient training resources, and this may have been due to inadequacies in prioritisation brought about by severe production pressures.

The accident causation model is also used to provide the rationale for the auditing method which relies on the completeness and feedback in accident prevention mechanisms. This is illustrated in Fig 3 [24]. Thus in considering if personnel are competent for their tasks, the auditor would look for:

- evidence that personnel have been trained to the standards;
- standards for training defining the intended level of training;
- a formal training system to implement the standard;
- assessment of the effectiveness of training to check the intended standard is met; and
- a system of revising the standards and methods if the achieved standard of training is found to be inadequate.

Fig 3 emphasizes the need for a complete loop of control in order to ensure that the system is effective. Industry norms and any changes to regulatory guidance would also be expected to

influence the standards set for training. Recently the HSE has published a booklet [16] "Successful Health and Safety Management" which also emphasises the need for feedback to improve performance.

4. A BRIEF REVIEW OF STATISTICAL MODELS TO INCLUDE MANAGEMENT FACTORS IN RISK ASSESSMENT

4.1 Failures of Vessels and Pipework

Fig 4 illustrates the classification scheme for incident analysis which has been developed by this research work and which is described fully elsewhere (8, 13). The scheme consists of a number of layers of direct (immediate) causes. Each direct cause is associated with an underlying (root or basic) cause and a preventive or recovery mechanism which failed. Thus an incident can be classified as having a direct cause, a root cause and a possible preventive or recovery mechanism failure eg corrosion due to a design error not recovered by routine inspection. This is referred to as a 3-Dimensional classification.

The scheme allows contribution counts to be made in a number of different ways. Thus Fig 5 shows the direct causes of 230 vessel failures (12, 13). Similar data are available for failures of pipework (7-19).

When all the direct causes are taken together it is possible to consider the underlying structure of root causes and preventive mechanism failures. This is illustrated in Fig 6 for vessel failures. This shows, for example, that 29% of the vessel failures had their origins in design faults which were not recovered by an appropriate hazard study.

We have argued before (8) that the values of generic failure rates, such as those used in RISKAT, reflect the direct causes of the failures. For example, Fig 5 shows that 45% of vessel failures are due to overpressure. However, when considering the influence of a safety management system on failures it is the underlying causes and failures of preventive and recovery mechanisms which need to be considered. Thus we propose to use the percentage contribution of underlying causes/preventive mechanism failures to weight the different areas of the plant audit. Fig 3 shows how one part of the area of human factors of normal operations would be considered. The whole area would be assigned a weight of 24% (Fig 6) in calculating how management performance in this area would contribute to the failure frequencies of vessels. The results for the training assessment would contribute to the overall scoring in this area.

4.2 Isolation and Ignition of Releases and Escape and Evacuation Considerations

The above analysis of pipework and vessel failures has been recently extended to include the issues of isolation of releases, the ignition of flammable releases and escape and evacuation considerations. The 3-Dimensional classification scheme has been applied to the pipework and vessel releases previously assessed.

This approach was adopted as a means of identifying the human and managerial influences on these factors [17].

Isolation of Releases

The results of the analysis of isolation failures show that the vast majority of releases cannot reasonably be expected to be isolated using standard hardware. In particular, it is considered unlikely that the release of material from vessels after a catastrophic rupture or major leak from a vessel seam or vent could reasonably be expected to be isolated prior to the release of the tank's contents or its depressurisation.

The data available on pipework releases provides a limited basis for developing a means of modifying isolation failure rates in accordance with the quality of safety management at a plant. Thirty-four per cent of pipework releases involve short duration releases (squirts/splashes) which cease before demanding isolation and a further 16% fail for unknown reasons.

Of the failures with known causes, 45% are considered recoverable. Of these, half are recoverable by better design in the form of reducing the length of non-isolatable sections of line. This mode of isolation failure is often already incorporated into the procedures of classical QRA.

It is possible to identify a proportion of 23% of all isolation failures with known causes which could be theoretically recovered by improving the isolation facilities available in a way which is not currently considered in QRA. These recoverable isolation failures are mainly manual isolation failures. Therefore, it is suggested that the one possible candidate for modification by a management audit, in the context of isolation, is the probability of manual isolation. The data indicates that the success of manual isolation is dependent on the detection and isolation equipment available which will in turn be determined by the attention given to the human factors aspects of emergency response capability. In particular, the facilities for remote manual isolation, detection of releases and emergency equipment such as breathing apparatus should be optimised.

Ignition of Releases

The ignition of the majority of pipework flammable releases and vessel flammable releases are theoretically preventable. The maximum proportion of preventable ignitions, which defines the limit of risk reduction, is 82% and 70% for pipework and vessels respectively. A significant proportion of these preventable ignitions relate to human and managerial factors not modelled in classical QRA.

