

## Article

# Predicting Employer and Worker Responsibilities in Accidents That Involve Falls in Building Construction Sites

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**Abstract:** Fall-related accidents have received more attention in building construction than in civil construction as fall-from-heights is more common in building construction. In addition to social costs, construction companies face a significant financial burden when fall-related accidents occur. The major portion of the direct cost of accidents that involve falls includes the compensation paid by the employer to the worker. The employer and the worker try to reach an agreement on the size of the compensation, however, most of the time the process is contentious. The objective of this study is to predict the parties' responsibilities for a fall-related accident by modeling the relationship between the employer and the worker using a multi-agent system. The research pursued a three-step method, including collection of data, development of a multi-agent model, and testing of the model. The model provides satisfactory results and can be used to quantify the employer's and the worker's responsibilities in construction fall accidents, hence avoiding any escalation to pursue arbitration or litigation.

**Keywords:** construction accident; construction safety; worker compensation; falls; multi-agent systems



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## 1. Introduction

The construction industry is one of the most hazardous industries [1,2]. It has a poor safety record all over the world [3,4]. There were 4779 worker deaths recorded in all sectors in the U.S. in 2018, 21.1% of which occurred in the construction industry [5]. In other words, one out of every five deaths was caused by accidents on construction sites [6]. In the U.K., 111 workers lost their lives on the job between the years 2019–2020, 40 of them in construction [7]. Although there is a gradual decrease in the number of occupational incidents on construction sites thanks to preventive laws and regulations [8], the construction industry still experiences higher rates of accidents compared to other industries. This is a problem that can be resolved if adequate precautions are put in place to eliminate the most common reasons that cause accidents on construction sites.

Falls have received more attention than any other type of occupational accident as falls have been very common in the construction industry [9]. According to OSHA [10], 33.5% of total fatalities in the U.S. construction industry in 2018 were fall-related. Additionally, falls were responsible for 25% of all fatal injuries in the U.K. [7]. Besides social costs, construction companies also face a significant financial burden caused by falls. The direct cost of falls in U.S. construction sites has been estimated to be about USD 70 billion annually [11]. The economic impact of falls has been significant not only in the US but also in other countries such as the U.K. [12], European Union Countries [13], Australia [14], South Africa [15], Singapore [16], and Taiwan [17]. The prevention of fall-related accidents on construction sites is therefore of paramount importance.

The major portion of the direct cost of accidents that involve falls includes the compensation paid by the employer to the worker. When an accident occurs, the employer and the

worker (or the worker's family) try to reach an agreement on the size of the compensation, however, on many occasions they fail to reach an agreement and must go to court for a settlement. In Turkey, there were 180,000 court cases between the employer and worker in the period 2017–2018 [18]. As it is extremely time-consuming to consider these many cases, the Turkish Government encourages employers and workers to settle using arbitration, and skip court. In addition to preventing the occurrence of fall-related accidents, it is important to reach a mutually agreed settlement that is fast and fair to both parties.

The arbitration process involves discussions between the employer and worker. These discussions depend to a large extent on the employer's and the worker's responsibilities for the accident. In other words, it should be easy to calculate the size of the compensation by using the rules provided by the government that make use of the employer's and the worker's responsibilities for the accident, however, it seldom is. Most of the time, the process is contentious and often results in ill feelings on the part of one of the parties. This research aims to predict the parties' responsibilities for an accident by modeling the discussion between the employer and the worker using a multi-agent system, hence skipping painful and lengthy arbitration or litigation and creating an objective and fast solution that is acceptable to both parties. This study is expected to contribute to the literature in building construction safety management and to safety practice in the building construction industry by streamlining the settlement of worker compensation in the aftermath of fall-related accidents. In addition, this study provides procedural benefits to the legal system that is routinely congested.

## 2. Literature Review

This research builds on and extends studies about (a) accidents that involve falls on construction site, (b) multi-agent systems, and (c) dispute resolution in construction. The issues that are encountered in fall-related accidents on construction sites, the basic principles and the pros and cons of multi-agent systems, and the studies about construction dispute resolution are briefly discussed in the next three subsections.

