DECISION SUPPORT TOOL FOR THE QUANTIFICATION OF FAULT RATES IN CONSTRUCTION FALL ACCIDENTS

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After the occurrence of construction work accidents, expert witness reports received with the aim of quantifying fault rates among parties, play an important role on the court's final decision. However, conflicting fault rates assigned by different expert witness groups for the similar cases are quite common practice, leading to unnecessary and iterative objections raised by the related parties until a consensus among reports has been reached. This unfavourable situation mainly originates due to subjectivity of expert judgments and unavailability of objective information about the causes of accidents. This paper proposes a decision support tool (DST) for the quantification of fault rates in construction fall accidents. The aim of developed DST is to eliminate the contradiction between fault rates assigned by different experts and decrease subjectivity prevailing in expert witness reports. For this purpose, 84 inspection reports prepared by the inspectors of Ministry of Labour and Social Security have been investigated and root causes of construction fall accidents in Turkey have been identified. By using this information, an evaluation form has been designed and submitted to experts. Experts are requested to evaluate the importance of the factors that govern fall accidents and determine fault rates under different scenarios. Based on expert judgments, a rule-based DST has been developed which may enable a decision maker to arrive at an objective conclusion about fault rates of parties involved in construction fall accidents. The proposed DST has been tested with the most frequently occurring cases in Turkey and satisfactory results have been reached.

Keywords: construction accidents, expert systems, safety.

INTRODUCTION

Improving occupational safety has been a major goal for all industries, particularly for the construction industry due to its hazardous nature. The statistics published by the Turkish Social Security Organization reveal that in the year 2003, 811 occupational fatalities were reported for all industries. When the distribution of these fatalities is analysed, construction industry appears to be the most hazardous one since 34% of the fatalities have been reported from the construction jobsites. In addition to the number of fatalities, the number of nonfatal injuries reported from construction jobsites is also high. Failure in managing construction safety results in worker injuries and impacts on financial losses, human conflicts and civil penalties (Hadikusumo and Rowlinson 2004). In order to maintain the safety of workers, governments set regulations and

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Birgonul, M T, Dikmen, I and Demirel, T (2005) Decision support tool for the quantification of fault rates in construction fall accidents. *In:* Khosrowshahi, F (Ed.), *21st Annual ARCOM Conference*, 7-9 September 2005, SOAS, University of London. Association of Researchers in Construction Management, Vol. 2, 1027-36.

supervise the jobsites to check whether employers comply with the regulations or not. However, occupational accidents are still a serious problem. Some of the main causes of accidents could be listed as; insufficient knowledge of employer and workers, insufficient supervision of jobsites by governmental organizations, inadequate punishment/compensation mechanisms enforceable to employers when failing to implement safety issues.

Each work accident has to be evaluated within its specific enabling factors, while arriving to a conclusion for the determination of fault rates and associated responsible parties. Thus, accident investigations are generally conducted either by the inspectors of governmental institutions or expert witnesses, whose field of expertise is construction safety.

The expert witness reports, submitted to courts are the essential tools for the judges while coming to a final decision both in criminal and compensation cases. However, apart from the very common and obvious cases, one expert witness report is not usually sufficient for the judge before arriving to a conclusion, as either the plaintiff or the defendant could object to this report. These objections are usually made to the fault rates assigned to the parties who are considered to be faulty for the occurrence of that accident. If the court decides that these objections are reasonable, then a supplementary report could be demanded from the same expert witnesses addressing the objections. In case that this report is found inadequate by the judge or there exist further objections, then a different team of experts are called for the duty of preparing a new report. Although the same governing laws and regulations are utilised by the experts, the final output achieved which is the quantification of fault rates might display great fluctuations due to the subjective nature of expert judgments. Within this context, the main goal of the proposed DST, named as dsSafe (Demirel 2005) is to eliminate these contradictions by setting standards for the quantification of fault rates.