Two areas of management influence the cause of ignition which are not explicitly modelled in classical QRA have been identified. These are:

i 35% of pipework and 31% of vessel ignitions relate to the planning and conduct of construction, maintenance, operations and emergency responses.

ii A 2% and 15% contribution of component design failures for pipework and vessel respectively.

Therefore, at least 37% of pipework and 46% of vessel ignitions were found to be influenced by human and managerial factors which are not explicitly modelled in classical QRA procedures.

Of the remaining instances of preventable ignitions, 45% of pipework and 22% of vessel ignitions related to Plant Design. These are taken here to constitute that proportion of ignitions currently modelled in QRA by the mapping of ignition sources in an area. The remainder are non-recoverable causes of ignition, such as auto-ignition.

The most effective strategy to prevent the ignition of released material would involve a combination of plant design and management actions. Plant design actions should include locating 'fixed' ignitions sources such as flare stacks, boilers and electrical equipment out of the range of flammable releases and/or flameproofing such equipment. Managerial actions could include the following:

- Reviewing the chances of igniting a release through portable equipment and placing appropriate controls on its use.
- Developing safe maintenance procedures by reviewing the chances of a gas leak/release during maintenance, and prescribing appropriate precautions such as water curtains, gas checks, shut-down of equipment etc.
- Ensuring that personnel have and use standard procedures for operating and maintaining equipment.
- Ensuring that Permits-to-Work are used in maintenance and that safety checks are carried out before cutting into pipes etc.

Escape and Evacuation

The historical incident data available on the offsite escape and evacuation behaviour of persons in the event of flammable releases indicates the following:

- A significant number of successful evacuations of people around flammable gas sites have been completed in the event of vessel rupture due to flame impingement.
- The data available on flash fires and vapour cloud explosions does <u>not</u> provide a basis for suggesting that offsite persons may evacuate an area prior to ignition of a vapour cloud, or for escape actions to succeed.

It is suggested that the cases of successful evacuations prior to vessel BLEVE arise from the clear warning of an impending threat given by initial fires/explosions, the decision to evacuate immediately by competent persons and the availability of between about 10 and 120 minutes in which to complete an evacuation, In contrast, vapour clouds are likely to ignite prior to any offsite evacuation attempt, typically within a few seconds or minutes.

It is further concluded that the probability of successful evacuation prior to BLEVE could be modelled using a combination of historical data and site specific assessments [16]. It is not suggested that a consideration of escape/evacuation be incorporated into QRA for any flammable releases other than BLEVE's.

The data that is available on escape from toxic releases indicates that persons in high concentration areas of clouds will be incapacitated. In contrast, persons in lower concentration areas have a high chance of escaping indoors or out of the affected area. The latter probability is in the order of 80%.

This is consistent with the assumptions used in Toxic RISKAT [3].

5 SUMMARY OF APPLICATION TO MAJOR HAZARD ONSHORE PLANT

Fig 1 illustrates the current state of the research work which has been carried out. The key points are:

- A comprehensive question set has been produced which covers the main underlying causes of failure and failures of management control systems.
- A statistical analysis of the contribution of these underlying causes (Fig 6) to failure rates enables weights to be applied to the different areas of the audit question set.
- An accident causation model (Fig 2) emphasises the need to ensure that management control systems are complete and that feedback takes place to allow for constant monitoring and control improvements.
- An audit method (Fig 3) will concentrate on completeness of these systems.
- The audit method allows different questions to be asked in specific areas without changing the weights attached to that area.
- The audit method does not involve checklist completion but structures the application of professional expertise by providing suitable guidance.
- Future work in the UK (and Europe) will pursue adequate validation of the system against lost time injury, failure data and other performance indicators.

- Outputs from the audit may provide an input into risk assessment for land-use planning, prioritised areas for risk reduction and may be relevant to other applications including inspection of major hazard plant and assessment of CIMAH safety reports.

The remainder of this paper will consider potential application of this work to the offshore industry.

6. APPLICATION TO THE OFFSHORE INDUSTRY

6.1 General Quantification Issues

The link between safety management and the control of accidents and their prevention was given increased emphasis to all offshore operators in the North Sea when 167 men died in the Piper Alpha disaster. Lord Cullen's penetrating inquiry into the accident [18] has resulted in dramatic changes in the way that the offshore industry must approach safety. Primary recommendations require operators to prepare safety cases demonstrating that their safety management systems adequately control the design and operation of their installations, that the potential major hazards have been identified and controlled, and that adequate provisions have been made for refuge and escape should a major accident occur.

In considering possible applications offshore the starting point of this paper is proposals published by the Health and Safety Commission [19] for consultation, in February 1992. These may be modified as a result of consultation. This could affect the validity of the analysis that follows.

