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Uncertainty management in time estimation of construction projects: A systematic literature review and new model development

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KEYWORDS
Time estimation;
Uncertainty;
Fuzzy logic;
Risk management;
Construction projects.

Abstract. Nowadays, the very low reliability of project planning in certainty-based approaches has led to the use of more intelligent methods for uncertainty management in construction projects. This systematic study aims to survey the methods which have been used to manage the uncertainties in time estimation of construction projects. A series of steps were undertaken during the review. The study was started with determining the purpose, selecting appropriate keywords, and reducing the selected papers using some criteria. A deeper analysis was carried out on the final paper that met the criteria for this review. The study was limited solely to papers referred to in six top online databases. It aimed to review how the papers had been distributed by a period of publishing, country, and the domains that the methods had been applied for. The result confirmed that uncertainties which affected any project were controlled by Risk Management and Fuzzy Logic based on probability and possibility theories. Finally, a hybrid method for uncertainty management in project scheduling was proposed. The result of the implementation of this method in the construction project of Iranian Gas Company showed that the proposed method increased the accuracy of time estimation by about 8 to 24 percent.

1. Introduction

Nowadays, the importance of time management in the field of construction projects is well known. Time management can be effective in a project when the project schedule is based on reasonable and comprehensive time estimation. Uncertainties that affect the project are based on two theories: probability and possibility. This paper aims to survey the methods which have been used to manage the uncertainties in time estimation of construction projects and proposes a comprehensive method for uncertainty management in construction projects scheduling. A series of steps are undertaken during the review according to research methodology.

2. Research methodology

In this paper, the literature related to uncertainty management in construction project scheduling is reviewed, comprehensively, by documents referred to in six main scientific online databases, namely Science Direct (Elsevier), ASCE Online Library, Taylor and

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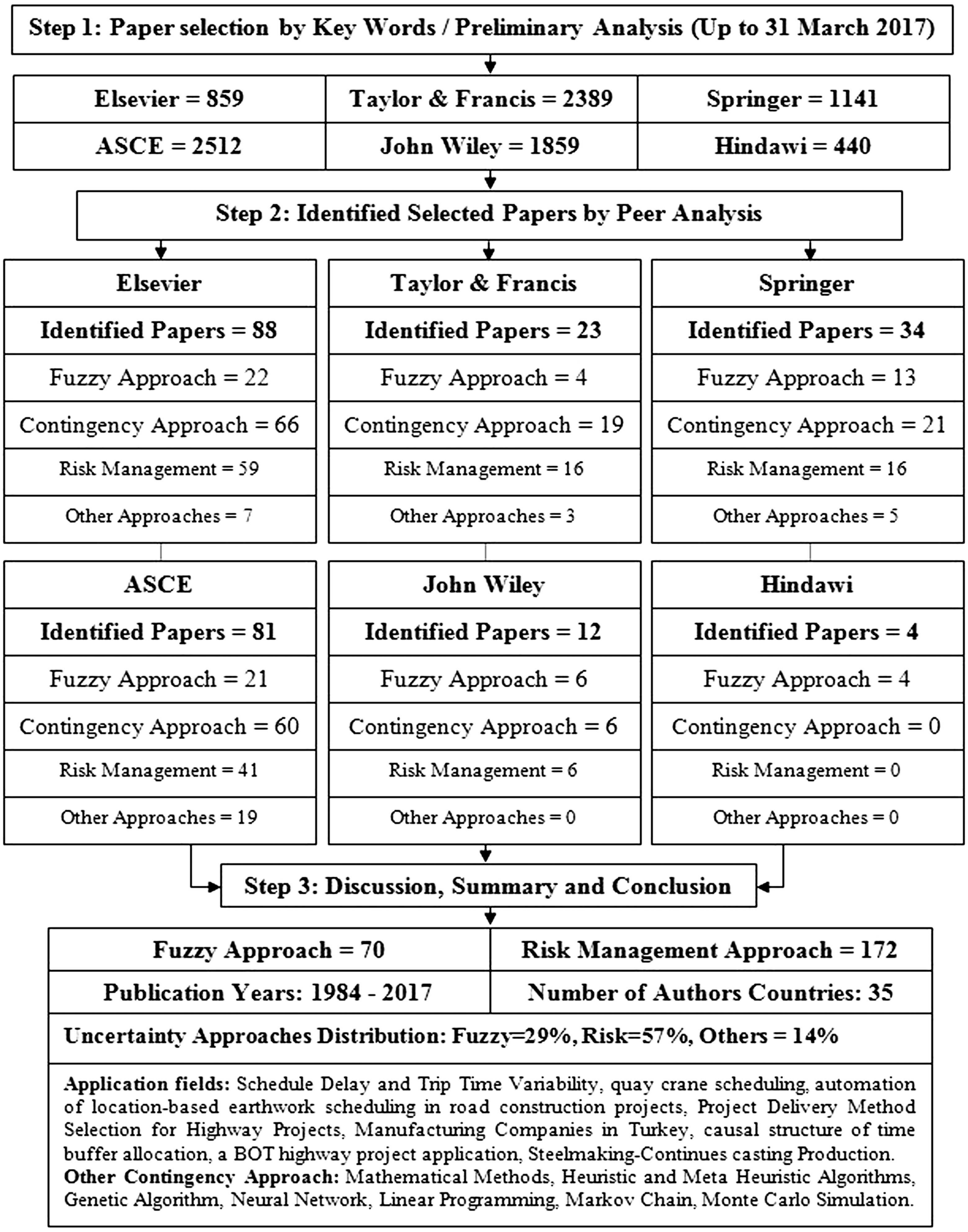

Figure 1. Research methodology diagram.

Francis, Springer journal collection, Hindawi, and John Wiley online databases.

Following to the diagram presented in Figure 1, the first publications in the area up to March 31, 2017 are reviewed. Three groups of combinations of the methods devoted to calculating the relative significance of criteria and ranking of alternatives can be identified:

1. Uncertainty + project scheduling + construction management;
2. Project stochastic scheduling + uncertainty + comprehensive time management;
3. Project scheduling methods + artificial intelligence + metaheuristic and hybrid methods.

There are 9236 publications on the topic of uncertainty referred to in the mentioned six databases. Figure 1 shows the research methodology diagram.

3. Detailed review results

The result of this research indicates that the methods of uncertainty managing in construction project scheduling are divided into three approaches: fuzzy, risk, and

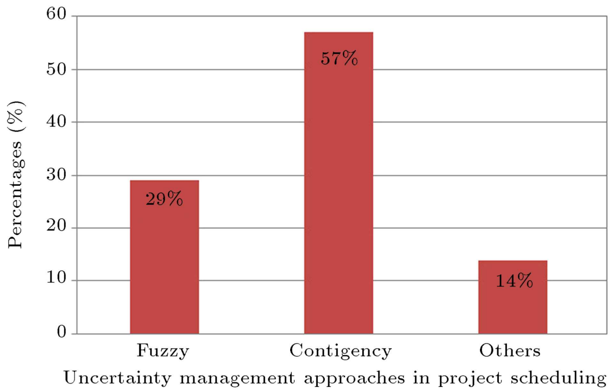

Figure 2. Statistical view of uncertainty management approaches in project scheduling.

