A FEASIBILITY STUDY INTO THE USE OF EXPERT SYSTEMS FOR EXPLOSION RELIEF VENT DESIGN

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The feasibility study reviewed the methods available for sizing relief vents for dust, gas, and vapour explosions and for the protection of chemical reactors against runaway exothermic reactions. It concluded that expert systems could be constructed in each case with benefits to HSE and Industry. A shell based prototype system was successfully demonstrated for basic dust explosion vent design. Alternative methods of expert system construction were examined and the use of an AI language recommended for the application. Market research gave very favourable indications that such systems would be popular.
[KEYWORDS: Expert system; Explosion relief; Feasibility.]

INTRODUCTION

The 1988/89 Annual Report from the Health and Safety Commission made the following reference to areas of expanding research commitment:

> "Other areas of expanding research commitment include construction, microbiology and expert systems in which computers are used to encapsulate and apply the accumulated knowledge of experienced personnel to practical problems. These are being investigated as an aid to efficiency and to retain valuable in-house expertise otherwise lost by staff retirements. It is planned to develop some expert systems for use by industry itself and other outside bodies."

Expert systems have become increasingly widely understood, researched, developed and used in recent years. In 1987 within HSE the appreciation of their potential was still low and a number of feasibility studies were commissioned.

This paper describes the progress made by HSE in one such area. In 1987 a proposal was put forward to fund, as an extra mural research project, a feasibility study into the use of expert systems for explosion relief, and approval was given for the project to start in April 1989.

PROJECT OBJECTIVES

The provision of an area of weakness as a vent is a fundamental philosophy widely accepted to protect a wide range of types and sizes of structures and vessels against the hazard of an explosion within them. It is frequently recommended for equipment varying, for example, from gas fired plant, solvent evaporating ovens and equipment handling explosible dusts to chemical reactors and buildings used for gas cylinder storage and other processes. Over recent years the design of relief has progressed from the use of crude rules of thumb to the use of complex equations and nomographs. Variables such as the strength of the plant or vessel, the properties of the explosible materials, shape, weight and position of relief panel, length of duct, turbulence, and strength of source of ignition have all been investigated and increasingly taken into account. As the amount of technical data increases, its retrieval and use in a correct and relevant manner has become more difficult. Review papers and books have appeared but are not always known to or readily used by those requiring the relevant data.
An expert system should be able to assess the adequacy of existing venting provisions, and provide data for their improvement if necessary, as well as providing basic design data for new equipment. It is anticipated that the use of such systems would improve the consistency of advice given by HSE and and others, whilst not replacing professional judgement in difficult cases.

The project proposal identified three primary project objectives, namely:

1. To examine the feasibility of developing an expert system to assist designers, users and enforcement authorities in the design and assessment of explosion relief in the areas of Dust Explosions, Gas/Vapour Explosions, and Exothermic Runaway Reactions.

2. To examine the feasibility of collaborating in the development of any proposed system with other interested parties such as professional bodies or commercial organizations.

3. To examine the commercial viability of any systems proposed in terms of market size and product cost.

PROJECT ORGANIZATION

The project was put out to tender by invitation and awarded to Salford University Business Service Ltd (SUBSL). A team of specialists, from within and outside the University, was assembled and a plan of work agreed:-

(a) Survey extent of fields of application and use.

(b) Survey existing expert systems for suitability, availability and cost.

(c) Determine whether or not it would be necessary to develop a specific system or whether an existing system could be used.

(d) Estimate costs/benefits of development of a system.

TECHNICAL FEASIBILITY

It is outside the scope of this paper to reproduce the extensive surveys of the methodologies of explosion relief vent design carried out as part of this project. The detailed conclusions of each survey are summarized below.
At an early stage in the project it became apparent that possible expert systems should be divided into those with topics that are combustion based (dusts, and gases and vapours) and that which is non-combustion (exothermic runaway reactions). A compendium system was ruled out. Because of the relative amounts and quality of information available separate systems were envisaged for dusts, and for gases and vapours. The problem of hybrid systems, involving combined dust and gas hazards, could not be addressed with present knowledge.

