

ADDRESSING THE PROBLEMS OF ROOT CAUSE ANALYSIS: A NEW APPROACH TO ACCIDENT INVESTIGATION

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A comprehensive survey of accident investigation procedures across UK industry showed that only a small proportion of companies systematically address the underlying causes. This paper describes a practical approach to accident investigation which allows trends in the underlying causes to be identified. This information provides the basis for developing cost effective accident prevention strategies.

INTRODUCTION

Root Cause Analysis (RCA) is carried out in order to understand the underlying causes of accidents, and develop recommendations to prevent a recurrence. RCA can be defined as identifying the direct and underlying causes of an accident and developing effective recommendations to manage the identified risks. Almost all organisations carry out incident investigations following an incident. However, in general, there is considerable scope for improving the RCA aspects of these investigations. This conclusion is based on a survey which was commissioned by the Health and Safety Executive (HSE) and carried out by Human Reliability Associates (HRA) to evaluate the current state of the art in accident investigation across UK industry. The reason for the survey was the possible introduction of legislation requiring a duty for companies to conduct a formal investigation following an incident.

In the first section of this paper two approaches to accident investigation will be described. This description includes an illustration of the way that assumptions held by the investigator can have a major impact on the type of investigation and the resulting recommendations. The next section of the paper summarises some of the main findings from the HSE study. The following sections describe a new approach to incident investigation, which is designed to address many of the deficiencies in existing approaches to RCA that were revealed by the survey. Finally, a case study will be described in which the methodology was applied across a number of sites of a multinational chemical company.

THE INDIVIDUAL VIEW OF ACCIDENT CAUSATION

The individual based approach assumes that the primary cause of accidents lies in the individual characteristics of people. These include their inherent capabilities (e.g. the physical and mental resources they possess, together with any assumed negative predisposing traits such as accident proneness), their motivation and attitudes (which affect their commitment to avoid unsafe acts and adhere to procedures) and their skill and knowledge, acquired through training and experience within the organisation. If an organisation holds a predominantly individually based view of accident causation, the recommendations arising from the investigation usually focus on disciplinary actions, retraining, or re-writing procedures, on the basis that the accident arose from a lack of understanding on the part of the operator. However, these causes provide only a limited choice of interventions. A more comprehensive view of the factors that contribute to accident causation is provided by the systems based approach. The analysis of accidents from this perspective provides a much richer choice of preventive strategies.

THE SYSTEMS-BASED VIEW OF ACCIDENT CAUSATION

The systems-based view of accident causation assumes that accidents arise from the interaction between the characteristics of people and aspects of the situation within which they work. Examples of these factors are set out in Figure 1 below.

If the investigation is conducted from a systems perspective, factors such as those set out in Figure 1 will investigated in addition to possible individual causes. Often recommendations will include specific interventions in some of these areas. As will be discussed in the following sections, only the larger and more sophisticated companies consider systems factors when investigating accidents and performing RCA. In most cases, the results of investigations prescribe remedial measures that are predominantly aimed at the individual(s) who 'caused' the accident. This approach is not in accordance

Task characteristics Complexity Level of distractions Requirement to perform more than one task in parallel (multitasking) Familiarity Duration (fatigue effects) Physical and mental demands	***Organisation of work*** Time available to perform tasks (work scheduling issues) Shift systems (implications for fatigue and disruption of body rhythms) Clarity of definition of roles and responsibilities (implications for accidents arising from tasks not being carried out because of lack of clear responsibilities)
Physical environment Heat Cold Presence of toxic and other hazards requiring personal protective equipment to be worn)	***Communications*** Shift hand-overs Availability of critical task information at the point of use Provision of warnings
Equipment design Equipment usability Design of process interfaces (e.g. in control rooms)	***Competence*** Experience Knowledge and skills acquired through training Extent of refresher training
Quality of procedures Accuracy Appropriate level of detail Alignment with practicalities of the job	

Figure 1. Examples of accident causation factors used in the systems based approach

with the views of most accident researchers (see for example references[1,2]) who emphasise the benefits of the systems based view, particularly as this has the potential to create a more open reporting culture. One of the reasons for the lack of a systems based approach to accident investigation is the absence of a comprehensive set of tools that are specifically designed to implement this approach. This paper describes a toolset that has been developed over the last few years with support from organisations such as the HSE, and which is now being deployed by multinational organisations in the process industry.