Researchers have proposed different methods to handle legal disputes. Hadipriono (2001) has investigated a fall accident to determine the most probable causes using fault tree analysis. Arditi et al. (1998) have proposed a model to predict outcomes of construction litigation using neural networks. Arditi and Tokdemir (1999) have conducted a different study with the same data using case based reasoning for the prediction of construction litigation. The aim of these two studies is to predict the outcome of construction litigation with reasonable accuracy and reliability, thus to save considerable money and time. dsSafe, which is the subject of this paper, is an expert system application that uses an innovative approach to handle legal disputes arising from the quantification of fault rates in fall accidents.

DATA COLLECTION AND KNOWLEDGE ACQUISITION

The first part of the research has been conducted in order to identify the causes of accidents. With this purpose, previously written inspection reports that have been kept in the archives of Ministry of Labour and Social Security have been requested. Out of the received 117 construction related inspection reports, 84 of them found to be related to construction fall accidents. A more detailed investigation of accidents under this category indicated that, the most frequently occurring fall types of accidents are; falls from the edge of floors, falls from scaffoldings, falls from roofs, falls through floor openings, falls from ladders and falls from utility poles, respectively. Therefore, the scope of the proposed DST has been limited with the investigation of these 6 types of construction fall accidents. After this classification, the primary and secondary causes of the accidents, which have been considered within inspection reports, have been identified. It has been observed that, although the secondary causes of accidents are similar for each type of accident, the primary causes show great variance from one accident type to another, according to the location and characteristics of each accident. As an example, the lack of medical report is a common factor (secondary cause) that is applicable to each type of accident, whereas bad planking is a specific factor (primary cause) that has to be considered while evaluating fall accidents from scaffoldings only.

In the second phase of the research, after determination of all relevant factors specific to each type of accident, an evaluation form consisting of 60 scenarios has been designed. These evaluation forms have been submitted to 20 construction safety experts, who accepted to participate in this survey. Respondents have been asked to determine the importance levels of the factors associated with each type of accident and finally assign fault rates under developed scenarios. Experts have been requested to assign fault rates to the parties in percentages and also determine the importance levels of factors, over a scale of 0 to 10, where 10 corresponds to the highest importance level. Within this study, related parties who could be held responsible and assigned fault rates in the occurrence of any construction fall accident are collected under two broad categories. The first category is the employer main group that indicates the contractor firm, subcontractor firm, project manager, owner of contractor firm, owner of subcontractor firm, safety engineers. The second category is the worker main group that covers the victim/injured worker, other workers, foreman, operator. The force majeure events, where neither employer nor worker can be blamed for the occurrence of the accident, are excluded from the system. The received evaluation forms have been analysed and the fault rates of parties and the importance levels of each factor have been determined by calculating the weighted averages of values assigned in each scenario. The collected data have been used within the models developed for each type of fall accident.

PROPOSED DECISION SUPPORT TOOL – DSSAFE

Within the context of this research, an expert system has been constructed to represent the knowledge of experts for the quantification of fault rates. The constructed expert system is a knowledge-based expert system which is supported by rules. A knowledge-based expert system is defined as a computer program that contains heuristic knowledge and performs a task (such as design or interpretation) normally done by an expert (Allen 1992). dsSafe fully fits to this definition since it proposes fault rates to the parties and prepares an investigation report which explains the reasons why these rates are assigned to related parties.

Expert system is selected as the most appropriate artificial intelligence tool for the solution of the problem, as problem can be modelled by IF….THEN rules and additional input factors can be specified by the users. Performances of similar models that might be constructed by using other artificial intelligence tools such as case-based reasoning (CBR) and artificial neural networks (ANN) are expected to be low due to unavailability of sufficient input data to train those models and difficulty to modify those models in case additional factors are specified by the user. The expert system, dsSafe, has a higher explanation capability when compared with an alternative ANN system. The dsSafe proposes a report that explains the reasons why the calculated fault rates are assigned to corresponding parties.

The dsSafe investigates an accident by following the below given steps;

- Determination of the related parties
- Selection of the accident type
- Furnishing the system with necessary information
- Entering and defining additional information, if required by the user
- Determination/modification of importance levels of factors
- Quantification of fault rates and preparation of investigation report

MODELS DEFINED WITHIN DSSAFE

In dsSafe, the investigation of an accident is undertaken by pre-defined questions which follow a sequence. These sequences are defined within the models developed for each type of fall accident. Within the context of this paper, due to the page limitation, only the flowchart for fall accidents through floor openings is presented, as shown in Figure 1.