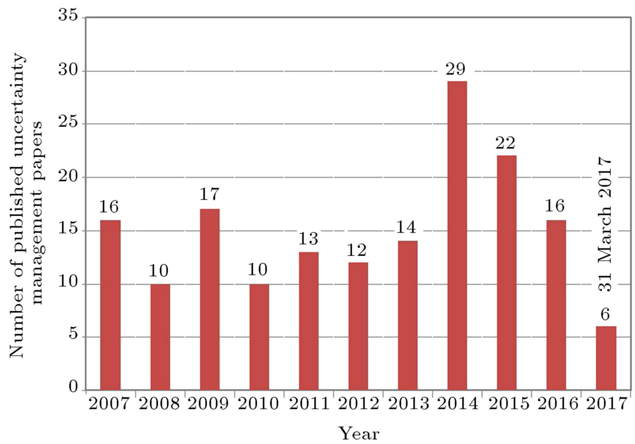

Figure 3. Researches in the last decade on uncertainty management in project scheduling.

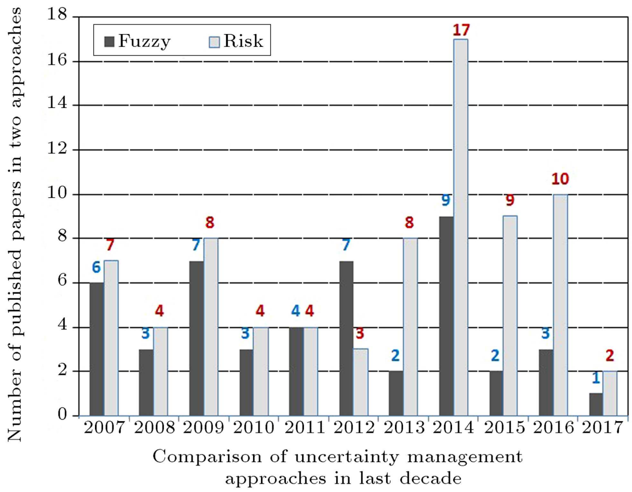

Figure 4. Comparison of uncertainty management approaches in the last decade.

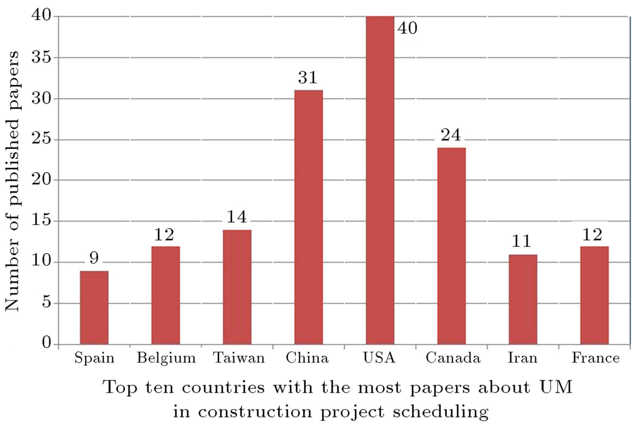

Figure 5. Countries with the most papers on uncertainty management in project scheduling.

other mathematical and heuristic approaches. Figure 2 shows the distribution of the mentioned approaches.

Statistical view of published papers with the title of uncertainty management in construction project scheduling in the last decade (from 2007 up to March 31, 2017) is shown in Figure 3.

Also, the comparison of published papers with the title of uncertainty management by fuzzy and risk in the last decade is shown in Figure 4. According to the result of this research, about 250 authors from 35 countries have contributed to improving the application of uncertainty management in construction projects. Figure 5 indicates the top ten countries that have the most related papers about this research subject. As it can be seen in this figure, USA, China, and Canada have the most researches. Also, a statistical view of the journals with the most papers about uncertainty management in construction project scheduling is shown in Figure 6. According to this figure, the Journal of Construction Engineering Management (ASCE) with 40 related papers is the top journal in this subject of research.

It is worth mentioning that 230 out of 242 selected papers have only described the theory and only 12 papers are applications, as explained in Table 1. Also, 6 papers have hybrid approaches and the combinations of their approaches are described in Table 2.

In the following, Tables 3, 4, and 5 show the selected research papers according to the mentioned 3 approaches of uncertainty management in construction project scheduling. According to the result of this review, most papers that use fuzzy approach have concentrated on possible uncertainty management in project scheduling, and the papers with risk management approach have concentrated on managing the probable uncertainties. Also, other mathematical, heuristic, and hybrid methods have concentrated on managing the probable uncertainties. As a result, it is worth mentioning that the best approach to managing possible uncertainties is fuzzy method, because in fuzzy method, uncertainty of project activities remains in the whole calculation stages; but in other mathematical algorithms and artificial intelligence methods,

Table 1. List of the application papers with the title of uncertainty management in project scheduling.

Considered issues and problems	Applied method	Author(s), publishing year
Presenting a scheduling algorithm for the real-world steelmaking-continuous casting production	Mathematical heuristic method	Jiang et al., 2016 [1]
GA approach for the quay crane scheduling under uncertainty	Genetic algorithm method	Al-Dhaheri et al., 2016 [2]
GA approach for remanufacturing process planning and scheduling	Genetic algorithm method	Zhang et al., 2015 [3]
Robust algorithm for scheduling of manufacturing tasks	Simulated Annealing (SA) algorithm	Józefezyk & Thomas, 2007 [4]
Modeling completion risk using stochastic critical path: a BOT highway project application	A BOT highway project application	Kokkaew & Chiara, 2010 [5]
A stochastic dynamic programming based model for uncertain planning	Planning of e-manufacturing system	Li et al., 2009 [6]
Critical risk factors in project delivery of highway projects	Risk management	Tran & Molenaar, 2012 [7]
Action-based union of the temporal opposites and elastic activity network in scheduling	Automation of location-based earthwork scheduling in road construction projects	Yagi & Arai, 2006 [8]
Simulation multi-agent approach for scheduling modular construction	Scheduling modular construction	Taghaddos et al., 2012 [9]
Uncertainty modeling in development projects (case study)	Manufacturing companies in Turkey	Özdamar & Alanya, 2001 [10]
Integrating the mean-variance and scheduling approaches to allow for schedule delay and trip time variability under uncertainty	Schedule delay and trip time variability	Li et al., 2016 [11]
Robust multi-objective maintenance planning of deteriorating bridges against uncertainty in performance	Maintenance planning of deteriorating bridges against uncertainty in performance model	Ok et al., 2013 [12]

certainty based tools such as learning rules in neural networks method reduce the mentioned uncertainty in calculation stages and this leads to reduction in time estimation accuracy. Also, the best way to manage probable uncertainties is the implementation of risk management in construction projects. Therefore, a comprehensive way of managing uncertainties in construction project scheduling is a method of dual approach. In the following, a hybrid model is proposed to solve this problem. It is worth mentioning that the