### 2.1. Fall-Related Accidents in Construction Sites

Falls on construction sites have always drawn the attention of many researchers (e.g., [9,19–24]) as falls are the leading cause of occupational injuries and fatalities on construction sites [10], especially on building construction sites.

As seen in Table 1, several studies were conducted about fall detection, fall prevention, fall protection, safety training, causes of falls, and fall-related accident patterns, each study using different methods such as statistical methods, qualitative evaluations, sensor and camera-based techniques. Despite the existence of quite a few research studies related to fall-related accidents, there was no study published in the literature that focused on modeling the interaction between the employer and the worker to predict each party's responsibility for this kind of accident. To fill this gap, this research proposes a model that simulates the discussion between employer and worker to predict the employer's and worker's responsibilities for the accident.

**Table 1.** Research about Fall-Related Accidents.

Topics Investigated in Research about Fall-Related Accidents	Tools Used	Selected Sources
Fall detection	Sensor-Based Technology	[25–28]
Conditions that provoke fall-related accidents	A static balance tool for proactive tracking	[29]
Fall prevention	Fall prevention index (Measuring center of posture of 30 participants)	[30]

**Table 1.** *Cont.*

Topics Investigated in Research about Fall-Related Accidents	Tools Used	Selected Sources
Worker safety training	The relationship between the social learning and construction workers' fall risk behaviors (Virtual Reality)	[31]
Fall protection and risk factors	Statistical techniques	[32,33]
Fall protection analysis	Evaluation of regulations, construction practices and fall protection plans	[34]
Causality patterns of unsafe behavior leading to fall hazards	Motion detection camera (Workers' unsafe behavior)	[35]
Falls in steel erection	Bayesian Network approach	[36]
Fall-related accident patterns	Statistical techniques	[24,37–40]

## 2.2. Multi-Agent Systems

A multi-agent system is an artificial intelligence technology that consists of autonomous intelligent agents to create an intelligent behavior within a system to achieve a common objective [41]. These intelligent agents have not only the capability to act independently according to their personal objectives, but they can also interact with each other in the same system [42]. Multi-agent systems first appeared in the 1980s, and have been extensively used in different disciplines to solve complex and dynamic problems [43]. As the construction industry is highly fragmented, it mostly involves complex and fragmented problems. Hence, multi-agent systems have been widely used in construction management for simulating different problems. As seen in Table 2, several multi-agent studies were conducted to solve supply chain problems, to simulate the negotiation process to resolve conflicts between parties, to achieve energy savings, and to simulate worker safety behavior.

**Table 2.** Research about Multi-Agent Systems.

Agent-Based System Applications	Selected Sources
Modeling complex negotiations in multi-echelon supply chain networks	[44]
Optimizing cost management in supply chains	[45]
Modeling scheduling workflows in supply chains	[46]
Modeling supply chain management	[47–50]
Developing framework for supply chain coordination	[51]
Improving negotiation efficiency in supply chains	[52]
Modeling the negotiation process between contractor and client about sharing cost overruns in construction projects	[41]
Resolving schedule conflicts between subcontractors	[53]
Modeling incentive contracts to regulate the relationship between risk-neutral owners and risk-averse contractors	[54]
Developing energy-saving systems	[55–58]
Proposing a model to simulate the safety behaviors of workers	[59,60]

As seen in Table 2, the first six rows concern issues encountered in supply chain management, while the remaining rows include studies as diverse as negotiation processes between parties, energy consumption, and workers' safety behaviors. Out of the eighteen papers cited in this table, only Karakas et al. [41], Kim and Paulson [53], and Hosseinian et al. [54]

used agent-based systems to resolve conflicts between parties, a topic of particular interest relative to the study presented in this paper. Karakas et al. [41] developed a multi-agent system to simulate the negotiation process between contractor and client about sharing cost overruns in construction projects, while Kim and Paulson [53] used multi-agent systems to resolve schedule conflicts between subcontractors. Hosseinian et al. [54] developed a multi-agent sharing model for incentive contracts to regulate the relationship between risk-neutral owners and risk-averse contractors. It is noteworthy that none of these studies looked into the discussion/negotiation process that takes place between contractors and workers after a fall-related accident has occurred to agree upon the compensation (if any) to be received by the worker.

