# Safety Hazard Identification on Construction Projects

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**Abstract:** Hazard identification is fundamental to construction safety management; unidentified hazards present the most unmanageable risks. This paper presents an investigation indicating the current levels of hazard identification on three U.K. construction projects. A maximum of only 6.7% of the method statements analyzed on these projects managed to identify all of the hazards that should have been identified, based upon current knowledge. Maximum hazard identification levels were found to be 0.899 (89.9%) for a construction project within the nuclear industry, 0.728 (72.8%) for a project within the railway industry, and 0.665 (66.5%) for a project within both the railway and general construction industry sector. The results indicate that hazard identification levels are far from ideal. A discussion on the reasons for low hazard identification levels indicates key barriers. This leads to the presentation of an Information Technology (IT) tool for construction project safety management (Total-Safety) and, in particular, a module within Total-Safety designed to help construction personnel develop method statements with improved levels of hazard identification.

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## Introduction

The construction industry's safety record has always been poor. It remains one of the most dangerous industries in which to work. Statistics from the Health and Safety Executive (HSE) show that U.K. construction workers are approximately five times more likely to be killed and two times more likely to be seriously injured compared to the average for all industries (HSE 2000; Whitelaw 2001). U.S. construction workers are over three times more likely to be killed than the all-industry average and one in six construction workers can expect to be injured every year (Kartam 1997). In 1998 the U.K. average annual fatal accident rate per 100,000 employees was 5.6, while the E.U. average was 13.3 (Whitelaw 2001).

In the literature on construction safety research, perhaps the main topic is behavior-based safety (BBS) management. BBS techniques have the potential to significantly improve safety when implemented in an environment supportive of safe performance (Lingard and Rowlinson 1997). These writers stated, via reference to Furnham's (1994) sequential model of accident occurrence, that BBS techniques fail if workers are unable to perceive and recognize hazards at the workplace. Research concerning the integration of safety with construction schedules features prominently in the available literature (Kartam 1997; Chen et al. 2000; Coble et al. 2000). The aim of these systems is to integrate safety into planning by introducing health and safety considerations into the project at an early stage. These systems can successfully identify general safety hazards and issues associated with broadly classified schedule activities and can prove very useful for far-in-advance planning. Safety training systems have also been developed. One system (Aranda 2000) involves the use of navigable movies to train users in hazard identification and safety improvement. Other areas of research concentrate on accident cause and analysis and Hinze in particular has been very influential in this field. For example, Hinze et al. (1998) considered Occupational Safety and Health Administration (OSHA) records on accident causation; while Hinze et al. (2005) concentrates on the analysis of OSHA's records of "struck-by" accidents.

This paper presents an investigation of safety hazard identification within the U.K. construction industry. Starting with a discussion of an accident causation model, within the context of how hazards lead to accidents, it indicates that managing hazardous events is a fundamental aspect of construction safety management. Within the construction industry, risk assessment is the practical means by which hazardous events are managed. However, unidentified hazards negate the risk assessment process; risks cannot be assessed and control measures cannot be developed and implemented if those involved are not aware of the hazard in the first place. Thus operatives will remain unprotected, or will feel a level of protection exists that is not justified by the risk assessment.

In order to provide an indication of the level of unidentified hazards within construction the paper then describes investigations conducted on three projects, within separate industry sectors, over an extended period of time. The paper presents a procedure that indicates the level of hazard identification within method statements via calculation of minimum and maximum *hazard identification indices*. A "method statement" is a carefully prepared document which outlines the description, location, and sequence of work, the resources to be used, and risk assessments in terms of health and safety and environmental impact. Within

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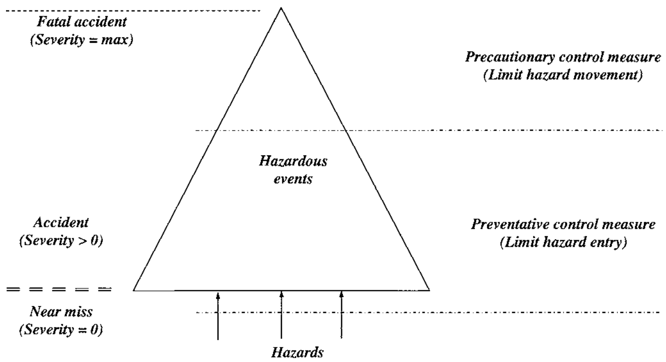


**Fig. 1.** Modified statistical triangle of accident causation

the safety risk assessment part of the method statements examined it was determined that only a small proportion identified all potential hazards (using currently available knowledge). In many cases there was significant room for improvement.

Based upon the investigations conducted at the projects, the writers conclude that hazard identification levels are significantly lower than ideal levels and that there are barriers which prevent these levels being higher. Within the context of these barriers an Information Technology (IT) tool for construction safety management, named Total-Safety, was developed.