1. Dust Explosions

a. Sufficient data is available for generalized design methods for Dust Explosion relief to be laid down.

b. Account could be taken of vent covers and vent ducting and their effect on vent area to maintain a given reduced explosion pressure.

c. An expert system is likely to be feasible since the relief venting of dust explosions is thoroughly covered in the literature.

d. The Fire Research Station (FRS) have a large amount of data on explosible dusts which, subject to agreement with the FRS and their Commercial clients, might be made available for the proposed system.
Other databases are also available, some in the public domain.

e. The work carried out by The Production Engineering Research Association (PERA) on weak structures offers a valuable means of estimating the strength of structures subject to dust explosion hazards. The work could easily be incorporated into an expert system, but it should be validated prior to inclusion in any proposed system.

[The work by PERA is the subject of a current research project sponsored by the British Materials Handling Board and supported by HSE and industial contributors. It will, when completed, provide a method of assessing the strength of equipment such as filters, cyclones, hoppers, ovens, etc which will enable the sizing of explosion relief vents to be made with greater accuracy].

2. Gas/Solvent Vapour Explosions

a. Sufficient information is available for the more common geometries of industrial plant handling flammable gases and vapours to enable generalized design methods for explosion relief to be laid down.

b. Compact enclosures such as ovens and driers may be divided according to their mechanical strength; low strength enclosures are well-documented although the data for vent design may not be wholly consistent. A good deal of it consists of experimental findings with limitations on size of enclosure investigated and general applicability of results. The PERA work, noted above, is equally applicable to gas and solvent vapour explosions. High strength enclosures are less well documented, but the data is consistent.

c. Data on the venting of ducting and pipelines is mainly concerned with plant of relatively high strength, which is straightforward to obtain in practice but which is often not done. When designing relief vents particular attention needs to be given to the velocity of flow of the gas mixture at the time of ignition, since this velocity affects the explosion pressure *strongly*.

d. The relief of explosion pressures in buildings is covered in the literature, including the explosion of flammable layers, and could be incorporated in an expert system, but practical application of available methods is limited.

e. An expert system covering the relief venting of gas and vapour hazards is likely to be feasible, since there is a considerable amount of data available in the literature. This data covers the principal types of industrial plant units and components. It is however not in generalized form and needs to be brought together so that its applicability can be maximized. One consequence of using an expert system would be that, for a particular problem, the relevant data available on venting design would automatically be considered. The current methodology is more subjective and may not employ the available data to best advantage.

3. Exothermic Chemical Reactions

It seems fairly clear that the fundamental understanding and methodology of designing explosion relief system for runaway reactions has taken a giant step forward with the completion of the Design Institute for Emergency Relief Systems (DIERS) research programme and the publications of the results. On the other hand, the calculations required to size vents are not trivial, and the complications of the various types of chemical reactant systems, the need for check calculations, the need for correction factors and so-called "safety factor" in applying the formulae, and the availability of databases of physical properties needed in the calculations, make the development of an expert computer system almost the ideal way of handling the problem and a logical progression from the calculation programs already available.

The strongest argument against the feasibility of such an expert system is the present paucity of heat release data for a wide range of chemical systems. This has led to the development by DIERS and others of adiabatic calorimeters for measuring directly the quantities required by the various methods. In the absence of such direct heat release data, it may be possible to develop a way of making use of kinetic and thermochemical data provided this is available. Failing that, various schemes have been worked out for estimating the physical and chemical properties of substances, either electrolytes or non-electrolytes, with known molecular structure. It may be possible to use such schemes , relying on existing databases such as the IChemE's Physical Properties Data System (PPDS) and those of the Royal Society of Chemistry, to estimate the unknown parameters with the aim of ending up with conservative calculations of vent sizes. If the properties of the compounds involved could not be safely estimated then the expert system would simply have to indicate to the user that it was necessary to go away and measure certain quantities before it could proceed further.

There seems no good reason to doubt that a useful expert system for designing explosion relief for exothermic reactions could not be built, given a sufficiently powerful approach and in particular that based on an AI programming language.

EXPERT SYSTEMS

Expert systems are computer programs which can perform some tasks that normally require human expertise. Unlike conventional programs which are procedure oriented, expert systems are knowledge based making them capable of providing better explanations, allowing experimentation with a "what if" capability, and simplifying modifications or extensions to the program.