The risk criterion proposed for consultation by the Health and Safety Executive [19] has focussed attention on the Temporary Safe Refuge (TSR). This is a place of protection for personnel from the consequences of accidental events, particularly fire, heat and smoke. The concept of the TSR extends to access and evacuation routes. The TSR must not only provide protection and tolerable conditions for personnel, but also enable command and control activities to be carried out. Either the TSR must maintain its functional integrity for the duration of an incident, or, if this is not possible, provide sufficient time to enable all personnel to safely evacuate the installation and eventually reach a place of permanent safety. The proposal of the consultative document suggests that the frequency of loss of integrity of the TSR, in less than the required endurance time, should be as low as is reasonably practicable and in any event, no greater than 1 in 1000 per year.

The nature of the design of offshore installations, particularly large fixed production platforms with 100-200 or more personnel on board, means that the personnel living quarters/TSR maybe very close to hazardous areas. In any case, the TSR must be easily accessible from these areas. The TSR, as currently designed, is potentially vulnerable to escalating events which could lead to intolerable conditions such as smoke or intense heat, or to structural failure, where such events could lead to injury or loss of life.

Although escalation can be minimised by appropriate design solutions, the ideal means of control would be to prevent loss of containment accidents in the first place. Cullen emphasised this priority. Should such an accident occur, however, minimising the size of the inventory involved and preventing ignition are obvious candidates for control. Again, should these controls fail, there must be protective barriers to prevent impact on personnel.

The historical failure frequency data being used in offshore risk assessment cannot reflect the improvements that operators are making to their Safety Managements Systems. The risk assessment approach is only sensitive to hardware design modifications or to operational upgrades which have an effect on the direct human causes of mitigation failure (eg for manual blowdown operations) or on the ability of personnel to access a safe refuge, or to evacuate by helicopter or lifeboat. The risk assessment methodology does not address the SMS influences on failure.

This is very restrictive in terms of focussing attention on improvements in the management of construction, operations and maintenance and providing appropriate design and procedural support for these activities.

6.2 Linking the Risk Assessment for The Temporary Safe Refuge (TSR) to the Safety Management System (SMS)

It will be some time before improvements in Safety Management Systems in the offshore industry become evident in the incident data that are used in risk assessment. Achieving sufficient reduction in risk to be well within the proposed acceptance criteria for loss of TSR integrity may prove difficult with hardware solutions alone.

It is always important to consider also the human element in the safety equation, and there is no reason why it should not be subjected to an analysis as rigorous as that achieved using risk analysis methods.

Human reliability assessment is one way of incorporating the human factor into risk assessment [20], Kirwan and Cox. However, its uses are limited to analysing specific tasks [21] and would require incorporation into QRA primarily by using fault tree modelling to integrate the human and hardware aspects. Not only would this be extremely resource intensive, it would not fully address the SMS in terms of its influence on failure, escalation, and impact on people. It has been pointed out [22] that fault tree analysis (FTA) will not review the whole process but only one undesired event at a time, and that it is not very useful for analysing simple systems with few initiating events of concern, but many possible outcomes. A number of other problems are discussed in their paper, such as the difficulty of accounting for unavailability of a component due to maintenance, the probability of failure of restoring a component correctly after

testing, failure of maintenance to correct identified problems, or maintenance causing new problems. FTA involving human error may be best applied in the offshore context in a limited way as a qualitative analysis tool to identify the relationships between human and hardware components such that the tasks for which an application of human reliability assessment is appropriate is more readily identifiable.

We have already demonstrated the important link between the Safety Management System and accident prevention and control in the onshore chemical industry. We do not see how the 'bottom up' approach of breaking down the initiating events into their components would provide any additional insight into the failure causes for the purposes of quantification of the SMS influences upon them. Conversely, the 'top down' approach described in this paper for onshore applications would not only be 'global' in its coverage and provide a quantitative link between the SMS and risk assessment but also focus attention on the influences which the SMS could have on a particular activity such as a major maintenance task. The remainder of this paper will develop this theme.

6.3 Development of a Modification of Risk Methodology for the Offshore Context

The offshore adaptation of the methodology is shown in figure 7. The aim would be, primarily, to quantitatively assess the influence of the SMS on the risk to the TSR.

The first important step would be to analyse offshore industry incident data to determine direct and underlying causes of failure so as to provide the empirical model from which a weighting of influences can be derived. Each incident does not necessarily need to have been captured in a detailed description [7], although this helps in the analysis. Therefore, any weaknesses in an incident data collection scheme need not be a stumbling block.

There are, however, differences between the onshore and offshore contexts which must be accounted for in the analysis:

1. Land planning applications of QRA do not consider the risk to the workforce as the primary interest relates to people outside the site boundary. Impact of an accident on personnel on an offshore installation is, conversely, of central importance

2. Onshore QRA does not explicitly address escalation of events, whereas this is a dominant theme in offshore risk assessment since the Piper Alpha disaster.

3. Mitigation measures used offshore are developed specifically for that context and also have special hardware problems such as in the reliability of deluge systems, or human-hardware ones as in detection of a gas release.