Total-Safety is a web-based application that makes use of a central safety database. The database pools together knowledge and experience of all personnel within a company, along with data contained within industry health and safety publications and project safety files. The principles of the system will be discussed and the process of creating a method statement will be described.

## Overview of Hazards and Accident Causation

Fig. 1 shows a modified statistical triangle of accident causation. When a hazard occurs it enters the triangle at its base and this is termed a hazardous event. The interior area of the triangle represents the hazardous events; "movement" up the triangle is determined by the severity of the event. The lower boundary condition is termed "near-miss," which exists when the hazardous event resulted in no physical harm, i.e., zero severity. The upper boundary condition is a fatal accident, at the apex of the triangle, which exists when a human life is lost as a result of the hazardous event. An intermediate condition is that of an accident, which exists when the hazardous event does result in physical harm, i.e., severity is greater than zero.

There are two aspects to the control and management of construction hazards: first, the prevention of hazardous events and, second, limiting the potential severity of hazards if they do occur. In terms of Fig. 1, the first of these are preventative control measures that are designed to limit the entry of a hazard into the triangle by reducing its probability of occurrence. The second type is the precautionary control measure, which is designed to limit the movement of the hazardous event within the triangle. This second type reduces risk by reducing the severity of the hazard if it occurs.

Consideration of hazards in terms of their probability of occurrence and severity of consequence provides the general rationale for performing all safety risk assessments, which are undertaken as follows:

1. Estimate the probability of a hazard's occurrence, i.e., its frequency, and its probable severity if it does occur;
2. Evaluate the risk associated with the hazard based upon the frequency and severity estimations; and
3. Respond to the hazard by implementing suitable control measures.

The accident causation and risk control scenario discussed above has one major assumption: that the hazard is identified in the first place. If a hazard is not identified it will have:

1. Complete freedom of entry into the triangle, i.e., the hazard will have an uncontrolled probability of occurrence; and
2. Complete freedom of movement within the triangle, i.e., the hazard will have an uncontrolled severity if it does occur.

The remainder of this paper will discuss firstly an investigation into the quantification of this problem and secondly proposals on how it may be overcome.

## Hazard Identification Levels in U.K. Construction

There is a problem in that an individual is unlikely to possess all the knowledge and experience required to identify every potential hazard associated with the often broad scope of work defined in the method statement. This leads to the uncontrollable situations described previously whereby nonidentified hazards lead to noncontrolled risks. A hypothesis can therefore be presented that this is a serious problem within the industry and that current levels of hazard identification are far from ideal.

To test this hypothesis, investigations into hazard identification levels have been initially targeted on three different industry sectors: U.K. rail, nuclear, and general construction. Three projects were chosen for the investigations. At the time of writing all of these projects were still "live" which means they cannot be directly identified. The first was a £35 million rail project, the second was a £150 million nuclear project, and the third was a £200 million project that involved work within both rail and general construction sectors. In order to measure the level of hazard identification on these projects it was first necessary to establish an objective procedure for doing so. Each project was then investigated in an intensive manner which varied between 2 and 4 months during which time 15 method statements were scrutinized to determine their hazard identification levels.

### *Procedure for Establishing Hazard Identification Levels*

Method statements are the documents that, amongst other areas, detail safe systems of work. One of their aims is to identify hazards relating to discrete sections of work and to perform a risk assessment for those hazards; they provide, therefore, an indication of the level of hazards identified for that work. As indicated above, the procedure established is centered on actual method statements prepared on these projects and follows the following five steps.

*Step 1: Data collection*. Method statements were collected from the construction projects. Construction activities are many and varied so care was taken to select method statements relating to broadly similar types of work across the three projects. All of the method statements analyzed described work relating to one or more of the following areas:

1. Concrete work;
2. Steel work;



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3. Earth work; and
4. Brick work.

The above information allows determination of hazards actually identified. Data is also required indicating all potential hazards and this was taken from two main sources:

1. Construction industry publications, such as the Construction Health and Safety Manual and the Construction Industry Training Board Manual; and
2. Information held by the contractor operating on both projects, such as project risk logs, the safety section of the company intranet, and other safety related data held on the individual projects.

It is important that knowledge is not applied in retrospect—activities would always be done in a different manner as later knowledge is gathered. By considering this pool of "current knowledge," an attempt is being made to assign a measure of the potential level of hazard identification. It is appreciated that it is unlikely to be achieved with 100% surety that all potential hazards are accounted for (indeed, it would never be known if this state were reached), therefore the aim is to achieve a benchmark level of hazard identification that can be used to compare different projects.

*Step 2: Method statement preanalysis*. The construction method is the part of the method statement that details the work to be done. It is essentially a list of discrete tasks to be performed by operatives on site. For each of these tasks the information sources were searched to determine which hazards were associated with a particular task. Some hazards were associated with more than one task, e.g., manual handling, so duplicate hazards were removed. This list indicates, assuming the sources of information to be comprehensive, the potential hazards associated with particular sequences of work. Finally, each potential hazard was examined to determine relevance, within the context of the method statement. This process resulted in a final shortlist of hazards that should have been identified from the sequence of work in the method statement.