### 2.3. Dispute Resolution in Construction

As the complexity and scale of construction projects increase, disagreements and legal disputes have been very common in recent years [61]. As seen in Table 3, a vast number of researchers have published studies about various aspects of construction disputes.

**Table 3.** Research About Construction Disputes.

Topics Investigated in Research about Legal Disputes in Construction Projects	Selected Sources
Identifying the major causes of disputes in the UAE	[62]
Identifying the common causes of disputes in the Indonesian construction industry	[63]
Developing dispute causal model	[64]
Proposing BIM-based claims analysis model	[65]
Identifying the major causes of dispute in the Nigerian construction industry	[66]
Identifying the causes of contractor claims in Engineering-Procurement-Construction Projects	[67]
Identifying major causes of disputes in Bahrain	[68]
Adopting machine learning models to predict the outcome of differing site condition disputes	[69]
Developing an integrated prediction model to predict the outcome of construction disputes	[70–74]
Developing a dispute resolution selection model	[75]
Offering a case retrieval approach based on text-mining to resolve disputes	[76]

A review of the literature in Table 3 reveals that research in construction disputes mostly emphasizes (a) the investigation of the causes/types/severity of disputes, and (b) the development of alternative dispute resolution methods for resolving the disputes. El-Sayegh et al. [62] who investigated the major causes of construction disputes in the United Arab Emirates stated that identifying the causes of disputes have a great importance in reducing the occurrence of disagreements and disputes between owners, designers, and contractors. While Hayati et al. [63] identified the common causes of disputes in the Indonesian construction industry, Viswanathan et al. [64] developed a dispute causal model that considered the relationships between the causes of a dispute.

Concerning the development of predictive models for construction dispute resolution, Mahfouz and Kandil [69] adopted machine learning models to predict the outcome of differing site condition disputes, whereas Pulket and Arditi [70,71] developed an integrated prediction model to predict the outcome of construction disputes. Although quite a few research studies related to dispute resolution have been conducted, only a limited number were related to construction accidents. For example, Fan and Li [76] offered a

case retrieval approach based on text-mining to resolve disputes, but only in certain types of construction accidents. The literature includes several studies related to construction dispute resolution, but no study offers a multi-agent system to simulate the discussions between an employer and a worker to settle with mutual satisfaction the employer's and the worker's responsibilities in fall-related accidents.

### 3. Research Method

Before the arbitration or litigation process, a discussion takes place between the employer and the worker to determine the parties' responsibilities. The discussion between the worker and the employer can be thought of as a negotiation process where the parties aim to achieve their respective goals within a specified period. If the parties are not able to reach an agreement, a lengthy arbitration or litigation process starts where both parties spend considerable time/effort and incur significant cost. Given the general lack of relevant research in the literature, a multi-agent system was used to model the discussion between the employer and the worker in this research for two reasons:

1. The multi-agent system allows researchers to create agents that have their own objectives and their own strategies. These agents can make autonomous decisions based on their objectives and strategies. These decisions reflect the real-life strategies of the parties in the discussions.
2. The multi-agent system gives the flexibility to select a suitable negotiation strategy by considering the characteristics of the negotiation, which reflect the dynamic discussion process between the worker and the employer.

The objective of this study is to construct a multi-agent system to simulate the discussion between an employer and a worker to agree on the employer's and the worker's responsibilities in fall-related accidents. To accomplish this objective, this research involves three steps, including collection of data, development of a multi-agent model, and testing of the model. The flow diagram of the research method is presented in Figure 1.