The second step is to generate audit questions. The onshore database requires extension to cover those areas of special interest in the offshore context. This has to be supported by both the 3-D analysis and the theoretical pyramid model (Fig 2). With regard to the latter, its relevance to the offshore context could be demonstrated by application to major offshore accidents such as Piper Alpha or Alexander Kielland, for example. A systems failure review of the latter accident can be found in [23].

Having established the methodology, the application follows that principally outlined for the onshore industry. The important difference is in defining the modification of risk multiplying factors which are to be applied to the generic data. Some guidance can be obtained by considering the possible range of failure frequencies for offshore system components. The HSE's consultative document also gives some indications relating to expectations of SMS influences on accident frequencies [ref. 18 Section on cost/benefits.]

In our opinion the benefits to the offshore industry in reviewing their SMSs in this way would be not only to assist in accounting for SMS improvements in quantitative risk assessment, but more importantly to provide a global and systematic approach to SMS evaluation which could be used to identify and prioritise "human" risk reduction measures. Hopefully, this paper has provided enough background to arouse the interest of operators in this respect. In the meantime, we might expect that QRA done offshore using generic failure-rate data would produce somewhat conservative results, given the time-lag in effect of improved SMS on such data. While any claims for the extent of such conservatism would require supporting evidence (eg changes in SMS, or trends in failure and incident rates), we would expect operators and HSE to make due allowance in considering the results of QRA.

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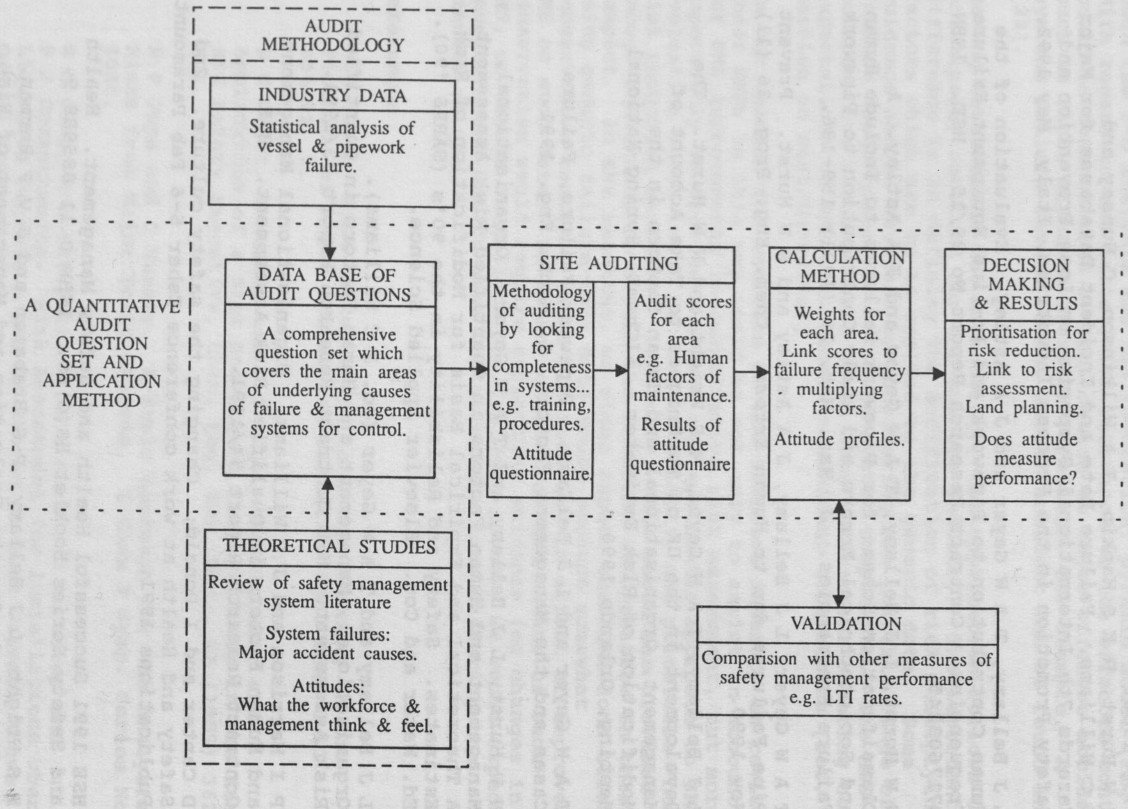

Fig.1 - Summary of Research Results to produce an Audit question-set, application method and use of results.

