Hybrid fuzzy-system dynamics approach for quantification of the impacts of construction claims

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Abstract

Purpose – The purpose of this paper is to present a novel hybrid fuzzy-system dynamics (SD) approach for the quantification of the impacts of construction claims.

Design/methodology/approach – The most significant claims affecting a project are identified. The various factors affecting the impacts of claims are identified. Then, the qualitative model of construction claims is constructed considering the complex inter-related structure of the influencing factors. The mathematical relationships among the variables are determined and the quantitative model of claims is built. Finally, fuzzy logic is integrated into the proposed model to take into account the existing uncertainties.

Findings – To show the capabilities of the proposed simulation model, it is implemented on a real project and the impacts of the identified claims on the project cost are quantified. It is shown that the external interactions among different claims can intensify their overall impact.

Research limitations/implications – Identification of interactions among various influencing factors is not an easy job when there are a large number of claims in a project. Well-qualified experts and the existence of historical data may limit the application of the proposed method in projects with limited data and/or qualified experts.

Practical implications – The proposed hybrid fuzzy-SD approach provides a practical and flexible tool that can be used in various construction projects to assess the cost impacts of construction claims taking into account their complex interactions. Using the proposed method, the accuracy of achieved results is increased compared to conventional methods that are used for the quantification of claims since the complex inter-related structure of influencing factors and the claims interactions are taken into account. One of the capabilities of the proposed hybrid fuzzy-SD method is its flexibility. Depending on the type of contract and the parties involved in the project, the proposed hybrid fuzzy-SD method can be used during different stages of the project life cycle to model and quantify claims.

Originality/value – The proposed approach may present a flexible and robust method for quantification of construction claims. The novelty aspects of this paper are as follows: the extensively complex structure of claims arising from both internal and external interactions is accounted for using SD. The existing uncertainties affecting the impacts of a claim are taken into account.

Keywords Construction, Case study, Project management, Simulation, Fuzzy logic, Construction projects, Claim, Novel method, Modelling, System dynamics

Paper type Technical paper

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1. Introduction

A claim is defined as a written demand or assertion by one of the contracting parties to seek payment of money, the adjustment, interpretation of contract terms or other relief arising or related to a given contract (Mitchell, 2016). A "construction claim" is the seeking of consideration or change by one of the parties involved in the construction process (Arditi and Patel, 1989). Claims can also be described as the assertion of the right to money, property or remedy (Powell-Smith and Stephenson, 2000). Claims have become the norm rather the exception in construction projects. As such, successful projects are not those that attain a minimal number of claims, but rather those with the best handling of claims (El-adaway, 2017).

Construction claim management is the greatest challenge that contractors are facing in today's vacillating business environment (Kululanga *et al.*, 2001). Ho and Liu (2004) stated that construction claims are considered by many project participants to be one of the most disruptive and unpleasant events of a project. The appropriate management of claims plays a crucial role in the ultimate success of construction projects (Yousefi *et al.*, 2016).

In the last 30 years, the occurrence of claims in the construction industry has substantially increased (El-adaway and Kandil, 2009, 2010a, b). Perceptions of how claims arise may vary according to the views of owners, contractors and consultants. Frequently cited causes of claims include poor site investigation, bidding with incomplete drawing sets, inadequate and untimely design revisions, construction disruption delays materials delivery, weather, owner changes, differing site conditions and design errors and poor construction quality (Mehany and Grigg, 2015). In two of the most recent studies, Shen *et al.* (2017) identified causes of contractors' claims in international engineering–procurement–construction projects. From the perspective of contractors in EPC projects, the causes of claim was refined to external risk (sociopolitical risks, economic risks and natural hazards), clients' organizational behavior (untimely payment, change orders and inefficient processing) and project definition in the contract (unclear scope of works and unclear technical specification). Mishmish and El-Sayegh (2018) identified and assessed the most frequent causes of claims in road construction projects. Variations, contractor's delay and inadequate site investigation before bidding were identified as the most frequent cause of claims.

Various studies have been conducted in the area of construction claims. Most of previous studies, however, investigated the reasons for the emergence of claims, and few studies have been conducted to quantify the effects of construction claims on project performance criteria.