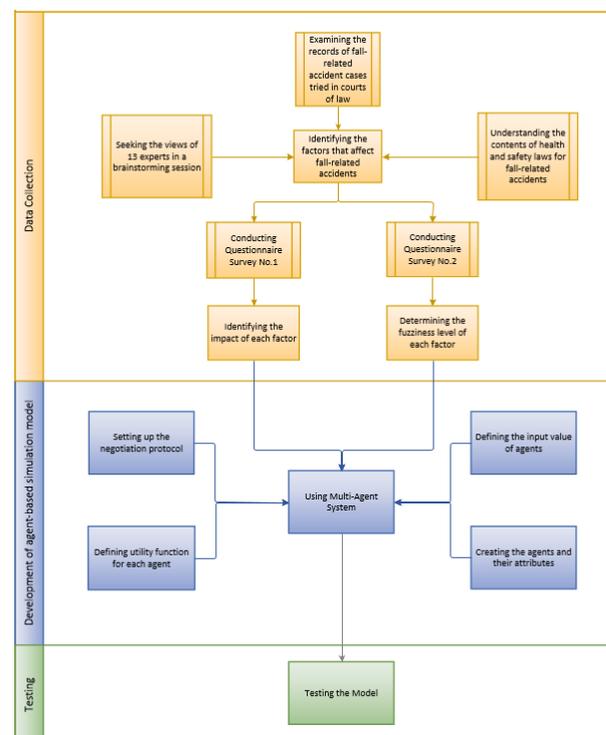


Figure 1. Flow Diagram of Research Method.

### 3.1. Data Collection

Data collection consisted of two stages including identification of the factors that affect fall-related accidents, and identification of the impact of each factor. It was conducted in the Turkish building construction industry and the Turkish court system.

#### 3.1.1. Identification of the Factors That Affect Fall-Related Accidents

The identification of the factors that influence the discussions between the employer and the worker was performed by examining the records of fall-related accident cases tried in courts of law, understanding the contents of health and safety laws for fall-related accidents, and seeking the views of thirteen experts in a brainstorming session. It should be noted that all participants in the brainstorming session had been tasked at one time or another by Turkish courts to serve as experts in cases involving fall accidents. The profiles of the participants are provided in Table 4.

**Table 4.** Profile of the thirteen Participants in the Brainstorming Session.

Respondent ID	Profession	Years of Experience	Sector	Number of Reports Prepared for Courts
1	Civil engineer	10–15	Public	10–20
2	Lawyer	5–10	Private	<10
3	Lawyer	15–20	Private	20–30
4	Mechanical engineer	10–15	Public	10–20
5	Civil engineer	35–40	Private	>30
6	Electrical engineer	10–15	Private	10–20
7	Academic	40–45	Public	>30
8	Academic	40–45	Public	>30
9	Academic	20–25	Public	20–30
10	Civil engineer	15–20	Private	<10
11	Lawyer	20–25	Private	20–30
12	Environmental engineer	5–10	Public	<10
13	Industrial engineer	10–15	Private	10–20

The brainstorming session involved two stages. In the first stage, the participants examined a total of 27 fall accident cases and discussed the employer's and of the worker's responsibilities for each court case by examining the relevant laws. In the second stage, based on what they learned in these court cases, and with the help of their experiences, the participants identified the factors that affect the quantification of the employer's and the worker's responsibilities. They identified five factors:

1. Evidence of worker training: The first factor is whether workers have received safety training. According to the regulations, an employer should provide mandatory safety training to all workers. If an employer has evidence attesting to worker safety training, it proves that the employer has complied with government regulations. In this case, the employer has the power during the negotiations. On the other hand, if the employer is not able to present such evidence, the worker has the power;
2. Presence of site engineer: The second factor is whether the site engineer was present on the construction site. Another government regulation requires that a site engineer always be present on the construction site. If the site engineer was present on the construction site at the moment of the accident, the employer has the negotiating power. On the other hand, if the site engineer was not present on the site at the moment of the accident, the worker has the negotiating power;
3. Responsible behavior of worker: The third factor is the behavior of the worker. If the worker exhibits unsafe behavior, the employer has the negotiating power, whereas if the worker consistently demonstrates safe behavior, the worker has the power during the negotiations;