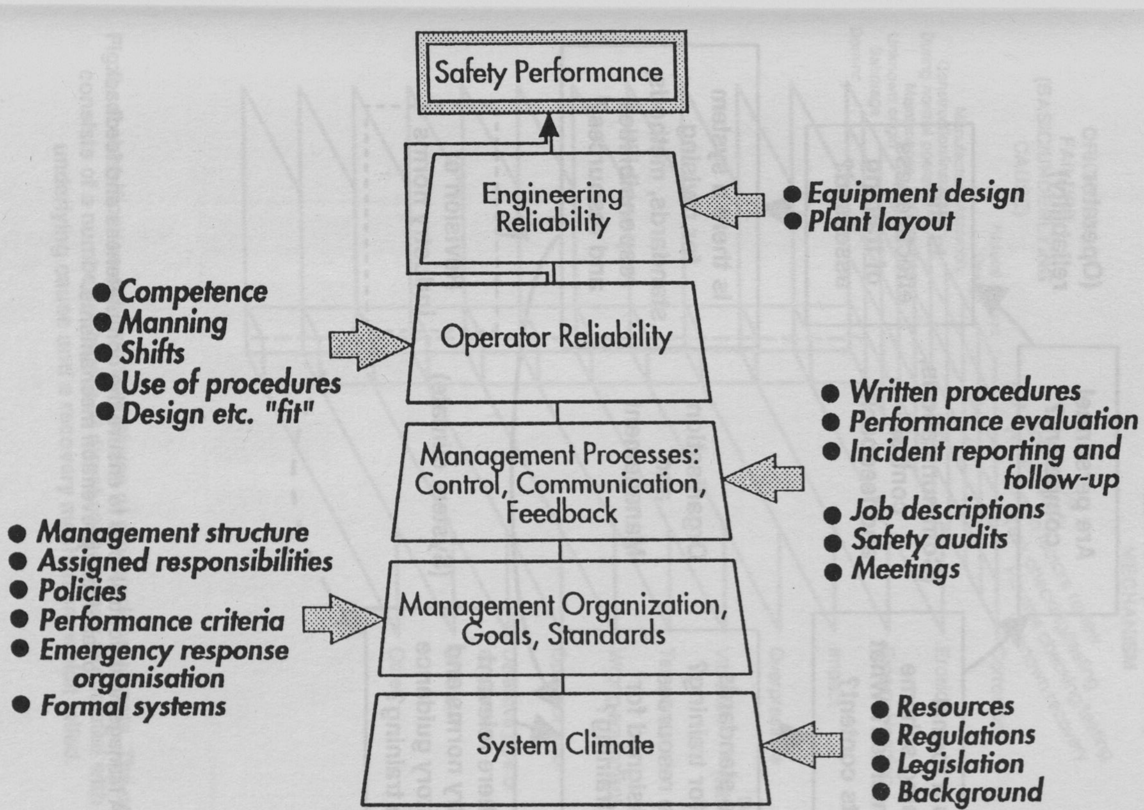

Fig.2 - A hierarchical scheme of accident causation. The Figure is used to illustrate the potential effects of actions or inactions at different levels within a system on the safety at a plant.

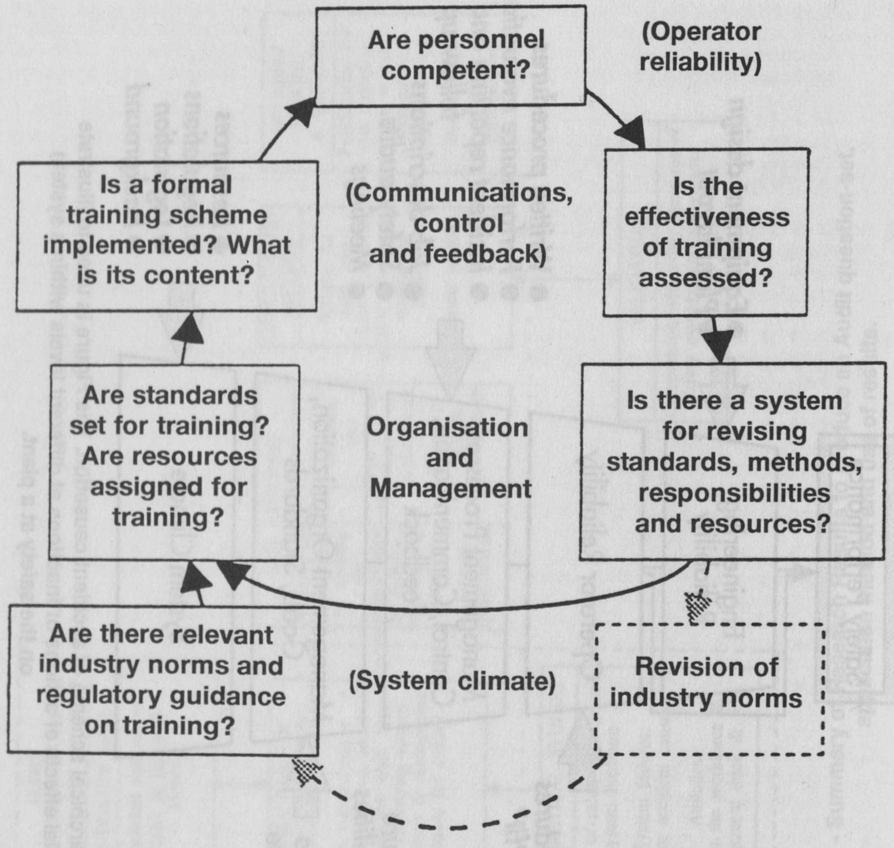

Fig.3 - A Management control loop to ensure the completeness and feedback of accident prevention mechanisms.

