A METHODOLOGICAL APPROACH TO THE DEVELOPMENT OF AN INDUSTRIAL EMERGENCY RESPONSE SYSTEM

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The need to make provisions for the occurrence of an industrial emergency is a statutory requirement placed on all operators of potentially hazardous installations. The purpose of this paper is to consider the issue of emergency planning from the perspective of human factors. A development process is outlined aimed at ensuring that emergency plans are compatible with the performance capabilities of the human operator. The method involves three strands of activity in which an infrastructure to support the emergency response system is first put in place. The response system itself is then developed using the tools and techniques of human factors engineering. Finally, the system is implemented along with supporting sub-systems designed to ensure that the response system remains sensitive to the changing needs and demands of the organisation.

Keywords: Emergency planning, human factors engineering, human error reduction.

1. Introduction

The purpose of this paper is to consider the issue of emergency planning from the perspective of human factors and to outline a preliminary methodology aimed at ensuring that provisions for the occurrence of a major industrial emergency are compatible with human performance capabilities. The motivation for the work comes from the experience of evaluating the adequacy of emergency preparedness in a number of high-risk process industries where shortcomings in the effectiveness of an emergency response were attributed to the occurrence of human failures of various types.

In this particular paper we focus primarily on the problem of planning a "human-centred" emergency response for land-based petrochemical facilities. Thus many of the special considerations which might apply to an off-shore installation have not been directly considered. The major theme of this paper is that greater attention must be paid in the planning process to the human factor. This applies with equal force to all large-scale industrial activities irrespective of the nature of hazard involved or the geographical location of the operation. Our concern is with the generic issue of optimising human performance in situations characterised by complexity, uncertainty and high psychological stress, and not with the specific technical aspects of incidents which vary from domain to domain.

2 Statutory Requirements

The need to make adequate provisions for the occurrence of a major industrial emergency is a statutory requirement placed on all operators of potentially hazardous installations. Most of the regulations relating to emergency planning in the petrochemical industry derive from the

Control of Industrial Major Accident Hazard 1984 Regulations (e.g. CIMAH) and associated legislation (Jones, 1987 (1); Davies, 1989 (2)). These statutes charge the operator with responsibilities in four main areas. Specifically, the operator must:

- Assume responsibility for the preparation of an on-site emergency plan.
- Cooperate in the preparation of off-site emergency plans with the relevant local authority/emergency services which have responsibility for civil emergency plans.
- Inform members of the public who may be affected by the operational activities about the nature of the risk they face and how they might minimise that risk in the event of an accident.
- Prepare a safety case for the installation which demonstrates that the potential for major accidents has been identified and that the necessary degree of protection and control is being exercised.

In addition, the regulations also specify that the Health and Safety Executive must be informed about the occurrence of any significant incident involving hazardous materials. One purpose of the notification requirement is to permit the collection and collation of an international database of accident information which can be used to identify potential sources of risk. The Major Hazard Incident Data Service (MHIDAS) operated by the United Kingdom Atomic Energy Authority (UKAEA) is one example of such a database.

Perhaps the best summary of the practical implications of the emergency planning legislation for the petrochemical industry has been that provided within the Chemical Industries Association booklet on "Recommended Procedures for Handling Major Emergencies". This document states that:

> ***"Health and Safety Inspectors will wish to be satisfied that employers have made adequate arrangements for handling emergencies of all types, including major emergencies. They will require to see well documented procedures and may seek evidence of the practical exercise of them. In particular, they will be concerned to see that employees understand those parts of the procedures which relate to them. Inadequate procedures or a failure to make such an arrangement may be the subject of an improvement notice"***
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> *(Chemical Industries Association, 2nd Edition, 1987: pp. 13-14: (3))*

3 Emergency Planning Guidance for Petrochemical Installations

To assist in the process of ensuring that emergency plans are both effective and conform to legal requirements, several guidance documents have been produced by organisations with special interest in petrochemical operations. The most commonly cited publications in this regard are listed for purposes of reference in Table 1. In addition, a number of alternative guideline documents have been prepared which consider the topic from a variety of different perspectives (e.g., Banarjee 1991 (4); Cooney, 1989 (5); Ranby & Hewitt, 1982 (6); Willcock, 1989 (7)). Together these publications constitute a useful source of information for ensuring

that emergency plans are fully integrated and combined in such a way as to form a "corporate response" to any emergency situation.