4. **Safe site conditions:** The fourth factor involves the safety conditions on the construction site. An employer who provides safe site conditions implies that the employer has a good sense of responsibility. In this case, the employer has the power during the negotiations. On the other hand, if the employer has failed to provide safe site condition, the worker has the negotiating power;
5. **Use of protective equipment:** The fifth factor involves the availability and use of worker protective equipment. In this case, the worker and the employer share the negotiation power as availability and use of worker protective equipment is considered by governmental regulations to be the responsibility of both parties. In other words, while the employer has the obligation to provide safety equipment, the worker has the right to demand that proper safety equipment be provided.

### 3.1.2. Identification of the Impact of Each Factor

A web-based questionnaire was prepared and administered to 48 experts to identify the impact of each factor. The demographic information of the respondents is presented in Table 5.

**Table 5.** Profile of the 48 Experts who responded to the Survey.

Category	Properties	Frequency	Percentage (%)
Profession	Civil engineer	12	25.0
	Lawyer	9	18.8
	Mechanical engineer	5	10.4
	Electrical engineer	4	8.3
	Academician	8	16.7
	Environmental engineer	4	8.3
	Industrial engineer	6	12.5
Years of experience	0–5	1	2.1
	5–10	4	8.3
	10–15	10	20.8
	15–20	11	22.9
	20–25	9	18.8
	25–30	7	14.6
	30–35	2	4.2
	35–40	1	2.1
	40–45	3	6.3
Sector	Public	17	35.4
	Private	31	64.6
Number of reports prepared for the court	<10	11	22.9
	10–20	13	27.1
	20–30	14	29.2
	>30	10	20.8

In this questionnaire, each expert rated each factor by using a nine-point Likert Scale where one indicates very low impact and nine indicates very high impact. A Relative Importance Index (RII) was calculated to analyze the data. The RII of each factor was calculated by using Equation (1) and helped to identify the importance of each factor relative to the perceptions of the respondents.

$$RII = \frac{\sum W}{A \times N} \quad (1)$$

where RII is the relative importance index;  $W$  denotes the weight assigned to each factor by the respondents (in this case, it ranges from one to nine);  $A$  is the highest weight (in this case, it is nine); and  $N$  is the total number of respondents.

The value of RII varies between zero and one. A negotiation factor that has a higher RII has larger impact compared to a factor with a lower RII. The questionnaire results, RII

values, and their weighted percentages are presented in Table 6. To check the reliability and the internal consistency of the collected data, the Cronbach's Alpha coefficient was calculated. It was found that the Cronbach's Alpha coefficient of 0.892 is greater than the acceptable minimum value of 0.7 suggested by Santos [77].

**Table 6.** Data, RII values, and fuzziness levels.

Negotiation Factor	RATING									RII	Weighted Percentage (%)	Fuzziness Level
	1	2	3	4	5	6	7	8	9			
Evidence of worker training	1	2	2	4	11	14	9	4	1	0.63	17.1	Low
Presence of site engineer	1	1	1	1	5	4	9	22	4	0.77	21.1	Low
Responsible behavior of worker	1	0	4	4	7	16	9	5	2	0.65	17.8	High
Safe site conditions	0	0	6	4	4	3	4	18	9	0.75	20.6	Medium
Use of protective equipment	0	1	1	3	2	1	6	9	25	0.86	23.5	Low

As each factor involves a level of uncertainty, a level of fuzziness should be incorporated into the weight of each factor. For this purpose, another questionnaire was administered to the thirteen experts who took part in the brainstorming session at the beginning of the study (see Table 4). The questionnaire was administered orally as it was more convenient for respondents to answer. Respondents assessed the level of vagueness as low, moderate, and high. Later, these values were converted into percentage values. To reduce the range of the answers, the Delphi method was performed in two successive rounds. The Delphi method is a group decision-making and forecasting method that involves successively collating the judgments of experts with the aim of seeking consensus. The fuzziness level of each factor is shown in Table 6.