*Step 3: Establish a hazard scoring system*. A scoring system had to be implemented in order to determine hazard identification levels numerically, taking into account both the identification and the assessment of hazards. Unfortunately, there are no suitable models for which to base such a scoring system within the relevant literature and so the following was established. The present state of knowledge in this research area is such that the relative importance of a hazard's identification and assessment are not widely understood and so the solution adopted was to assign equal importance to both of these parameters, reported as a proportional value, and thus there are three cases:

1. The hazard is identified and assessed—score of "1.0;"
2. The hazard is identified but not assessed—score of "0.5;" and
3. The hazard is not identified or assessed—score of "0.0." Such a score would also be given to the situation where a hazard was identified but then *deliberately* ignored. This would avoid such a rare event being given a score higher than is warranted. It should be noted that no such occurrences were found in this investigation.

If there is equal weighting on both *hazard identification* and *hazard assessment* then there is, technically, a fourth case of "The hazard is not identified but is assessed" but this is clearly not possible.

These scoring cases represent the underlying quantification of a hazard in terms of its identification and assessment status. In order to determine this status it is necessary to consider each hazard within the context of its method statement. Application of scoring cases to hazards is dealt with in Step 5. In order for hazard identification levels to be determined these scoring cases need to be clearly defined. It should be clear what the term *identified* means but the term "assessed" requires clarification. This is dealt with in the next step.

*Step 4: Determination of the reasonably practicable risk*. Risk assessment philosophy (British Standards Institute 1996) dictates that the meaning of the term "assessed" is fundamentally related to the notion of "reasonably practicable" (Health and Safety Executive 1994), i.e., the level of consideration and response, or assessment, of the hazard should be consistent with the risk posed by that hazard. To put it another way, risk governs the level of response necessary for a hazard to be deemed "assessed." Within a method statement there is clearly a risk value that acts as a cutoff point for inclusion of hazards within the risk assessment. This value is called the "reasonably practicable risk" (RPR) and is established in the following way:

1. Examine the risks associated with hazards that appear in the formal risk assessment to determine the minimum risk value; and
2. Assume that this risk value represents the limit of reasonable practicability, i.e., this is the RPR. Considering the nature of the risk assessment process and legislature surrounding the process, this is a fair assumption.

Therefore the meaning of "assessed" is dependant upon the RPR. If a hazard's risk is greater than or equal to the RPR then the hazard would have to be included in the formal risk assessment in order to be considered "assessed." If a hazard's risk is lower than the RPR then it does not necessarily need to be included in a formal risk assessment to be considered "assessed;" upon estimating the risk and weighing that against response the engineer may conclude that formal assessment is not warranted. According to allowances made in the legislature surrounding the risk assessment process this hazard would still be deemed "assessed."

*Step 5: Determination of hazard identification levels*. This would be accomplished by calculating the *hazard identification index* (HII) for a method statement. Broadly, this index is defined as

$$\mathrm{HII} = \frac{H_1}{H_0} \tag{1}$$

where $H_0$ represents the total number of relevant hazards in a method statement and $H_1$ represents the combined identification and assessment status of those hazards. Therefore if the total number of potential hazards in a construction method were $x$ and if all had been both identified and assessed (thus obtaining a score of "1" per hazard) then $H_0 = H_1 = x$ and $\mathrm{HII} = 1$, the best possible rating.

Initial studies by the writers concluded that no single value could adequately describe the level of hazard identification in method statements. This was due mainly to the fact that such a value would have to take account of both the hazards explicitly covered in the method statement and those that were not. The solution was to calculate two values of HII that place limits on the level of hazard identification. $\mathrm{HII}_{\mathrm{min}}$ took account of hazards that were explicitly included in the method statement; this value represents the lower limit for the level of hazard identification in a method statement. $\mathrm{HII}_{\mathrm{max}}$ took account of those same hazards plus hazards that were relevant but not explicitly included in the



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method statement; this value represents the upper limit for the level of hazard identification in a method statement.

