International Journal of Services and Operations Management

ISSN online: 1744-2389 - ISSN print: 1744-2370
https://www.inderscience.com/ijsom

Railway construction project risk assessment techniques: systematic literature review

Tesfaye Gashaw, Kassu Jilcha

DOI: 10.1504/IJSOM.2020.10037643

Article History:

Received:	27 August 2020
Accepted:	07 December 2020
Published online:	13 February 2023

Railway construction project risk assessment techniques: systematic literature review

Tesfaye Gashaw*

African Railway Centre of Excellence,
Institute of Technology,
Addis Ababa University,
Addis Ababa, Ethiopia
Email: tesgass@yahoo.com
*Corresponding author

Kassu Jilcha

School of Mechanical and Industrial Engineering,
Institute of Technology,
Addis Ababa University,
Addis Ababa, Ethiopia
Email: jkassu@gmail.com

Abstract: The purpose of this study is to conduct a systematic literature review of risk analysis techniques for railway construction projects. This review includes related papers on construction project risk analysis methods published between January 2000 and March 2020. For this review, the existing project risk analysis methods are classified as probabilistic, fuzzy logic, multi-criteria decision-making (MCDM) and system dynamics approaches. The results of the review showed that fuzzy analytic hierarchy process (FAHP) and fuzzy analytic network process (FANP) are dominant hybrid MCDM approaches for construction project risk assessment. Nonetheless, these approaches have their own limitations to handle dynamic and feedback effects of project risks as well as update new information when available. Hence, for railway construction project risk assessment, hybrid approaches that can deal with uncertainty, causal relationship, feedback, correlated and conflicting criteria are recommended for future research.

Keywords: railway construction project; risk analysis; risk assessment techniques; system dynamics; systematic literature review; fuzzy analytic hierarchy process; FAHP; fuzzy analytic network process; FANP; multi-criteria decision-making; MCDM.

Reference to this paper should be made as follows: Gashaw, T. and Jilcha, K. (2023) 'Railway construction project risk assessment techniques: systematic literature review', *Int. J. Services and Operations Management*, Vol. 44, No. 1, pp.21–42.

Biographical notes: Tesfaye Gashaw is a PhD candidate in Railway Engineering at African Railway Center of Excellence, Addis Ababa University. He obtained his BSc degree in Industrial Engineering from Bahirdar University and MSc degree in Industrial Engineering from Addis Ababa University, Institute of Technology in 2016. His research interests include project management under uncertainty, system dynamics modelling and system design and engineering.

Kassu Jilcha is a graduate in BSc degree from Bahir Dar University, Faculty of Technology and Engineering in 2006. He obtained his Master of Science degree in 2010 and his Doctor of Philosophy in 2017 in Industrial Engineering from Addis Ababa University (AAU), Addis Ababa Institute of Technology, School of Mechanical and Industrial Engineering. Currently, he is working as an Assistant Professor of Industrial Engineering at AAU. He is also a Director for Students Career Development Center. He has experience of publishing in reputable journals with more than 20 high-impact articles. Also, he is a reviewer at five open access journals, and is a member of Ethiopian Industrial Engineering Society.

1 Introduction

Construction projects are one of the projects with several unique features, such as long period, complicated processes, an abominable environment, financial intensity and dynamic organisational structures (Gupta and Thakkar, 2018; Taylan et al., 2014). Compared to other construction projects, railway projects have a long construction period, require substantial investment and are also characterised by large-scale operations and complex structures (Li et al., 2014b). Since railway projects include roadbeds, rail, tunnels, bridges, station facilities, electrification, drainage and buildings, cooperation between a number of stakeholders is required (Lin et al., 2011).

Due to their complexity and dynamic nature, as well as the involvement of different stakeholders, construction projects are subjected to the effects of a wide variety of risk factors contributing to cost and time overruns (Arashpour et al., 2016; Ebrat and Ghodsi, 2014; Nasirzadeh et al., 2008). These factors make it necessary to manage the railway construction project in the light of the risks involved. As a result, an effective risk management approach is needed to reduce the impact of risks on project time, cost and related objectives. Suitable and effective risk assessment techniques for railway construction projects are therefore required to ensure the success of the projects (Lin et al., 2011; Elbarkouky et al., 2016).

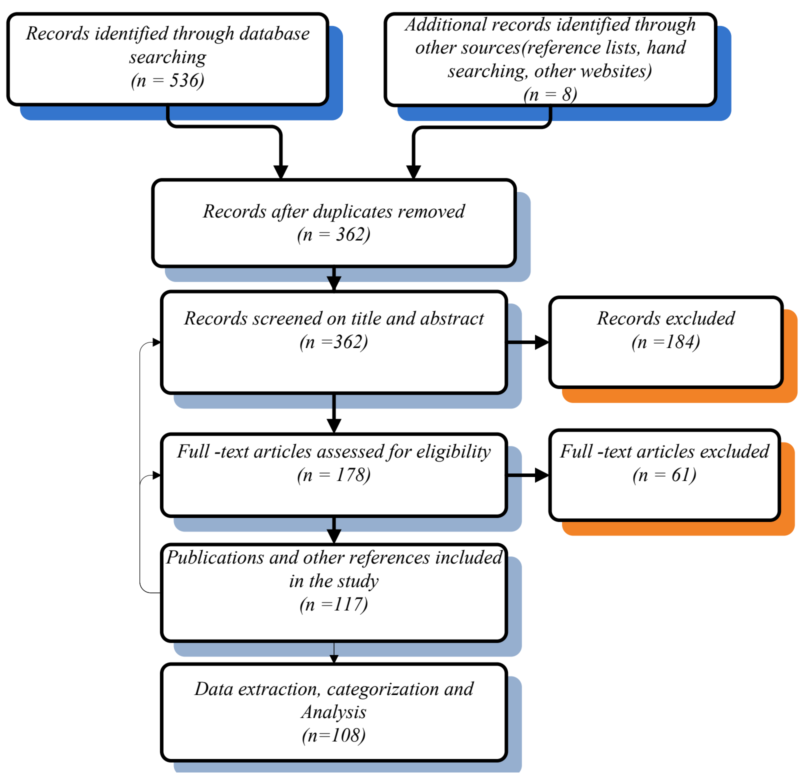
For these reasons, various researchers have implemented different qualitative and quantitative risk assessment techniques to evaluate the effect of risks on the construction project. On the other hand, other researchers have analysed current risk assessment methods used in railway and other construction projects to identify shortcomings and suggest an appropriate risk assessment approach. Taroun (2014) conducted a chronological analysis of papers on construction project risk assessment methods implemented between 1980 and 2012 with an emphasis on probability-impact assessment, probabilistic and AHP approaches. The author argued that the probability-impact assessment tool, which takes the risk cost as a common scale, would be a practicable choice for risk assessment. In addition, Islam et al. (2017) analysed numerous papers that used fuzzy logic and fuzzy hybrid methods to assess the risks of construction projects. The analysis included the relevant papers published between 2005 and 2017. The authors concluded that fuzzy BBN and Credal network approaches are viable techniques for dealing with project uncertainties, limited objective data and the reliance on expert judgement for risk assessment. Although different scholars have conducted a systematic literature review of the project risk assessment, they have not considered the system dynamics (SD) methods and their implementations for construction project risk assessment in depth. The aim of this paper is therefore to conduct a systematic literature review of various risk analysis methods, including probabilistic, fuzzy logic, multi-criteria decision-making (MCDM), SD and hybrid approaches, to identify research gaps, and to make recommendations for future research in risk assessment techniques for railway construction projects. The remaining section of this paper includes methodology, results, discussion and conclusion.

2 Methodology

2.1 Search strategy and data source

A systematic review of the literature on the risk assessment of the railway construction project was carried out in this paper. The main phases of the preferred systematic review and meta-analysis (PRISMA) reporting items procedure, including the search for literature, the selection of qualifying papers, the extraction and categorisation of data, were followed in the review process. A combination of keywords has been used to search for related articles from Science Direct, Emerald Insight, Taylor & Francis, Springer and the Google scholar. The keywords used to search the relevant literature were 'risk analysis' OR 'risk assessment', 'railway construction project risk analysis' OR 'railway construction project risk assessment', 'construction project risk analysis techniques', 'construction project risk assessment' and 'construction project risk management'.

Figure 1 Flow diagram of systematic literature review (see online version for colours)



The search from these sources covered papers published between January 2000 and March 2020. As a result, according to the search strategy, a total of 544 publications were found in these sources. Of these a total of 362 papers were retained after duplicate elimination. The next task was to pick the publications that are relevant to the scope of the topic. Publications that used various risk analysis methods to assess the risks of construction projects were chosen. Finally, 117 publications that comply with the inclusion criteria were considered eligible for this review after the title, abstract and full text screening. Out of these 108 articles are used for analysis while the remaining nine publications and books are used as a reference in this paper. The required data was then extracted from the selected 108 papers. These papers were classified according to the project risk analysis methods adopted for construction projects.