THE HSE ACCIDENT INVESTIGATION SURVEY

This study[3] was intended to provide background information for proposed new legislation requiring employers to investigate the causes of work-related accidents and ill health, and to provide guidance for the HSE regarding the type and level of practical support which industry may need to successfully implement the new requirements.

The study design consisted of two stages, a large-scale telephone survey (1500 organisations) and a smaller follow-up face-to-face interview survey (100 companies). The telephone interviews were intended to reflect the whole spectrum of commerce and industry, including micro-businesses, SMEs and larger companies. The purpose of this stage was to obtain a comprehensive and nationally representative overview of accident and work-related ill health investigation procedures. The second stage of the study consisted of on-site interviews with safety or line managers. This was designed to provide general verification of the information obtained via the telephone survey, to provide further details of typical investigation processes and procedures and to generate some case studies which could be used to illustrate these processes and procedures.

In order to assess the quality of the accident investigation systems in place in the companies that were investigated in the study, a set of requirements was developed which was intended to define the desirable characteristics of these systems:

- A causal model that provides a good balance between the individual and systems based approaches to accident investigation
- The involvement of relevant individuals within the investigation
- Procedures or protocols to structure and support the investigation
- The identification of both immediate and underlying causes
- The development of recommendations that address both immediate and underlying causes
- The implementation of these recommendations and the updating of relevant risk assessments
- Follow up to ensure that actions taken are successful in reducing the risk of further incidents
- Feedback to relevant parties to share immediate learning
- The development of an accessible database

In the following sections, the findings that are relevant to the issue of incident investigation techniques and RCA will be discussed. Detailed discussions of the other issues can be found in the original survey report.

CAUSAL MODEL ADOPTED BY COMPANIES AND INVESTIGATORS

The study found a range of approaches to incident investigation, from system-based through to traditional individual models. However, the majority of companies operated closer to the traditional end of this continuum rather than using a system-based approach.

In the absence of any formal accident investigation approach or training in the company, the quality of the investigation is totally dependent on the investigator. Even where there are formal investigation systems in place, the abilities of the investigator still have a significant impact on the process and output of the investigation. The majority of the investigators were found to hold an individual rather than a systems view of accident causation, and hence the investigation process tended to reflect this opinion.

STRUCTURE AND SUPPORT FOR INVESTIGATIONS

The level of structure and support provided for incident investigation was classified into four main categories representing increasing levels of formal structure and sophistication of approach.

About half the companies in the interview survey would be prepared to use a more structured approach with qualifications about value and the need for simplicity. Those 30% who said they would not be prepared to incorporate more structure tend to be satisfied with their current approach or feel that a different approach would involve too much time or resources. The larger the company, the more receptive it would be to using a more structured approach.

An overall evaluation of the four main approaches against the requirements listed above concluded that, in relative terms, Approaches 2.2 and 3 were most likely to result in the identification of both immediate and underlying causes, to result in recommendations that address these causes and to ensure that such recommendations are implemented and subsequently followed up. The results in Figure 2 indicate that only 18% of the companies surveyed use structured processes represented by these approaches. However, as indicated below, the results of the interview survey suggest that, even when a

Category	Description of approach	Distribution findings
Approach 1	A complete absence of any documented structure or support for incident investigation.	38%
Approach 2.1	A minimum formal support with the focus on identifying immediate cause.	55% (44% of all companies employ Approach 2.1)
Approach 2.2	More structured, with a more sophisticated approach to identifying immediate and underlying causes	
Approach 3	A causal analysis is supported by specific analysis tools and techniques	7% (Large or high-risk organisations)

Figure 2. Degree of structure and support for an investigation

high level of support for incident investigation is in place, this does not guarantee that companies always meet these requirements to a satisfactory standard.

IDENTIFICATION OF IMMEDIATE AND UNDERLYING CAUSES

The findings of the interview survey, and the impression gained from the respondents, suggest that the majority of companies do not effectively discriminate, or indeed understand, the distinction between immediate and underlying causes. Despite the limitations of many of the investigations examined in this study, the vast majority of respondents *felt* that their current approach had led them to identify the underlying cause of incidents.

RECOMMENDATIONS AND ACTIONS TAKEN

The most common recommendations and actions taken following an incident were changing equipment, modifying procedures, and/or further training and awareness-raising.