Hazards are quantified in terms of their identification and assessment status according to the scoring cases described in Step 3. In order to apply these scoring cases successfully two factors need to be considered for each hazard within each method statement. The first is the hazard's location within the method statement. The second is the risk of the hazard in relation to the RPR for the method statement. Based upon consideration of these factors it was found that each shortlisted hazard could be placed into only one of five possible categories. Each of these categories was matched with one scoring case for $HII_{min}$ calculations and one for $HII_{max}$ calculations, thus allowing the hazards to be quantified. The categories and associated scores are

1. *The hazard appears in the formal risk assessment*. Clearly, hazards in this category were explicitly identified and assessed. Thus a score of "1.0" was assigned to these hazards for both $HII_{min}$ and $HII_{max}$ calculations.
2. *The hazard appears elsewhere in the method statement and has risk greater than or equal to the RPR*. Hazards in this category were identified but, according to Step 4, they were not assessed. This means that scoring case 2 is appropriate so a score of "0.5" was assigned for both $HII_{min}$ and $HII_{max}$ calculations.
3. *The hazard appears elsewhere in the method statement and has risk lower than the RPR*. Hazards in this category were identified but there is no evidence to either confirm or deny that the hazard was assessed (see Step 4). This posed the problem of there being two plausible scoring cases for this category. The adopted solution was to assume that the hazard was assessed, i.e., give the engineer the benefit of the doubt. This approach ensures that results from this research would underestimate the lack of hazard identification rather than overexaggerate it. Thus scoring case 1 became the only choice and a score of "1.0" was assigned for both $HII_{min}$ and $HII_{max}$ calculations.
4. *The hazard does not appear anywhere in the method statement and has risk greater than or equal to the RPR*. $HII_{min}$ is only concerned with hazards that were explicitly contained within the method statement, i.e., $HII_{min}$ represents the lower limit of hazard identification. From a different perspective, $HII_{min}$ reflects hazard identification levels minus any "benefit of the doubt" assumptions made on nonexplicit data. Thus a score of "0.0" was assigned for $HII_{min}$ calculations. Now to deal with $HII_{max}$. According to Step 4, the hazard should have been in the risk assessment in order to be deemed "assessed." Although there is no direct way to establish from the data if the hazard was identified there are only two possible explanations for the lack of assessment, which indirectly determine the identification status of the hazard. The first is that the hazard was not actually identified thus making assessment impossible. The second is that the hazard was identified but the engineer decided not to respond to the hazard despite its risk. The reasons for this second explanation would be impossible to determine—they could range from a deliberate violation to a simple oversight—but the outcome is the same in that there is the lowest possible score for the hazard identification level, i.e., "0.0" was assigned for $HII_{max}$. This is covered in the definition of scoring Case 3.
5. *The hazard does not appear anywhere in the method statement and has risk lower than the RPR*. A score of "0.0" was assigned for $HII_{min}$ calculations for the same reason detailed in Category 4. For $HII_{max}$ calculations all three scoring cases are plausible; there is no evidence to either confirm or deny that the hazard was identified and assessed. In line with the approach taken in this procedure both identification and assessment had to be assumed. Thus a score of "1.0" was assigned for $HII_{max}$ calculations.

**Table 1.** Hazard Identification Levels for Method Statements Analyzed on Three Projects

| Project A (rail) | | Project B (nuclear) | | Project C (general/rail) | |
|---|---|---|---|---|---|
| $HII_{min}$ | $HII_{max}$ | $HII_{min}$ | $HII_{max}$ | $HII_{min}$ | $HII_{max}$ |
| 0.682 | 0.773 | 0.881 | 0.881 | 0.368 | 0.421 |
| 0.714 | 0.762 | 0.875 | 0.875 | 0.368 | 0.421 |
| 0.867 | 0.867 | 1.000 | 1.000 | 0.579 | 0.632 |
| 0.632 | 0.684 | 1.000 | 1.000 | 0.900 | 0.900 |
| 0.694 | 0.694 | 0.929 | 0.929 | 0.684 | 0.737 |
| 0.565 | 0.609 | 0.813 | 0.813 | 0.731 | 0.808 |
| 0.767 | 0.900 | 0.813 | 0.813 | 0.679 | 0.688 |
| 0.735 | 0.735 | 0.875 | 0.875 | 0.636 | 0.818 |
| 0.769 | 0.846 | 0.833 | 0.833 | 0.618 | 0.676 |
| 0.714 | 0.714 | 0.794 | 0.853 | 0.500 | 0.556 |
| 0.708 | 0.708 | 0.857 | 1.000 | 0.559 | 0.618 |
| 0.816 | 0.868 | 0.867 | 0.867 | 0.450 | 0.600 |
| 0.526 | 0.526 | 0.867 | 0.867 | 0.324 | 0.618 |
| 0.559 | 0.559 | 0.938 | 0.938 | 0.611 | 0.778 |
| 0.679 | 0.679 | 0.938 | 0.938 | 0.633 | 0.700 |
| Mean | | | | | |
| 0.695 | 0.728 | 0.885 | 0.899 | 0.576 | 0.665 |

Note: Each row represents a method statement analyzed to determine its $HII_{min}$ and $HII_{max}$. Fifteen such method statements were analyzed for each project.

Finally, $HII_{min}$ and $HII_{max}$ for each of the 15 method statements for each project were calculated by summing the respective scores assigned to each shortlisted hazard in the method statement and dividing those sums by the total number of shortlisted hazards. Table 1 indicates the scores and averages for each of the three projects. Thus $HII_{min}$ and $HII_{max}$ are reported as proportional values on a scale of 0.000 (0.0%), which indicates the theoretical minimum level of hazard identification, to 1.000 (100.0%), which indicates the maximum possible level of hazard identification for a method statement.