Table 1: Design Guidance for Emergency Planning in the Chemical Industry

Sourc	Title	General Topic
HSE	Further Guidance to Emergency Planning (8)	CIMAH
CIA	Recommended Procedures for Handling Major Emergenci (3)	Petrochemicals
CIA	Guidelines for Chemical Sites on Off-site Aspects of Emergency Planning (9)	Petrochemicals
IChemE	Handling Emergencies (10)	Petrochemicals
SIESO	Guide to Emergency Planning (11)	General Industrial Emergencies
EFCE	The Development of Effective Emergency Procedure for a Toxic Hazard Site	EC/SEVESO Directive
HMHO	Emergency Planning Guidelines for Local Authorities (12)	Local Authority Emergency Plans

While the general standard of information provided in these publications is high, it needs to be made clear that they are not intended to provide a complete solution to the problem of emergency planning. Consequently, there are many aspects of the planning process which are left to the discretion of the individual(s) allocated the task of developing emergency plans for particular locations. In the past this has meant that the quality of emergency preparedness can vary widely from facility to facility and this finding holds irrespective of whether the sites in question are operated by different companies or are elements of the same parent organisation. Fortunately, this situation is now changing and several manufacturers are making moves towards the development of a corporate strategy in this area although there is still some way to go before this aim will be realised.

4 Current Shortcomings in the Guidance Literature

An informal review of the emergency planning literature was made and two areas of weakness were identified. Firstly it was noted that there was little attention given in the literature to the specification of a methodology by which emergency planning concepts (e.g., hazard control) could be implemented in the form of a planned operational response. Secondly, no principles were identified which could be used to ensure that response goals were matched to human performance criteria. In both these respects the performance of the chemical industry falls some way behind corresponding work in the nuclear domain where several attempts have been made to develop industry-wide emergency planning methods which are sensitive to the needs of the user (Hanson et al, 1990 (13; Hanson et al 1991 (14).

In the following sections a preliminary methodology is described which will improve the overall efficiency of any given emergency response by reducing human error. The strategy involves three strands of activity. Firstly, an infrastructure to support an emergency response system (ERS) is put in place. Secondly, the response system itself is developed using the tools and techniques of human factors engineering. Finally, the response system is implemented along with the supporting sub-systems designed to ensure that the ERS remains sensitive to the changing needs and demands of the organisation and major user groups.

5 Methodology for the Development of an Emergency Response System

The development process proposed is shown in overview in Figure 1. This figure describes the 6 stages of development which are assumed to be a necessary part of preparing a petrochemical facility for the occurrence of emergencies of all types. Each stage has a clearly identifiable objective and a range of tools and techniques to assist in the attainment of those objectives. Special attention is given at each stage of development to the needs of individual response team members and emphasis is placed on protecting the integrity of the response at all times.

5.1 Preliminary Assessment

Overview

The first phase of activity involves a preliminary assessment of the ERS infrastructure to determine the quality of the overall organisation of the emergency response. The elements of the infrastructure assessed during this stage can be categorised according to those aspects of the system which form an integral part of an actual emergency response. These would include procedures, robustness to failure, communication and co-ordination, and those parts of the system which "service" the ERS. These latter aspects emphasise, training, personnel selection and incident investigation methods. Improvements in each of these areas should be made where deficiencies are found (see Figure 2).

Systems Perspective

The approach to assessing the organisation's capability to respond to an emergency situation is based upon a systems view of emergency response. In systems theory an early aim is to identify the basic elements which make up the system and to chart their interactions. The goal structure which defines the system would also be specified during the analysis to identify potential areas of conflict. A cost-benefit analysis should be performed to resolve all potential sources of conflict once identified.

While many elements will be specific to the facility in question there are a number which are generic and should be included in all preliminary assessments of the organisation's capability to mount an effective response. The framework outlined in Figure 2, or example, shows the essential elements of any emergency response system.