In addition, this paper analysed publications on the basis of the year, journals and conference proceedings. The entire review process is shown in Figure 1.

2.2 Inclusion and exclusion criteria

This review covered peer-reviewed papers on risk analysis of construction projects published between 2000 and March 2020. Articles in languages other than English have been omitted. In addition, articles not relevant to risk assessment of railway construction projects, lecture notes and unpublished papers were excluded in this literature review.

2.3 Data extraction and analysis

Relevant data (authors, year of publication, and type of journal/conference proceedings) for this review were extracted and analysed from the refined articles using Mendeley.

3 Results and discussion

3.1 Results

This section summarises the results of the literature review on railway construction project risk assessment.

3.1.1 Search results

The search was conducted in accordance with the strategy mentioned above (Figure 1). A total of 108 publications that comply with the inclusion criteria were selected. These articles were taken from journals relevant to the risk assessment of railway construction projects. The key journals cited in this literature review are shown in Figure 2. These journals are *Journal of Construction Engineering and Management* (12 articles), *International Journal of Project Management* (ten articles), *Expert Systems with Applications* (five articles), *Safety Science* (three articles), *Reliability Engineering and System Safety* (three articles), *Risk Analysis* (three articles), *Applied Soft Computing* (two articles), *Automation in Construction* (two articles), *Canadian Journal of Civil Engineering* (two articles), *Civil Engineering and Environmental Systems* (two articles) and *Construction Management and Economics* (two articles).

Figure 2 Distribution of relevant articles by publication journals (see online version for colours)

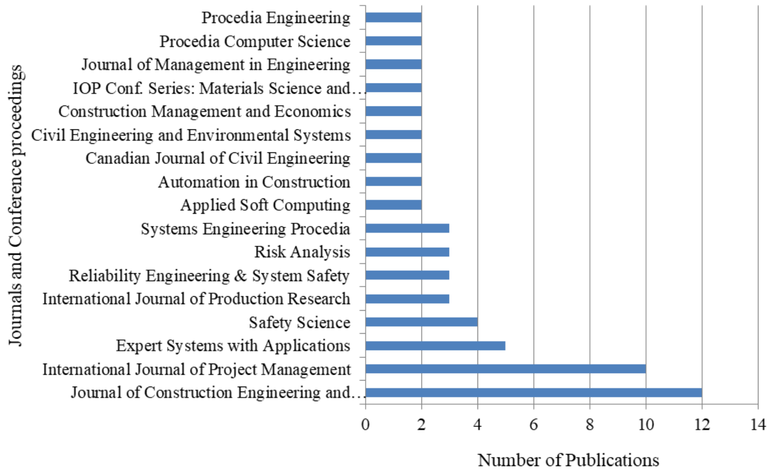


Figure 3 Distribution of relevant articles by publication year (2000 and March 2020) (see online version for colours)

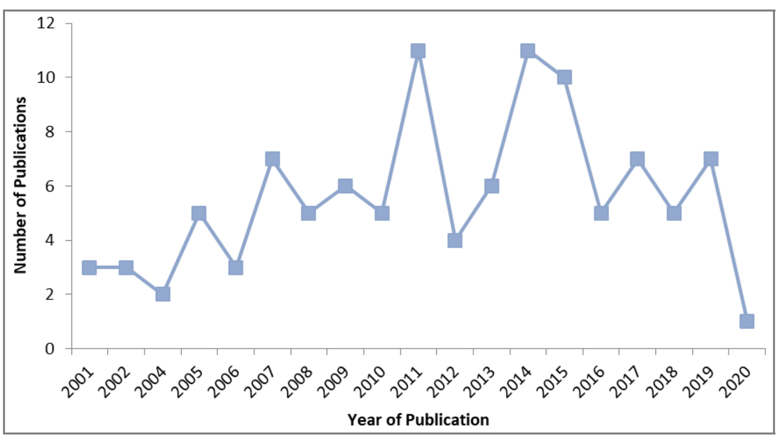


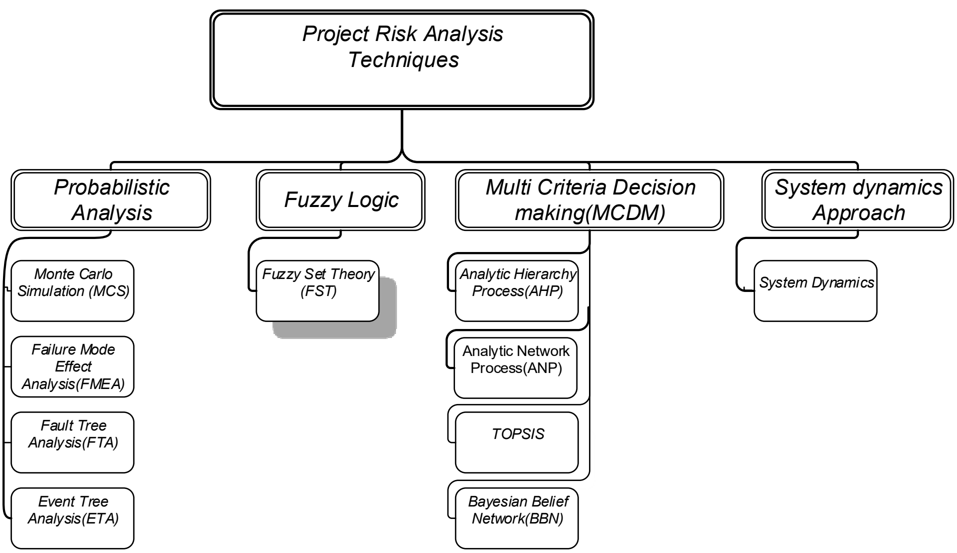
Figure 3 depicts the frequency distribution of selected publications between 2000 and March 2020. According to this figure, the use of the risk assessment techniques for construction projects has experienced substantial growth over the last two decades. The number of papers written on the topic has risen from 36 articles in the first ten years (2000–2009) to 72 in the last ten years (2010–2019). Thirty percent of the papers in this area were written in three years (2011, 2014 and 2015). Due to the benefits of project risk management and the increased interest of researchers on the subject, it is expected that the number of studies on railway construction project risk assessment will continue to increase in the coming years.

3.2 Risk analysis techniques for railway construction projects

In project risk analysis, there are two general methods commonly used: qualitative risk analysis and quantitative risk analysis. Qualitative risk analysis is a method of prioritising project risks for further analysis or action by assessing their likelihood of occurrence and impact as well as other features, while quantitative risk analysis is a method of numerically assessing the impact on overall project goals of the identified project risks and other sources of uncertainty (PMI, 2017). These project risk assessment techniques were categorised based on the decision-making problems-deterministic, stochastic/risk and uncertain (Baloi and Price, 2003) and also classified as statistical methods, fuzzy set theory (FST), Monte Carlo simulation (MCS) and decision support system (Arashpour et al., 2016).

Considering the existing literature reviews on railway and other construction project risk analysis approaches, this paper grouped the refined articles into four categories as shown in Figure 4: probabilistic analysis (n = 25), fuzzy logic (n = 10), MCDM (n = 62), and SD approach (n = 11).

Figure 4 Categorisation of risk analysis techniques



The first category is probabilistic analysis that adopts probability theory to analyse impact of risks on project objectives. The category comprises MCS, failure mode and effects analysis (FMEA), event tree analysis (ETA) and fault tree analysis (FTA). The second category is fuzzy logic approach which is used to handle uncertainty and imprecise judgements of experts through the use of linguistic variables or fuzzy numbers. Fuzzy logic is a dominant technique used in combination with other approaches to handle uncertainty: fuzzy Monte Carlo simulation (FMCS), fuzzy analytic hierarchy process (FAHP), fuzzy analytic network process (FANP), fuzzy technique for order performance by similarity to ideal solution (FTOPSIS), fuzzy Bayesian belief network (FBBN) and fuzzy SD. The third category is MCDM problem analysis approaches that help decision-makers to deal with complex problems. The approaches under this category are analytic hierarchy process (AHP), analytic network process (ANP), technique for order performance by similarity to ideal solution (TOPSIS) and Bayesian belief network (BBN). The fourth category is SD approaches that are used for analysing dynamic and feedback effects of project risks.