Each number appearing in the flowchart corresponds to a question that needs to be answered by the user. The question list for this model is presented in Table 1. As understood from the model, some of the questions are dependent to each other. These conditional questions should be considered together, otherwise system may ask illogical questions. For example, one of these conditional circumstances is related with safety belt. The system asks whether the employer provided safety belt or not, if the user answers that the employer provided the safety belt, then the system asks whether the worker used the provided safety belt or not, otherwise the system will not ask any question about the usage of safety belt.

At the bottom of the flowchart presented in Figure 1, the features of dsSafe are displayed. In case that any additional factor that has not been covered within the standard menu of the model has to be considered, this could be inserted to the system by making use of the “Add” button. The user could enter more than one factor, if he/she thinks that is important. However, the user should also define the corresponding importance level of the defined factors, as well as the fault rates of associated parties into the system. A screenshot of this feature is presented in Figure 2. Another feature of dsSafe is its flexibility to modify importance levels of the factors that are previously defined in the database. The system assigns default importance levels to the factors which are determined from the analysis of evaluation forms. However, the user has an opportunity to modify these levels according to his/her perception. A screenshot of this feature is shown in Figure 3.

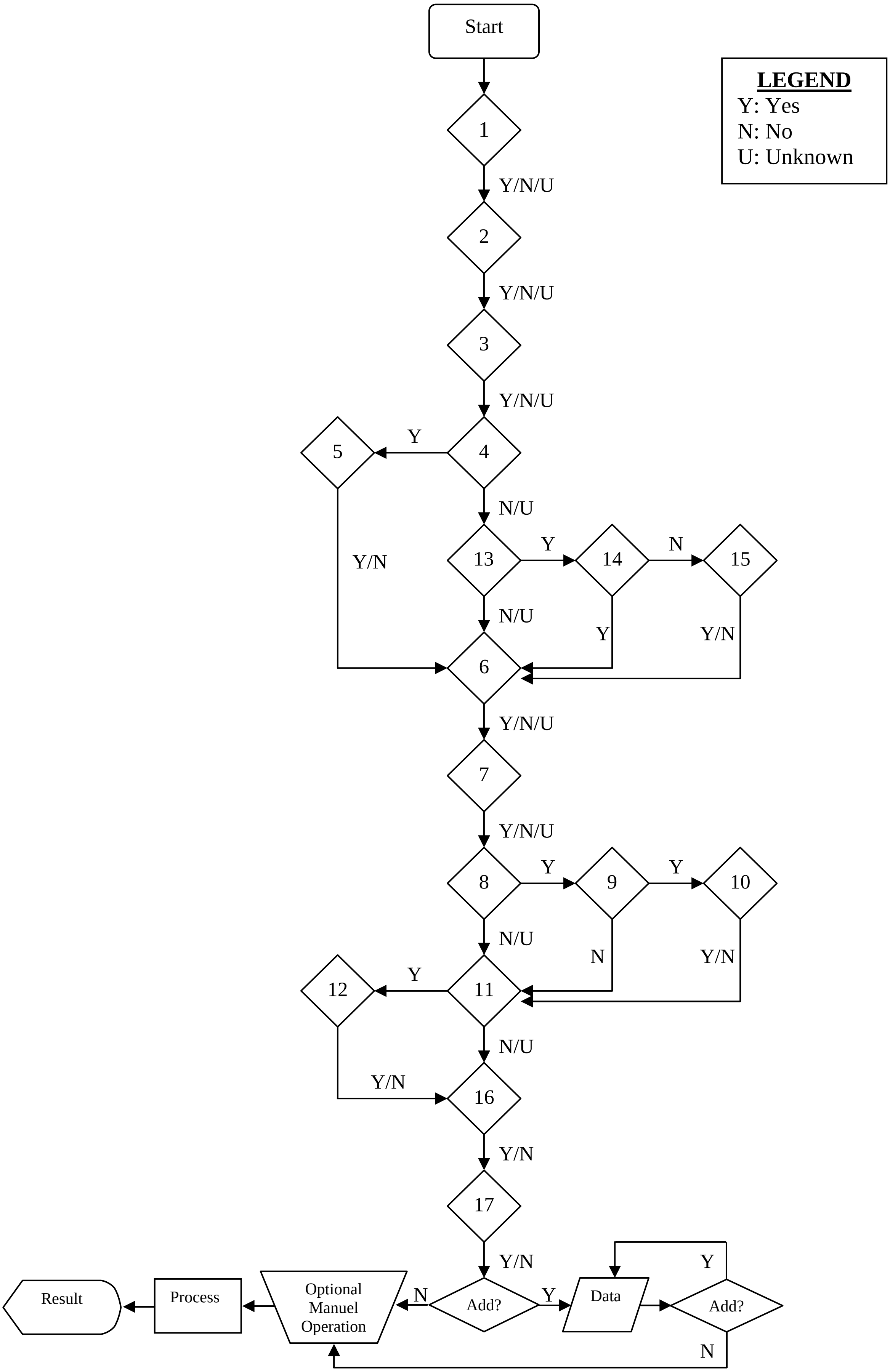

Figure 1: Flowchart for the analysis of fall accidents through floor openings

Table 1: Question list for the fall accidents through floor openings

No	Questions
1	Did the worker have medical report?
2	Was there any engineer responsible for construction site?
3	Was the worker an experienced person?
4	Was any available protection equipment removed from the jobsite?
5	Did the workers uncover the floor opening without informing the employer?
6	Did the worker fall due to his/her personal carelessness, in a moment of abstraction or while feeling dizzy?
7	Was the surrounding of the floor opening sufficiently illuminated?
8	Considering the type of work, was it required to provide safety belt?
9	Did the employer provide safety belt?
10	Did the worker use the safety belt?
11	Did the employer provide hard hat at the construction jobsite?
12	Did the worker use the hard hat?
13	Were there any fall prevention equipments present at the jobsite such as guardrails, work platforms or safety nets for preventing accident?
14	Did the accident happen due to the failure of these equipments?
15	Did the accident happen due to the slipping of these equipments?
16	Were there any warning signs informing about hazards?
17	Were the workers informed by the employer about the potential hazards of works?