- Changes to equipment and procedures were more common in companies employing Approaches 2 and 3.
- Raising awareness and further training were more common in companies employing Approach 1.
- Risk assessments were revised in 24% of the cases, and this was most common in companies employing Approach 3.

The above results indicate a more system-based approach than was apparent in the interviews or in the causal analysis methods documented in the case studies. However, when respondents were asked to indicate what they considered to be the most common recommendations made following an incident investigation, the results indicate a strong bias towards more person-centred recommendations. In general terms, the study results also suggest that companies that employ Approaches 1 and 2.1 tend not to have formal systems to ensure that recommendations are acted upon. Only a small number of companies have a formal system in place to ensure that recommendations have been effective in reducing the likelihood of similar or related incidents.

NEAR-MISSES

Nearly all companies recognise the potential value of following up near-misses and the majority of companies attempt to investigate them, if incidents are brought to their attention. Companies are generally aware of the difficulties in obtaining good levels of reporting, but do little proactively to encourage such reporting. There is an assumption that, because there is an incident reporting system in place, this means that they always address near-misses.

IMPLICATIONS OF THE HSE SURVEY FOR ACCIDENT INVESTIGATION AND ROOT CAUSES ANALYSIS

The results of the survey present a somewhat depressing picture from the point of view of the quality of accident investigation and RCA. The widespread ignorance regarding the nature of accident causation gives rise to complacency which leads companies to incorrectly believe that they have identified causes and developed action plans based these causes. In fact there is a strong tendency to focus on the shortcomings of individuals involved in the incident to the neglect of systems factors that may create the preconditions where human errors, and the resulting accidents, are inevitable. Although the situation is better for larger companies, there is clearly a widespread need for increased training of accident investigators to provide a more fundamental understanding of the nature of accident causation, and its implications for RCA. Once training has raised the awareness of safety practitioners with regard to the need to address systems causes, there will be an increased demand for tools and techniques to support accident investigation in line with this understanding. In subsequent sections, such an approach will be described, and a case study provided regarding its implementation in a multinational company.

A NEW APPROACH TO ACCIDENT INVESTIGATION

The HSE survey indicated a number of problem areas in accident investigation and RCA. Nevertheless more than half of the companies surveyed were open to the need for a more structured approach to accident investigation. In subsequent sections we first set out the requirements for such an approach, and then describe a methodology that has been developed to satisfy these requirements.

PROBLEMS WITH EXISTING APPROACHES TO ROOT CAUSE ANALYSIS AND THE DEVELOPMENT OF INCIDENT PREVENTION STRATEGIES

In both the HSE survey and as a result of our involvement in accident investigation over a number of years, we have identified a number of deficiencies in the majority of existing approaches. These deficiencies will need to be addressed in any proposed new approach.

Focus on individual rather than systems causes

There is often an assumption that the primary causes of accidents are blameworthy deficiencies on the part of the individuals involved, such as failures to attend fully to their work, reckless non-compliance with procedures, lack of competence or intrinsic individual traits such as accident proneness. There is little consideration of underlying systems causes such as deficiencies in training, procedures, job and communication design which can create the preconditions for accidents.

Focus on the accident description rather than causes

The amount of resource devoted to the investigation of an accident and to investment in preventive measures tends to depend on the severity of the outcome. However, this severity arises from chance conjunctions such as when or where the contributing failure occurred, and whether there were hazards such as flammable gases, high voltages or toxic substances present which could be released by the failure. Using only severe outcome accidents as the basis for prescribing preventative measures may lead to an inappropriate strategy and therefore a waste of resources if the accident is atypical in terms of its underlying causes.

Focus on single rather than multiple underlying causes

In most causal analysis only direct causes are usually considered and the underlying causes are rarely addressed within a systematic analysis framework. However, these direct causes are often the product of a combination of several causal factors, which need to be assessed in order to develop an effective preventive strategy.

For example, in a pharmaceutical plant, charging of an incorrect chemical into a vessel led to a batch having to be discarded with consequential losses of nearly one million pounds. Contributory factors included a failure to communicate changes in work processes where there was a change from pallets containing single chemicals to mixed pallets. This was combined with the introduction of a new label scanning system whose function was not clearly understood by operators. Possible checks that had been built into the process such as independent checking of charges also failed. Although this incident resulted in financial losses rather than safety outcomes, the same errors could easily have given rise to personnel injuries if the chemicals had the potential for hazardous reactions.