The key difference between a conventional and an expert system is its structure (Figure 1).The inference engine uses the knowledge in the knowledge base, and the current state to solve the problem. The current state is an area of working memory which holds information supplied by a user, or deduced by the inference engine. Hence, the key difference between the two structures is that aspects of control are in a separate module in an expert system.

This enable one to provide a system that has an inference engine but leaves the knowledge base empty. The knowledge can then be filled for a particular problem. Such systems are called expert system shells.

There are various ways of representing knowledge in the knowledge base. The most common knowledge representation schemes are:

Rules
Frames
Semantic networks
Logic

There are many commercial products for the development of expert systems. However, there are just three common approaches to the development of experts systems:

Use a Shell
Use an AI language
Use a toolkit (or environment)

The main requirements of an expert system for explosion relief are as follows:-

1. It must check any constraints to ensure that a method is only recommended when it is applicable.

2. It must explain its reasoning. Thus it should be capable of explaining why a particular method is chosen (or not), and how it obtains an answer.

3. It must provide a What-If capability. The user should be able to examine the effect of changing an input parameter.

4. It must enable experts to maintain, or modify existing methods, and enable them to add new methods.

5. It should enable backward calculations. This is, a user should be able to obtain a value for an input parameter given the other input parameters and the output parameter. This requirement is particularly relevant to the inclusion of the PERA work on weak vessels.

In addition, due to the need 'spread good practice' the system must be made available on common hardware. The system should, of course, provide a friendly user interface with facilities like unit conversions, a comprehensive help system and a log of the session.

There are, of course, significant differences in the methods of designing explosion relief for dusts, vapours and gases, and exothermic reactions. However, in terms of software development, the methods have the following common features:-

1. Each area has several methods,

2. The methods have a range of applicability defined by constraints on the situation.

3. Several methods may be applicable in a given situation. There may, or may not be sound rules to enable the choice of a particular applicable method.

4. Some parameters must be obtained by experiment. Some parameters can also be obtained from the literature. Sometimes it may also be possible to estimate the parameters.

PROTOTYPE

In order to make a practicable assessment of the feasibility of developing a system and to obtain feedback from potential users, a simple prototype system for sizing vents in the area of dusts was developed. The prototype includes 5 methods for vent sizing. It was developed using the expert system shell called CRYSTAL and runs on a PC-compatible.

More than 18 users, including site inspectors, experts on dust explosions, and computer scientists, evaluated the system. In general the comments received were favourable, and no fundamental objections were made. A number of useful suggestions about the system were made, the most significant being that once a list of applicable methods has been selected, the system should make a definite recommendation. Provided that the rules for carrying out such a recommendation are available, there is no technical reason why they cannot be incorporated in a real system.

The prototype is capable of finding out which methods are applicable and capable of explaining its reasoning. For example it shows why a method is not applicable. It also allows a 'What-If' capability. Since the domain characteristics of the areas are similar, there is no reason why these requirements could not be met for systems in the areas of gases, vapours and dusts.

The prototype is not capable of displaying a given method. More significantly, the prototype does not enable experts to maintain, modify and add methods. That is, to add, or modify a method, one has to be familiar with CRYSTAL as well as the code. However, these requirements can be met provided that a suitable software development strategy is adopted.

CHOOSING THE SOFTWARE DEVELOPMENT STRATEGY

As noted above there are 3 development strategies that could be followed:

1. Use a shell

2. Use a toolkit
3. Use an AI language

Shells provide an inference engine for reasoning with a particular kind of knowledge representation scheme. Shells are therefore ideal for those problems whose requirements match the inference engine and the representation scheme offered.

Experience with the development of the prototype, and examination of several other shells shows that the requirement for an expert to add and modify methods cannot normally be met by using an existing shell. Indeed, the only way it could be met is to use a programming language (eg C, Lisp), offered as a last resort by some shells.

This deficiency in existing shells is a consequence of the fact that the inference engine of most of the shells originates from early shells like EMYCIN (developed in the mid 70's) which in turn were based on diagnostic systems like MYCIN. That is, the inference engines do not provide a suitable control mechanism for reasoning about constrained methods. Another consequence of this deficiency is that the number of rules needed to represent constrained methods would result in unmanageable systems. For example, the prototype needed over 400 rules for 5 methods.