### 3.2. Development of a Multi-Agent System

The multi-agent system requires that a decision variable be defined at the beginning of the development process. In this study, the choices were the worker's or the employer's responsibility for the accident. Since this is a zero-sum situation, the selection of one or the other does not make any difference in the functioning of the model. In this study, the responsibility of the worker for the fall was selected as the decision variable. Therefore, the discussion between the worker and the employer was modeled to quantify the responsibility of the worker rather than the responsibility of the employer.

The agents of the multi-agent system developed in this study are the worker and the employer. The employer makes the initial determination of responsibility, typically by assuming little responsibility and assigning most of the responsibility for the fall to the worker. The worker counters with the worker's perspective, typically assigning most of the responsibility to the employer. Both agents have a "reservation value" that defines their limit in making concessions to each other. For the employer, the reservation value is the lowest worker responsibility that can be accepted by the employer, whereas for the worker, it is the highest worker responsibility that can be accepted. In other words, if the worker's responsibility is lower than the employer's reservation value, the employer's responsibility becomes so high that it is not acceptable to the employer; if the worker's responsibility is higher than the worker's reservation value, then the worker assumes such a high responsibility that it makes it unacceptable to the worker. The parties are privy to each other's reservation values. The initial determination of the employer, the initial response of the worker, and the reservation values are inputted into the system by using the fuzzy logic approach proposed by Akcay et al. [42] and Karakas et al. [41]. The initial determination and reservation value of the employer, and the initial response and the reservation value of the worker are set using Equations (2)–(5).

$$F_e = \sum_{i=1}^5 (W_{ei} + W_{si}) \times (1 + F_i) \quad (2)$$

where  $F_e$  is the initial determination of the employer;  $W_{ei}$  is the weighted percentage of the  $i^{\text{th}}$  factor where the employer has the power;  $W_{si}$  is the weighted percentage of the  $i^{\text{th}}$  factor where the power is shared;  $F_i$  is the fuzziness level of the  $i^{\text{th}}$  factor.

$$F_w = \sum_{i=1}^5 (W_{ei} + W_{si}) \times 0.4 \quad (3)$$

where  $F_w$  is the response of the worker to the employer's initial determination;  $W_{ei}$  denotes the weighted percentage of the  $i^{\text{th}}$  factor where the employer has the power;  $W_{si}$  is the weighted percentage of the  $i^{\text{th}}$  factor where the power is shared.

$$R_e = \sum_{i=1}^5 (W_{ei}) \times (1 - F_i) \quad (4)$$

where  $R_e$  is the reservation value of the employer;  $W_{ei}$  denotes the weighted percentage of the  $i^{\text{th}}$  factor where the employer has the power;  $F_i$  is the fuzziness level of the  $i^{\text{th}}$  factor.

$$R_w = \sum_{i=1}^5 W_{ei} + W_{si} \quad (5)$$

where  $R_w$  is the reservation value of the worker;  $W_{ei}$  denotes the weighted percentage of the  $i^{\text{th}}$  factor where the employer has the power;  $W_{si}$  is the weighted percentage of the  $i^{\text{th}}$  factor where the power is shared.