In many cases, the observable direct causes of accidents and incidents can be traced to less obvious underlying deficiencies in the formulation, implementation and verification of the policies which form the Safety Management System. In the case of the pharmaceutical incident cited above, the management of change aspects of the Safety Management System were ineffective. A comprehensive root cause system should be able to identify these policy level causes and the manner in which these influence the observable direct causes of incidents. This would allow any fundamental policy changes that are required to address systems failures to be explicitly identified.

Accident sequences are analysed in detail but underlying causes are neglected

Most accident investigations spend a considerable proportion of their resources on delineating the details of ***what*** happened in an incident, with insufficient attention being devoted to ***why*** the incident occurred and to developing preventative measures based on this causal analysis. Root cause analysis is frequently concerned primarily with identifying the sequence of events that led to the undesirable outcome. This arises from the dominance of the so-called ‘Domino Theory’ approach to accident causation, which sees accidents primarily in terms of chains of events leading to the undesirable consequences. From this perspective, prevention can be achieved by eliminating one or more of the dominoes or sequential events that make up the postulated accident sequence. However this approach is flawed from a number of perspectives.

Firstly, it relies on identifying the exact sequence of events that occurred, which is frequently extremely difficult to achieve, particularly in the case of severe accidents where key witnesses may have died, or memories of what happened may be flawed because of the trauma experienced during the incident. In addition, legal pressures to assign blame may make it very difficult for individuals to be completely honest about exactly what happened, if this honesty could lead to either themselves or their colleagues being subject to severe sanctions such as dismissal or even prison sentences.

The Domino Theory approach of eliminating an event from the chain may prevent a specific event sequence from re-occurring. However, this approach may not be effective where a slightly different sequence results in the same outcome. The particular event sequence that occurred may simply be a specific instance of the many ways in which the outcome (or other accidents with equally undesirable outcomes) could have arisen, given underlying states of the system (e.g. poor procedures, frequently occurring workload arising from poor planning, inadequate communication systems) that were present. Deficiencies in these underlying causes will increase the likelihood of many possible accident sequences, not only the sequence that actually occurred.

Interventions are chosen on the basis of investigations of single severe incidents rather than evidence from a number of investigations

The above analysis suggests that analysing recurring causes from a wide range of incidents, including near misses, will provide better returns than focusing investigation resources exclusively on high consequence accidents. Such an evidence base can potentially provide objective data regarding the factors that have the greatest influence on certain classes of incident. Because such an evidence base cannot be developed using only rarely occurring major accidents, it is essential that a process be developed for analysing near misses (or 'close calls') and incorporating evidence from these analyses in cumulative databases.

In fact, a process to determine the overall quality of the factors which influence the probability of incidents in a particular system does not need to rely on the occurrence of incidents, (with serious or minor consequences) at all. A proactive audit process, which regularly samples the state of the presumed underlying causes of accidents, can also contribute to the overall evidence base regarding the factors which give rise to incidents, as long as the results of this process can be aggregated with data from both actual incidents and near misses. In fact such a non-contingent measurement of the state of the accident drivers is desirable from a statistical analysis standpoint, in that it provides evidence regarding the state of these indicators when the system performs without malfunctions, as well as when there is a negative outcome or near miss.

In order for such a process to function effectively, a methodology is required to provide a standardised framework for identifying candidate underlying factors that drive incidents, and for allowing the state of these factors to be reliably assessed during the incident investigation. There is a need for a structured process which will allow specific models of accident causation to be developed for particular domains, e.g. control room operations, maintenance tasks, and batch production processes. These models can then be used to structure the questions that need to be asked during the accident investigation and RCA process.

Focus on the use of narrative descriptions of the state of causal factors reduces the capability to aggregate data to identify recurring causes

The arguments presented above provide a strong case for the aggregation of information from a variety of sources on the state of the factors that drive the likelihood of incidents.