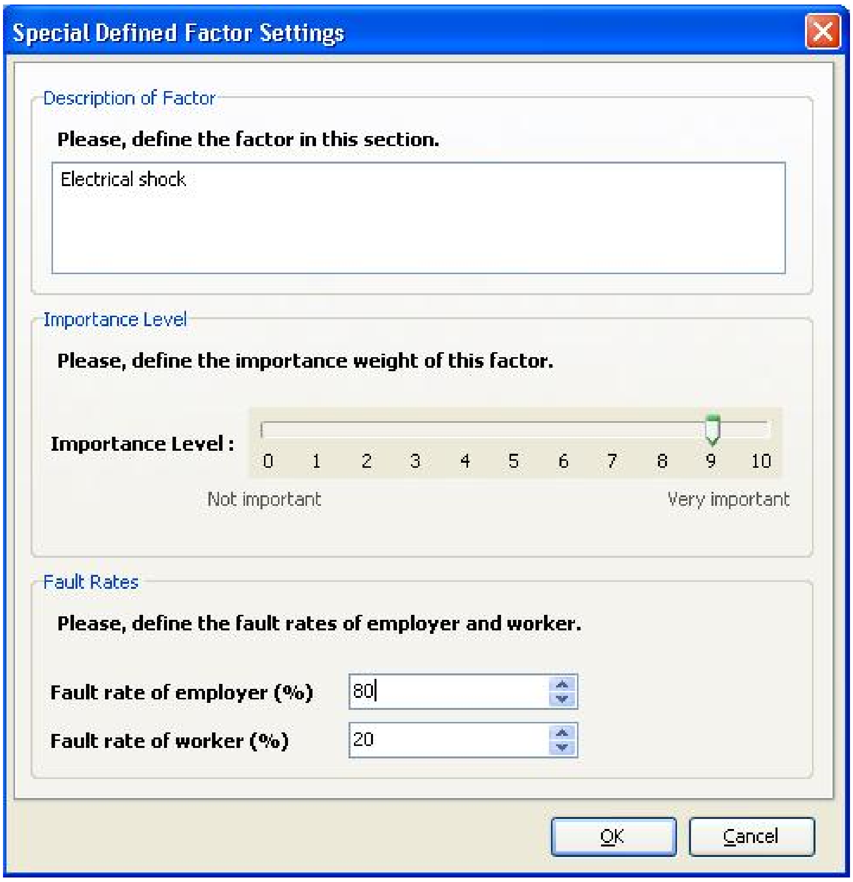

Figure 2: Defining additional factors to the system

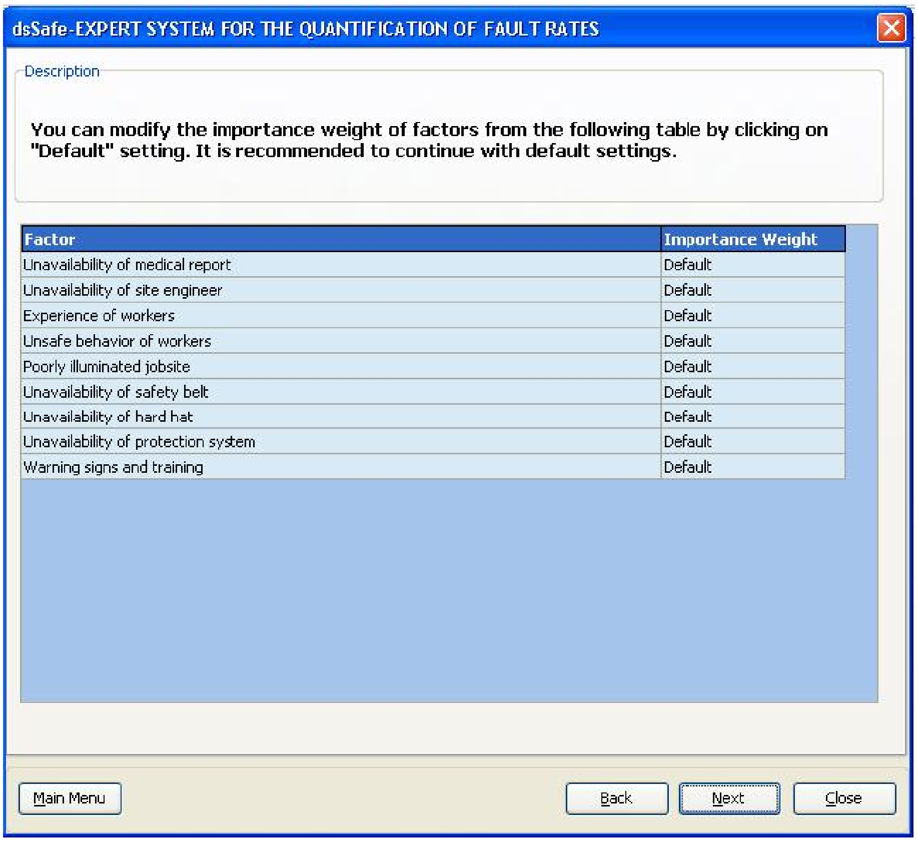

Figure 3: Modification of importance levels

METHODOLOGY FOR THE QUANTIFICATION OF FAULT RATES

As stated previously, the fault rates for each scenario defined within the models have been assigned by the experts. Together with the evaluation of the scenario, the experts have determined the importance levels of the factors related with those scenarios. A sample is presented below.

“Question: Did the worker have medical report? (Y/N/U)”

“Rule 1: If the user answers as “Yes”, then the fault rate of employer is zero and the fault rate of worker is zero.”

“Rule 2: If the user answers as “No”, then the fault rate of employer is 90 % and the fault rate of worker is 10 %.”

“Rule 3: If the user answers as “Unknown”, then the fault rate of employer is zero and the fault rate of worker is zero.”

In the above given example, there are three scenarios related with the existence of a medical report. Rule 2 shows the scenario that must be evaluated by the experts. As well as assigning fault rates to corresponding parties, experts are also requested to assign importance levels for the specified factors. In the above given example, respondents have evaluated the importance level of “Unavailability of medical report” by using the importance scale given in dsSafe. The fault rates assigned by the experts are based on governing laws and regulations.