As the discussion between the employer and the worker relative to the quantification of employer and worker responsibilities is a dynamic process, and the parties are fully informed about their respective reservation values, the Zeuthen Strategy was selected as a most appropriate settlement protocol. This strategy is performed by comparing the parties' tolerance to risk, which shows the ratio of the utility loss when a party accepts the determination of the other party and the utility loss when the party rejects the other party's determination [78]. The maximum risk acceptable to the employer and to the worker can be calculated using Equations (6) and (7), respectively.

$$R_e = \frac{U_{ee}^n - U_{ew}^n}{U_{ee}^n - U_e(C)} \quad (6)$$

where  $R_e$  denotes the maximum risk that is acceptable to the employer in round  $n$ ;  $U_{ee}^n$  denotes the utility to the employer of the employer's determination in round  $n$ ;  $U_{ew}^n$  denotes the utility to the employer of the worker's response to the employer's determination in round  $n$ ;  $U_e(C)$  is the utility to the employer of a breakdown in the discussions.

$$R_w = \frac{U_{ww}^n - U_{we}^n}{U_{ww}^n - U_w(C)} \quad (7)$$

where  $R_w$  denotes the maximum risk that is acceptable to the worker in round  $n$ ;  $U_{ww}^n$  denotes the utility to the worker of the worker's response to the employer's determination in round  $n$ ;  $U_{we}^n$  denotes the utility to the worker of the employer's determination in round  $n$ ;  $U_w(C)$  is the utility to the worker of a breakdown in the discussions.

As per Karakas et al. [41], the recommended utility of the employer's initial determination and the worker's first response was set to one, whereas the utility of the reservation value for each party was set to 0.6. It should be noted that the utility curve between these two values is linear and shows the degree of the agent's satisfaction. The parties calculate their gains and losses at each round by using these functions.

The model was created by using a Java Agent Development Framework (JADE), which is one of the most widely used software environments that enable users to perform agent communications.

### 3.3. Case Example

In the starting interface of the program (Figure 2), the user specifies the status of the factors that affect fall-related accidents in the building project in question and clicks on the “start discussion” button. In the first round, the system calculates the initial determination of the employer agent using Equation (2), the worker agent’s initial response to the employer agent’s initial determination (Equation (3)), and each agent’s reservation values (Equations (4) and (5), respectively) as depicted in Figure 3. The reservation values remain the same in each round.

Figure 2. Starting Interface.

Employer Agent		Worker Agent	
Initial determination	48.86 %	Initial response	16.48 %
Reservation	12.39 %	Reservation	41.20 %

Figure 3. Employer Agent’s Initial Determination and Worker Agent’s Response to the Initial Determination in the First Round.

After these values are calculated by the system, the discussion about the employer agent’s determinations and the worker agent’s responses to these determinations proceeds by using the Zeuthen Strategy. In this strategy, the parties compare the maximum risk that is acceptable to them and their opponents (using Equations (6) and (7)) in each round. The agent who has the lower acceptable maximum risk, makes the next offer. The discussion between the agents continues until the value of  $R_e$  (Equation (6)) equals to the value of  $R_w$  (Equation (7)). In this example, the system generates the responsibility of the worker for this case as 18.43%.

### 3.4. Performance of the Model

Seven court cases related to fall-related accidents were used to test the performance of the proposed multi-agent system. The condition of each factor and the responsibility that the court assigned to the worker were determined by examining the court records. The responsibility that the court assigned to the worker was compared with the worker's responsibility obtained by using the proposed model. The comparison was performed by calculating the percentage difference in each case using Equation (8).

$$D = |E - T| \quad (8)$$

where  $D$  is the percentage difference for each case;  $E$  is the worker's responsibility obtained by using the proposed multi-agent system;  $T$  is the worker's actual responsibility of the worker assigned by the court.

Table 7 summarizes the information extracted from the court records and the output of the proposed model for each case. With the exception of the outlier, Case 4, which has a difference of 11.03%, the average differences of the remaining six cases amounts to  $\pm 4\%$ , indicating that the performance of the model is quite satisfactory. Courts give their final decisions by considering the reports of safety experts. The minor variation in the differences between the determinations of the courts and the outcomes generated by the proposed model can be explained by the subjectivity of the experts' judgments.

Table 7. Performance Results.