However, this aggregation process requires the availability of a method for providing a numerical assessment rather than a purely narrative description of the state of these factors. In general, incident analyses are primarily descriptive in nature and hence it is very difficult to aggregate evidence from causal analyses obtained from a number of incidents. Some alternative approach is necessary to provide numerical inputs for identifying trends and supporting other forms of statistical analysis. One of the characteristics of this process is that it should carry out measurement at a level that is as objective as possible. Having said this, it is nevertheless desirable that the process is able to handle 'soft' data such as opinions, since these will sometimes be the only means available for assessing important causal factors. Another important requirement is that the assessment of the state of the causal factors is as reliable as possible, even when dealing with soft data. As will be discussed in the next section, this requires that the assessment is made by trained evaluators, and that the factors are described in as unambiguous a manner a possible.

A METHODOLOGY TO SUPPORT THE CAUSAL ANALYSIS OF INCIDENTS

The issues discussed in the previous sections indicate that an effective methodology for performing causal analyses and for aggregating the results of these analyses across a number of incidents has to have the following characteristics:

Focus on causation rather than accident description

Although it is important to develop a comprehensive description of *what* happened in an incident, there are a number of techniques available that are able to provide such a description of the event sequence prior to and following an incident. The main focus of the proposed technique is therefore on the direct and underlying causes of the accident, although the description of the incident and the events that led up to it also needs to be comprehensively addressed as part of the overall analysis.

Focus on human caused failures

It is widely recognised that the major source of risk in safety critical industries is human caused failures. The technique that will be proposed in this section therefore focuses on this area, although there is no reason why a similar methodology cannot be applied to hardware related failures.

Ability to address both individual and systems factors

The HSE study indicated that most investigators focus on the individual causes of incidents, whereas in safety critical industries such as petrochemicals, rail transport aviation and nuclear power[1] it is widely accepted that systems factors make a major contribution to human caused failures.

Ability to consider multiple causes
As discussed previously, almost all incidents have multiple causes and hence the causal analysis process needs to be able to provide a broad range of causes from which the analyst can select a subset relevant to the incident being investigated. There is also a need to address causation at a number of levels. Thus, although it is possible to say that the occurrence of a set of incidents were influenced by shortage of time, poor procedures, and inadequate communications, the question of how these conditions came to be in that state is important for the generation of preventive measures. This means that ideally, direct causes such as inadequate competence should be linked to underlying causes such as the training system itself and the policies that give rise to this system.

Ability to aggregate causal data across a number of incidents
As discussed above, one of the important features of the proposed process is that it moves the emphasis away from investigating individual incidents in isolation, to aggregating data from a large number of incidents with different levels outcome severity. This is based on the assumption that the underlying causes of all types of incident are similar. The severity of the outcome is often a function of factors such as the level of protection of the hazard, or the feedback from the system that a potential problem has arisen, which are separate from the causes of the incident itself. Thus, the ability to aggregate data will allow trends in the possible causes to be evaluated, and hence possible causal relationships to be identified. This will provide a more defensible evidence base to differentiate between alternative prevention strategies.

Linkage between proactive risk management and RCA
If a range of causal models can be developed for the situations such as control room tasks, maintenance and routine plant operations, these models can also be used as audit tools to proactively identify potential areas of risk as well as providing a framework to collect data on incidents and near misses. In fact this linkage would provide the possibility of developing risk assessment tools in which the factors used for assessment had been validated on the basis of incident data. Thus risk assessments would not only consist of the identification of specific hazards, but would also evaluate contextual factors that would determine the likelihood that a hazard would be released. In fact, one of the major problems identified in current practices for incident investigation is a failure to revise previous risk assessments on the basis of deficiencies identified during the RCA. The use of a methodology that links RCA with proactive risk identification and assessment would assist in addressing this problem.

Adjustable level of detail of the investigation depending on the level of resources available and accident severity
The HSE study made it very clear that in general there is very little resource available for incident investigation unless the consequences are very serious. However, one of the underlying principles of our approach to accident investigation is that there are considerable benefits to be gained by evaluating a wide range of events, in order to observe trends

in the quality of factors that are likely to increase the risks of accidents. In practical terms, if we want a large number of events to be evaluated, it is necessary to provide a methodology that will still allow useful results to be obtained, even if only limited investigation resources are likely be made available.

OVERVIEW OF THE CCA INCIDENT INVESTIGATION METHODOLOGY

The incident investigation and RCA approach that has been developed is called Causal Context Analysis (CCA). It is based on the concept of performing an analysis of the context within which a task or operation is performed. This evaluates factors that affect the likelihood of an accident, based on a model of incident and accident causation developed for the type of situation being addressed.