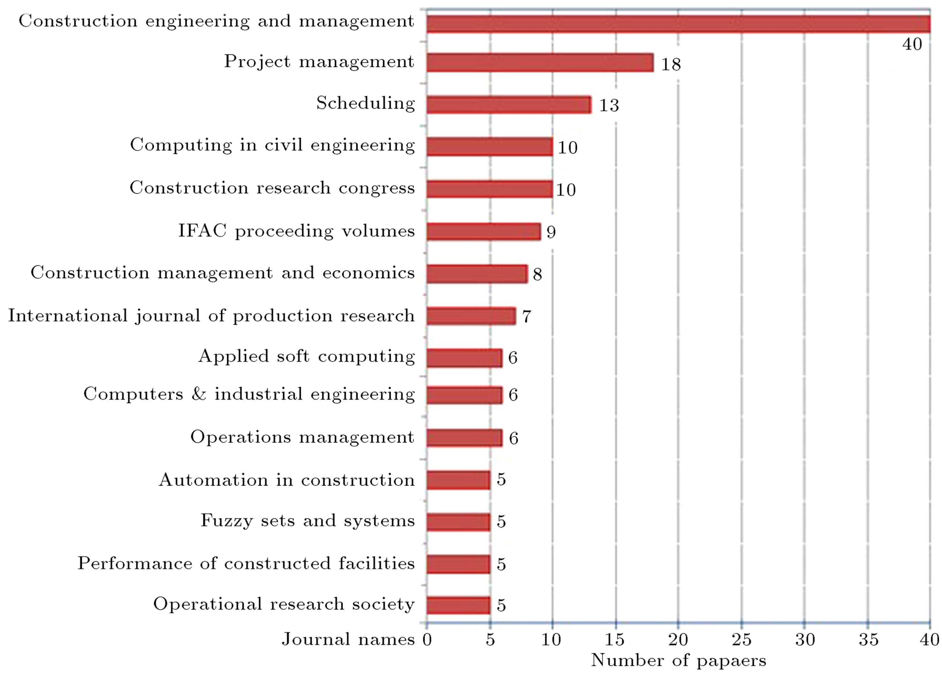

Figure 6. Journals with the most papers on uncertainty management in project scheduling.

Table 2. List of the hybrid papers with the title of uncertainty management in project scheduling.

Considered issues and problems	Applied method	Author(s), publishing year
A new fuzzy TOPSIS hybrid method for green supplier selection using fuzzy time function	Fuzzy TOPSIS hybrid method	Arshadi Khamseh & Mahmoodi., 2014 [13]
A new time-invariant fuzzy time series forecasting method based on genetic algorithm	Fuzzy + GA	Eğrioğlu, 2012 [14]
Measuring duration of the risk-associated activity: a fuzzy set theory application	Fuzzy + risk	Ock & Han, 2010 [15]
Fuzzy neural network-based rescheduling decision mechanism for semiconductor manufacturing	Fuzzy + neural network	Zhang et al., 2014 [16]
Fuzzy flexible resource constrained project scheduling based on genetic algorithm	Fuzzy + GA	Zha & Zhang, 2014 [17]
A GA-based fuzzy optimal model for construction time-cost trade-off	GA + Fuzzy	Leu et al., 2001 [18]

proposed model has been implemented in construction projects of Iranian gas refineries; the related result is described after the model description.

4. A new proposed model for managing uncertainties in construction project scheduling

According to the result of the systematic review in this paper, a new model based on the comprehensive integration of possible and probable uncertainty management is proposed for optimum scheduling of construction projects. Figure 7 indicates the diagram of the proposed model. In fact, this model is an integration of risk management and fuzzy expert systems to manage uncertainties in construction projects scheduling.

5. Implementation of the proposed model in SGPC construction projects

For implementing the proposed model, at first, two professional questionnaires were distributed among 200

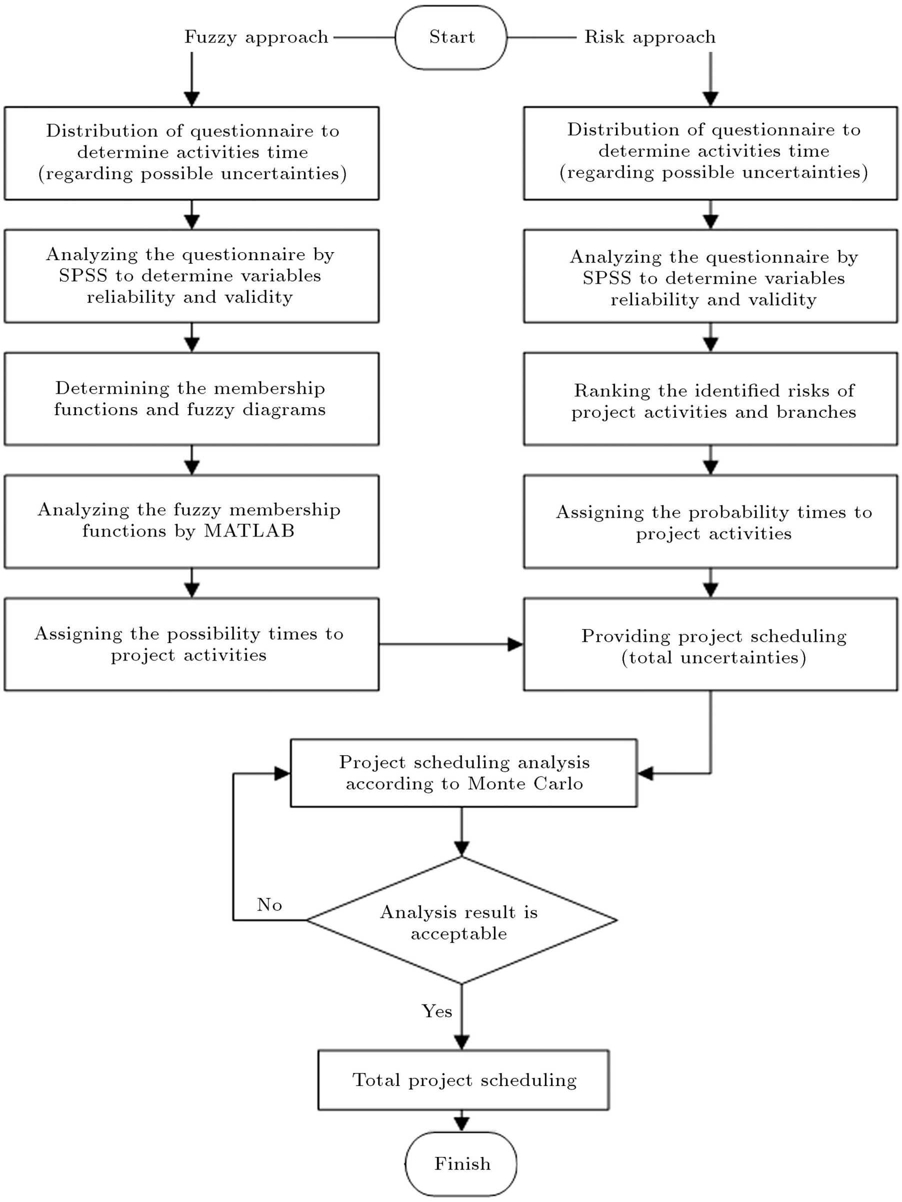

Figure 7. Diagram of the proposed model.

experts of a professional team, which were selected by the staff of 70 contractors, consultants, and client companies. The first questionnaire was designed to identify effective factors such as site organization, weather, labor skills, and quality of equipment in doing project activities. Then, the obtained linguistic variables were translated into mathematical measures. For instance, the questionnaire designed for painting activity is presented in Table 6. As it can be seen in the mentioned table, the values of the linguistic variables were classified into five types. As shown in Table 6, seven factors were considered to estimate the time of painting activity. To examine the reliability of the questionnaire, data analysis was done by SPSS. The results showed that factors 2, 3, and 7 did not have considerable influence on the timing of painting activity (Table 7). Therefore, these factors were eliminated, and calculations were repeated. In the new analysis, the index rose to 0.938, which was desirable. Table 8 shows the result of the second analysis. The main factors of painting activity were climatic condition, quality of paint, availability of skilled workers, and rate of surface opening.