We are not alone in encountering deficiencies in existing expert system shells. For example, Jackson Reichgelt and van Harmaelen (Ref.1), write:

"Buyers of a shell often believe, and manufacturers often claim, that a shell is appropriate for a range of different applications. However, a large number of people have expressed dissatisfaction with expert system shells..."

Toolkits offer a rich set of representation schemes, as well as object oriented programming. They do offer an ideal platform for developing most kinds of expert systems. Most toolkits, however require a workstation with a lot of memory (more than 16Mb) for the development system. It is difficult to predict the memory requirement of a run-time system for particular applications (4 Mb min). We therefore believe, that using a toolkit would substantially restrict the market for such a system.

The use of an AI programming language offers the most flexible development strategy. It would enable one to develop a representation scheme in terms of 'constrained methods' rather than just rules. This would result in a more transparent system that would enable experts to add and modify methods. They would not require a knowledge engineer to translate a new method into several rules that would include side effects (like input/output). In addition there is a need for an equation solver. Such equation solvers are best developed in AI language. If necessary, this approach also allows one to change the source code. The source code of a commercial shell or toolkit is not normally available. Further, a particular language is available from a range of suppliers on a range of hardware while a particular shell is tied to its supplier. Unlike any shell, there is even a prospect that there will be an ISO standard for an AI programming language (Prolog 89).

It is recommended that, for the purposes of a system for vent design, an AI programming language which follows the Edinburgh style (eg Prolog-2) should be adopted.

PROGRAMMING THE SYSTEM WITH KNOWLEDGE

The ease with which new knowledge (calculation methods) could be input into the system can be described by examining the proposed interface with which the expert would interact.

Knowledge input would be controlled by a series of schemas which would guide the expert through a series of requests for information. Three schemas are likely to be used as follows:-

ACTUAL SCHEMA
This schema would be specific to the particular method being entered. It would contain a name for the method, the desired output information, the constraints and the body (the mathematical formulae).

OPTIONAL SCHEMA
This schema would contain a reference to all methods in the system and would control the selection of the preferred method based upon a series of rules described by the expert.

DATA SCHEMA
This schema would control the use by the system of data, for example from databases or users. It would permit the experts to prioritize the systems choice of data.

MARKET RESEARCH

Having concluded that, technically, an expert system could be developed in each field and that an AI programming language would be the recommended method, it was necessary to consider the need for any such system. In otherwords, "it can be done - is it worth doing?".

The reaction by experts to expert systems is often found to range from scepticism to support. "Some experts are overjoyed at the prospect of no longer being the only one in the company who can do a particular task, or in knowing that their expertise will not be lost if they retire; the advent of an expert system is a freeing experience for this kind of person.....
Diametrically opposed to this attitude are those experts who feel that not only their job security, but their very worth as a human being, is based on their unique ability to do a particular task better than anyone else. To take away that task, or even suggest that a computer might be able to do it, becomes a personal insult and is often met with overt hostility." (Ref 2)

Within HSE, and especially within the Field Inspectorate, computers were not (and are still not) widely used for technical purposes. Amongst those familiar with computers support for the project was, predictably, high but elsewhere it has been seen to grow slowly as the possible benefits became clear. Such benefits were seen as follows:

1. Such a system would reduce the burden of routine work on HSE specialists making them available for the more complex work.

2. The system would bring greater consistency and uniformity of approach to explosion relief assessment by being available throughout HSE and also to industrial users.

3. The cause of safety in general would be served by making guidance more readily available to potential users.

4. Because an expert system can be readily updated software based guidance could be kept up to date more easily than the present written guidance.

The cost of the development of any expert system in these fields would be likely to be beyond the resources of most of its potential users and development within a "club", pooling resources, expertise,and liability was seen as an advantageous method.

However, it was envisaged from the outset that any system, if developed, would (when satisfactorily tested and proven) be made available in some way outside HSE, and might be commercially viable.

In order to examine the commercial viability of the proposed system it was decided to construct a questionnaire which could be used to investigate a cross section of potential users of the system.

The questionnaire was made as simple as possible commensurate with obtaining answers to two fundamental questions; would potential users consider using an expert system and how much would they be prepared to pay for a suitable system? Further information on the company size, their principle activity and their present use of computers was also included in the questionnaire.