The stages of the process are as follows:

- The sequence of events that lead up to an incident (the 'what' of accident investigation) is documented using a systematic graphical method, which is designed to be easier understand than a narrative description
- The accident investigation process considers the systems factors (i.e. those factors that contributed to the accident that were not necessarily under the control of the people directly involved, but which are potentially controllable by the organisation)
- A standard accident causation model is used (tailored for specific domains such as office and process plant operations) to generate a specific set of questions about causes that are applied to all accidents
- The answers to these questions provide guidance for preventive measures for the specific accident being investigated. However they can also be aggregated over a number of accidents to identify the systemic causes that are likely to be implicated in a range of accidents

STAGES OF APPLYING THE CCA TECHNIQUE

Preparation (prior to applying the methodology to investigations)

This preparation will be carried out as part of the process for tailoring the generic CCA causal model to the particular application. For example, certain factors, such as the quality of procedures, presence of time stress, competence of the personnel involved, are likely to be generic across a wide range of situations. Other factors, such as the quality of communications may need to be interpreted differently in, for example, an on-plant maintenance task, as compared with control room operations. For each situation, the following activities are required:

- Develop relevant model of accident causation based upon expert knowledge and available data
- Develop scales for each of the factors in the model so that the quality of these factors can be assessed in the scenario under investigation

CCA based Incident analysis

For each incident, the following operations are performed:

- Evaluate and document the incident structure and event sequence
- Evaluate each of the causal factors in the model
- Collect information regarding factors that appear to be potentially causal, but which are not currently part of the causal model, and record these in free text format
- Update the incident database using both the numerical ratings of the factors and the free text information

Collection of control data

The cumulative database should include evaluations of the variation in the causal factors even where no adverse events or near misses have occurred. This is equivalent to using the CCA in a proactive mode, as a means of auditing the factors that could adversely influence the likelihood of incidents. The possession of these data also allows an evaluation of whether the causal factors may combine together in particular ways that increase the probability of accidents (i.e. interaction effects). This enables an investigation of whether there are particular combinations of negative factors that will produce a high incident probability.

Analysis of the incident specific data

The incident specific data will evaluate the Causal Context factors to see if they are significantly different from the profile of factors for other incidents and near misses in the database. This will indicate whether any of the factors was significantly worse than those in a typical incident profile, and also be a starting point for the development of preventive strategies.

Analysis of the cumulative data

When a significant number of incidents have been accumulated in the CCA database, the range of variation in the causal factors can be investigated. It would obviously be of interest, for example, to establish the variations in factors such as the perceived levels of fatigue, task loading, procedure quality and competence in a safety critical situation such as a plant control room. This provides evidence regarding systemic deficiencies in the Safety Management system, and indicates the need for remedial actions.

The second aspect of the analysis investigates the correlations between the variations in these factors and the recorded incident rates. Although it has to be recognised that association does not necessarily imply causality, epidemiological data could be collected that would indicate whether there was a strong statistical association between variations in particular causal factors and corresponding changes in the incidence of accidents and near misses. If such associations are established, this provides a basis for prioritising which factors should be improved in order to have the greatest impact on accident rates.

Model update

If data collected from a number of incidents indicates that the model is incomplete, or that certain factors need to be deleted, this will require an update of the content of the model. This may involve both the deletion of factors that are rarely rated as poor, or the addition of new factors not present in the original model, but which frequently arise in narrative descriptions of incidents.

DEVELOPING ACCIDENT CAUSATION MODELS FOR CCA USING INFLUENCE DIAGRAMS

The approach that is used for developing the causal models involves the use of a graphical representation, called an Influence Diagram (ID), of the possible direct and indirect influences on the likelihood of an accident. Normally, an initial ID is constructed off-line, based on research findings, incident reports and other formal sources of evidence. This ID is then developed further in an interactive group setting, which includes subject matter experts with direct working knowledge of the domain of interest. This group is called a Consensus Group, and is designed to ensure that all available sources of evidence are combined within a highly structured process. The Consensus Group is led by a facilitator, whose role is to manage the group interaction effectively, to ensure that the views of all the participants are captured.