Also, the result of correlation survey by Pearson coefficient indicated that the mentioned factors correlated (Table 9). Consequently, the volume of statistical society was enough, and there was no need for an extension.

In the next step, the second questionnaire, which was related to estimation of activity durations, was

Table 3. Specifications of the most important fuzzy approach papers.

Considered issues and problems	Author(s), publishing year
Real-time task scheduling by fuzzy method	Muhuri & Shukla, 2017 [19]
Flexible scheduling model by fuzzy method	Dubios et al., 2003 [20]
Linguistic approach to non-identical parallel processor scheduling with fuzzy processing times	Geyik & Elibal, 2017 [21]
Using trapezoidal intuitionist fuzzy number to find optimized path in a schedule network	Jayagowri & Ramani, 2014 [22]
A new fuzzy TOPSIS-TODIM hybrid method for green supplier selection using fuzzy time function	Arshadi & Mahmoodi, 2014 [13]
Fuzzy networked systems design by scheduling restrictions	Benítez-Pérez et al., 2012 [23]
A new time-invariant fuzzy time series forecasting method based on genetic algorithm	Eğrioğlu, 2012 [24]
Fuzzy multi-objective optimization of finance-based scheduling for construction projects with uncertainties in cost	Afshar & Fathi, 2009 [25]
An integration of the fuzzy reasoning technique and optimization method in construction project management decision-making	Lam et al., 2001 [26]
Some design issues in cellular manufacturing using the fuzzy programming approach	Shanker & Vart, 1999 [27]
Project scheduling using fuzzy set concepts	Ayyub & Haldar, 1984 [28]
Fuzzy optimal model for resource-constrained construction scheduling	Leu et al., 1999 [29]
Fuzzy project scheduling	Bonnal et al., 2004 [30]
Fuzzy approach for activity delay analysis and schedule updating	Oliveros & Fayek, 2005 [31]
Fuzzy scheduling method for projects with repeating activities	Maravas & Pantouvakis, 2010 [32]
A process for the estimation of the duration of activities in fuzzy project scheduling	Maravas & Pantouvakis, 2011 [33]
Emergency scheduling model of multi-objective-to-resource under uncertain requirements	Xiong and Wang 2014 [34]
Inexact fuzzy chance-constrained nonlinear programming approach to crop water allocation under precipitation variation and sustainable development	Guo et al., 2013 [35]
Estimating precipitation impacts for scheduling	Smith & Hancher, 1989 [36]
Network resource allocation with support of a fuzzy system	Chang et al., 1990 [37]
Scheduling demand-responsive transportation vehicles using fuzzy-set theory	Kikuchi & Donnelly, 1992 [38]

Table 3. Specifications of the most important fuzzy approach papers (continued).

Considered issues and problems	Author(s), publishing year
Fuzzy-set approach to optimizing sludge application land selection	Crump et al., 1993 [39]
Application of fuzzy linear programming in civil engineering	Kumar et al., 2000 [40]
Forecasting project status by using fuzzy logic	Li et al., 2006 [41]
Construction project scheduling using fuzzy mathematical models and critical path method	Castro-Lacouture et al., 2009 [42]
Multi-objective evolutionary finance-based scheduling: entire projects' portfolio	Abido & Elazouni, 2010 [43]
New approach to modelling material-related problems contributing to project delays using rotational fuzzy set	Al-Humaidi & Tan, 2011 [44]
Possibility moments for the task duration in fuzzy PERT	Chrysafis &Papadopoulos, 2014 [45]
A fuzzy discrete event simulation for construction applications	Sadeghi et al., 2016 [46]
A process for the estimation of the duration of activities in fuzzy project scheduling	Maravas & Pantouvakis, 2011 [47]
Application of fuzzy sets for remaining life assessment of corrosion affected reinforced concrete bridge girders	Anoop & Balaji Rao, 2007 [48]
Fuzzy logic approach to activity delay analysis and schedule updating - Journal of Construction Engineering and Management	Oliveros & Fayek, 2005 [49]
Fuzzy optimal model for resource-constrained scheduling	Leu and Hung, 2002 [50]
Robustness measure for fuzzy maintenance activities schedule	Marmier et al., 2007 [51]
Location of cross-docking centers and vehicle routing scheduling under uncertainty: a fuzzy possibilistic programming model	Mousavi et al., 2014 [52]
Modeling project time-cost trade-off in fuzzy random environment	Ke & Ma, 2014 [53]
Procurement scheduling for complex projects with fuzzy activity durations and lead times	Dixit et al., 2014 [54]
Project scheduling under uncertainty using fuzzy modeling and solving techniques	Masmoudi and Hait 2013 [55]
Intelligent timetable evaluation using fuzzy AHP, expert systems with applications	Isaai et al., 2011 [56]
Real-time scheduling of periodic tasks with processing times and deadlines as parametric fuzzy numbers	Muhuri & Shukla, 2009 [57]
Fuzzy hierarchical production planning	Torabi et al., 2010 [58]
MRP with flexible constraints: a fuzzy mathematical programming approach	Mula et al., 2006 [59]

Table 3. Specifications of the most important fuzzy approach papers (continued).

Considered issues and problems	Author(s), publishing year
Material requirement planning with fuzzy constraints and fuzzy coefficients	Mula et al., 2007 [60]
Fuzzy critical chain method for project scheduling under resource constraints and uncertainty	Long & Ohsato, 2008 [61]
Fuzzy project scheduling system for software development	Hapke et al., 1994 [62]
A fuzzy project scheduling approach to minimizing schedule risk for product development	Wang , 2002 [63]
Fuzzy logic-based secure and fault tolerant job scheduling	Wang et al., 2007 [64]
Real-time task scheduling with fuzzy uncertainty in processing times and deadlines	Muhuri & Shukla, 2008 [65]
Fuzzy resource-constrained project scheduling using taboo search algorithm	Atli & Kahraman, 2012 [66]
The fuzzy project scheduling problem with minimal generalized precedence relations	Ponz-Tienda et al., 2015 [67]
Estimating risk adjusted cost or schedule using fuzzy logic	Bellagamba, 1999 [68]
Fuzzy Monte Carlo simulation and risk assessment in construction	Sadeghi et al., 2010 [69]
Computer-aided project duration forecasting subjected to the impact of rain	Guo, 2000 [70]
Survey of fuzzy shop scheduling	Behnamian, 2016 [71]
Resource preprocessing and optimal task scheduling in cloud computing environments	Liu et al., 2015 [72]
Fuzzy due-date scheduling problem with fuzzy processing time	Itoh & Ishii, 1999 [73]
Survey of fuzzy shop scheduling	Behnamian, 2016 [74]
Demand uncertainty in construction supply chains: a discrete event simulation study	Vidalakis et al., 2013 [75]
A new approach to solving time-cost trade-off problem with fuzzy decision variables	Ghazanfari et al., 2009 [76]
A theoretical and practical framework for scheduling in a stochastic environment	Bidot et al., 2009 [77]
A fuzzy set approach to activity scheduling for product development	Wang, 1999 [78]
Project scheduling problem for software development with random fuzzy activity duration times	Huang et al., 2009 [79]
Two uncertain empirical models for project scheduling problem	Ding & Zhu, 2015 [80]
Criticality analysis of activity networks under interval uncertainty	Fortin et al., 2010 [81]

Table 4. Specifications of the most important authors of papers with risk management approach.