In one of the earliest studies, Jergeas and Revay (1993) quantified a contractor's loss of productivity on a four-story commercial building in Western Canada using the differential cost method. Kartam (1999) developed a generic methodology for analyzing delay claims by analyzing the contractor's original CPM schedule. Love and Li (2000) quantified the causes, magnitude and costs of rework experienced in two construction projects that were procured using different contractual arrangements. Kululanga *et al.* (2001) presented the principles that underlie the construction claim process and proposed a generic framework that aims at facilitating the measurement of the construction claim process as one of the strategies for improving construction business processes. They concluded that claims targeting delay issues can be formulated in multiple ways. Ameen *et al.* (2003) quantified a claim for extra payment to a subcontractor for work on a substantial construction earth-moving project, using multiple linear regression analysis. Gulezian and Samelian (2003) provided an objective, measurement-based approach that can be used to establish a productivity baseline applied to construction productivity loss claims, based on the application of statistical methods aided by a process control chart. Klanac and Nelson (2004) discussed the methodologies for asserting and defending against loss of productivity claims, and recent judicial decisions addressing these claims. Chester and Hendrickson (2005) quantified the cost and time overruns of specific schedule impact scenarios on a single project and analyzed possible claims for damages. Chau (2007) used artificial neural networks to help predict the outcome of construction claims. Arditi and Pattanakitchamroon (2008) summarized the advantages and disadvantages of widely used delay analysis methods. They assessed the factors that seem to be of importance to practitioners in the selection of a delay analysis method in time-based claims. In the most recent work, Ballesteros-Pérez *et al.* (2017) presented a weather-aware planning tool for improving construction productivity and dealing with claims. They proposed a new stochastic model to objectively evaluate weather-related claims. The potential use of system dynamics (SD) for costing claims has also been indicated by a few researchers. Howick (2005) proposed SD for litigation audiences. Williams *et al.* (2003) described some guidelines as to when it is necessary to use SD analysis rather than more simplistic techniques in project claims. Eden *et al.* (2005) compared the "measured mile" and SD and argued that the measured mile method is unreliable in cases where disruptions and delays are a significant part of the explanation for additional costs and late delivery of a project.

Although few studies have been conducted to quantify the effects of construction claims on project performance criteria, they are faced with some major defects. The complex inter-related structures of various factors affecting the impacts of a claim on the project objectives are not accounted for in the previous studies. Moreover, the complex interactions that exist among different claims have not been considered in the previous studies. These interactions may exacerbate the effects of one claim due to the interactions with the other claims. Finally, the existing uncertainties affecting the impacts of a claim on the project performance are not taken into account in previous studies.

In this research, a hybrid fuzzy-SD approach is proposed for the quantification of the impacts of construction claims. Although the potential use of SD for the quantification of construction claims is discussed in the last cited works, the impacts of construction claims were not quantified taking into account their interactions in the previous studies.

In this research, the impact of construction claims is quantified using a new hybrid fuzzy-SD approach considering the internal and external interactions among the influencing factors. In order to quantify the impacts of claims using the proposed method, the most significant claims affecting a project are first identified based on the opinions of experts involved in the project and by conducting interviews. The various factors affecting the impacts of the identified claims are determined by conducting a literature review and interviewing experts involved in the project. The complex inter-related structure of various influencing factors is modeled using the SD approach and the qualitative model of the claims is drawn and validated by the experts. Then, the mathematical relationships among the effective variables are determined and the model is quantified. Using the developed quantified model, the impact of each of the claims on the project cost is simulated. Finally, fuzzy logic is integrated into the proposed SD approach and claims consequences are simulated considering the existing uncertainties. The impact of different claims on the project cost is finally determined as a fuzzy number. At the end, to show the strengths and capabilities of the proposed simulation model, it is implemented on a real project and the impacts of the identified claims are quantified.

2. Research methodology

2.1 System dynamics (SD) approach

SD introduced by Forrester (1961) is an object-oriented simulation methodology that accounts for various interactive cause and effect feedback loops. The SD approach provides a rigorous method for description, exploration and analysis of complex systems (Rodrigues, 1994). The capacity of the human mind for formulating and solving complex problems is very small compared with the size of the problem whose solution is required for objectively rational behavior in the real world or even for a reasonable approximation to such objective rationality (Simon, 1957).

SD modeling is useful for managing and simulation of processes with two major characteristics: they involve changes overtime and they allow feedback from the transmission and receipt of information (Richardson and Pugh, 1981; Nasirzadeh *et al.*, 2008). Much of the art of SD is to discover and represent the feedback processes, which, along with stock and flow structures, time delays and nonlinearities, determine the dynamics of a system (Sterman, 2000). Each causal link is assigned a polarity, either positive or negative to indicate how the dependent variable changes when the independent variable changes. The important loops are highlighted by a loop identifier which shows whether the loop is a positive (reinforcing) or negative (balancing) feedback (Sterman, 2000).

SD deals with the mathematical modeling of dynamic systems and response analyses of such systems with a view toward understanding the dynamic nature of each system and improving the system's performance (Ogata, 2004).

2.2 Fuzzy set theory

Fuzzy set theory provides a useful tool to deal with decisions in which the phenomena are imprecise and vague. It enables us to qualify imprecise information, to reason and make decisions based on vague and incomplete data (Li *et al.*, 2007 In the classic logic, a member can belong to a set of data or not. In contrast, when fuzzy logic is used, the degree of belonging of a member may be selected from a set of fuzzy numbers defined as fuzzy membership function (Naieni *et al.*, 2012).

A fuzzy set is a class of objects with a continuum of grades of membership. A fuzzy set (class) A in X is characterized by a membership (characteristic) function $f_A(x)$ which associates with each point in X a real number in the interval [0, 1], with the value of $f_A(x)$ at x representing the "grade of membership" of x in A. Thus, the nearer the value of $f_A(x)$ to unity, the higher the grade of membership of x in A (Zadeh, 1965):

$$\tilde{A} = \left\{ \left(x, \mu_{\tilde{A}}(x) \middle| x \in X \right) \right\}, \tag{1}$$

when A is a set in the ordinary sense of the term, its membership function can take only two values 0 and 1, with $f_A(x) = 1$ or 0 according as x does or does not belong to A (Zadeh, 1965).