Figure 1: A Proposed ERS Development Process

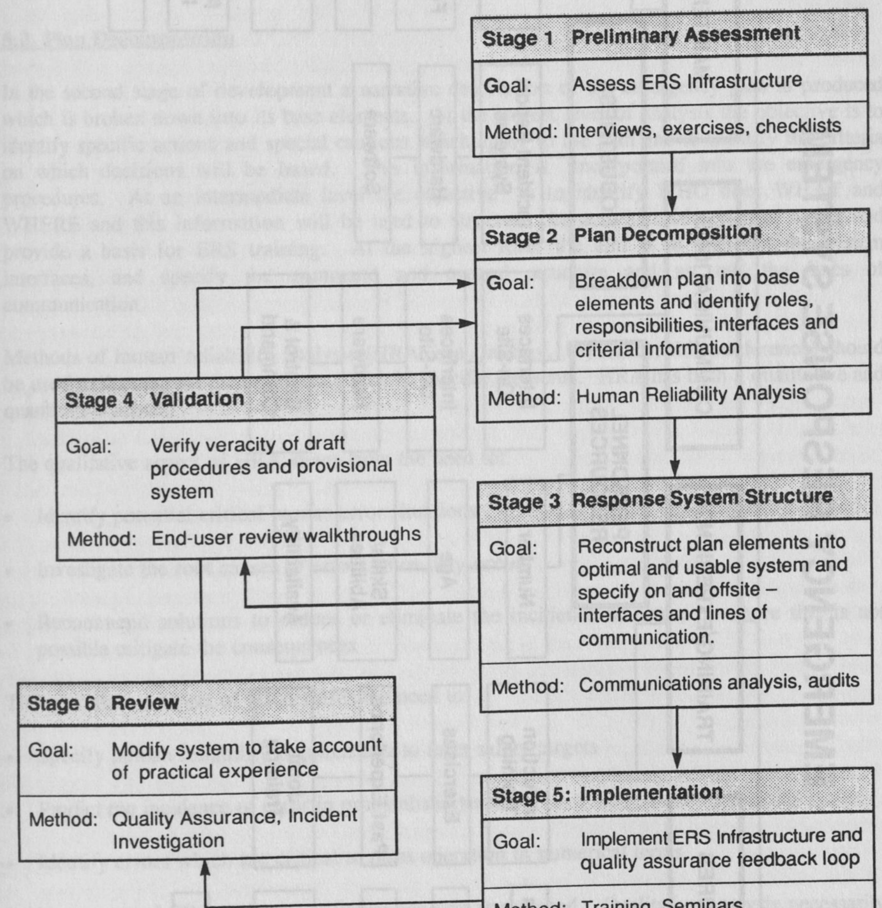
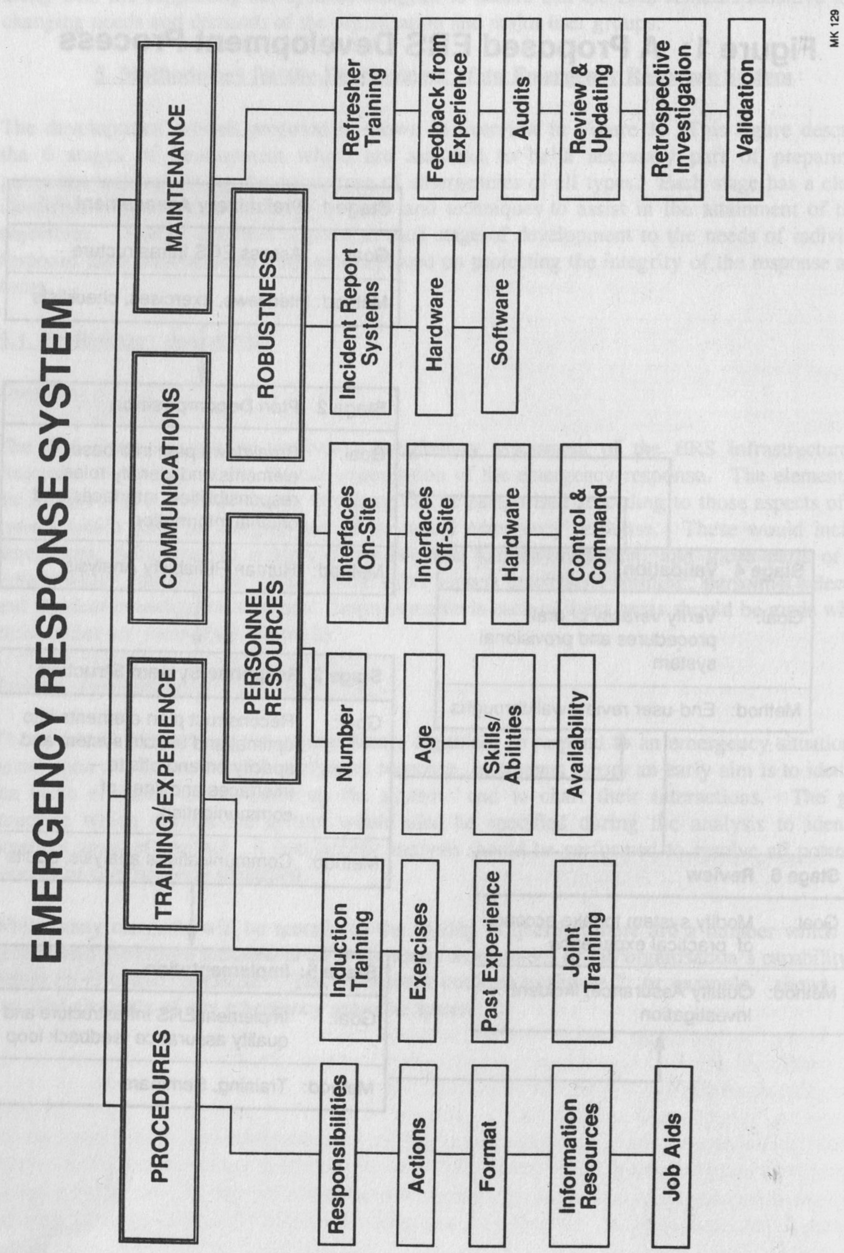