No.	Author(s), publishing year	No.	Author(s), publishing year
1	Keller & Bayraksan, 2009 [82]	51	Mawlana & Hammad, 2015 [131]
2	Fernandez et al., 1998 [83]	52	Mínguez & Conejo, 2011 [132]
3	Reed & Knight, 2013 [84]	53	Likhachev & Stentz, 2009 [133]
4	Küchler & Vigerske, 2010 [85]	54	Öztaş & Ökmen, 2005 [134]
5	Kang et al., 2011 [86]	55	Zwikael & Sadeh, 2007 [135]
6	Poshdar et al., 2016 [87]	56	Li, 2015 [136]
7	Shahtaheri et al., 2016 [88]	57	Zhang et al., 2017 [137]
8	De Marco et al., 2015 [89]	58	Ryu et al., 2015 [138]
9	Li and Xu 2014 [90]	59	Dehghan & Ruwanpura, 2011 [139]
10	El-Kholy, 2013 [91]	60	Yang & Chang, 2005 [140]
11	Yang et al., 2013 [92]	61	Tabrizi & Ghaderi., 2016 [141]
12	Perrenoud et al., 2014 [93]	62	Jozefezyk & Thomas, 2007 [4]
13	Park et al., 2014 [94]	63	AlNasseri & Aulin, 2015 [142]
14	Khamooshi & Cioffi, 2012 [95]	64	Herroelen & Leus, 2004 [143]
15	Tran & Molenaar, 2012 [7]	65	Zilberstein & Mouaddib, 2000 [144]
16	Dikmen et al., 2012 [96]	66	Gálvez & Capuz-Rizo, 2016 [145]
17	Barraza, 2010 [97]	67	Lawrence & Sewell, 1997 [146]
18	Mohamed et al., 2009 [98]	68	Kadipasaoglu & Sridharan, 1995 [147]
19	Schatteman et al., 2008 [99]	69	Gong & Rowings, 1995 [148]
20	Ökmen & Öztaş, 2008 [100]	70	Rahmani et al., 2013 [149]
21	Feng et al., 2000 [101]	71	Shah, 2014 [150]
22	Mulholland & Christian, 1999 [102]	72	Izák et al., 2010 [151]
23	Creemers, 2015 [103]	73	Izák et al., 2008 [152]
24	Rostami et al., 2017 [104]	74	Tang & Grubbström, 2002 [153]
25	Fu et al., 2015 [105]	75	Herroelen & Leus, 2005 [154]
26	Zhu et al., 2007 [106]	76	Wang et al., 2017 [155]
27	Lee et al., 2015 [107]	77	Chang et al., 2013 [156]
28	Choi et al., 2007 [108]	78	Arashpour et al., 2016 [157]
29	Zafra-Cabeza et al., 2005 [109]	79	Fiedler, 1987 [158]
30	Pontrandolfo, 2000 [110]	80	Bushuyev & Sochnev, 1999 [159]
31	Gong, 1997 [111]	81	Zhao & Lee, 1993 [160]
32	Mahjoub and Pecero Sánchez 2011 [112]	82	Koo et al., 2011 [161]
33	Ahuja & Nandakumar, 1985 [113]	83	Sridharan & LaForge, 1998[162]
34	Bruun, 1992 [114]	84	Alzraiee et al., 2015 [163]
35	Lansey & Menon, 1993 [115]	85	Acebes et al., 2014 [164]
36	Ben-Haim & Laufer, 1998 [116]	86	Van Marrewijk et al., 2008 [165]
37	Guillaumot et al., 2003 [117]	87	Raturi et al., 1990 [166]
38	Moussa et al., 2007 [118]	88	Garaix et al., 2013 [167]
39	Vaziri et al., 2007 [119]	89	Demeulemeester & Herroelen, 2007 [168]
40	Bocchini & Frangopol, 2011 [120]	90	Golizadeh et al., 2016 [169]
41	Nguyen et al., 2013 [121]	91	Vujanic et al., 2016 [170]
42	Ma et al., 2014 [122]	92	Lamas & Demeulemeester, 2016 [171]
43	Russell et al., 2015 [123]	93	Jeang, 2015 [172]
44	Wang et al., 2014 [124]	94	Ke and Liu, 2015 [173]

Table 4. Specifications of the most important authors of papers with risk management approach (continued).

No.	Author (s), publishing year	No.	Author (s), publishing year
45	Ji & Yao, 2014 [125]	95	Shtub, 1986 [174]
46	Gan & Xu, 2013 [126]	96	Lambrechts et al., 2008 [175]
47	Russell et al., 2014 [127]	97	Chen & Huang, 2006 [176]
48	Wang et al., 2016 [128]	98	Gil et al., 2004 [177]
49	Li et al., 2016 [129]	99	Abdeddaïm et al., 2003 [178]
50	Artigues et al., 2013 [130]	100	Zhu et al., 2005 [179]

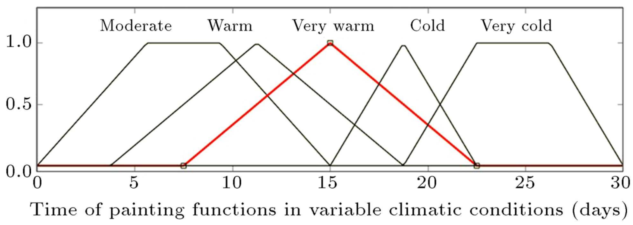

Figure 8. Fuzzy membership function of painting activity model in variable climatic conditions.

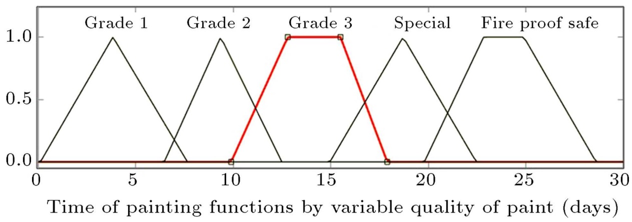

Figure 9. Fuzzy membership function of painting activity model with variable paint quality.

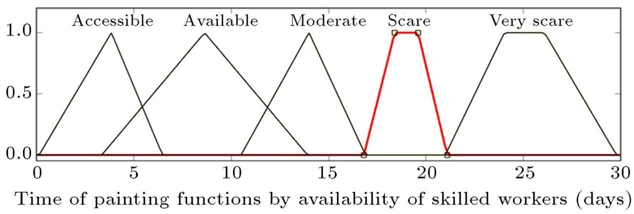

Figure 10. Fuzzy membership function of availability of skilled workers factor.

distributed among the mentioned team members. The second questionnaire was about estimating the time of each activity based on the experience of the professional team. After summing up the results of the first and second questionnaires, the obtained results were examined by a team composed of 9 expert project managers to determine content validity. In the next stages of the proposed model, time factors of membership functions of the activities were drawn according to the second questionnaire. In this research, fuzzy diagrams were of triangular and trapezoidal types. In the present example, Figures 8 to 11 indicate the fuzzy membership functions of painting activity factors. These diagrams were considered as the input in the MATLAB analysis.