## *Analysis of Results Obtained*

Is there a lack of hazard identification within the industry? Qualitative analysis of the results shown in Table 1 show that only two (4.5%) of the method statements analyzed achieved a perfect $HII_{min}$ and only one additional method statement achieved a perfect $HII_{max}$, even allowing for the "benefit of the doubt" approach adopted in the above procedure. Mean $HII_{min}$ for Projects A, B, and C were 0.695, 0.885, and 0.576, respectively. Corresponding mean $HII_{max}$ were 0.728, 0.899, and 0.665.

Quantitative analysis took the form of two-sample $t$-tests assuming unequal variances, $p < 0.05$. First, hazard identification levels for each project were compared with each other. Comparisons were made between all possible pairings of projects: AB, AC, and BC. The $t$-tests would determine if there was a significant difference between the mean hazard identification levels of the projects; they would also determine the magnitude of any difference. Hypothesized mean differences between $HII_{min}$ for



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pairs AB, AC, and BC were 0.129, 0.022, and 0.219, respectively. Differences between $HII_{max}$ for pairs AB and BC were 0.101 and 0.152; there was no statistically significant difference between $HII_{max}$ for pairing AC. These results show that hazard identification levels differed across the three projects. Second, hazard identification levels for each project were compared to a "control" project in which a perfect level of hazard identification was achieved, i.e., for this control project all $HII_{min}$ and $HII_{max}$ values were set to 1.000. The hypothesized mean differences between $HII_{min}$ for the control roject and Projects A, B, and C were 0.252, 0.079, and 0.338, respectively. Values for the corresponding $HII_{max}$ were 0.209, 0.065, and 0.259.

These results show that the $HII_{min}$ and $HII_{max}$ for all three projects were significantly different from those of the control project and, further, that there is a significant lack of hazard identification within the industry.



### *Barriers to Improving Hazard Identification*

The analysis above indicates that a significant quantity of hazards on the projects investigated remained unidentified. Based on the assertion given earlier in the paper that unidentified hazards provide uncontrollable situations it can be concluded that a substantial problem exists in the first step of the risk assessment process.

Based upon the above analyses and discussions and also the extended time spent on the three construction projects with safety and construction management professionals, the writers believe that, within the scope of this research, the following barriers exist to improved levels of hazard identification:

1. Knowledge and information barriers:
   - Lack of information sharing across projects;
   - Lack of resources on smaller projects, e.g., industry publications, full-time safety department, etc.;
   - Subjective nature of hazard identification and risk assessment; and
   - Reliance upon tacit knowledge.
2. Process and procedures barriers:
   - Lack of standardized approach; and
   - Undefined structure for tasks and hazards.

### *Overcoming Barriers to Improving Hazard Identification*

Knowledge management (KM) can accomplish this. The same experiences that enabled the above barriers to be stated indicate that the information required to improve hazard identification levels already exists, albeit in a fragmented state. The problem is that the individual creating the method statement is not usually able to obtain all the necessary information due to the existence of the aforementioned barriers. Implementing the concept of KM into a practical system to provide such information to the individual is key to improving hazard identification.

#### Overcoming Knowledge and Information Barriers

First, existing explicit knowledge, i.e., knowledge contained on hard-drives and other "real" sources, needs to be pooled together in a central source. This will begin to solve the problem of poor sharing of information and lack of resources.

Second, the system built around the data source must tap into "tacit" knowledge:

> "At least 90% of the information you need is, in the lingo of the business, "tacit." In other words, it lives inside the heads of people, not on hard drives or in filing cabinets somewhere." (Hewson 1999)

and allow it to be transformed into explicit knowledge, thus making it available to any individual. This is perhaps the most important requirement.

Third, the system should incorporate as much embedded knowledge, i.e., "hidden" knowledge contained within processes and procedures, as is practicable while still being flexible enough to adapt to the unique nature of individual construction projects. With such a system, even a relatively inexperienced engineer on a small construction project should have the capability to access the wealth of information held within the organization and to take advantage of safety data gathered by larger projects that have greater resources.

#### Overcoming Process and Procedures Barriers

The barriers here exist because, although method statements and associated risk assessments are widely accepted as the standard means of planning for safety, there is no standard structure or process for creating these documents. In addition, levels of detail within the construction method and the risk assessment can vary substantially between individual method statements even on the same construction project, depending upon the individual who creates the document. A clearly defined structure for developing the construction method and risk assessment needs to be established.

## System for Hazard Identification Improvement

It has been established that unidentified hazards present difficult situations for construction projects and that, for three significant projects, ideal levels of hazard identification were not achieved. Based on the hypothesis that barriers exist to improve these levels the work was continued to develop a new system of hazard and risk management, *Total-Safety*.