3.2.1 Probabilistic analysis

Probabilistic risk analysis is a systematic approach to examine the transformation of an undesired initiating event into a set of potential outcomes and their consequences (Lee and McCormick, 2011). Probabilistic-based risk assessment techniques adopt probability theory to deal with uncertainties associated with risk events. For construction project risk assessment, the techniques used probability distribution to offer estimates of likelihood of achieving project targets and the likely range of outcomes of the project (Smith et al., 2014). These methods include MCS, ETA, FTA and FMEA.

3.2.1.1 Monte Carlo simulation

MCS is a probabilistic risk analysis technique based on multiple uncertain activity combinations to evaluate uncertainty (Hendradewa, 2019). The approach adopts random sampling and statistical modelling to estimate mathematical functions and mimic the operations of complex systems (Harrison, 2010). Using a random number generator and the related cumulative distribution function, MCS generates artificial variable values and then utilises the results to extract values from the probability distribution that describes the behaviour of the stochastic variable (Platon and Constantinescu, 2014; Purnus and Bodea, 2013).

MCS is a common risk analysis technique for construction projects (Sadeghi et al., 2010). It was adopted for scheduling and cost estimation of a fixed-price design – build construction project (Öztaş and Ökmen, 2004), for evaluating the impact of environmental risks on technical and economic objectives of energy investment projects (Olaru et al., 2014). Moreover, the technique was employed for analysing cost risk of highway megaprojects (Molenaar, 2005) and for identifying and analysing risks of bridge construction (Choudhry et al., 2014).

Even though MCS is employed for problems involving random variables with known or assumed probability distributions (Smith et al., 2014), some variables are estimated on the basis of expert judgement and extracted from historical data. For these reasons, researchers have proposed fuzzy MCS approaches to deal with the limitations of MCS for construction project risk analysis. A fuzzy MCS was developed to analyse risks for highway construction projects (Sadeghi et al., 2010) and for road and bridge construction project (Attarzadeh et al., 2017).

3.2.1.2 Failure mode and effects analysis

FMEA is a risk assessment tool for various engineering and management problems (Yazdani et al., 2019). It is an inductive modelling approach for identifying failure modes in a system, analysing main causes, assessing failures impact and formulating corrective actions (Mohammadi and Tavakolan, 2013). Risk priority number (RPN) is used as a weighted assessment number for prioritising the risk items and it is the product of occurrence rating (O), severity rating (S) and detection rating (D) (Ayyub, 2014). However, it is difficult to determine the precise values of these risk factors when there is unavailable or imprecise information. Hence, to make the analysis more consistent and logical, fuzzy logic was introduced to assess the factors in linguistic form (Sharma et al., 2005).

Different researchers adopted FMEA and fuzzy FMEA for risk assessment; for instance, a fuzzy FMEA has been developed for determining construction project risk magnitude (Roghanian et al., 2015). Wang et al. (2009b) also used a fuzzy FMEA method to evaluate risk factors and their relative weights in a linguistic manner and fuzzy RPNs were calculated for prioritisation of failure modes. Moreover, in order to overcome the drawbacks of FMEA, it was integrated with FST and AHP to deal with uncertainty and to determine the relative weight of the risk impacts on the objectives of the project (Abdelgawad and Fayek, 2010; Mohammadi and Tavakolan, 2013). In these hybrid models, fuzzy numbers of linguistic variables are used to determine the ratings of risk factors (occurrence, severity, and detection) and AHP to assess the relative weight of risk impacts on project objectives.

3.2.1.3 ETA and FTA

ETA is an inductive modelling approach for identifying various possible outcomes of a given initiating event (Huang et al., 2001). In this approach, probabilistic data of initiating event and pivotal events are used to measure the probability of success and failure (Ayyub, 2014). FTA is a deductive graphical model for constructing logical combinations of parallel events and a series of potential causes leading to the occurrence of undesired events called the top event (Ayyub, 2014).

In order to handle uncertainty and vagueness, ETA and FTA are integrated with FST. For these reasons, fuzzy FTA was adopted to calculate the fuzzy likelihood of drilling failure for pipeline construction projects (Abdelgawad and Fayek, 2011) and to establish a risk probability and impact assessment framework for Indian build-operate-transfer (BOT) road projects (Thomas et al., 2006). On the other hand, fuzzy FTA-ETA was used to identify the main causes of risks and to determine the possible outcomes of the risk event for construction projects (Abdollahzadeh and Rastgoo, 2015; Aboshady et al., 2013; Nasirzadeh et al., 2019).

3.2.2 Fuzzy logic

Since uncertainty in construction projects typically emerges from either partial information, inherent imprecision or fuzziness in parameter estimates (Thomas et al., 2006), probabilistic approaches cannot address these uncertainties. On the basis of these facts, the FST was introduced by Zadeh (1965) to deal with approximate rather than precise reasoning (Li, 2013).

Following the introduction of FST, many risk assessment methods have adopted the method as a risk modelling and analytical tool to address vague, imprecise and complex risk analysis problems (Nieto-Morote and Ruz-Vila, 2011). Fuzzy risk assessment is a preferred method to measure risk ratings where risk impacts are vague and described by subjective judgement rather than by objective data (Dikmen et al., 2007).

Many researchers used this approach to analyse and assess construction project risks. FST and hierarchical risk breakdown structure were used to evaluate project risk exposure based on project objectives: time, cost, quality and safety (Tah and Carr, 2000; Carr and Tah, 2001). Cho et al. (2002) also used the FST to develop a risk assessment method for construction projects in Korea, and they suggested fuzzy membership curves to consider the range of uncertainty that reflects the degree of uncertainty involved in both probabilistic parameter estimates and subjective judgements. FST was also used to assess risks for underground construction projects (Choi et al., 2004) and for metropolitan construction projects (Samantra et al., 2017). It was also combined with web-based technology to develop a fuzzy risk assessment tool that allows remote project team members to evaluate risks at the design stage of construction projects (Huiping et al., 2005) and also integrated with influence diagrams to estimate cost overrun risk ratings for international construction projects (Dikmen et al., 2007).

3.2.3 MCDM approaches

MCDM approach is a decision-making analysis method that has been developed since the 1970s and is a study of approaches that concern multiple conflicting criteria (Wu et al., 2012). MCDM techniques (AHP, ANP, TOPSIS, etc.) have the common goal of helping decision-makers to address complex issues, and the steps followed are identifying objectives, identifying options for achieving objectives, identifying criteria to be used to compare options, analysing options, making choices and feedback (Kubler et al., 2016).

3.2.3.1 Analytic hierarchy process

AHP is a MCDM technique that allows subjective and objective factors (Dey, 2012) and helps to evaluate complex multiple-criteria alternatives (Wu et al., 2012). AHP analyses the MCDM problem by creating a hierarchy of criteria and sub-criteria that could be either quantitative or qualitative in nature. This can be achieved by making pairwise comparisons between those criteria, which are determined by experts in the relevant sector (Dey, 2012; Chan and Wang, 2013).

Numerous studies used AHP to evaluate risks in various areas of application. An International Construction Risk Assessment Model using AHP has been developed to assess the impact of potential risks to international construction projects by evaluating risk at country, market and project level (Hastak and Shaked, 2000). AHP was also used to analyse the schedule delay risk for the nuclear power plant construction project (Hossen et al., 2015), to evaluate the risks and opportunities of an international construction project (Dikmen and Birgonul, 2006), to rank the construction project risk factors for the construction of highway tunnels (Zhang et al., 2011) and to evaluate sources of risk and prioritise highway construction projects in China (Zayed et al., 2008).

In order to improve the effectiveness of project risk assessment, the AHP approach has been integrated with other methods. A decision support system using AHP and decision tree analysis (DTA) was developed to manage the risks of construction projects (Dey, 2001). The system helps identify risk factors, analyse their impacts on different activities and create cost-effective responses to mitigate quantified risks. Likewise, a construction project risk assessment model that incorporated World Wide Web and company databases was developed using AHP and utility theory to minimise the risk of joint ventures in China (Hsueh et al., 2007).

Although AHP models are designed to capture expert knowledge or opinions, the inputs of the models are subjective in nature and rely on the information available and the reliability of the sources (Hastak and Shaked, 2000; Wang et al., 2009b). As a consequence, fuzzy logic linguistic expressions are regarded as natural representations of judgements in vague, imprecise and uncertain contexts (Chan and Wang, 2013; Wang et al., 2009b).