Figure 2: Elements of an Emergency Response System



Methods

There are four basic techniques available for determining the quality of infrastructure provisions: (a) interviews conducted with response team members and emergency planners; (b) observation of emergency response exercises; (c) case history studies of past emergency response failures; and, (d) checklists which have been developed as audit tools.

5.2 Plan Decomposition

In the second stage of development a narrative description of the emergency plan is produced which is broken down into its base elements. At the lowest level of analysis the objective is to identify specific actions and special cautions which apply to the plan and to identify the criteria on which decisions will be based. This information is incorporated into the emergency procedures. At an intermediate level the objective is to identify WHO does WHAT and WHERE and this information will be used to structure the activities of response teams and provide a basis for ERS training. At the highest level the aim is to map out the system interfaces, and specify the command and control structure and set out the lines of communication.

Methods of human reliability analysis (HRA: see Embrey, 1992 (15), this conference) should be used to decompose the emergency plan in specific elements. HRA has both a qualitative and quantitative aspect:

The qualitative aspect of HRA stems from the need to:

- Identify potential critical human error situations
- Investigate the root causes of errors when they occur
- Recommend solutions to reduce or eliminate the incidence of error, or where this is not possible mitigate the consequences

The quantitative aspect of HRA fulfils the need to:

- Specify human reliability requirements to meet safety targets
- Predict the incidence of error in probabilistic terms
- Identify errors which are critical to plant operation in numerical terms

In the context of ERS, only a qualitative analysis is required. Qualitative analysis necessarily draws on social scientific disciplines in order to define the underlying mechanisms which contribute to human error. HRA methods also form the basis for the design of emergency procedures discussed in the third stage of ERS development.

5.3 Response System Structuring

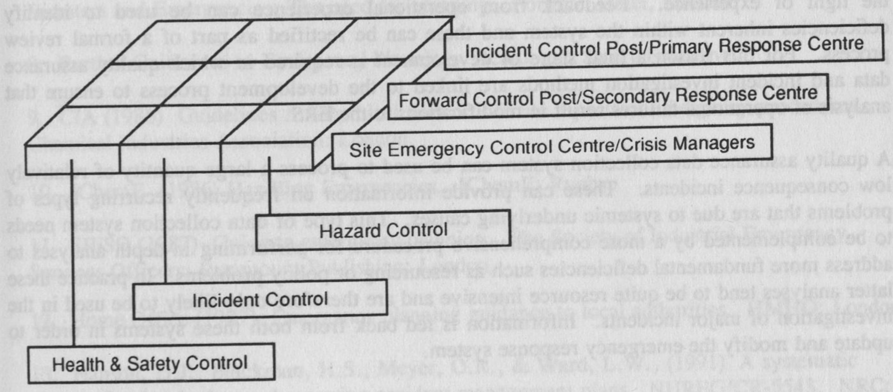
The objective in the third phase of development is to draft a preliminary structure for the emergency response. This structure should be reviewed using human factors guidelines to take account of what is known about the performance of the human in complex dynamic situations involving uncertainty. There are two major products of this phase in the development process: A set of emergency procedures which specify the roles and responsibilities of response team members; and a communications matrix which specifies the structure of communication and co-ordination. Emergency procedures may be presented in both textual and flow-diagrammatic form. The communication and co-ordination matrix relates incident severity with response capability.