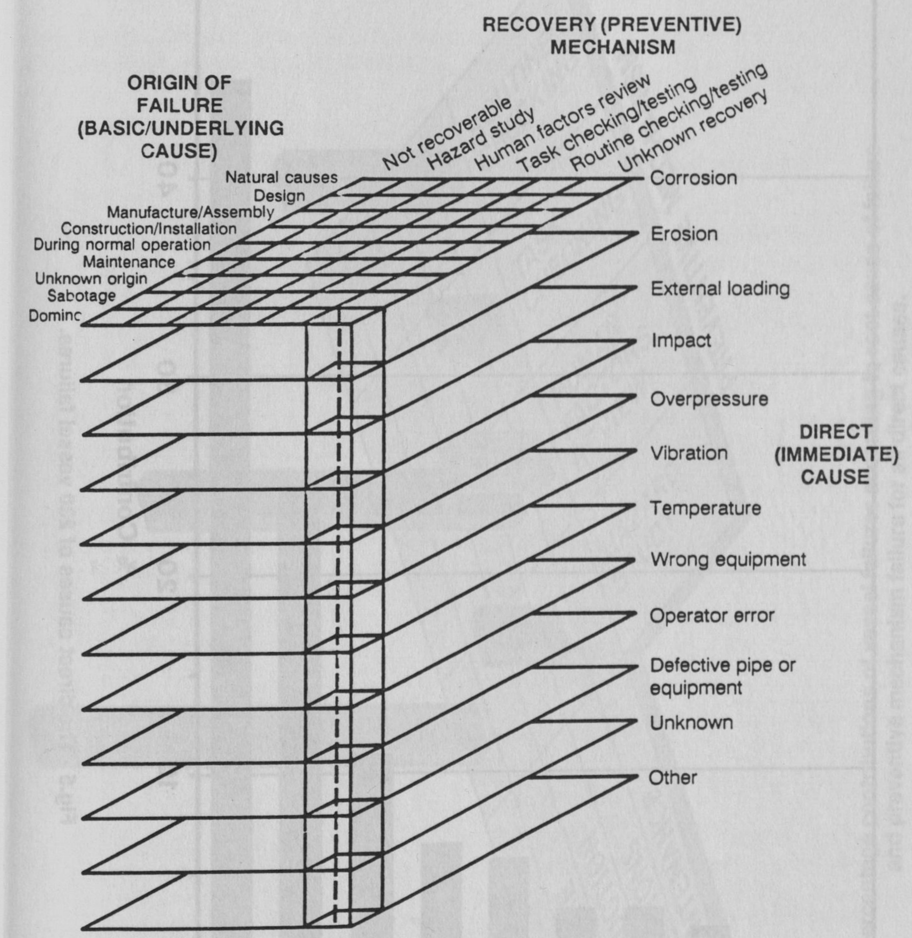

Fig.4 - A classification scheme for failures of pipework or vessels. The scheme consists of a number of layers of direct causes each associated with an underlying cause and a recovery mechanism which failed.