Fuzzy logic is quite appropriate to consider the uncertain nature of construction claims based on the experience and managerial subjective judgments. Therefore, fuzzy logic is used in this research to account for the existing uncertainties.

3. Model application

To show the performance and capabilities of the proposed hybrid fuzzy-SD model, it was employed in a fire station project located in Iran. The project was executed under traditional (Design-Bid-Build) contract. The contract type and contractual clauses are among the most significant factors that may influence the claims and their cost and should be taken into account. The initial duration and cost of this project were estimated as 365 days and $2,857,147, respectively. The most significant claims were identified based on the opinions of eight experts involved in the project. The experts had an average of 20 years of experience in different construction projects and were familiar with fuzzy logic concepts and with well-developed mental models of claim quantification process. Considering this limitation, the total number of eight qualified experts was identified in this project. The potential claims were identified during the construction phase of the project and all the project documents were reviewed for identification and quantification of the claims. Three claims were finally selected as the most significant claims affecting the project including defects in the drawings, existence of unpredicted obstacle (UO) in the project and request for acceleration in the project execution. The impacts of the identified claims on project cost were quantified using the proposed hybrid fuzzy-SD approach as explained below. It should be noted that the identified claims were modeled jointly by a team of contractor and client's representatives to quantify the impacts of claims fairly.

3.1 Qualitative modeling of construction claims

After identification of the most significant claims, the qualitative model of the identified claims is drawn using cause and effect feedback loops. Figure 1 represents the inter-relations that exist among the most significant identified claims including defects in the drawings, existence of UO in the project and request for acceleration in the project execution.

As shown, the existence of defects in drawings will slow the progress of work and consequently will affect the acceleration of the project execution. On the other hand, the acceleration in the project execution will intensify the negative consequences of defects in the drawings. The reason is that the defects are identified with delay that may exacerbate the costs associated to resolve them.

The existence of UO in the project will cause major delays in the project and affects the project acceleration adversely. On the other hand, the client request for acceleration in the project execution will affect the consequences of UO in the project since the UO is exacerbated due to the changes in the project schedule. In the following section, the qualitative model of each claim has been drawn considering all the influencing factors and will be explained briefly.

3.1.1 The qualitative model of the claim for defect in the drawings. Defect in drawings is one of the most common problems in the construction projects. This problem is generally causing the emergence of claims by contractors because of defect in the performance of the consultant and the employer. In the studied project, the structural details provided in the drawings were not sufficient to enable contractor to prepare detailed shop drawings and it was considered as one of the most important issues in this project by the experts. In Figure 2, the SD model of