### *Overview of Total-Safety*

An IT tool, Total-Safety exists as a data-driven website. The intention is to have a tool that is available on virtually every construction project within an organization; an application that is platform independent and used within an ordinary web browser allows this to be achieved without the need for high-specification hardware and specific software. It continues to be developed using *Macromedia ColdFusion (CF)* (Forta 1998), a commercially available web application server.

The overall system has a three-tiered structure (Fig. 2). The first tier is the client side of the system, or user interface, and is accessible to users via a standard web browser. Individual web pages are produced using the *ColdFusion Markup Language (CFML)*, which *Macromedia* modeled on the *Hypertext Markup Language (HTML)*. The second tier contains the *CF* server, which is essentially part of the normal web server. When the browser requests a *CFML* page, the *CF* server processes the code and connects with backend systems, e.g., databases or *Excel* files, to manipulate any required data. The *CF* server then dynamically generates the page in standard *HTML* format, which the normal web server then sends back to the client. The client can view this *HTML* page on any standard Internet browser. The third tier consists of a central safety database, which does not have to be on the same server so long as *CF* knows where to find it. *CF* connects to



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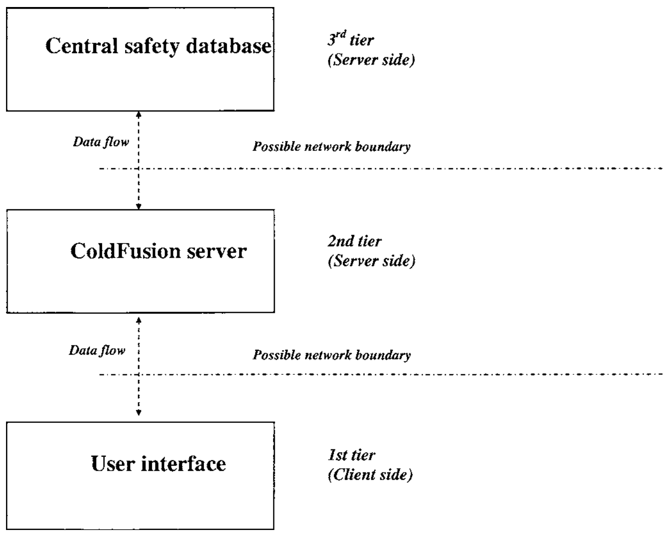


**Fig. 2.** Design structure of Total-Safety



the database, created in *Microsoft Access*, via Open Database Connectivity (ODBC). *CF* is an ODBC client so the *Structured Query Language (SQL)* is used to interact with the database. In plain English, all of this means that the user has the power to view, update, insert, or delete data from the database using a web-based interface.

As a two-way tool it is intended to facilitate the flow of tacit knowledge throughout an organization; in short, to allow tacit knowledge to become explicit knowledge. In terms of human versus computer control, Total-Safety can also be described as a decision support system. It is intended to present the user with the best knowledge available at that time upon which to base decisions.

> "The days when people thought computers alone could solve complex business problems are passing rapidly. So-called expert systems have failed to deliver the goods." (Hewson 1999).

Therefore, with Total-Safety, the user still maintains control, i.e., it is not an expert system with strict and inflexible decision making rules. This makes database design important. The database is split into generic and specific parts. The generic part contains all of the basic data, such as tasks, hazards, control measures, etc. It also contains the underlying relationships between the data, such as those between tasks and hazards, etc. The specific part of the database contains user decisions. For example, when creating a method statement, the user will access information contained within the generic part of the database and modify it, or fine-tune it, to the needs of the particular project and the particular package of work defined in the method statement. The user is given all available knowledge with which to make decisions but the system does not take decision control away from the user.

Total-Safety currently exists with two sections, or *modules: Safety Database Management* and *Method Statement Development*. The *Safety Database Management* module maintains the generic part of the database while the *Method Statement Development* module allows users to create method statements using the generic data as a starting point. This module will now be discussed in more detail.

## *Method Statement Development Module*

In the context of developing a safe system of work, the two fundamental components of a method statement are the construction method and the risk assessment. This module enables users to create methods and perform task-based risk assessments, with the benefit of the central safety database.

### Construction Method

The construction method is a discrete list of tasks that describe the work outlined in the scope of the method statement. Before this part of the method statement development module is demonstrated two questions must be answered.

The first question is: how are the tasks structured? The writers are using a structure analogous to that of project work-breakdown structures, which are usually split into three levels, although sometimes four or five levels are required for larger projects. The first two levels are intended for reporting purposes only. They summarize broad areas of work and can be thought of as categories and subcategories. The third level is usually the "working" level at which method statements for particular packages of work are defined. Occasionally this level needs to be broken down into even smaller units within a detailed work-breakdown structure. In the Total-Safety prototype, four task levels are defined. Task Levels 1 and 2 represent categories and subcategories. Task Level 3 represents the "method-level tasks," or just "tasks" for simplicity. Task Level 4 is the most detailed task level and is intended for managing task-hazard relationships within the safety database management module of Total-Safety.