Fuzzy AHP was used for resolving the risks associated with construction projects in complicated circumstances (Zeng et al., 2007), for analysing risks relevant to JVs in China to help decision-making by project stakeholders (Zhang and Zou, 2007), for assessing the risk level of housing projects (Cebi, 2011) and for risk identification and structuring, and assessing the overall risk factors for building rehabilitation projects (Nieto-Morote and Ruz-Vila, 2011). The fuzzy AHP also provides the ability to overcome complex risk assessments of public private partnership (PPP) projects. This integrated technique has been used for modelling the vagueness of human judgement and to improve the accuracy of risk assessment for expressway projects (Li and Zou, 2011), for risk evaluation model for PPP projects in China (Li and Wang, 2018) and for ranking the risks of public construction projects in Brazil (Beltrão and Carvalho, 2019).

Although it is an effective approach to prioritise alternatives and select options for improvement, the method does not consider the interaction between criteria (Wu et al., 2009). AHP does not explicitly consider the interactions within various factors/clusters and to address the limitations of AHP models, ANP has been used to fix the issue of dependency among alternatives or criteria (Chan and Wang, 2013).

3.2.3.2 Analytic network process

The independence between the higher and lower level elements and the independence within the level assumptions of AHP makes the calculation easier to analyse MCDM problems (Saaty, 1994). However, the complexity of the decision-making problems arising from the interdependence between higher and lower level elements, as well as within the level, make it difficult for the elements to be hierarchically structured using AHP. To address these limitations of AHP, Saaty (1996) proposed ANP that can deal with the complexity and dynamic nature of decision problems by considering dependency and feedback in the decision-making system. Comparing their structure, ANP is a nonlinear structure for establishing interrelationships between criteria in different clusters or within the same cluster, while AHP is a hierarchical and linear structure with the goal at the top level and the alternatives at the bottom level (Lin, 2012). ANP is used to handle numerous, correlated and conflicting criteria (Sayyadi and Awasthi, 2018).

Various studies have been conducted to provide a solution for MCDM problems using ANP. It has been utilised to empirically prioritise a set of projects for selecting construction projects in Australia (Cheng and Li, 2005), to select the best site for a shopping mall in Hong Kong (Cheng et al., 2005), and to prioritise risks for wind energy installation project (Fera et al., 2017) and for large-scale transport infrastructure projects (Yucelgazi and Yitmen, 2018). Likewise, risk responses from the contractors' point of view were prioritised using ANP for bridge construction projects (Yücelgazi and Yitmen, 2020). Moreover, an integrated model of the ANP and the decision making trial and evaluation laboratory (DEMATEL) has been developed for assessing construction project risks (Soofifard et al., 2017).

Although ANP is capable of dealing with the complexity and interrelationship of the elements (risk factors), it cannot handle the uncertainty among the factors and the imbalanced scale of the judgement (Ayağ and Özdemir, 2007). Thus, the integration of fuzzy logic with ANP can handle uncertain parameters and information in the pair-wise comparison of ANP. Fuzzy ANP was utilised to assess risk impact on highway construction projects in Iran (Valipour et al., 2015); to analyse the risks of campus construction project (Lin and Jianping, 2011), to establish a risk evaluation system for the urban rail project in China (Tang et al., 2011) and also to develop a risk evaluation methodology to address the challenges of the MCDM project evaluation problem (Yazdani et al., 2019).

3.2.3.3 Technique for order performance by similarity to ideal solution

TOPSIS is a technique to evaluate the performance of alternatives through the similarity with the ideal solution (Chan and Wang, 2013). The main concept of this technique is to define the positive ideal solution and negative ideal solution. The positive ideal solution is the one that maximises the benefit criteria and minimises the cost criteria, while the negative ideal solution maximises the cost criteria and minimises the benefit criteria (Abdullah and Nashwan, 2015). The idea behind TOPSIS is to select the option that best achieves a balance between two conditions: to be as close as possible to the positive ideal solution and to be as far as possible from the negative ideal solution (Emrouznejad and Ho, 2017). Even though TOPSIS is an appropriate method for project selection, bid and risk assessment (Islam et al., 2017; Taylan et al., 2014), it has a drawback of inability to handle vague and uncertain problems (Krohling and Campanharo, 2011; Torfi et al., 2010). Hence, FST was integrated with TOPSIS to overcome these limitations and the fuzzy TOPSIS was then applied to solve various MCDM problems in bridge risk assessment (Wang and Elhag, 2006). Moreover, the FAHP-TOPSIS combination inherits the advantages of TOPSIS: it allows the use of evaluation parameters with varied scales and units, including negative values (Emrouznejad and Ho, 2017). Fuzzy AHP and fuzzy TOPSIS integrated approach was adopted to prioritise and categorise project risks (Taylan et al., 2014). Fuzzy AHP was utilised to weigh fuzzy linguistic variables of construction project overall risk and fuzzy TOPSIS was used to solve group decision making problems under the fuzzy environment.

Although TOPSIS and fuzzy TOPSIS approaches are simple to compute and understand (Wang et al., 2009a), they do not take into account the hierarchical structure between main sub criteria (Kahraman et al., 2007). Moreover, the TOPSIS techniques do not analyse different criteria comparatively (Ertuğrul and Karakaşoğlu, 2008) and hence they are more effective in one-tier decision making problems than multi-tier problems (Bottani and Riszi, 2006).

3.2.3.4 Bayesian belief network

Bayesian network (BN) is a directed acyclic graph in which the nodes represent the probabilistic system variables and the arcs represent dependency or causal relationships between variables (Oliva et al., 2009). There are three important elements in the development of a BBN: nodes (key factors), networks and conditional probabilities (Liu et al., 2015).The nodes that are the starting ones and do not have an inward arrow referred to as the parent nodes, while the nodes which have inward arrows connected to them are the child nodes (Khodakarami and Abdi, 2014). BNs can be described in terms of a qualitative component, consisting of the causal structure of the system variables, and a quantitative component, consisting of the conditional probability tables (CPTs) assigned to variable nodes (Aliabadi et al., 2020; Kjærulff and Madsen, 2013).

Various researchers employed the BBN approach for construction project risk assessment; for instance, Bayesian analysis and Delphi technique have been used to develop an expert elicitation model to analyse construction payment delay risk in international contracts and to assess the impact of perceptions on risk estimation (Adams, 2008). BBN was also used to quantify the likelihood of construction delays (Luu et al., 2009) and to develop a framework for quantifying uncertainty in project cost for a hospital building project (Khodakarami and Abdi, 2014). In the case of large-scale engineering projects, BBN and expected utility theory (EUT) were used to develop a model called project complexity and risk management (ProCRiM) that helps capture the interdependence between project complexity, complexity induced risks and project objectives in construction projects (Qazi et al., 2016). BBN was adopted to capture risk interdependence (Nepal and Yadav, 2015), while EUT was used to make decisions uncertainty (Ruan et al., 2015).

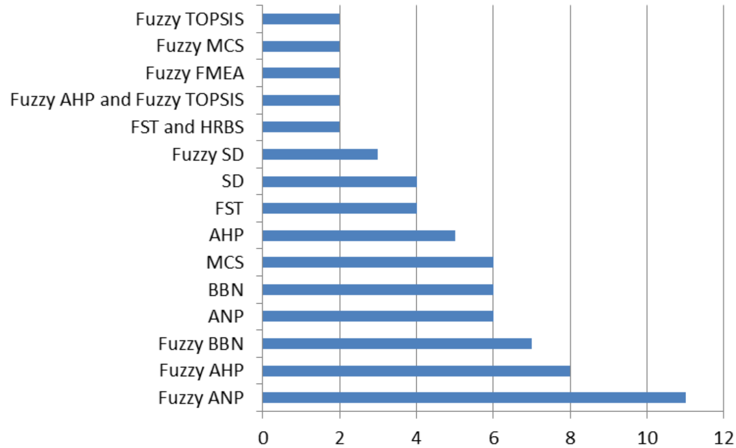
BBN uses probability to assess uncertainty; however, due to inadequate data, vagueness and incomplete knowledge, it is difficult to obtain accurate information (Zhang et al., 2016). Thus, fuzzy logic is incorporated with BBN to enable the conditional probabilities to be defined as ranges rather than as crisp values (Liu et al., 2015). An FBBN model was then employed for the analysis of risk effects on cost overruns in power plant projects (Islam and Nepal, 2016) and was also used to perform a causal analysis of pipeline safety in the tunnel construction project (Zhang et al., 2016) and to assess safety risk in metro construction projects in China (Wang and Chen, 2017).

Risk assessment models using BBN are advantageous as they use inputs from historical data and expert judgement for causal relationship and probability distribution, and have the ability to update the CPTs and the belief of the nodes when new information is available (Kabir et al., 2016). However, the cause effect network relationship formation and CPTs assignment are laborious to implement (Cárdenas et al., 2014). In addition, as BBN is a directed acyclic graph, the feedback loops, delays and dynamic effect of risk factors and their CPs over time cannot be handled (Liu et al., 2012; Mohaghegh, 2010).