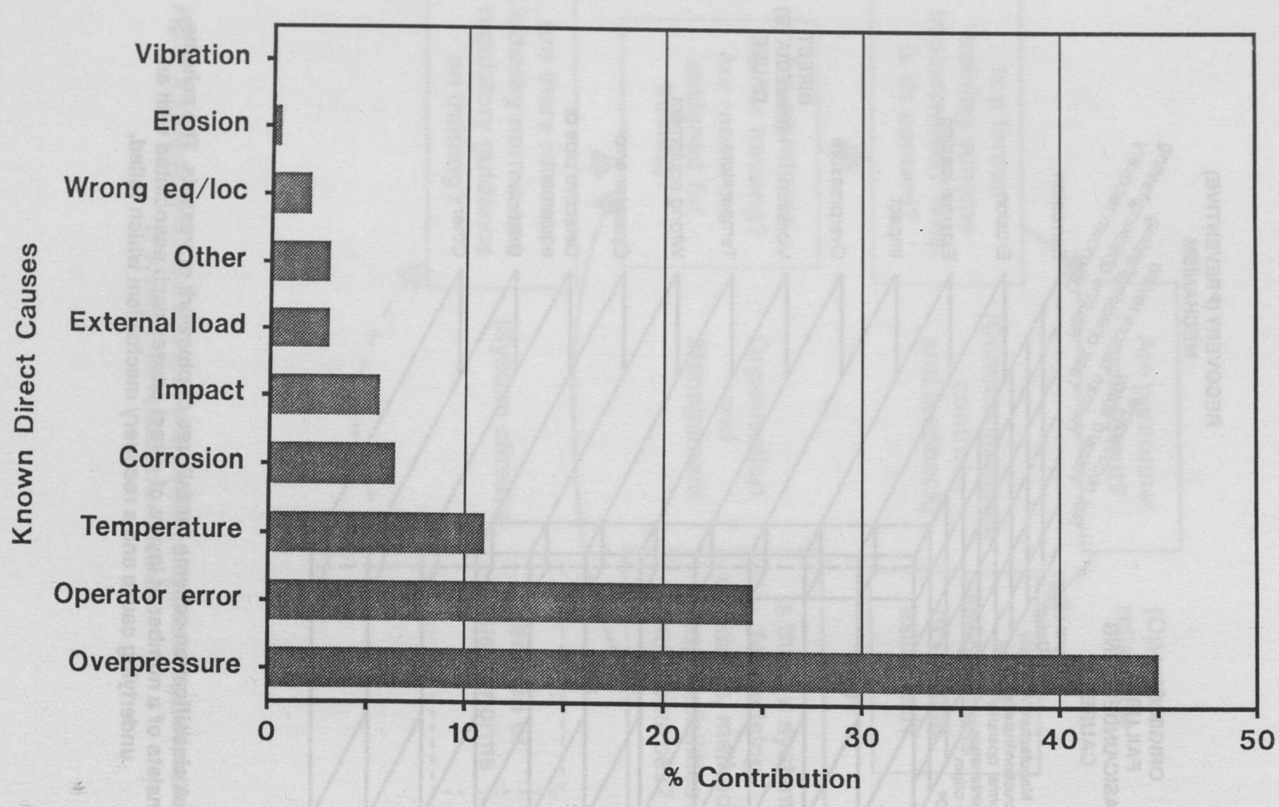

Fig.5 - The direct causes of 230 vessel failures.

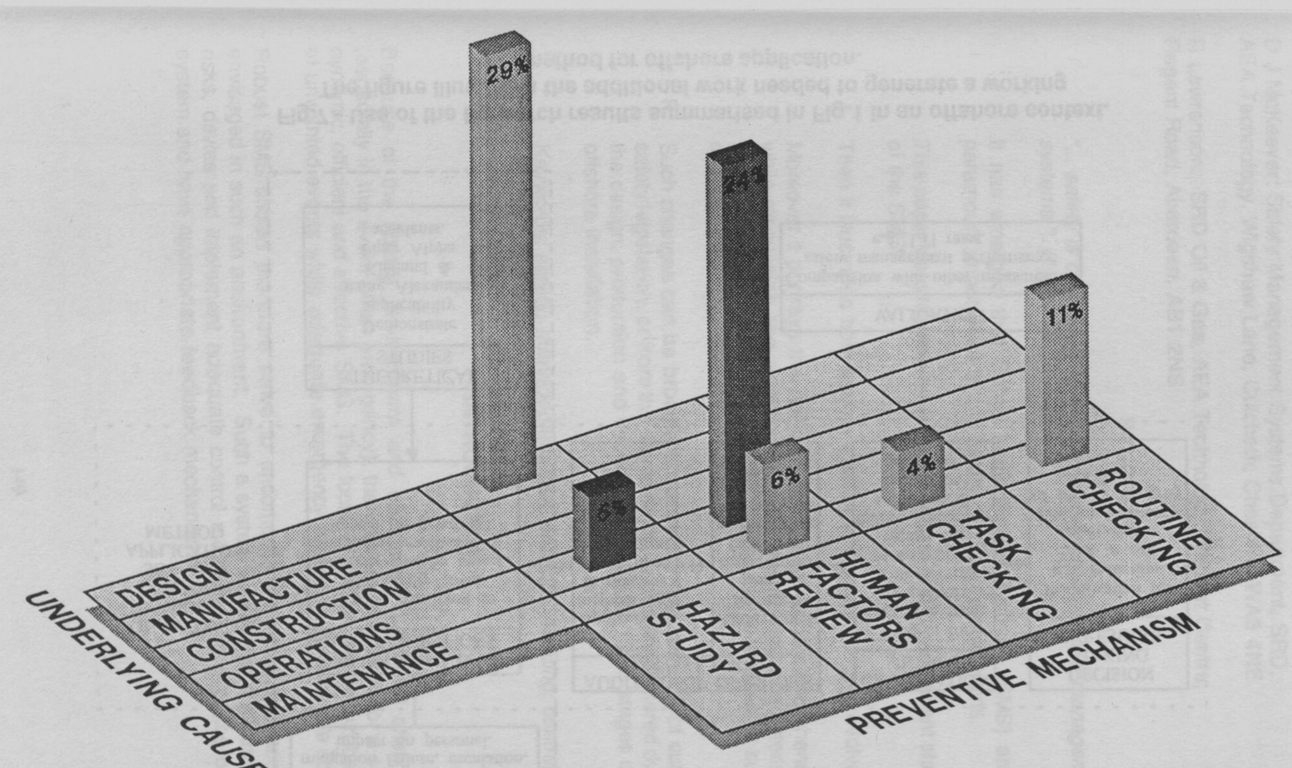

Fig.6 - Percentage contributions of vessel failures according to root cause of failure and preventive mechanism failure for all direct causes.