The second question is: what is a task? The writers are using a definition for task inspired by a particular definition for a gene (Dawkins 1989). A task is a package of work small enough to be distributed throughout many method statements without any significant distortion to the basic task description. The more likely the particular package of work is to be distorted or broken up by variations within different method statements, the less it qualifies to be called a task within the context of this definition. The only property that a task requires to be a task is high copying-fidelity. In the context of this research that means analyzing historical method statements and identifying Level 3 Tasks as those that consistently appear within the method statement methodologies.

The initial step in preparing a construction method is to select a Level 3 Task for inclusion. The user is then shown the current construction method for that method statement (Fig. 3). From this screen the user can continue to add more tasks, delete tasks, reposition tasks within the method, and add specific text to the tasks. As previously discussed, these operations do not affect the contents of the generic database. The contents of a method statement reside within the specific database so changes will only affect that particular method statement. When satisfied, the user clicks a button to start the risk assessment process.

### Task-Based Risk Assessment

> "A risk assessment is nothing more than a careful examination of what, in your work, could cause harm to people, so that you can weigh up whether you have taken enough precautions or should do more to prevent harm." (HSE 1998)

Task-based risk assessment groups hazards by each task, thus maintaining the task-hazard relationships in the assessment. The



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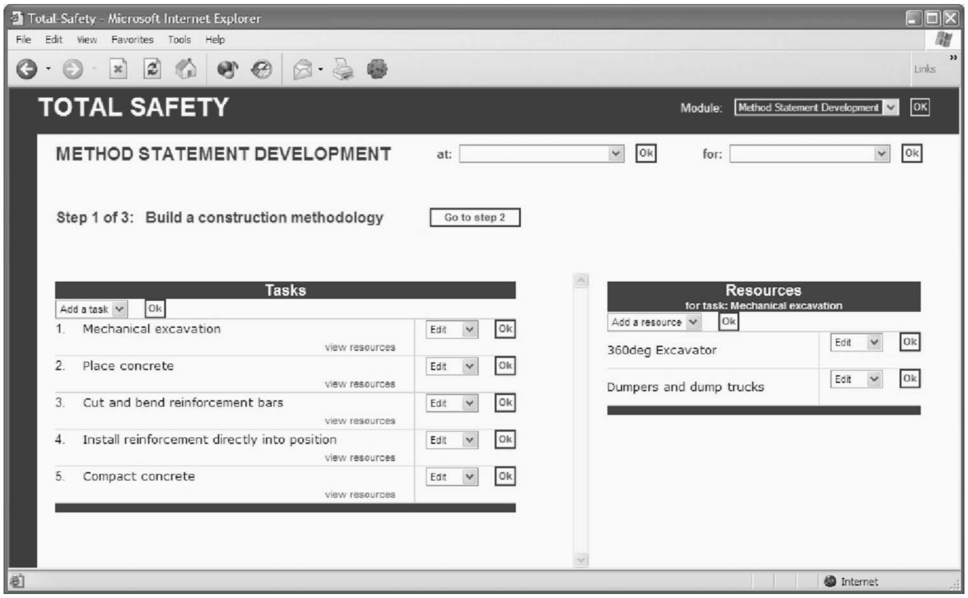


**Fig. 3.** Total-Safety: Construction method screenshot

hazards can be examined in the context of the associated task, as opposed to generating a shortlist of hazards from the method and then examining them in an abstract and isolated manner. Most risk assessments studied during this research were of the "task-based" type.

Some terms need to be defined and explained before this part of the module is demonstrated. The structure for this part of the module is based upon Fig. 1. A hazard is defined as

> "A source of potential harm or a situation with potential for harm in terms of human injury, damage to property, damage to the environment or a combination thereof." (International Electro-technical Committee 1990)

As previously discussed, the occurrence of a hazard is termed a *hazardous event*. How do hazards become events? A facilitator is required, i.e., something that can tie hazards to physical operative acts. This is called an *event method*, and is defined as

> "A mechanism by which the hazard can occur."

Now the module can be demonstrated. The initial screen in the risk assessment part of the module shows the user all hazards and event methods associated with each task in the method, along with an assessment status indicating which of the event methods have been examined (Fig. 4). At this point the user has the option to add specific hazards and event methods to the existing lists obtained from the generic database. The user can perform a detailed assessment by selecting the event method. At this stage the user has two choices: (1) assess the event method, which includes it in the final printed risk assessment, or (2) disregard the event method, which excludes it from the final risk assessment. If the event method is to be assessed, the user can estimate risk and add, edit, or delete possible events and control measures to the existing lists. When satisfied, the user clicks a button to return to the initial screen; when all event methods have been examined, i.e., either assessed or disregarded, the user is given the option to print out the now completed method statement document.