3.2.4 System dynamics

SD was developed by Forrester (1961) at the end of the 1950s as a modelling tool for large real world systems. It is defined by Coyle (1996) as: "an approach that deals with the time-dependent behaviour of managed systems with the aim of describing the system and understanding, through qualitative and quantitative models, how information feedback governs its behaviour, and designing robust information feedback structures and control policies through simulation and optimization". The SD approach reflects feedback processes together with stock and flow structures, time delays and nonlinearities (Sterman, 2000), and hence the approach is worthwhile for managing and simulating complex processes that involve changes over time and allow feedback systems. Due to these advantages, SD has been proposed for risk management that requires a systemic approach for feedback capture and quantification of subjective factors (Rodrigues, 2001). The approach has also been used as a possible solution to deal with the complexity of projects in different areas of application. SD has been used to develop a model to capture the dynamics of design errors and to assess their negative impact on delays for university building projects (Han et al., 2013), and also used to analyse the effect of risk interactions on infrastructure project schedule performance (Wang and Yuan, 2017; Xu et al., 2018). The approach has also been utilised to evaluate the consequences of alternative response scenarios and to analyse the impact of project risks on cost, quality and delay (Nasirzadeh et al., 2007), to valuate risk interactions and measure their effect on the cost of the construction project (Li et al., 2014a) and to develop a risk analysis model during project construction phase (Wan and Liu, 2014).

Figure 5 Summary of main construction project risk analysis techniques (see online version for colours)



However, SD models are unable to deal with vague and uncertain information of risk factors. Hence, fuzzy logic has been integrated with SD to deal with these drawbacks. A fuzzy SD approach was developed to model and quantify interrelated risks in terms of their effect on project time and cost for a bridge construction project (Nasirzadeh et al., 2008).

In summary, the key risk analysis methods used for construction project risk management are shown in Figure 5. The figure shows that most of the techniques used to assess construction project risks are hybrid techniques, which are mostly integrated with fuzzy logic. Moreover, the advantages and limitations of the existing risk analysis techniques are listed in Table 1.

3.3 Discussion

Different risk assessment approaches have been implemented to analyse the impact of construction project risks on project objectives. This paper reviewed various studies that used different techniques (probabilistic, fuzzy logic, MCDM and SD) to assess the risks of railway and other construction projects.

Probabilistic methods have been used to measure the probability of delay or cost by treating risk cost as an estimation variance (Taroun, 2014). Construction project risk assessment researchers have implemented probabilistic approaches to analyse project risk using probability theory. In general, these approaches are used to address the uncertainty of variables that result from randomness (Thomas et al., 2006).

However, since construction projects are risk-prone and reliant on expert judgement and experience, it is often difficult to measure subjective or qualitative information using probabilistic approaches (Thomas et al., 2006; Islam and Nepal, 2016). As a result, various researchers employed fuzzy logic to deal with vague and uncertain project risks and their impact on the project objectives (Thomas et al., 2006; Sharma et al., 2005; Abdelgawad and Fayek, 2011).

Table 1 Summary of project risk analysis technique advantages and limitations

Techniques	*Advantages*	*Drawbacks*
Probabilistic	Used when the uncertainty is known	Not used when there is lack of data
FMEA	Identify and present component failure modes, causes and effects on a readable format.	Time consuming difficult and tedious for complex multi-layered systems
FTA	Highly systematic and flexible approach	Uncertainties in the probabilities of base events Fault trees can only deal with binary states
MCS	Relatively simple to develop	The accuracy relies on the number of simulations
	Models can be easily understood	Large and complex models may be challenging
FST	Handles uncertainty, used when there is lack of information	Cannot handle the causal relationships and dependencies
AHP	Used for hierarchical structure of elements	Unable to deal with interactions, dependencies, and feedback between higher and lower level elements.
ANP	Deal with the complexity of decision problems considering dependency and feedback	Constructing a pair wise matrix for large number of risks is laborious and lengthy
TOPSIS	Capture additional risk evaluation criteria (e.g., risk detectability and vulnerability)	Unable to handle vague and uncertain problems
BBN	Deal with complex relationships, and updating new information to the system	Require a lot of time and effort Require an exact probability of each risk factor Cannot deal with feedback effects
SD	Dynamic and feedback effects Causal relationships and dependencies among risks Capture long-run behavioural patterns and trends	Highly dependent on the developer Easy to conceptualise erroneous CLDs and SFDs

On the other hand, in order to understand and rank risks in different hierarchy levels by considering MCDM problems, AHP was utilised for project risk assessment. Furthermore, AHP was combined with FST to handle uncertainty and with TOPSIS to determine variable weights. However, due to the complexity and dynamic nature of project risks, fuzzy AHP cannot overcome relationships, dependencies and feedback between higher and lower level elements and are also unable to determine the impact of risks in different phases of project life cycle (Islam et al., 2017). Owing to this, ANP technique was introduced by Saaty (1996) to deal with the interdependence of complex decision-making factors and to help decision-makers determine the relationship between decision-making levels and their corresponding attributes (Ayağ and Özdemir, 2007; Yazdani et al., 2019). However, developing and constructing a pair wise matrix for large number of risks is laborious and lengthy. In addition, the ANP and FANP approaches are unable to update when new information/data is available (Kabir et al., 2016). Hence, BBN was adopted to deal with the limitations of ANP and FANP for risk assessment (Kabir et al., 2016; Li et al., 2012). FBBN has been utilised as an approach that can handle uncertainty, vagueness and imprecision of data, deal with complex relationships, and updating new information to the system (Kabir et al., 2016; Wang and Chen, 2017). However, FBBN techniques depend on experts, require a lot of time and effort (Zhang et al., 2016) and are unable to deal with feedback effects. On the other hand, SD approaches for project risk assessment were used to assess the dynamic effect of project risks and their feedback effects (Wan and Liu, 2014; Wang and Yuan, 2017). These techniques are also combined with FST to address the uncertainty and imprecision of input data as well as subjectivity of experts (Nasirzadeh et al., 2014).

In short, the results of this review on railway construction project risk assessment differ in part from the previous reviews (Taroun, 2014; Islam et al., 2017). Islam et al. (2017) based on papers that used fuzzy and hybrid techniques published between 2005 and 2017 and concluded that FBBN had the greatest potential to overcome limitations in addressing project uncertainties, limited objective data, and reliance on expert judgement. Taroun (2014) focused on related publications between 1980 and 2012 that employed probability-impact assessment, probabilistic and AHP approaches, and concluded that the probability-impact assessment approach is an effective and practical risk assessment method for construction projects. However, uncertainty, vagueness and imprecise information cannot be addressed through probability-impact assessment approaches and feedback effects of project risks cannot be handled through fuzzy BBN techniques. In addition, most of the previous railway construction project risk assessment studies have not adequately considered SD approach as a tool that can deal with dynamic and feedback effects of project risks. As a consequence, this review concludes that hybrid risk analysis methods addressing uncertainty, causal relationship, likelihood and impact, dynamic and feedback effects, correlated and conflicting criteria are viable approaches for risk assessment of railway construction projects.

4 Conclusions

This paper reviewed risk assessment approaches related to railway construction projects. The review is conducted on publications that adopted different risk assessment techniques for construction projects. These publications were compiled from Science Direct, Emerald Insight, Taylor & Francis, Springer, and Google scholars that were published over the last two decades (January 2000 and March 2020). The probabilistic, fuzzy logic, MCDM, and SD methods adopted for the construction project risk assessment were reviewed and their respective limitations were identified.

The result of the review indicated that the fuzzy logic approach was a dominant method which was integrated with other approaches for dealing with uncertainty and vagueness. More specifically, the MCDM, fuzzy ANP and fuzzy AHP methods were primarily used for risk assessment of construction projects. However, they were unable to update the emergence of new information/data. It was also tiresome and time-consuming to create a pair of wise matrix for a large number of project risks. Hence, BBN was adopted to deal with the limitations of FANP or FAHP. However, BBN and FBBN cannot handle the dynamic and feedback effects over time. Hence, system dynamic approaches have been suggested to analyse both the dynamics and the feedback effects of project risks. Nonetheless, SD was unable to correlate and prioritise risk factors based on their impact on project objectives. To bridge the gap of implementing effective risk assessment methodology for railway construction project, a hybrid approach that can address the probability and impact of risks, uncertainty, causal relationship, correlation of factors as well as dynamic and feedback effect of risks is recommended for future research.