The contribution of each factor to the quantification of fault rates is calculated by multiplying the fault rate of each party with the importance level of determined factor. Thus, the multiplied fault rate of each party is calculated for each factor. The total of multiplied fault rates of each party is obtained by accumulating the multiplied fault rates of all factors. The total of multiplied fault rate of each party is divided by the total fault rate of both employer and worker for the determination of relative fault rates of parties. A representation of this quantification is presented in Table 2.

Table 2: Quantification of fault rates

Factors	**Fault Rates (%)**		**Importance Level of Factor**	**Multiplied Fault Rates**	
	Employer	Worker		Employer	Worker
Lack of medical report	90	10	3	270	30
Unavailability of safety belt	90	10	9	810	90
Unsafe behaviour of worker	20	80	9	180	720
Absence of site engineer	70	30	4	280	120
			Total Multiplied Fault Rates	1540	960
			Relative Fault Rates	**62%**	**38%**

The factors listed at Table 2, depend on the answers which the user furnishes to the system. For example, if the user answers the question “Was there any site engineer at jobsite?” as “No”, the system displays this factor as “Absence of site engineer”. The system determines all of these factors depending on the answers of user and the fault rates of parties are quantified using these factors.

PREPARATION OF REPORTS

dsSafe prepares an investigation report based on the factors obtained from the answers furnished to the system. The current Labour Law (2003) and related regulations for occupational safety are all reviewed for the explanation of results. The factors and explanations of these factors are stored in the knowledge base of the system. The structure of the investigation report consists of three sections. The first section defines the parties to whom the fault rates will be assigned, whereas the other sections are “Determined issues and assessment” and “Decision” respectively. In the second section of the report, the factors are listed and explanations about these factors are displayed. For example, if the system recognizes the factor “Unavailability of medical report”, then it displays the explanation of this factor as “The employer can not employ any worker without a medical report determining his/her health conditions. The employer should consider if workers are convenient for that work or not. Otherwise, the employer will be in faulty situation in respect of Labour Law item 86, OHSR (2003) items 14 and 6 and HHWR (2004) item 5. If workers are aware of any diseases regarding their health, they should work in kind of works which do not threat their health and safety”. Finally, in the decision section of the reports, the fault rates of parties are determined.

CONCLUSIONS

The system has been tested with several real cases and it has been observed that, dsSafe provides satisfactory results. The comparison of fault rates assigned by dsSafe and experts are presented in Table 3. The experts, who assigned the fault rates shown in Table 3, are academicians having knowledge of occupational safety more than sixteen years.

Table 3: Comparison of fault rates assigned by experts and dsSafe (in percentages)

Case	Determined issues	Experts		dsSafe	
		Employer	Worker	Employer	Worker
Fall from the utility pole	- The worker was experienced - The pole was failed due to insufficient base - The worker was careless - No engineer at jobsite - The workers were not informed about the hazards of work - No protection systems were provided - The utility pole was failed due to the work done by worker	60	40	65	35
Fall from the edge of floor	- The worker fell while feeling dizzy - No guardrails - The plank was broken - No engineer at jobsite	80	20	80	20
Fall from ladder	- Despite safe alternative gates, the worker used the ladder where the accident happened - The worker was careless - The step of ladder was broken - No guardrails at the surrounding of the ladder	60	40	70	30

Above given examples demonstrate that fault rates assigned by the experts and dsSafe are very close to each other. It can be claimed that dsSafe is a reliable tool which can successfully simulate experts' judgment. However, more cases must be examined to realistically evaluate the performance of dsSafe. Moreover, there are some shortcomings of dsSafe. For example, dsSafe can assign fault rates to only two broad parties, worker and employer groups. However, there are sub-parties under those broad groups. In case that a further sub- distribution and fine tuning is required within these groups, this could be done manually by the experts. Also, it should be reminded that dsSafe is based on the judgments of 20 experts which can not be claimed to be a fully objective basis. Finally, it is hoped that construction related work accidents will drop to a minimum possible level, thus necessitating the least frequent usage of the proposed DST, dsSafe.

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