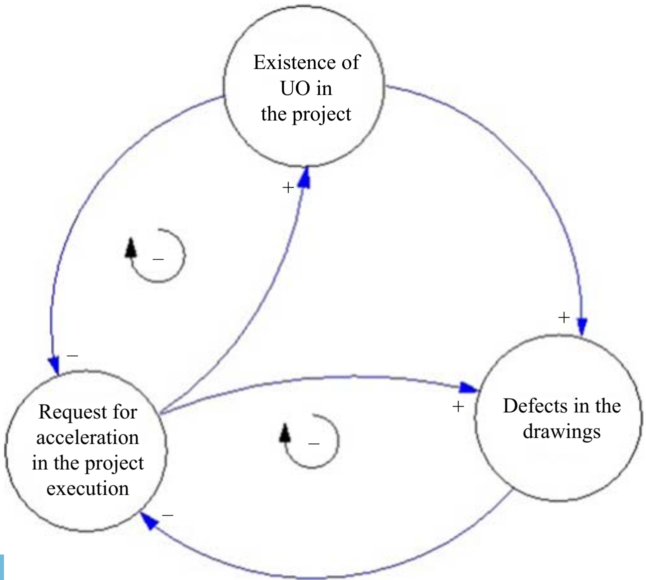

Figure 1.
The inter-relations among the three identified claims

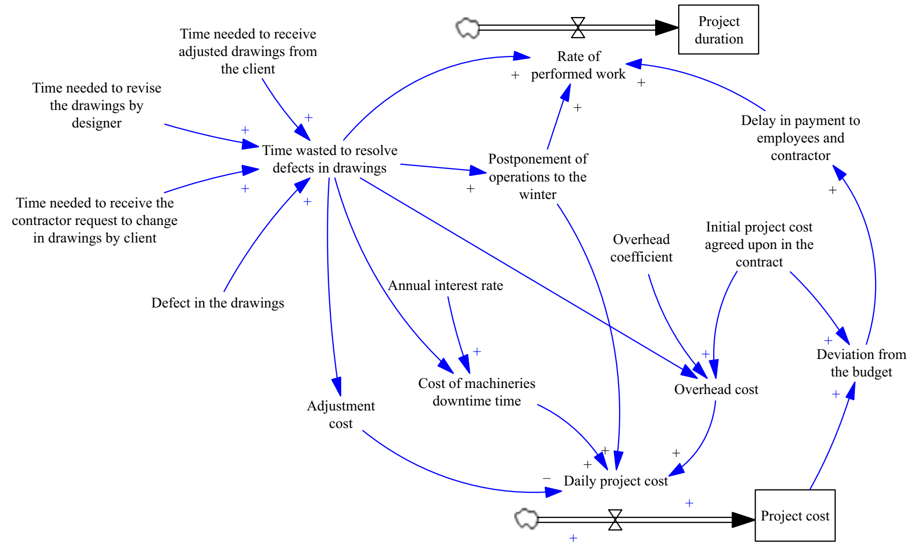

Figure 2.
The qualitative model of the claim of defects in drawings

this claim has been shown considering all the influencing factors and the effect of this claim on the project duration and cost is demonstrated in a qualitative way. As it can be seen in this figure, the major defects in the drawings are detected by the contractor and reported. The time wasted to resolve defects in drawings will increase the project duration accordingly. Although the time required for the elimination of defect(s) in the drawings and sending them again to the contractor will be added to the original duration of project by the client, it will increase the undesirable cost for the contractor. As an example, the postponement of the operations to the winter will result in an increase in the contractor's cost. Moreover, the time wasted to resolve defects in drawing will increase the overhead cost and machinery downtime related costs which will in turn increase the project cost. The contractor receives a portion of the perceived additional cost as an adjustment cost. However, the adjustment costs will not compensate all the additional costs imposed on the contractor as explained before.

3.1.2 Qualitative model of the claim for the existence of unpredicted obstacle (UO) in the project. The SD model of the claim showing UO in the project is shown considering all the influencing factors in Figure 3. When something blocks or delays a construction project, it means that an obstruction exists for continuation of project. In the studied project, the contractor encountered an existing gas pipeline during the excavation. This UO resulted in project delay and project cost overrun. The effect of this claim on the project duration and cost has been depicted in Figure 3. As shown, the time required for the elimination of the UO will postpone the project that will result in an increase in project duration. The project cost is also increased due to the postponement of operations to the winter, increase in overhead costs and machineries downtime cost.

3.1.3 The qualitative model of request for acceleration in the project execution. Client's request to accelerate the project execution is one of the problems that affect most of the construction projects. In Figure 4, the qualitative model of this claim is shown considering all the influencing factors. As it can be seen in Figure 4, the reduction in the project duration to accelerate finishing it as requested by the client can cause an increase in the contractor's cost. The reason is that in the case of employer's request to accelerate the project, the contractor will use different strategies such as increase in the number of labor/equipment and labor overtime. Increase in the number of labor/equipment will result in work interferences which will

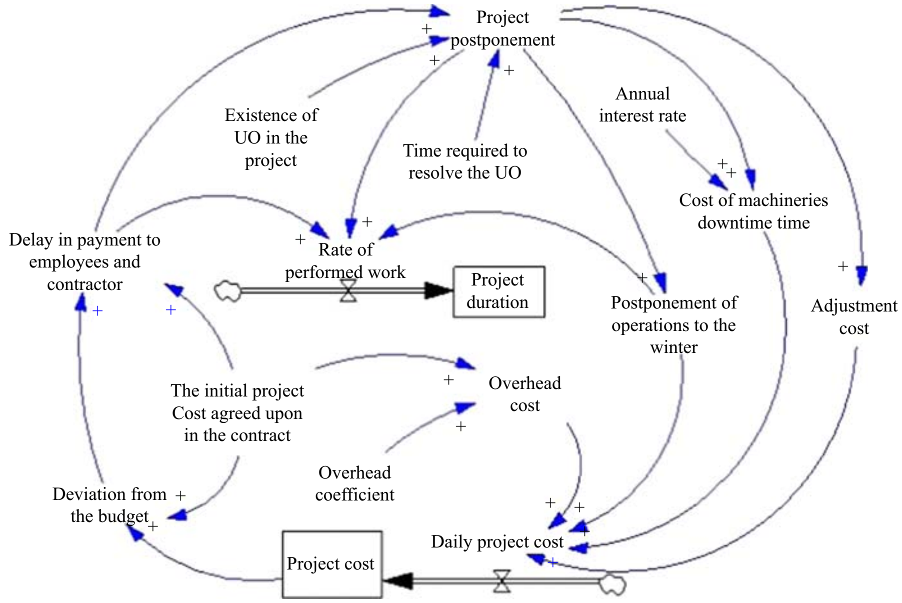

Figure 3. The qualitative model of claim for the existence of unpredicted obstacle in the project

decrease the rate of performed work. Similarly, the labor overtime will result in fatigue which will decrease the rate of performed work. The decrease in the rate of performed work will consequently result in an increase in the project duration and cost. Moreover, supplying the material ahead of schedule to accelerate the project will increase the project cost as shown in Figure 4. The contractor receives a portion of the perceived additional cost as acceleration's cost. However, the acceleration's cost will not compensate all the additional costs imposed on the contractor as explained before.