References

Abdelgawad, M. and Fayek, A.R. (2010) 'Risk management in the construction industry using combined fuzzy FMEA and fuzzy AHP', *Journal of Construction Engineering and Management*, Vol. 136, No. 9, pp.1028–1036.

Abdelgawad, M. and Fayek, A.R. (2011) 'Fuzzy reliability analyzer: quantitative assessment of risk events in the construction industry using fuzzy fault-tree analysis', *Journal of Construction Engineering and Management*, Vol. 137, No. 4, pp.294–302.

Abdollahzadeh, G. and Rastgoo, S. (2015) 'Risk assessment in bridge construction projects using fault tree and event tree analysis methods based on fuzzy logic', *ASCE-ASME Journal of Risk and Uncertainty in Engineering Systems Part B: Mechanical Engineering*, Vol. 1, No. 3, pp.1–12.

Abdullah, A. and Nashwan, D. (2015) 'Development of a client-based risk management methodology for the early design stage of construction processes: applied to the KSA', *Engineering, Construction and Architectural Management*, Vol. 22, No. 5, pp.493–515.

Aboshady, A.M., Elbarkouky, M.M.G. and Marzouk, M.M. (2013) 'A fuzzy risk management framework for the Egyptian real estate development projects', *Proceedings of the 2013 Architectural Engineering National Conference*.

Adams, F.K. (2008) 'Risk perception and Bayesian analysis of international construction contract risks: the case of payment delays in a developing economy', *International Journal of Project Management*, Vol. 26, No. 2, pp.138–148.

Aliabadi, M.M., Pourhasan, A. and Mohammadfam, I. (2020) 'Risk modelling of a hydrogen gasholder using fuzzy Bayesian network (FBN)', *International Journal of Hydrogen Energy*, Vol. 45, No. 1, pp.1177–1186.

Arashpour, M., Wakefield, R., Lee, E.W.M., Chan, R. and Hosseini, M.R. (2016) 'Analysis of interacting uncertainties in on-site and off-site activities: implications for hybrid construction', *International Journal of Project Management*, Vol. 34, No. 7, pp.1393–1402.

Attarzadeh, M., Chua, D., Beer, M. and Abbott, E. (2017) 'Fuzzy randomness simulation of long-term infrastructure projects', *ASCE-ASME Journal of Risk and Uncertainty in Engineering Systems, Part A: Civil Engineering*, Vol. 3, No. 3, pp.1–12.

Ayağ, Z. and Özdemir, R.G. (2007) 'An intelligent approach to ERP software selection through fuzzy ANP', *International Journal of Production Research*, Vol. 45, No. 10, pp.2169–2194.

Ayyub, B.M. (2014) *Risk Analysis in Engineering and Economics*, 2nd ed., CRC Press, Boca Raton.

Baloi, D. and Price, A.D.F. (2003) 'Modelling global risk factors affecting construction cost performance', *International Journal of Project Management*, Vol. 21, No. 4, pp.261–269.

Beltrão, L.M.P. and Carvalho, M.T.M. (2019) 'Prioritizing construction risks using fuzzy AHP in Brazilian public enterprises', *Journal of Construction Engineering and Management*, Vol. 145, No. 2, pp.1–11.

Bottani, E. and Rizzi, A. (2006) 'A fuzzy TOPSIS methodology to support outsourcing of logistics services', *Supply Chain Management*, Vol. 11, No. 4, pp.294–308.

Cárdenas, I.C., Al-Jibouri, S.S.H., Halman, J.I.M. and Van Tol, F.A. (2014) 'Modeling risk-related knowledge in tunneling projects', *Risk Analysis*, Vol. 34, No. 2, pp.323–339.

Carr, V. and Tah, J.H.M. (2001) 'A fuzzy approach to construction project risk assessment and analysis: construction project risk management system', *Advances in Engineering Software*, Vol. 32, Nos. 10–11, pp.847–857.

Cebi, S. (2011) 'Developing a fuzzy based decision making model for risk analysis in construction project', *Journal of Multiple-Valued Logic and Soft Computing*, Vol. 17, No. 4, pp.387–405.

Chan, H.K. and Wang, X. (2013) *Fuzzy Hierarchical Model for Risk Assessment*, Springer-Verlag, London.

Cheng, E.W.L. and Li, H. (2005) 'Analytic network process applied to project selection', *Journal of Construction Engineering and Management*, Vol. 5, No. 2, pp.83–97.

Cheng, E.W.L., Li, H. and Yu, L. (2005) 'The analytic network process (ANP) approach to location selection: a shopping mall illustration', *Construction Innovation*, Vol. 5, No. 2, pp.83–97.

Cho, H-N., Choi, H-H. and Kim, Y-B. (2002) 'A risk assessment methodology for incorporating uncertainties using fuzzy concepts', *Reliability Engineering and System Safety*, Vol. 78, No. 2, pp.173–183.

Choi, H.H., Cho, H.N. and Seo, J.W. (2004) 'Risk assessment methodology for underground construction projects', *Journal of Construction Engineering and Management*, Vol. 130, No. 2, pp.258–272.

Choudhry, R.M., Aslam, M.A. and Arain, F.M. (2014) 'Cost and schedule risk analysis of bridge construction in Pakistan: establishing risk guidelines', *Journal of Construction Engineering and Management*, Vol. 140, No. 7, pp.1–9.

Coyle, R.G. (1996) *System Dynamics Modelling: A Practical Approach*, Springer-Science+ Business Media, B.Y, UK.

Dey, P.K. (2001) 'Decision support system for risk management: a case study', *Management Decision*, Vol. 39, No. 8, pp.634–649.

Dey, P.K. (2012) 'Project risk management using multiple criteria decision-making technique and decision tree analysis: a case study of Indian oil refinery', *Production Planning and Control*, Vol. 23, No. 12, pp.903–921.

Dikmen, I. and Birgonul, M.T. (2006) 'An analytic hierarchy process based model for risk and opportunity assessment of international construction projects', *Canadian Journal of Civil Engineering*, Vol. 31, No. 1, pp.58–68.

Dikmen, I., Birgonul, M.T. and Han, S. (2007) 'Using fuzzy risk assessment to rate cost overrun risk in international construction projects', *International Journal of Project Management*, Vol. 25, No. 5, pp.494–505.

Ebrat, M. and Ghodsi, R. (2014) 'Construction project risk assessment by using adaptive-network-based fuzzy inference system: an empirical study', *KSCE Journal of Civil Engineering*, Vol. 18, No. 5, pp.1213–1227.

Elbarkouky, M.M.G., Fayek, A.R., Siraj, N.B. and Sadeghi, N. (2016) 'Fuzzy arithmetic risk analysis approach to determine construction project contingency', *Journal of Construction Engineering and Management*, Vol. 142, No. 12, pp.1–11.

Emrouznejad, A. and Ho, W. (2017) *Fuzzy Analytic Hierarchy Process*, Chapman and Hall/CRC, Boca Raton.

Ertuğrul, I. and Karakaşoğlu, N. (2008) 'Comparison of fuzzy AHP and fuzzy TOPSIS methods for facility location selection', *International Journal of Advanced Manufacturing Technology*, Vol. 39, No. 7, pp.783–795.

Fera, M., Macchiaroli, R., Fruggiero, F. and Lambiase, A. (2017) 'Risks prioritization in decision making for wind energy investments using analytic network process (ANP)', *International Journal of Applied Engineering Research*, Vol. 12, No. 1, pp.2567–2573.

Forrester, J.W. (1961) *Industrial Dynamics*, MIT Press, Cambridge, MA.

Gupta, V.K. and Thakkar, J.J. (2018) 'A quantitative risk assessment methodology for construction project', *Sadhana – Academy Proceedings in Engineering Sciences*, Vol. 43, No. 7.

Han, S., Love, P. and Peña-Mora, F. (2013) 'A system dynamics model for assessing the impacts of design errors in construction projects', *Mathematical and Computer Modelling*, Vol. 57, No. 9, pp.2044–2053.

Harrison, R.L. (2010) 'Introduction to Monte Carlo simulation', *AIP Conference Proceedings*, Vol. 1204, pp.17–21.

Hastak, M. and Shaked, A. (2000) 'ICRAM-1: model for international construction risk assessment', *Journal of Management in Engineering*, Vol. 16, No. 1, pp.59–69.

Hendradewa, A.P. (2019) 'Schedule risk analysis by different phases of construction project using CPM-PERT and Monte-Carlo simulation', *IOP Conference Series: Materials Science and Engineering*.

Hossen, M.M., Kang, S. and Kim, J. (2015) 'Construction schedule delay risk assessment by using combined AHP-RII methodology for an international NPP project', *Nuclear Engineering and Technology*, Vol. 47, No. 3, pp.362–379.