Figure 3 provides a simplified example of a communication and co-ordination matrix for a facility with the capability to mount a planned response to an incident in three ways: (a) Hazard control (e.g., toxicity); (b) Incident control (e.g., fire/gas/security); and, (c) Health and Safety (e.g., medical). The focal point for primary response activity in each of these areas is the incident control post which is set up at the scene of the incident. As the severity of the incident escalates it is advisable that a secondary response is mounted to provide back-up facilities and these activities would be co-ordinated from a forward control point set up near to the incident scene. For all major emergencies a third tier "crisis management" response must be implemented and these activities would be centred around the site emergency control centre and, where appropriate, off-site district emergency control centres. Effective crisis management requires that information about an incident is passed rapidly to the appropriate incident commanders in order that decisions can be made, resources provided and communications co-ordinated.

The primary function of the incident control team is to deal with immediate consequences of the emergency (e.g., fire, explosion). The hazard assessment team provide intelligence relating to the control and assessment of the toxicity implications of the incident, while the health and safety response teams function to protect the well being of employees and members of the public in terms of medical requirements (e.g., first aid, decontamination, etc.). The matrix also specifies a command and control structure such that ultimate corporate responsibility for the control of the incident (from the point of view of the company) devolves to the senior managers of the incident control team.

Techniques for constructing an outline plan such as that shown in Figure 3 involve carrying out a communications analysis in which all the interfaces are specified between the various ERS teams. An audit of hardware resources which support the communication structure is also required during this stage of analysis. Once prepared, the matrix is used to identify the areas where emergency procedures need to be developed. For example, for the case shown in Figure 3 the minimum requirement is for 9 sets of emergency procedures one for each cell. In practice, however, it is usually the case that two sets of procedures are required per cell, one set for the commander and one for the team members under his or her control. The emergency procedures should be prepared using human factors design principles.

Figure 3: A Simplified ERS Communication and Co-ordination Matrix



It is important to perform a functional analysis of information needs during this stage of activity. Information processing is critical for the effective application of human and physical resources and information channels should facilitate the provision of critical data to support the human decision-making activities. An evaluation of information needs can also provide useful data regarding the organisation's capability to respond to an emergency situation and highlight weaknesses inherent within the system.

5.4 Verification and Validation

The fourth stage in the development process involves an evaluation of the draft response system and the primary goal here is to ensure that the roles and responsibilities specified within ERS procedures can be performed as required. Several methods are available for the assessment of procedures. However, the most important of these involve the end user in the evaluation process. Thus, group discussions are of fundamental importance during this phase as are task walkthroughs and simulation of the prescribed activities. When problems with the procedures are identified these must be rectified by returning to stage 2 of the development process. Once fully verified the ERS can be implemented in stage 5.

5.5 Implementation

Implementation of the site emergency plan and ERS involves a significant training effort in which the aim is to ensure that individuals are fully conversant with their roles and responsibilities. They should also be familiar with the ERS infrastructure and understand how the system will work. ERS standards must be maintained in the same manner as other complex work activities and for this purpose the adoption of a quality assurance programme to monitor the effectiveness of the response system is necessary.

5.6 Review and Modification in the Light of Experience

The ERS is never complete but always exists in the state of a "latest revision" to be modified in the light of experience. Feedback from operational experience can be used to identify deficiencies inherent within the system and these can be rectified as part of a formal review process. For this reason a final stage of development is required in which quality assurance data and incident investigation methods are linked to the development process to ensure that analysis of operational failures result in modifications to the ERS.

A quality assurance data collection system can be used to process a large quantity of relatively low consequence incidents. These can provide information on frequently recurring types of problems that are due to systemic underlying causes. This type of data collection system needs to be complemented by a more comprehensive procedure for performing in-depth analyses to address more fundamental deficiencies such as resourcing or policy problems. In practice these latter analyses tend to be quite resource intensive and are therefore only likely to be used in the investigation of major incidents. Information is fed back from both these systems in order to update and modify the emergency response system.

6 Conclusions

A methodology has been outlined which enables the development, implementation and maintenance of an emergency response system appropriate for petrochemical installations. The principles and techniques discussed focus upon the requirements and capabilities of the human component within such a system. It is recommended that emergency provisions should be designed with the human operator in mind to minimise the likelihood of error in the emergency response situation.

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