3.2 Quantitative modeling of construction claims

After constructing the qualitative model of all the claims using cause and effect feedback loops, the quantitative modeling of these claims will be done. This research aims to quantify the impact of construction claims on the project cost. Therefore, the project cost is simulated as the main output in the quantitative modeling stage. To do so, it is necessary to determine the mathematical relations among all the effective factors. The influencing input parameters affecting the impact of each claim are shown qualitatively in Figures 2–4. In this research, three methods were used to determine the mathematical relationships among the influencing factors. There are natural relationships among most of the factors that can simply be determined by mathematical functions. For those factors whose natural relationships cannot be easily determined, the extrapolation of historical data is used. Finally, expert judgment is used in case historical data do not exist.

4. Results and discussion

In the following section, the developed hybrid fuzzy-SD approach is employed in the fire station project and the impact of each of the identified claims on the project cost is simulated. Some of the existing uncertainties in the values of the influencing factors are as follows:

- the annual interest rate has a triangular fuzzy number of 18, 21 and 25 percent;

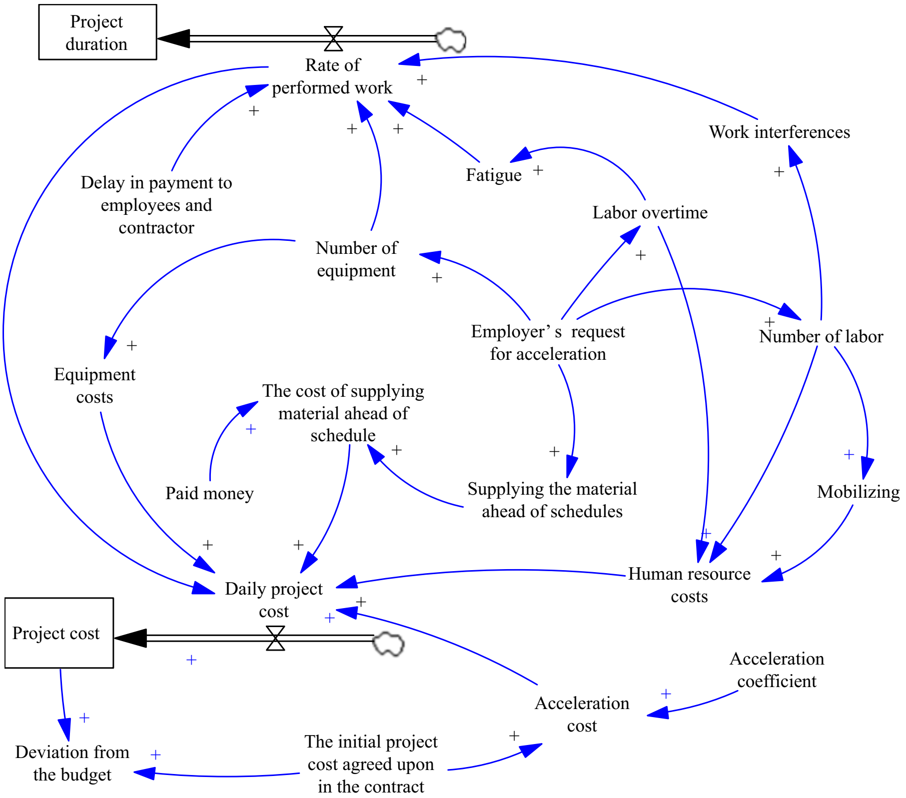

Figure 4.
The qualitative model of claim for request of acceleration in the project execution by the client

- the manpower's wages are determined as a triangular fuzzy number of \$14, 21 and 29 per day; and
- the overhead cost coefficient has a triangular fuzzy number of 0.31, 0.35 and 0.38.

Having the developed hybrid model as well as the values of the input parameters, the following simulated results for the effects of different claims on the project objectives will be achieved.

Considering the simulated results, the effect of a claim for the existence of UO on the project cost will be shown by a triangular fuzzy number of \$2,857,140, 3,894,030 and 4,515,880 (Figure 5).

It should be stated that impacts of the identified claims can be simulated at different confidence levels (α-cuts). In Figure 5, if the amount of α-cut is selected as 1, the existing uncertainties will completely be ignored and the project cost will be assessed in the amount of \$3,894,030, while if the α-cut is selected as 0, the lack of existing uncertainties is completely considered and the amount of the project cost will be calculated in the range of \$2,857,140 and 4,515,880.

Simulation results related to the effect of the claim for the existence of defect in the project's drawings on the project cost have been presented in Figure 6. As it can be seen in this figure, the existence of this claim has caused an increase in the project cost in the amount of \$3,305,230, 3,433,670 and 3,532,180. It has to be mentioned that this claim has not had any effect on the project duration.

The simulated results related to the effect of the claim for request of acceleration in the project execution by the client on the project cost are shown in Figure 7. As shown, under the effect of this claim, the project cost has increased in the amount of $3,284,620, 3,602,610 and 3,921,280 and still the project duration compared to the initial duration has remained unchanged. By comparing the simulation results for three claims, it is revealed that existence of UO in the project has the most significant impact on the project cost.