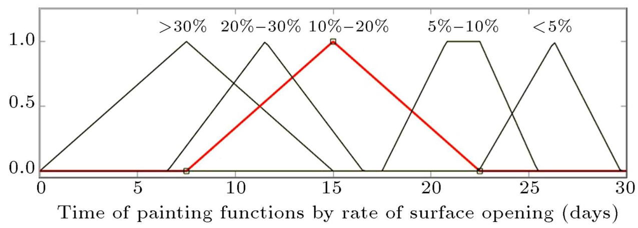

Figure 11. Fuzzy membership function of rate of surface opening factor.

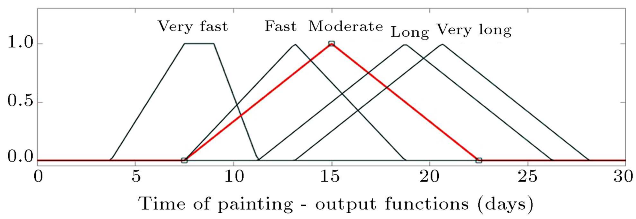

Figure 12. Time of painting activity-output functions.

Also, Figure 12 shows the output function of painting activity time. In the next stage, the results of the previous step as input were analyzed in Fuzzy Toolbox of MATLAB. This toolbox follows a rule-based system. Diagram of the analysis is presented in Figure 13. As it can be seen in this figure, inputs are processed by an intelligent rule-based system.

"IF ... Then ..." rules were set by the expert team in rule-based system. For example, for the 4 mentioned factors, 625 operating modes might occur. After analysis, the duration of activities under uncertainty and fuzzy approach could be achieved. Figure 14 shows the calculated painting time.

After calculating the time of all activities according to this model, project schedule was designed under possible uncertainty. Thus, in the next stage, in order to consider probable uncertainty, we needed to add project risks to the designed project schedule. The probable uncertainty in the model could be considered by two methods. The first method recognized the risks in terms of completed questionnaires and would handle other stages of project risk management based on the obtained results. In the second method, the results of previous studies through similar statistical data

Table 5. Specifications of the selected papers by other contingency-mathematical approaches.

Considered issues and problems	Author(s), publishing year
Presenting an uncertain model for scheduling the logistics projects	KE et al., 2015 [180]
GA approach to remanufacturing process scheduling	Zhang et al., 2015 [3]
Heuristic procedures for reactive project scheduling	Van de Vonder et al., 2007 [181]
A genetic algorithm-based optimal resource-constrained scheduling simulation model	Leu & Hung, 2002 [182]
Applicability of optimal control theory to adaptive supply chain planning and scheduling	Ivanov et al., 2012 [183]
Genetic optimization of order scheduling with uncertainties	Guo et al., 2008 [184]
A two-stage-priority-rule-based algorithm for robust resource-constrained project scheduling	Chtourou & Haouari, 2008 [185]
An event-driven approach with makespan/cost tradeoff analysis for project portfolio scheduling	Kao et al., 2006 [186]
Responding to schedule changes in build-to-order supply chains	Krajewski et al., 2005 [187]
Knowledge-based system for alternative design, cost estimating, and scheduling	Mohamed & Celik, 2002 [188]
A hybrid heuristic algorithm for flowshop inverse scheduling problem under a dynamic environment: cluster computing	Mou et al., 2017 [189]
A genetic algorithm-based optimizing approach for project time-cost trade-off with uncertain measure	Ke, 2014 [190]
A self-adjusting algorithm for driver scheduling	Li, 2009 [191]
Model for evaluating networks under correlated uncertainty	Wang & Demsetz, 2000 [192]
Monte carlo simulation analysis at Lester B Pearson international airport development project	Ersahin et al., 2003 [193]
Reliability buffering for construction projects. Journal of Construction Engineering and Management	Park M& Peña-Mora, 2004 [194]
Construction planning method using case-based reasoning (CONPLA-CBR). Journal of Computing in Civil Engineering	Ryu et al., 2007 [195]
System of multiple ANNs for online project planning	Yousefi et al., 2008 [196]
Real-time simulation for look-ahead scheduling of projects	Song et al., 2009[197]

Table 5. Specifications of the selected papers by other contingency-mathematical approaches (continued).

Considered issues and problems	Author(s), publishing year
Time-cost optimization of nonserial repetitive construction projects	Ezeldin & Soliman, 2009 [198]
Time-scale network simulation by chronographic relations	Francis & Miresco, 2011 [199]
Simulating construction duration for multistory buildings	Nguyen et al., 2013 [200]
A mathematical structure for modeling uncertainty in cost, schedule, and escalation factor in a portfolio of projects	Touran, 2014 [201]
Scenario-based optimization for critical-chain project scheduling	Ma et al., 2015 [202]
Real-time construction schedule analysis of long-distance diversion tunnels based predictions using a Markov process	Bi et al., 2014 [203]
Application of Weibull Analysis to evaluating and forecasting of schedule performance in repetitive projects	Baqerin et al., 2015 [204]
Simulating uncertainties in construction projects with chronographical scheduling logic	Francis, 2016 [205]
A genetic scheduling methodology for virtual cellular manufacturing systems: an industrial application	Mak et al., 2005 [206]
The application of the ant colony optimization algorithm to the construction site layout planning problem	Lam et al., 2007 [207]
A framework for developing intelligent real time scheduling	McPherson & White, 2006 [208]
Recommender system for software project planning, one application of revised CBR algorithm	Yang & Wang, 2009 [209]
Development of a gray critical path for construction planning	Huang et al., 1997 [210]

Table 6. Questionnaire of fuzzy expert system for painting activity.

Please determine the effect of each factor in the time of painting activity									
1- Climatic condition (very cold, cold, moderate. warm, Hot)									
Very cold	☐	Cold	☐	Moderate	☐	Warm	☐	Hot	☐
2- HSE criteria (classification of site in operational zones)									
Out site	☐	Guard fence	☐	Muster point	☐	Operational	☐	H2S penetrate	☐
3- Height of the surface (needing or not needing scaffolding)									
Very short	☐	Short	☐	Moderate	☐	Tall	☐	Very tall	☐
4- Quality of paint (Grade 1, Grade 2, Grade 3, Special, Fire-proof safe)									
Grade 3	☐	Grade 2	☐	Grade 1	☐	Special	☐	FP safe	☐
5- Availability of skilled workers									
Very scarce	☐	Scarce	☐	Moderate	☐	Available	☐	Accessible	☐
6- Rate of surface opening (30%, 20%-30%, 10%-20%, 55%)									
$> 30\%$	☐	20%-30%	☐	10%-20%	☐	5%-10%	☐	$< 5\%$	☐
7- Type of paint material (plastic color T1,..., oil color-T2)									
Plastic color 1	☐	Plastic color 2	☐	Plastic color 3	☐	Oil color-T1	☐	Oil color-T2	☐

Table 7. First reliability analysis of questionnaire (Cronbach's alpha = 0.538).

	Scale mean if item is deleted	Scale variance if item is deleted	Corrected item-total correlation	Cronbach's alpha if item is deleted
S1601	11.73	3.857	0.709	0.287
S1602	11.70	6.562	-0.161	0.647
S1603	11.33	5.816	-0.006	0.620
S1604	11.73	3.857	0.709	0.287
S1605	11.73	3.857	0.709	0.287
S1606	10.87	5.292	0.403	0.467
S1607	11.70	6.562	-0.161	0.647

Table 8. Second reliability analysis of questionnaire (Cronbach's alpha = 0.939).