Hsueh, S.L., Perng, Y.H., Yan, M.R. and Lee, J.R. (2007) 'On-line multi-criterion risk assessment model for construction joint ventures in China', *Automation in Construction*, Vol. 16, No. 5, pp.607–619.

Huang, D., Chen, T. and Wang, M.J.J. (2001) 'A fuzzy set approach for event tree analysis', *Fuzzy Sets and Systems*, Vol. 118, No. 1, pp.153–165.

Huiping, S., Anumba, C.J., Bouchlaghem, D.M., Miles, J.C., Mei, C. and Mark, T. (2005) 'An intelligent risk assessment system for distributed construction teams', *Engineering, Construction and Architectural Management*, Vol. 12, No. 4, pp.391–409.

Islam, M.S. and Nepal, M. (2016) 'A fuzzy-Bayesian model for risk assessment in power plant projects', *Procedia Computer Science*, October, Vol. 100, pp.963–970.

Islam, M.S., Nepal, M.P., Skitmore, M. and Attarzadeh, M. (2017) 'Current research trends and application areas of fuzzy and hybrid methods to the risk assessment of construction projects', *Advanced Engineering Informatics*, Vol. 33, No. 1, pp.112–131.

Kabir, G., Sadiq, R. and Tesfamariam, S. (2016) 'A fuzzy Bayesian belief network for safety assessment of oil and gas pipelines', *Structure and Infrastructure Engineering*, Vol. 12, No. 8, pp.874–889.

Kahraman, C., Büyüközkan, G. and Ateş, N. (2007) 'A two phase multi-attribute decision-making approach for new product introduction', *Information Sciences*, Vol. 177, No. 7, pp.1567–1582.

Khodakarami, V. and Abdi, A. (2014) 'Project cost risk analysis: a Bayesian networks approach for modeling dependencies between cost items', *International Journal of Project Management*, Vol. 32, No. 7, pp.1233–1245.

Kjærulff, U.B. and Madsen, A.L. (2013) *Bayesian Networks and Influence Diagrams: A Guide to Construction and Analysis*, 2nd ed., Springer Science+Business Media, New York.

Krohling, R.A. and Campanharo, V.C. (2011) 'Fuzzy TOPSIS for group decision making: a case study for accidents with oil spill in the sea', *Expert Systems with Applications*, Vol. 38, No. 4, pp.4190–4197.

Kubler, S., Robert, J., Derigent, W., Voisin, A. and Le Traon, Y. (2016) 'A state-of the-art survey and testbed of fuzzy AHP (FAHP) applications', *Expert Systems with Applications*, Vol. 65, No. 1, pp.398–422.

Lee, J. and McCormick, N. (2011) *Risk and Safety Analysis of Nuclear Systems*, John Wiley & Sons Inc., New Jersey.

Li, J. and Zou, P.X.W. (2011) 'Fuzzy AHP-based risk assessment methodology for PPP projects', *Journal of Construction Engineering and Management*, Vol. 137, No. 12, pp.1205–1209.

Li, P.C., Chen, G.H., Dai, L.C. and Zhang, L. (2012) 'A fuzzy Bayesian network approach to improve the quantification of organizational influences in HRA frameworks', *Safety Science*, Vol. 50, No. 7, pp.1569–1583.

Li, Q. (2013) 'A novel Likert scale based on fuzzy sets theory', *Expert Systems with Applications*, Vol. 40, No. 5, pp.1609–1618.

Li, P., Wang, J. and Yuan, H. (2014a) 'Analysis of the interactions between risks affecting construction project cost', in Yang, D. and Qian, Y. (Eds.): *Proceedings of the 18th International Symposium on Advancement of Construction Management and Real Estate*, Berlin, Heidelberg: Springer Berlin Heidelberg, pp.423–431.

Li, Q., Liu, R., Zhang, J. and Sun, Q. (2014b) 'Quality risk management model for railway construction projects', *Procedia Engineering*, Vol. 84, pp.195–203.

Li, Y. and Wang, X. (2018) 'Risk assessment for public – private partnership projects: using a fuzzy analytic hierarchical process method and expert opinion in China', *Journal of Risk Research*, Vol. 21, No. 8, pp.952–973.

Lin, R.H. (2012) 'An integrated model for supplier selection under a fuzzy situation', *International Journal of Production Economics*, Vol. 138, No. 1, pp.55–61.

Lin, W., Yaqi, L. and Enmao, W. (2011) 'Research on risk management of railway engineering construction', *Systems Engineering Procedia*, pp.174–180.

Lin, Z. and Jianping, Y. (2011) 'Risk assessment based on fuzzy network (F-ANP) in new campus construction project', *Systems Engineering Procedia*, Vol. 1, pp.162–168.

Liu, K.F.R., Kuo, J.Y., Yeh, K., Chen, C.W., Liang, H.H. and Sun, Y.H. (2015) 'Using fuzzy logic to generate conditional probabilities in Bayesian belief networks: a case study of ecological assessment', *International Journal of Environmental Science and Technology*, Vol. 12, No. 3, pp.871–884.

Liu, K.F.R., Lu, C.F., Chen, C.W. and Shen, Y.S. (2012) 'Applying Bayesian belief networks to health risk assessment', *Stochastic Environmental Research and Risk Assessment*, Vol. 26, No. 3, pp.451–465.

Luu, V.T., Kim, S.Y., Tuan, N.V. and Ogunlana, S.O. (2009) 'Quantifying schedule risk in construction projects using Bayesian belief networks', *International Journal of Project Management*, Vol. 27, No. 1, pp.39–50.

Mohaghegh, Z. (2010) 'Combining system dynamics and Bayesian belief networks for socio-technical risk analysis', *International Conference on Intelligence and Security Informatics: Public Safety and Security*.

Mohammadi, A. and Tavakolan, M. (2013) 'Construction project risk assessment using combined fuzzy and FMEA', *Proceedings of the 2013 Joint IFSA World Congress and NAFIPS Annual Meeting, IFSA/NAFIPS 2013*, https://doi.org/10.1109/IFSA-NAFIPS.2013.6608405

Molenaar, K.R. (2005) 'Programmatic cost risk analysis for highway megaprojects', *Journal of Construction Engineering and Management*, Vol. 131, No. 3, pp.343–353.

Nasirzadeh, F., Afshar, A. and Khanzadi, M. (2007) 'System dynamics approach to optimum response selection in construction project risks', *International Project Management Conference*.

Nasirzadeh, F., Afshar, A. and Khanzadi, M. (2008) 'Dynamic risk analysis in construction projects', *Canadian Journal of Civil Engineering*, Vol. 35, No. 8, pp.820–831.

Nasirzadeh, F., Ghasem Kashi, M., Khanzadi, M., Carmichael, D.G. and Akbarnezhad, A. (2019) 'A hybrid approach for quantitative assessment of construction projects risks: the case study of poor quality concrete', *Computers and Industrial Engineering*, Vol. 131, No. 4, pp.306–319.

Nasirzadeh, F., Khanzadi, M. and Rezaie, M. (2014) 'Dynamic modeling of the quantitative risk allocation in construction projects', *International Journal of Project Management*, Vol. 32, No. 3, pp.442–451.

Nepal, B. and Yadav, O.P. (2015) 'Bayesian belief network-based framework for sourcing risk analysis during supplier selection', *International Journal of Production Research*, Vol. 53, No. 20, pp.6114–6135.

Nieto-Morote, A. and Ruz-Vila, F. (2011) 'A fuzzy approach to construction project risk assessment', *International Journal of Project Management*, Vol. 29, No. 2, pp.220–231.

Olaru, M., Șandru, M. and Pirnea, I.C. (2014) 'Monte Carlo method application for environmental risks impact assessment in investment projects', *Procedia – Social and Behavioral Sciences*, Vol. 109, pp.940–943.

Oliva, G.M., Weber, P., Simon, C. and Iung, B. (2009) 'Bayesian networks applications on dependability, risk analysis and maintenance', *IFAC Proceedings*, Vol. 42, No. 5, pp.215–220.

Öztaş, A. and Ökmen, Ö. (2004) 'Risk analysis in fixed-price design – build construction projects', *Building and Environment*, Vol. 39, No. 2, pp.229–237.

Platon, V. and Constantinescu, A. (2014) 'Monte Carlo method in risk analysis for investment projects', *Procedia Economics and Finance*, pp.393–400.

PMI (2017) *A Guide to the Project Management Body of Knowledge (PMBOK® Guide)*, 6th ed., Project Management Institute, Inc., Pennsylvania.

Purnus, A. and Bodea, C-N. (2013) 'Considerations on project quantitative risk analysis', *Procedia – Social and Behavioral Sciences*.