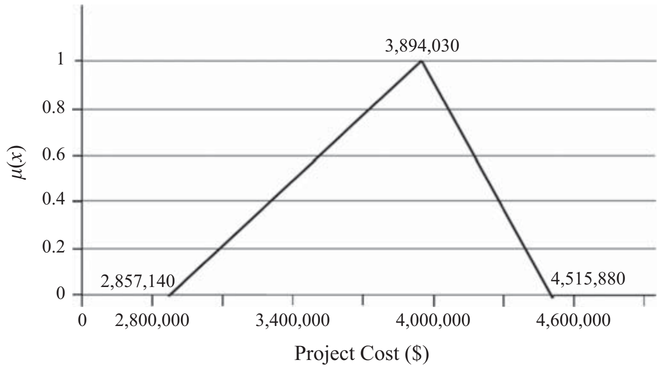

Figure 5. The simulation result of the effect of claim for the existence of unpredicted obstacle in the project on the project cost

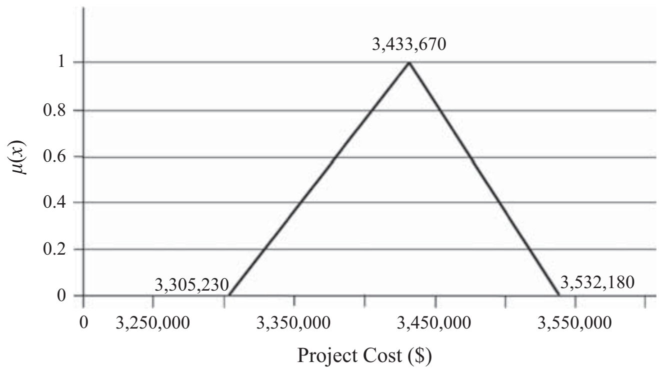

Figure 6. The simulated results of the effect of the claim for the existence of the defects in the drawings on the project cost

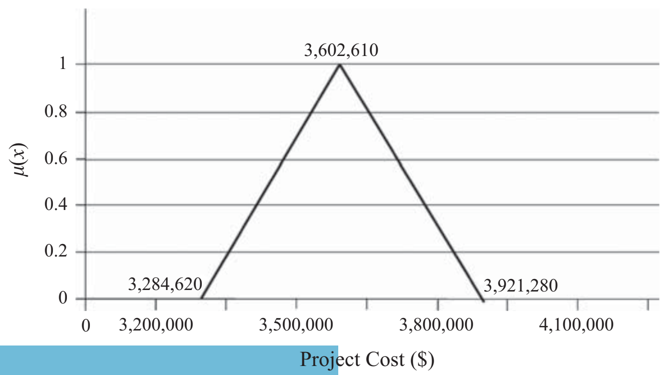

Figure 7. The simulated results related to the effect of the claim for request of acceleration in project execution on the project cost

After analyzing the effects of any of the claims separately, the effect of three claims happening simultaneously is presented. To show the capabilities of the suggested model in considering the complex inter-relations among claims and the assessment of the effect of these inter-relations, the effect of simultaneous happening of three claims is presented in two scenarios including considering the inter-relations among claims and disregarding the inter-relations.

4.1 First scenario: disregarding the inter-relations among claims

In Figure 8, the accumulative effect of three claims disregarding their mutual effects on one another is shown. As shown in this figure, because of the emergence of these three claims, the project cost will increase to the amount of $3,732,704, 5,216,024 and 6,255,054.

In Table I, the simulated results related to the effect of three claims on the project cost are presented disregarding their inter-relations.

4.2 Second scenario: considering the inter-relations among claims

In this scenario, the exact same input numbers in the previous scenario will be given to the developed hybrid model. The difference is that in this scenario, the existing interactions and inter-relations among the three claims is considered. The effect of simultaneous occurrence of the three claims on the project cost considering their inter-relations is shown in Figure 9 and Table II. Figure 9 depicts the simulated results related to the amount of effect of three claims on the project cost considering their mutual effects. As shown, because of the occurrences of these three claims, the project cost is increased from the initial value of $2,857,147 to $6,993,014, 8,269,504 and 9,227,704.

Figure 10 compares the results related to the amount of effect of three claims on the project cost in two scenarios including considering the inter-relations and ignoring them.

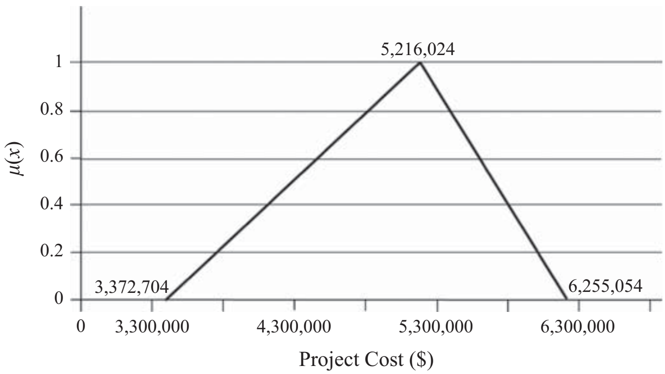

Figure 8.
The effect of simultaneous occurrence of three claims on the project cost disregarding their inter-relations

Table I.
The effect of three claims on the project cost disregarding their inter-relations