### *Practical Use of Total-Safety and "Face-Validity"*

Feedback from safety and construction management professionals has occurred at regular intervals during the development of Total-Safety, most recently during the extended visit to Project C. Such an exercise is important at this stage in the development of the tool and allowed the tool to be refined and improved.

Such an exercise also worked towards validation of the tool. In general terms validation allows comparison of the output of a system or model to be compared to the output from a real system. If the comparison is favorable then confidence in the future accuracy of the system is improved. For many model development exercises, validation is a crucial aspect and a model cannot be considered complete and successful without it. However, the Total-Safety system is not a "model" in that it will not attempt to provide a definitive answer to a problem, but merely supply information to allow informed decisions to be made. Nonetheless, confidence in the tool is needed and thus a feedback exercise is, in effect, an investigation into its *face-validity* (Naylor and Finger 1967). Face validity was initially devised as a concept in the validation of computer simulation models and allows users of the system being modeled to review its "reasonableness" (Law and Kelton 2000, p. 281). Potential users of the tool and those who are experienced in the system being investigated are invited to test it out and determine whether its output is consistent with perceived behavior. In this case users would see if the tool matched their own knowledge of hazard management and that it suggested relationships between activity and hazard which can be seen to be valid. In addition the potential users would note whether or not it would allow them to be more effective in their management of hazards and risks.

The following are excerpts from an "end of visit" report produced by site management. The full report is not given here but we conclude that, after modifications were made, reasonable face validity was achieved. It should be noted that not all comments were generally positive and these were welcomed:



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**Fig. 4.** Total-Safety: Risk assessment status screenshot

"To summarise we believe that this system will provide the authors and checkers of Method Statements and Risk Assessments with a tool to enable them to produce a thorough and complete assessment of hazards and risks associated with a specific operation. It will also allow for standardisation in the format of these documents."

"We also believe this system will have a net benefit in terms of time saved and risk management for [Company Name Deleted] and the industry as a whole."

"Our concern that the tool would encourage the production of method statements by rote, without requiring proper assessment of risk by a competent engineer is unfounded."

"Significant work is required to incorporate sufficient information into the database, and to make the tool simpler and faster to use."

These comments are encouraging from a safety management perspective. The first comment indicates that the system does have the potential to improve the quality of method statements, specifically the identification and assessment of hazards associated with the work. The comment regarding time savings indicates that the system also possesses nonsafety benefits in the form of reduced costs associated with producing method statements; this may turn out to be a significant benefit since construction projects of the size visited usually require production of between 200 and 500 individual method statements. The earlier statement that this is a flexible decision support system, not a strict decision making expert system, is validated by the third comment. The final comment reflects the fact that research and development of Total-Safety is ongoing. The objective of this research project was to produce a prototype system capable of demonstrating its role in improving hazard identification and the subsequent assessment of risk. Continued development will bring Total-Safety to the stage where it can be fully implemented within the company and the industry.

## Conclusions

The management of hazardous events is key to construction safety and this paper has presented a procedure to determine hazard identification indices that can be used as a measure of the degree of hazard identification within historical method statements. Broadly, the indices are obtained by comparing the number of hazards actually identified and assessed to the number that should have been identified and assessed, given currently available knowledge. The writers found that mean $HII_{min}$ and $HII_{max}$ for a construction project within the nuclear sector were 0.885 and 0.899, respectively. Values for a project within the railway sector were 0.695 and 0.728, while values for a project straddling both railway and general construction sectors were 0.576 and 0.665. There are two main conclusions to be drawn from the analysis.



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- Hazard identification levels are considerably lower than "ideal" for three construction projects within separate industry sectors. This is based on the current level of knowledge.
- There are significant differences between hazard identification levels achieved on the three projects. The project within the nuclear sector had the best performance while the project within both the railway and general sector had the worst performance in terms of the level of hazards identified.

This paper introduced a method statement development module within an IT tool called Total-Safety. The purpose of the module is to help engineers produce method statements with higher levels of hazard identification. This is achieved using a central safety database that contains knowledge relating to safety that exists within the organization as a whole, that is construction tasks, hazards, and the relationships between them. The principle is that when an engineer creates a construction method, Total-Safety will return all possible hazards associated with those tasks within that method. The engineer can then perform a risk assessment based upon the best available knowledge instead of existing procedures that rely upon tacit knowledge, subjective opinions, limited safety documentation, etc.

It has been proposed that there are two main types of barrier to improving hazard identification: knowledge and information barriers, and process and procedure barriers. Total-Safety overcomes the first barrier by utilizing the central safety database capable of containing the combined knowledge and experience of all personnel within the company, together with safety data from industry publications, project safety files, etc. The method statement development module within Total-Safety overcomes the second barrier by allowing the user to develop a construction method and perform a risk assessment in a structured and comprehensive manner. The end result is method statements with improved levels of hazard identification.

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