Case ID	Factor 1	Factor 2	Factor 3	Factor 4	Factor 5	Responsibility of Worker		Difference (%)
						Assigned by the Court (%)	Assigned by Multi-Agent System (%)	
Case 1	Yes	No	Yes	Yes	No	40	48.86	8.86
Case 2	No	Yes	No	No	No	20	18.43	1.57
Case 3	Yes	No	No	No	No	35	40.76	5.76
Case 4	Yes	No	Yes	No	Yes	75	86.03	11.03
Case 5	No	No	No	Yes	Yes	25	24.97	0.03
Case 6	No	No	No	Yes	Yes	30	24.97	5.03
Case 7	No	No	No	Yes	No	15	11.91	3.09

Factor 1 = Evidence of worker training. Factor 2 = Use of protective equipment. Factor 3 = Presence of site engineer. Factor 4 = Responsible behavior of worker. Factor 5 = Safe site conditions.

## 4. Conclusions

The construction safety literature routinely covers many aspects of fall-related accidents that frequently occur on construction sites, including the causes and consequences of these accidents, although none of the studies have ever modelled the interaction between the employer and the worker to predict each party's responsibility in fall-related accidents. Several dispute resolution methods have been developed as an alternative to lengthy and expensive litigation over the years and some of them like arbitration, mediation, and dispute review boards have been quite successful in achieving a fast, inexpensive, convenient, and fair resolution of disputes between construction owners and contractors, however, alternative dispute resolution methods have never been used to settle the parties' responsibilities over fall-related accidents. In response to this research gap, this paper proposes a multi-agent system to simulate the discussions between an employer and a worker for quantifying the responsibilities of these parties in fall-related accidents in construction sites, a major concern especially in building construction sites. Even though agent-based systems have been used by researchers to find solutions to various construction-related problems, only a few researchers attempted to regulate the relationship between contractors and their workers relative to their responsibilities in construction accidents, but never in fall-related accidents.

First, the factors that affect the discussions were identified by performing a brainstorming session with 13 experts, examining the records of 27 cases tried in courts of law, and getting closely acquainted with related laws and regulations. Second, the impact of each factor was determined by conducting a questionnaire survey administered to 48 experts. A Relative Importance Index (RII) was calculated to analyze the results. Third, another questionnaire survey was conducted to determine the fuzziness level of each factor. The Delphi method was performed to reduce the range of answers. Fourth, the model was constructed on the JADE platform by setting up the discussion protocol, creating agents, setting up the input values, and defining the utility function of each agent. Fifth, the performance of the model was assessed by comparing the output of the model and the actual court decisions in seven court cases. The model provides satisfactory results and can be used to quantify the employer's and the worker's responsibilities in construction fall accidents.

This research contributes to construction safety management in the context of fall-related accidents that constitute a serious problem especially in building construction sites. It also provides potential benefits to the legal system that is routinely used to settle differences between employers and workers in such accidents.

- This is the first study in the literature that offers a multi-agent system to simulate the discussions between an employer and a worker to settle with mutual satisfaction the employer's and the worker's responsibilities in fall-related accidents.
- This research provides fast, objective, and equitable solutions to the sensitive and usually controversial process of apportioning responsibility between employers and workers for fall-related accidents in the construction industry.
- The proposed model generates more sensitive results (two digits after the decimal point) than the traditional quantification used in court cases (integers in increments of five).
- Instead of waiting for the expert report, the courts or arbitrators can use this model to quantify the responsibilities of the parties, leading to a faster decision with a shorter stressful period for both parties. Better still, if the parties use the proposed model and settle out of court, the current case load of the severely congested court dockets can be radically reduced.
- The responsibilities for fall-related accidents can be assessed consistently for similar cases by using the proposed model. In other words, the proposed model's consistent outcomes do away with the subjectivity of the expert reports typically sought by courts of law.

It should be noted that the proposed model can be used to quantify the responsibilities of only the employer and the worker. The responsibilities of other parties such as the site engineer, the project manager, the subcontractor, etc., cannot be predicted. Simulating other parties' responsibilities in fall-related accidents can be explored in future research. In addition, the proposed model can be expanded to assess the responsibilities for other types of accidents other than falls.

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