Four sources of company information were used:-

a. The Kompass Company Directory Computer Database.
b. The Fraser Williams Consultants Directory (1989/90).
c. The membership list of the Solids Handling and Processing Association Ltd
d. Companies suggested by HSE

The results of the survey are given at Figure 2.

The level of replies was high for this type of mailshot and probably reflects its association with the HSE and genuine interest in the product.

The undoubtedly high level of interest from potential users was shown by the more than 4:1 ratio of respondents who would consider using an expert system in their work.

It was also clear that many would be prepared to pay substantial sums for a system meeting their needs.

Although a majority indicated a price range £100-£500 many indicated a willingness to pay in excess of £500. If allowance is made for the tendency of respondents to "aim low" in their price estimates and a comparison is made with systems of similar complexity to the one proposed a selling price of between £500 and £1000 appears readily achievable. Such a price could generate considerable revenues to support the development of further systems.

CONCLUSIONS

The project has examined the assessment methods currently available for relief sizing for both combustible (dust, gas and vapour) and non-combustible (exothermic chemical reaction) explosions and concluded that an expert system could be designed to incorporate each method.

Such a system could and should be regarded as an extension of a normal HSE activity as publishers of guidance on safety matters.

Expert system shells, tools and AI languages have been assessed for their suitability for the proposed expert system. An AI programming language (PROLOG) has been recommended as the most suitable architecture in which to develop the system.

The system would be designed to operate on the latest generation of "386" Microcomputers.

Discussions have been held with HSE experts, field inspectors, consultants and industrial users. A generally favourable response has been received. This has been reinforced by the results of a questionnaire sent to a wide range of potential users who responded in a ratio of more than four to one that they would consider using an expert system in this work.

SUBSEQUENT DEVELOPMENT

A project for the development of an expert system for the design of dust explosion relief vents has been set up by the BMHB, with support from HSE and industrial sponsors. It is intended that the first edition of the system will be completed at the end of 1991 and that it will be made available through the Institution of Chemical Engineers.

REFERENCES

1. Jackson, Reichgelt and Van Harmaelen, Logic Based Knowledge Representation, MIT Press (1989).

2 *Expert System Technology, Robert Keller, Yourdon Press, 1987.*

Footnote This paper summarizes a report, prepared by SUBSL for HSE, which contains complete details of the project. Any enquires to see the full report should be directed to HSE.

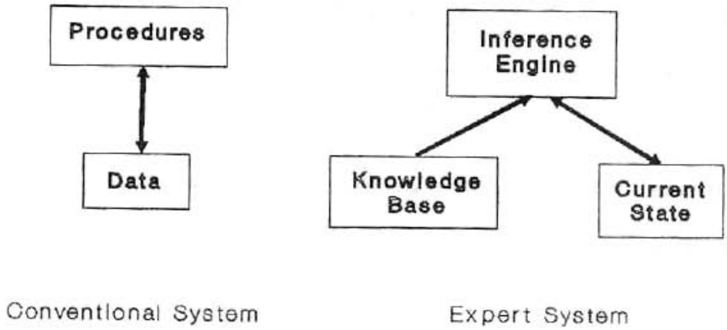

FIGURE 1 Structures of an expert system and a conventional system

COMPANY DETAILS

MAIN ACTIVITY	MANUFACTURING	66	PROCESS	27	CONSULTANCY	19	OTHER	4		
NUMBER OF EMPLOYEES	0-25	14	25-50	4	50-200	32	200-500	20	500+	41

IN WHAT AREAS OF EXPLOSION RELIEF IS YOUR ORGANISATION INTERESTED?

DESIGN	60	DUST	87
USER	64	GAS & VAPOUR	57
OTHER	4	RUNAWAY/EXOTHERMIC	47

WOULD YOU CONSIDER USING AN EXPERT SYSTEM FOR YOUR EXPLOSION RELIEF WORK?

YES	91	NO	21

WHAT PRICE WOULD YOU BE PREPARED TO PAY FOR SUITABLE SOFTWARE?

UP TO £100	9	£100-£500	60	OVER £500	21

Number of Questionnaires sent out:- 453

Number of Replies Received:- 117

The numbers inside the boxes indicate the number of replies received in each category.

FIGURE 2 Analysis of questionnaire returns