Example Influence Diagram for chemical process plant tasks

The ID shown in Figure 3 below is a simplified generic model for errors in plant based tasks. The box at the top of the ID is the outcome box. This describes the likelihood (or frequency) of the event for which the causal analysis is required, given the state of the influencing factors below it. Factors that influence the outcome box or other states in the network are called Performance Influencing Factors (PIFs).

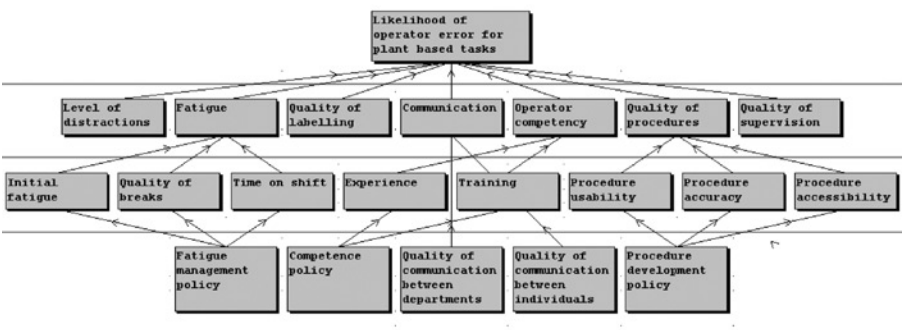

Figure 3. Generic Influence Diagram for plant based task errors

All PIFs below the direct PIFs are called underlying causes. Underlying causes can be further subdivided into State PIFs and Safety Management System (SMS) PIFs. It is assumed that all states which influence the likelihood of an error or accident (positively or negatively) ultimately arise from the SMS. For clarity, only a limited number of SMS PIFs have been represented in the diagram below. The model specifies the following direct and underlying causes for the broad category of operator errors at plant level that give rise to accidents:

Level of distractions: If there are a number of procedures being carried out simultaneously, or there are a number of distracting events in the area where the task is performed, then the likelihood of the error will be increased.

Operator Fatigue: Fatigue exerts a general negative effect on human performance in that it leads to a narrowing of attention (and therefore a decreased capability to identify a problem), lowered alertness and an enhanced likelihood that corners will be cut. In the model, it is assumed that fatigue is directly influenced by the initial fatigue at the beginning of a shift, the quality of rest breaks and the time on shift. All of these factors will in turn be influenced by the quality of the fatigue management policy.

Quality of labelling: A typical aspect of this factor would be the labelling of similar items of equipment, which could be easily confused in the work area, thus leading to accidents where maintenance operations were performed on plant that had not been made safe.

Communication: In many situations, accidents arise from failures in communication, e.g. between personnel on the same shift or because of inadequate communication between departments (e.g. upstream departments may make incorrect assumptions regarding the state of downstream plant).

Operator competency: This relates to the knowledge and skills relevant to the task possessed by the individual or the team performing it. In the ID, competence is represented as being influenced by a combination of training and experience. The quality of these PIFs is in turn influenced by the training and competency policy in the SMS.

Quality of supervision: This factor refers to the extent to which work is effectively checked and monitored, thus increasing the likelihood of detection and recovery if an error is made.

Quality of procedures: This PIF is further decomposed to the three factors of procedure usability, accuracy, and accessibility, all of which can be evaluated relatively easily. These factors will in turn be affected by the areas of the SMS that address procedures.

Evaluating the PIFs

The fact that the CCA model represents potential causal factors at different levels of detail means that the assessment of the state of the PIFs can be tailored to the resources available. In the CCA ID shown in Figure 3, the seven PIFs at the first (direct) level could be assessed directly. If more resources were available, the factors could be assed at the more detailed level. For example, in the case of the PIF ‘Fatigue’ as well as asking the person involved in the accident if they were tired, more objective factors such as how long they had been on shift, whether the breaks provided reasonable rest, and whether the person was tired when they came on shift could be evaluated.

The questions at each level can either be answered in a binary manner, i.e. rated as acceptable or unacceptable, or a rating scale may be provided, allowing a factor to be assessed on a numerical scale from best case to worst case. For example, the scale 'procedure accuracy' could be rated from 1 to 5 where 1 means that the procedures were full of errors, to 5 where they were almost completely free of errors. Normally the questions concerning the SMS at the bottom of the tree would only be evaluated if a more in-depth investigation were being carried out.