Qazi, A., Quigley, J., Dickson, A. and Kirytopoulos, K. (2016) 'Project complexity and risk management (ProCRiM): towards modelling project complexity driven risk paths in construction projects', *International Journal of Project Management*, Vol. 34, No. 7, pp.1183–1198.

Rodrigues, A.G. (2001) 'Managing and modelling project risk dynamics a system dynamics-based framework', *Fourth European Project Management Conference*, PMI Europe.

Roghanian, E., Moradinasab, N., Afruzi, E.N. and Soofifard, R. (2015) 'Project risk management using fuzzy failure mode and effect analysis and fuzzy logic', *International Journal of Services and Operations Management*, Vol. 20, No. 2, pp.207–227.

Ruan, X., Yin, Z. and Frangopol, D.M. (2015) 'Risk matrix integrating risk attitudes based on utility theory', *Risk Analysis*, Vol. 35, No. 8, pp.1437–1447.

Saaty, T.L. (1994) 'How to make a decision: the analytic hierarchy process', *Interfaces*, Vol. 24, No. 6, pp.19–43.

Saaty, T.L. (1996) *Decision Making with Dependence and Feedback: The Analytic Network Process*, RWS Publications, Pittsburgh.

Sadeghi, N., Fayek, A.R. and Pedrycz, W. (2010) 'Fuzzy Monte Carlo simulation and risk assessment in construction', *Computer-Aided Civil and Infrastructure Engineering*, Vol. 25, No. 4, pp.238–252.

Samantra, C., Datta, S. and Mahapatra, S.S. (2017) 'Fuzzy based risk assessment module for metropolitan construction project: an empirical study', *Engineering Applications of Artificial Intelligence*, Vol. 65, pp.449–464, https://doi.org/10.1016/j.engappai.2017.04.019.

Sayyadi, R. and Awasthi, A. (2018) 'An integrated approach based on system dynamics and ANP for evaluating sustainable transportation policies', *International Journal of Systems Science: Operations and Logistics*, Vol. 7, No. 2, pp.1–10.

Sharma, R.K., Kumar, D. and Kumar, P. (2005) 'Systematic failure mode effect analysis (FMEA) using fuzzy linguistic modelling', *International Journal of Quality and Reliability Management*, Vol. 22, No. 9, pp.986–1004.

Smith, N.J., Merna, T. and Jobling, P. (2014) *Managing Risk in Construction Projects*, 3rd ed., John Wiley & Sons Ltd., UK.

Soofifard, R., Ebrahimi, M. and Bafruei, M.K. (2017) 'Risk assessment of construction projects by using combined model of analytical network process and DEMATEL method', *International Journal of Services and Operations Management*, Vol. 28, No. 1, pp.1–25.

Sterman, J.D. (2000) *Business Dynamics Systems Thinking and Modeling for a Complex World*, McGraw-Hill Companies, Inc., USA.

Tah, J.H.M. and Carr, V. (2000) 'A proposal for construction project risk assessment using fuzzy logic', *Construction Management and Economics*, Vol. 18, No. 4, pp.491–500.

Tang, W., Zhang, F., Ye, Z. and Li, J. (2011) 'Research on risk evaluation in urban rail transit project', *Procedia Engineering*, Vol. 15, pp.5094–5099.

Taroun, A. (2014) 'Towards a better modelling and assessment of construction risk: insights from a literature review', *International Journal of Project Management*, Vol. 32, No. 1, pp.101–115.

Taylan, O., Bafail, A.O., Abdulaal, R.M.S. and Kabli, M.R. (2014) 'Construction projects selection and risk assessment by fuzzy AHP and fuzzy TOPSIS methodologies', *Applied Soft Computing*, Vol. 17, No. 1, pp.105–116.

Thomas, A.V., Kalidindi, S.N. and Ganesh, L.S. (2006) 'Modelling and assessment of critical risks in BOT road projects', *Construction Management and Economics*, Vol. 24, No. 4, pp.407–424.

Torfi, F., Farahani, R.Z. and Rezapour, S. (2010) 'Fuzzy AHP to determine the relative weights of evaluation criteria and fuzzy TOPSIS to rank the alternatives', *Applied Soft Computing*, Vol. 10, No. 2, pp.520–528.

Valipour, A., Yahaya, N., Md Noor, N., Kildienė, S., Sarvari, H. and Mardani, A. (2015) 'A fuzzy analytic network process method for risk prioritization in freeway PPP projects: an Iranian case study', *Journal of Civil Engineering and Management*, Vol. 21, No. 7, pp.933–947.

Wan, J. and Liu, Y. (2014) 'A system dynamics model for risk analysis during project construction process', *Open Journal of Social Sciences*, Vol. 2, No. 6, pp.451–454.

Wang, J. and Yuan, H. (2017) 'System dynamics approach for investigating the risk effects on schedule delay in infrastructure projects', *Journal of Management in Engineering*, Vol. 33, No. 1, pp.1–13.

Wang, Y.M. and Elhag, T.M.S. (2006) 'Fuzzy TOPSIS method based on alpha level sets with an application to bridge risk assessment', *Expert Systems with Applications*, Vol. 31, No. 2, pp.309–319.

Wang, J.W., Cheng, C.H. and Huang, K.C. (2009a) 'Fuzzy hierarchical TOPSIS for supplier selection', *Applied Soft Computing Journal*, Vol. 9, No. 1, pp.377–386.

Wang, Y.M., Chin, K.S., Poon, G.K.K. and Yang, J.B. (2009b) 'Risk evaluation in failure mode and effects analysis using fuzzy weighted geometric mean', *Expert Systems with Applications*, Vol. 36, No. 2, pp.1195–1207.

Wang, Z.Z. and Chen, C. (2017) 'Fuzzy comprehensive Bayesian network-based safety risk assessment for metro construction projects', *Tunnelling and Underground Space Technology*, September, Vol. 70, No. 1, pp.330–342.

Wu, C., Barnes, D., Rosenberg, D. and Luo, X. (2009) 'An analytic network process-mixed integer multi-objective programming model for partner selection in agile supply chains', *Production Planning and Control*, Vol. 20, No. 3, pp.254–275.

Wu, W., Kou, G., Peng, Y. and Ergu, D. (2012) 'Improved AHP-group decision making for investment strategy selection', *Technological and Economic Development of Economy*, Vol. 18, No. 2, pp.299–316.

Xu, X., Wang, J., Li, C.Z., Huang, W. and Xia, N. (2018) 'Schedule risk analysis of infrastructure projects: a hybrid dynamic approach', *Automation in Construction*, Vol. 95, No. 1, pp.20–34.

Yazdani, M., Abdi, M.R., Kumar, N., Keshavarz-Ghorabaee, M. and Chan, F.T.S. (2019) 'Improved decision model for evaluating risks in construction projects', *Journal of Construction Engineering and Management*, Vol. 145, No. 5, pp.1–13.

Yucelgazi, F. and Yitmen, İ. (2018) 'An ANP model for risk assessment in large-scale transport infrastructure projects", *Arabian Journal for Science and Engineering*, Vol. 44, No. 5, pp.4257–4275.

Yücelgazi, F. and Yitmen, İ. (2020) 'An ANP model for risk response assessment in large scale bridge projects', *Civil Engineering and Environmental Systems*, Vol. 37, No. 1, pp.1–27.

Zadeh, L.A. (1965) 'Fuzzy sets', *Information and Control*, Vol. 8, No. 3, pp.338–353.

Zayed, T., Amer, M. and Pan, J. (2008) 'Assessing risk and uncertainty inherent in Chinese highway projects using AHP', *International Journal of Project Management*, Vol. 26, No. 4, pp.408–419.

Zeng, J., An, M. and Smith, N.J. (2007) 'Application of a fuzzy based decision making methodology to construction project risk assessment', *International Journal of Project Management*, Vol. 25, No. 6, pp.589–600.

Zhang, G. and Zou, P.X.W. (2007) 'Fuzzy analytical hierarchy process risk assessment approach for joint venture construction projects in China', *Journal of Construction Engineering and Management*, Vol. 133, No. 10, pp.771–779.

Zhang, J., Cai, M., Li, X. and Mu, Z. (2011) 'Prioritizing highway tunnel risk factors with AHP method', *2011 International Conference on Information Science and Technology, ICIST 2011*.

Zhang, L., Wu, X., Qin, Y., Skibniewski, M.J. and Liu, W. (2016) 'Towards a fuzzy Bayesian network based approach for safety risk analysis of tunnel-induced pipeline damage', *Risk Analysis*, Vol. 36, No. 2, pp.278–301.