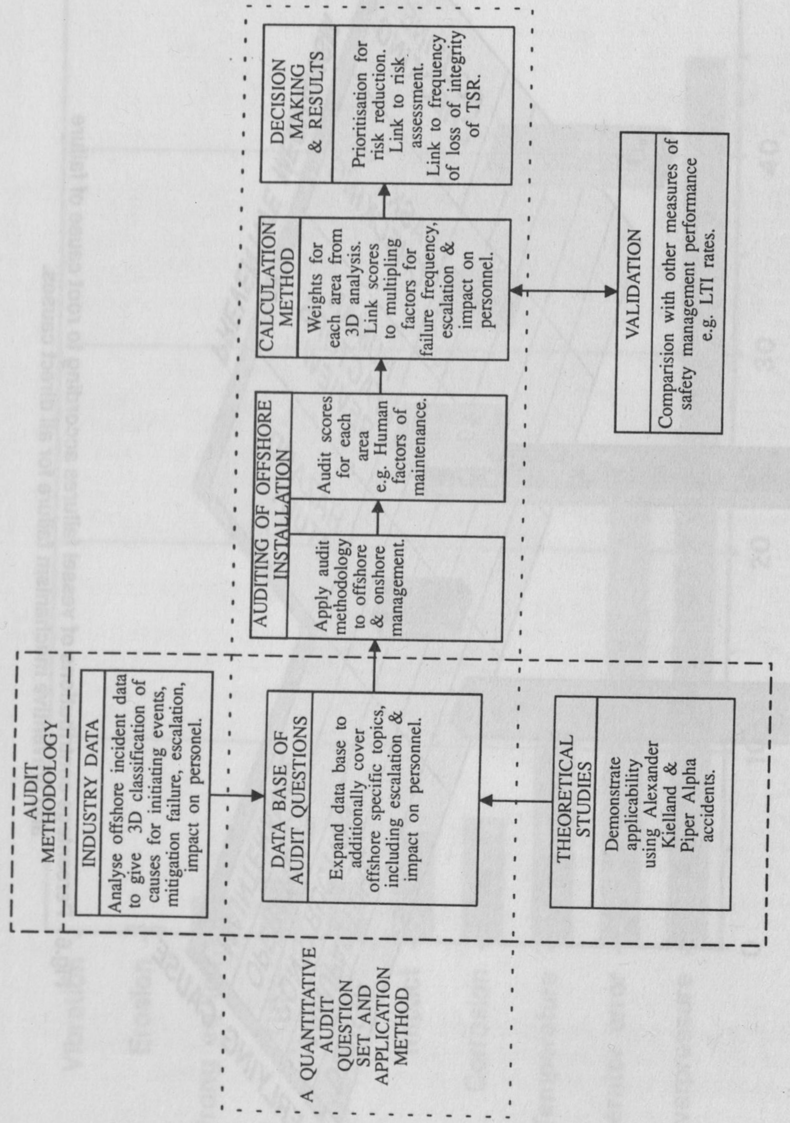

Fig.7 - Use of the Research results summarised in Fig.1 in an offshore context. The figure illustrates the additional work needed to generate a working method for offshore application.

SAFETY MANAGEMENT OFFSHORE - SYSTEM REQUIREMENTS

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SYNOPSIS

"... safety is crucially dependent on management and management systems." (1)

It has emerged that Safety Management Systems (SMS) are of paramount importance to the safety of offshore operations.

This paper details, step by step, the design and development stages of the SMS.

Then it illustrates how such a system would function and evolve.

Moreover it portrays the need for the system to be comprehensive, while discussing the appropriate mechanisms and characteristics which afford the system the ability to respond to sudden or subtle change.

Such changes can be brought about by the requirements of current safety legislation, or from the day to day changes encountered during the design, production and decommissioning life cycle stages of an offshore installation.

Keywords: *safety, management, risk, offshore, auditing, control.*

INTRODUCTION

Because of the hostile environment and hazardous nature of offshore operations (especially in the event of an emergency), there is pressing need for a comprehensive, dynamic, efficient and effective SMS. The focus of the system should be on prevention of unwanted events while adequate emergency response systems are still important.

Robust SMS should therefore strive to encompass the many scenarios that can be envisaged in such an environment. Such a system should (as a minimum) assess the risks, devise and implement adequate control measures, monitor the condition of the system and have appropriate feedback mechanisms.