The final form of assessment is to evaluate the relative impact that each of the factors in the model had on the specific incident under investigation. These data could be used to infer the possible relative contribution of these factors to incident causation as assessed by the investigators. These subjective evaluations of the relative influences (weights) of the factors on accident causation could be compared with weights derived from statistical methods such as regression analysis.

CASE STUDY OF THE APPLICATION OF THE CCA IN A CHEMICAL PROCESSING COMPANY

An organisation involved in operating a range of chemical process plants approached HRA with a request for assistance with their incident investigation system. They were developing a new IT system to manage the outputs from their incident investigations and saw this as an opportunity to refine and develop the investigation processes that they employed. HRA presented the CCA process to the organisation and the client decided to adopt this approach.

The company had a number of requirements for their incident investigation system:

- It should be applicable to all types of incident, e.g. in both the process plant and office domains
- It should support the investigator in the identification of underlying causes and suggest actions to be taken to reduce the likelihood of future incidents
- It should be usable by all levels of investigating personnel, following suitable training
- Guidance should be provided regarding the appropriate level of investigation required for specific incidents

In addition, the system was to be used at a variety of different locations in different countries across Europe. HRA worked closely with the client to develop a process, based around the CCA approach, that would fit their requirements. The project was split into three main phases:

1. Development of a tailored investigation process to suit the client's requirements
2. Refinement of the CCA model
3. Development and provision of a training course to support the process

DEVELOPMENT OF A TAILORED INVESTIGATION PROCESS

Following consultation with the client it was decided to produce a package of investigation tools. The aim of this approach was to allow the investigator to match the scale of the investigation to the potential severity of the outcome. Every incident, however, would require some form of CCA analysis. Guidance was provided to the investigator to advise them when particular aspects of the toolkit should be used.

The toolkit contained the following elements:

- A tool for representing the incident sequence in a graphical format
- A simple causal tree tool to enable the investigator/s to identify underlying causes
- Two versions of the CCA statement set, both of which covered the same topics but with one more detailed than the other

The tool for representing the incident sequence was provided for investigations where the sequence was particularly complicated or difficult to establish. The other tools and techniques all assisted the investigator in establishing the causes of incidents. It was decided that the CCA analysis should be used for every incident investigated, to allow for the collection of causal data over a number of incidents. However, for incidents where the outcome was less significant (and did not have the obvious potential to be more significant) a shorter CCA set was developed to save the investigator time.

REFINEMENT OF THE CCA MODEL

Some time was spent with the client refining the CCA model to fit their particular requirements. The main effort during this phase of the project was to ensure that the CCA model was sufficiently general to facilitate investigation in both the process plant and office environments. This requirement meant that a certain amount of detail was removed from the model. HRA worked closely with the client to ensure that the changes required to achieve this flexibility did not overly compromise the analysis output. The second aspect of this revision involved refining the model to ensure satisfactory integration with the IT system where it would be hosted.

DEVELOPMENT AND PROVISION OF TRAINING COURSES

The final phase of the project involved providing training courses to support the implementation of the incident investigation system. This training programme was developed and delivered collaboratively by HRA and the client. The two day training courses were held at all of the locations where the system was to be used. HRA provided background information about the CCA process designed to raise the investigators' awareness of the importance of looking beyond individual causes of incidents. In addition, guidance was provided in data collection and interviewing techniques. Finally, workshops were developed to provide the investigators with practice in the tools and techniques, including the CCA analysis.

CONCLUSIONS

This paper has described a systems-based approach to accident investigation, which is based on accident causation models developed within HSE supported projects. The main benefits of the CCA approach are as follows:

- The data collected within the CCA provide the evidence base for implementing changes and improvements which will address recurrent underlying causes and which are therefore likely to be extremely cost effective.
- The structured nature of the questions that are asked is likely to produce a much higher level of consistency between investigators than current approaches.
- The use of a standardised structure for the investigation process enables valid comparisons to be made between different sites as well as between different departments on a site.
- The capability to aggregate information on causes also allows improvements in causes to be tracked and compared with any changes in output measures such as traditional accident rates.
- The same process can be applied to near miss investigations, thus allowing insights to be gained into areas of strength and weakness in the safety management system without incurring the costs of actual accidents.

It is hoped that the availability of tools such as the CCA methodology will lead to much more effective approach to accident investigation in the future, particularly from the perspective of developing measures for preventing incidents that are based on a sound database of evidence.

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