Claim	The least likely value Cost ($)	The most likely value Cost ($)	The largest likely value Cost ($)	Difuzzified value Cost ($)
Defects in the drawings	3,305,230	3,433,670	3,532,180	3,423,693
Existence of unpredicted obstacle (UO) in the project	2,857,140	3,894,030	4,515,880	3,755,683
Request for acceleration in the project execution	3,284,620	3,602,610	3,921,280	3,602,837
Total	3,732,704	5,216,024	6,255,054	4,919,831

Considering Figure 10, it is seen that if the mutual effect of claims on one another is taken into account, it will have a considerable effect on the project cost. As shown, considering the inter-relations among claims, the effects of claims on the project cost will increase from $3,732,704, 5,216,024 and 6,255,054 to $6,993,014, 8,269,504 and 9,227,704.

The suggested method gives the project manager the ability to attain the results considering the confidence level he has in mind. For example, if the selected α-cut (the risk level) is 1, the confidence level of the project manager will be 0 and the existing uncertainties are completely ignored and the project cost is determined as a crisp certain value equal to $8,269,504. Similarly, in the case that α-cut is selected as 0, the existing uncertainties are fully considered and the project cost is determined with the maximum level of confidence by the project manager. In this case the project cost is determined in the range of $6,993,014 to 9,227,704.

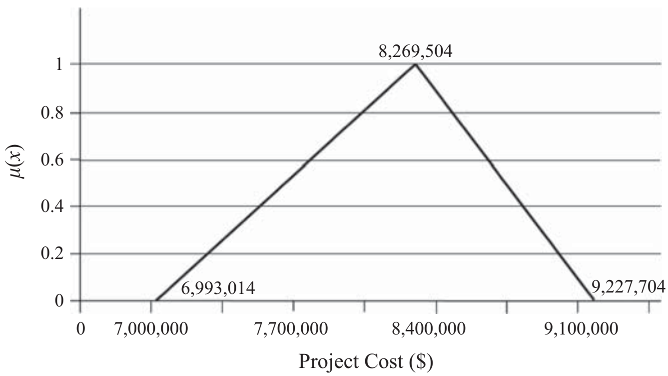

Figure 9. The effect of simultaneous occurrence of three claims on the project cost considering their inter-relations

Table II. The effect of three claims on the project cost considering their inter-relations

Claim	The least likely value Cost ($)	The most likely value Cost ($)	The largest likely value Cost ($)	Difuzzified value Cost ($)
Defects in the drawings	4,149,790	4,283,560	4,386,880	4,273,410
Existence of unpredicted obstacle (UO) in the project	5,290,050	6,129,160	6,680,830	6,033,347
Request for acceleration in the project execution	3,267,460	3,571,070	3,874,280	3,570,937
Total	6,993,014	8,269,504	9,227,704	8,057,311

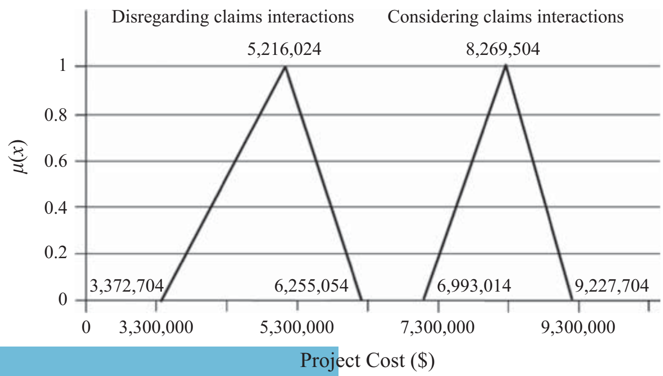

Figure 10. Comparison between the results of the effect of claims on the project cost in two cases including: considering claims interactions and disregarding claims interaction

Ultimately, after defuzzification of the resulted triangular fuzzy numbers, a definite amount for the effect claims on the project cost is achieved. Defuzzification is the operation of producing a non-fuzzy number, i.e., a single value that adequately represents the fuzzy number (Nieto-Morote and Ruz-Vila, 2010). Defuzzification is a process that can transform the resulting fuzzy values into a crisp value. The center of area (COA), also called center of centroid, is used for defuzzification (Pena Reyes, 2004). The COA method is calculated by the following equation (Zimmermann, 2001; Vries and Steins, 2008):

$$u^{COA} = \frac{\int_u u \cdot \mu^{conseq}(u)du}{\int_u \mu^{conseq}(u)du}. \tag{2}$$

The effects of the simultaneous occurrence of three claims on the project cost in two scenarios including considering and disregarding the inter-relations is finally determined as \$8,057,311 and 4,919,831, respectively. This shows that the existing complicated interactions among the claims have increased the project cost from \$4,919,831 to 8,057,311 which is equal to \$3,137,480.

The implementation of the proposed fuzzy-SD approach in this project case example illustrated the effectiveness of the proposed method in determining the effects of claims on the project cost. The results achieved by the proposed methodology are more reliable in comparison to the other existing methodologies since the complex inter-related structure of different influencing factors, the claims interactions and the existing risk and uncertainties are taken into account. The suggested method gives the project manager the ability to attain the results considering the confidence level he has in mind.