	Scale mean if item is deleted	Scale variance if item is deleted	Corrected item-total correlation	Cronbach's alpha if item is deleted
S1601	6.07	3.237	0.973	0.878
S1604	6.07	3.237	0.973	0.878
S1605	6.07	3.237	0.973	0.878
S1606	5.20	4.924	0.543	1.000

Table 9. Correlation survey by Pearson coefficient.

		S1601	S1604	S1605	S1606
S1601	Pearson correlation	1	0.843**	0.937**	0.742**
	Sig. (2-tailed)		0.000	0.000	0.002
	N	30	30	30	30
S1604	Pearson correlation	0.843**	1	0.711**	0.821**
	Sig. (2-tailed)	0.000		0.000	0.002
	N	30	30	30	30
S1605	Pearson correlation	0.937**	0.711**	1	0.953**
	Sig. (2-tailed)	0.000	0.000		0.002
	N	30	30	30	30
S1606	Pearson correlation	0.742**	0.821**	0.953**	1
	Sig. (2-tailed)	.002	0.002	0.002	
	N	30	30	30	30

**Correlation is significant at the 0.01 level (2-tailed).

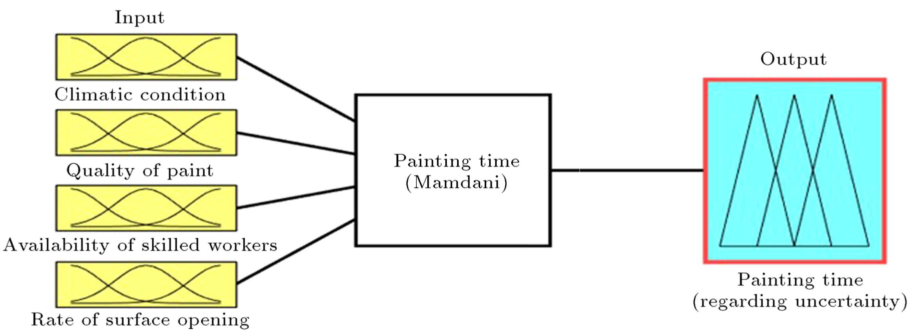

Figure 13. Diagram of the analysis of the proposed model for painting activity.

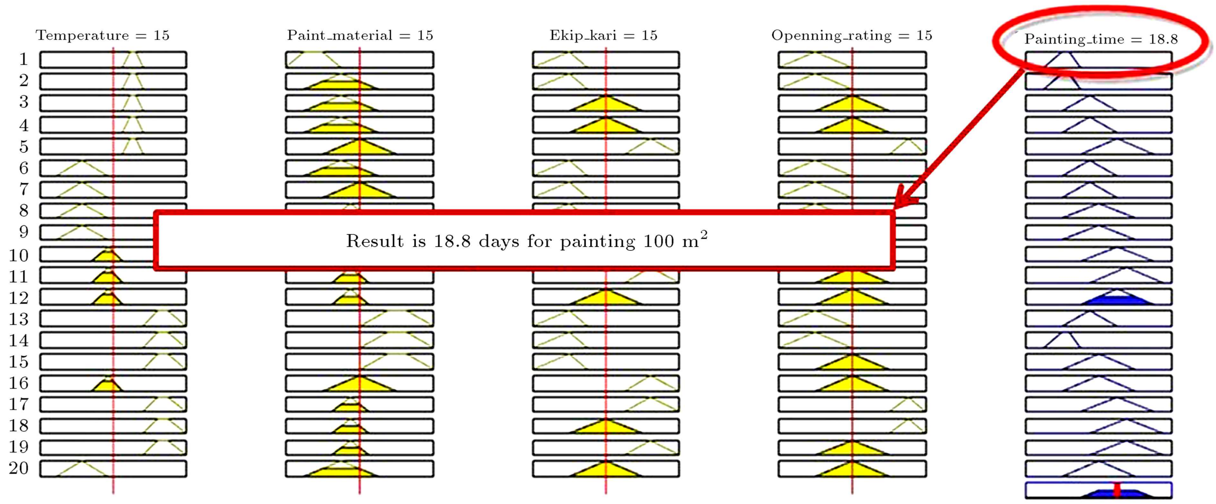

Figure 14. Painting time calculated by the output of the fuzzy approach in MATLAB software.

Table 10. The main historical researchers of risk management in Iranian gas refineries from 2010 to 2017.

Researcher(s)/year	Approach of research
Rudloff and Schultz, 2016 [211]	They reviewed project risk in the oil and gas industry.
Ghasemi et al., 2015 [212]	They presented a new method to scrutinize the insurable risk in Iranian gas refineries by FMEA.
Najafi et al., 2015 [213]	They reviewed risk quantification in complex and fast projects.
Doosti et al., 2014 [214]	They reviewed the risk management in the construction of gas refineries.
Ardeshir et al., 2014 [215]	They reviewed safety assessment in refinery and other construction projects based on analytic hierarchy process.
Bordbar et al., 2013 [216]	They reviewed the identification and allocation of risks in construction projects of Sarkhoon & Gheshm gas refinery.
Amanatyazdi & Moharramnejad, 2013 [217]	They reviewed risk management in Iranian oil and gas companies.
Hamzei & Alamtabriz, 2012 [218]	They proposed a new hybrid method for project risk assessment in construction projects. Also, they reviewed the risks in refinery projects.
Attarzadeh et al., 2011 [219]	They reviewed the risk management of Asaluyeh desalination projects.
Soltani et al., 2011 [220]	They reviewed the risks of projects in Shiraz refinery by FMEA method.
Jalaee & Mahdaviparsa, 2010 [221]	They studied risk management in Iranian construction projects such as gas refineries as a survey study.

derived from similar projects were utilized. Since the application of risk management in gas refineries goes back to many years ago, the second method is a high-priority one. Thus, this study attempts to review the literature on risk management in construction projects of Iranian gas refineries, which have been completed from 2010 to 2017 (Table 10). These studies were classified as a database for construction project risks in gas refineries (Table 11). In the following stages, the expert team allocated the selected risks to each project as probable activities.

Also, there were two procedures for allocating

Table 11. Sample database of construction project risk index (RPN) in gas refineries.

No	Risk description	RPN	No	Risk description	RPN
1	Damage caused by animals/insects	96	11	Toxicity of chemical spill	288
2	Work injury due to cutting	105	12	Explosion	373
3	Clash with underground pipes	120	13	Burns from an electric shock	383
4	Fire-damage to persons	120	14	Fire-refinery equipment damage	390
5	Welding-damage to the eyes	120	15	Damage due to excavation	392
6	Fluctuations in the price of cement	150	16	Work injury due to falling objects	424
7	Lack of necessary infrastructure	210	17	Falling from openings	524
8	Price eccentricity of contractors	216	18	Falling from structure	565
9	Fluctuations in steel prices and rebar	252	19	Falling from scaffolding	570
10	Political and economic sanctions	280	20	Falling from crane	600