The proposed hybrid fuzzy-SD approach is flexible and can be used in various construction projects to quantify the impacts of claims. The proposed method may present an alternative and robust tool for determining the cost consequences of construction claims. Using this method, the accuracy of achieved results is increased comparing to the conventional methods since the complex inter-related structure of influencing factors as well as the claims interactions are taken into account.

Identification of interactions among various influencing factors is not an easy job when there are a large number of claims in a project. Moreover, well-qualified experts with a well-developed mental model of construction claims are necessary to provide required input data for modeling construction clams using SD approach. The absence of such experts could be a limitation for the implementation of the proposed model on a new project. Finally, the existence of historical data may also limit the application of the proposed method in projects with limited data.

5. Model validation

In SD modeling, a variety of "standard" validation tests have been proposed to uncover flaws and to improve models (Sterman, 2000). In this research both the structural and behavioral validation tests were performed for building confidence in the developed model.

For the structural validation, the validity of the conceptual model was assessed and the feedback structure of different claims was validated through various interviews with experts involved in the project. Also inspection of model equations was carried out to assure the robustness of the developed model. The behavioral test was also performed. As it has been recommended by Sterman (2000), the model behavior was tested in the extreme conditions of input parameters to ensure whether the model shows a logical behavior. For instance, the project model produced results similar to the baseline simulation in a claim free environment.

6. Future works

Although more sample projects may be needed to validate the outputs of the model, accounting for the complex structure and uncertain natures of various factors affecting the impacts of construction claims may provide the decision maker with valuable information. This limitation generates future scope for this study as future studies may repeat this method in new construction projects using multiple experts to justify the validity of the study. Another important aspect of future research would be a reduction in model complexity in the case of a large number of construction claims.

7. Conclusions and remarks

Construction claims are considered by many project participants to be one of the most disruptive and unpleasant events of a project. This research presented a hybrid fuzzy-SD approach for the quantification of the impacts of construction claims. In order to quantify the impacts of claims using the proposed approach, the most significant claims affecting a project were identified based on the opinions of different experts involved in the project. These claims include defects in the drawings, existence of UO in the project and request for acceleration in the project execution. The various factors affecting the impacts of the identified claims were then determined. The complex inter-related structure of various influencing factors was modeled using cause and effect feedback loops. The relations among the influencing variables were then determined and the quantitative model of claims was built. For this purpose, three alternative methods were used to determine the mathematical relationships among the influencing factors. The natural relationships that exist among most of the factors were simply determined by mathematical functions. For those factors that their natural relationships cannot be easily determined, the extrapolation of historical data was used. Expert judgment was also used where historical data did not exist. Finally, fuzzy logic was integrated into the proposed SD approach to simulate the claims consequences considering the existing uncertainties.

Using the developed hybrid fuzzy-SD model, the impact of identified claims was simulated and claims consequences on project cost were finally determined as a fuzzy number. Ultimately, after defuzzification of the resulted triangular fuzzy numbers, a definite value for the effect of claims on the project cost was achieved. By comparing the simulation results for three claims, it was revealed that existence of UO in the project has the most significant impact on the project cost.

Finally, to show the capabilities of the proposed method, it was investigated that how the interactions among the identified claims may intensify their overall impact on the project cost. For this purpose, the impact of the simultaneous occurrence of three claims on the project cost was determined in two different cases including considering and disregarding the interactions as two triangular fuzzy numbers of $6,993,014, 8,269,504 and 9,227,704 and $3,732,704, 5,216,024 and 6,255,054, respectively. After defuzzification of the resulted triangular fuzzy numbers, a single value for the cost impact of simultaneous occurrence of three claims was determined for two different scenarios including considering and disregarding claims interactions as $8,057,311 and 4,919,831, respectively. This shows that the existence of complicated interactions among the claims increased the project cost from $4,919,831 to 8,057,311 that is equal to $3,137,480. Therefore, it was revealed that the existing complicated interactions among the claims have substantially increased the claims impacts on the project cost.

The implementation of the proposed fuzzy-SD approach in this project case example illustrated the effectiveness of the proposed method in determining the effects of claims on the project cost. The suggested method gives the project manager the ability to attain the results considering the confidence level he has in mind by selecting an appropriate α-cut level. Using the proposed method, the impacts of the identified claims was simulated at different confidence levels (α-cuts). It was shown that if the amount of α-cut is selected as 1, the existing uncertainties will completely be ignored and a single value for the project cost will be determined, while if the α-cut is selected as 0, the lack of existing uncertainties is completely considered and the widest range for project cost will be calculated.

It is believed that the proposed hybrid fuzzy-SD method may present a flexible and robust method for determining the consequences of construction claims since the complex inter-related structure of different influencing factors, the claims interactions and the existing risk and uncertainties are taken into account. The proposed hybrid fuzzy-SD method is flexible and can be used in any new construction project to quantify the cost consequences of construction claims. Using the proposed method, the cost impacts of construction claims can be determined more accurately comparing to the conventional methods since the internal interactions among the influencing factors for each claim as well as the external interactions among different claims are taken into account.

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