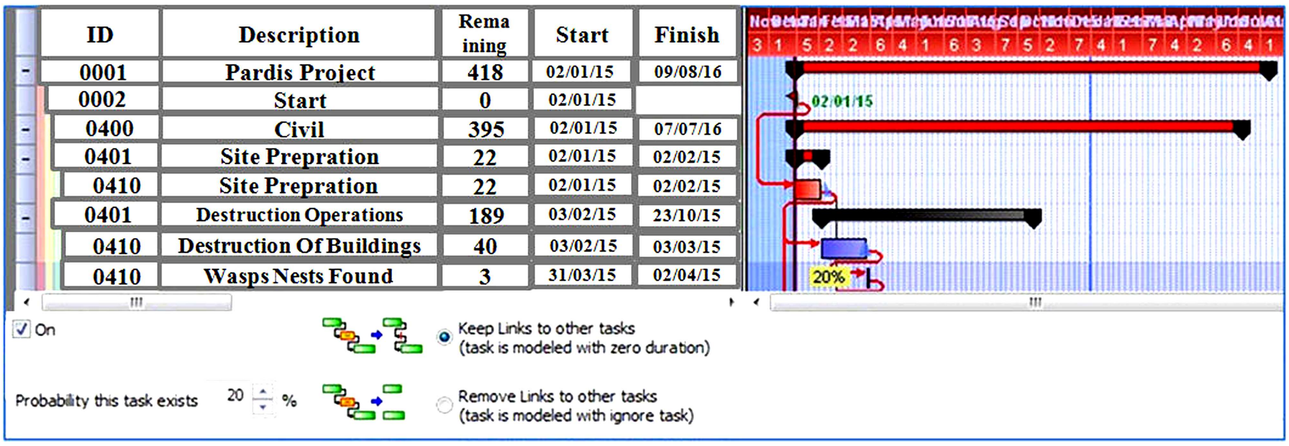

Figure 15. Sample of probable activity in project scheduling - wasps nests found.

risks to project activities in the proposed model of the present study. The first procedure was allocating the risks to each activity as a probable activity and the second one was allocating probable branches to the intended activities. For example, in a destruction operations activity, the risk of "Wasps nests found" with a probability of 5% was allocated to risk management in project scheduling (Figure 15). Also, risks could be allocated to activities as probable branches. For example, in "Excavation" activity, three probable branches were considered. These branches were: (1) "Normal condition" with the probability of 70%; (2) "Finding ground water in the site area" with the probability of 20%; (3) "Finding antique objects underground" with the probability of 5% (Figure 16).

In the final stage of the proposed model, project schedule was designed based on managing both types of uncertainties. Then, the provided schedule was analyzed on the basis of Monte Carlo model. This analysis was done by the Risk Analysis software. Primavera Risk Analysis is a full lifecycle risk analytics solution that provides a comprehensive means for determining confidence levels for project success with quick and easy techniques for determining contingency and risk response plans. If the project schedule has a confidence level of 95 percent, it will be accepted; otherwise, it should be rechecked to undergo possible modifications.

6. Results of implementation of the proposed model

The proposed model was implemented in a gas refinery in the north-east of Iran. This gas refinery provides cooking and industrial gas for 5 provinces in the north and east of Iran, including Khorasan area (three provinces), Semnan, and some parts of Golestan. The period of study was between 2014 and 2016, and the sampling of this study was composed of 30 projects based on Cochran formula. Table 12 presents the titles of the projects done in research studies in correspondence with project estimation accuracies in ascending order.

Figure 16. Sample of probable activity in project scheduling-excavation.

Table 12. The titles of projects that are used in the research studies.

Project ID	Title of project	Project ID	Title of project
P001	Construction of sculpture unit road	P016	Construction of housing center
P002	Construction of Pardis staff pension	P017	Movement of Gonbazli sole
P003	Construction of warehouse building	P018	Construction of oil loading pavement
P004	Degassing of granulation unit	P019	Performing of Pardis power & data line
P005	Construction of senior operator room	P020	Construction of loading HC-condensate area
P006	Performing of O.W.S supports	P021	Performing of general civil maintenance
P007	Construction of gas station	P022	Optimization of Shahid Mohajer pool
P008	Construction of HSE energy channel	P023	Construction of transportation sole
P009	Construction of Torshizi sewage	P024	Construction of contractor building
P010	Performing of refinery F&G system	P025	Restaurant's cold and mechanical rooms
P011	Installation of the 7th boiler of refinery	P026	Construction of TPL fencing
P012	Extending of central restaurant	P027	Performing of Pardis waterline
P013	Construction of sculpture platform	P028	P.F wall in Torshizi residential
P014	Construction of oily water separator	P029	Performing of Pardis gas line
P015	Performing of Pardis complex sewage line	P030	Construction of CMF pipe line

For implementing the proposed model, at first, two professional questionnaires were distributed among a professional team, which was selected by the staff of 70 contractors, consultants, and client companies. The first questionnaire was designed to identify effective factors on doing project activities. Then, obtained linguistic variables were translated into mathematical measures. In the following, obtained information was processed by MATLAB and fuzzy times were dedicated to project activities. In the second phase, risks were added to project as probable activities. Finally, the integrated time of projects activities was analyzed by Monte Carlo method; the outputs showed that the accuracy of project time calculation was improved by about 8 to 24 percent. Figure 17 indicates the improvement of the mentioned project time estimation.

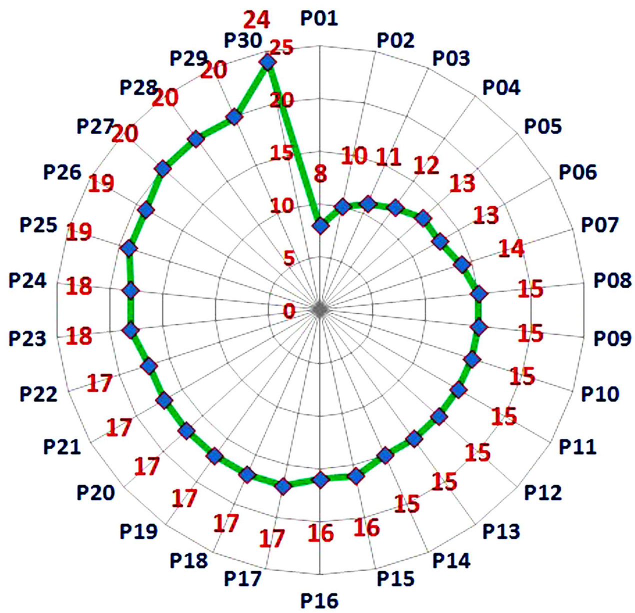

Figure 17. The rate of improvement in project time estimation by the proposed model.

7. Conclusions

In this paper, the literature on uncertainty management in construction projects was reviewed comprehensively. At first, 9236 papers from 6 main online databases were preliminarily reviewed and 242 papers were selected for precise review. According to the analysis of the mentioned papers, the following conclusions were derived:

1. About 29 percent of the last studies considered the possible theory to manage uncertainties in construction project scheduling. They applied fuzzy technique in this field. Thus, the fuzzy technique

was the most applicable method to manage possible uncertainties in construction project scheduling;

2. About 71 percent of the last studies considered the probable theory to manage uncertainties in construction project scheduling and about 80 percent of probable approach (equal to 57 percent of the last studies) belonged to the application of risk management in this field. Other contingency approaches were genetic algorithm, neural network, linear programming, Markov chain, Monte Carlo Simulation, and other mathematical methods and heuristic algorithms. Thus, Risk Management was the most applicable method to manage probable uncertainties in construction project scheduling;
3. Finally, a precise model was proposed to provide comprehensive project time estimation. The proposed model integrated the risk management and fuzzy expert systems in order to manage both modes of time uncertainty in the construction projects of Iranian gas refineries;
4. The result of the implementation of the proposed model showed that the accuracy of project time estimation increased by about 8 to 24 percent. According to successful results of this research, it is suggested that the proposed model could be generalized to projects of other industries.

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