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# Current research trends and application areas of fuzzy and hybrid methods to the risk assessment of construction projects

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ABSTRACT

Fuzzy and hybrid methods have been increasingly used in construction risk management research and this study aims to compile and analyse the basic concepts and methods applied in this field to date. A content analysis is made of a comprehensive literature review of publications during 2005–2017. It is found that the nature of complex projects is such that most risks are interdependent of each other. Therefore, a fuzzy structured method such as the fuzzy analytical network process (FANP) has frequently been used for different complex projects. However, the application of FANP is limited because of the tedious and lengthy calculations required for the pairwise comparisons needed and an inability to incorporate new information into the risk structure. To overcome this constraint, a fuzzy Bayesian belief network (FBBN) has been increasingly used for risk assessment. Further project-specific studies based on FBBN are recommended to justify its broader application. Beyond fuzzy methods, the Credal network – an extended form of Bayesian network- is found to have potential for risk assessment under uncertainty.


## 0. List of acronyms

| | |
|---|---|
| AC | *Automation in Construction* |
| ACME | *Archives of Civil and Mechanical Engineering* |
| AEIC | Architectural Engineering Institute Conference |
| AHP | Analytical hierarchy process |
| AMM | *Applied Mathematical Modelling* |
| ANFIS | Adaptive neuro-fuzzy inference system |
| ANN | Artificial neural networks |
| ANP | Analytical network process |
| ASCE | American Society of Civil Engineers |
| ASME | American Society of Mechanical Engineers |
| BBN | Bayesian belief networks |
| BOT | Build-operate-transfer |
| CAJCIE | *Computer-Aided Journal of Civil and Infrastructure Engineering* |
| CBR | Case-based reasoning |
| CEM | *Construction and Engineering Management* |
| CFPR | Consistent fuzzy preference relations |
| CIE | *Computer and Industrial Engineering* |
| CJCE | *Canadian Journal of Civil Engineering* |
| CME | *Construction Management and Economics* |
| COPRAS | Complex proportional assessment |
| DAG | Directed acyclic graph |
| EJGE | *Electronic Journal of Geotechnical Engineering* |
| EI | *Ekonomska Istrazivanja* |
| ER | Evidential reasoning |
| ESA | *Expert Systems with Application* |
| ETA | Event tree analysis |
| FAHP | Fuzzy analytical hierarchy process |
| F-ANN | Fuzzy artificial neural network |
| FANP | Fuzzy analytical network process |
| F-BBN | Fuzzy Bayesian belief network |
| FCE | Fuzzy comprehensive evaluation |
| FCOPRAS | Fuzzy complex proportional assessment |
| FES | Fuzzy expert system |
| FGDM | Fuzzy group decision making |
| FLIMAP | Fuzzy linear programming technique for multidimensional analysis of preference |

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|---|---|
| FMADR | Fuzzy Multi Attribute Direct Rating |
| FMCS | Fuzzy Monte Carlo simulation |
| FMEA | Failure mode and effect analysis |
| FR-MCS | Fuzzy randomness Monte Carlo simulation |
| FST | Fuzzy set theory |
| FTA | Fault tree analysis |
| GA | Genetic algorithm |
| HFES | Hierarchical fuzzy expert system |
| IEEE | Institute of Electrical and Electronics Engineers |
| ICTE | International Conference on Transportation Engineering IFEMCDM Integrated Fuzzy Entropy-weight Multiple Criteria Decision Making |
| IJET | *International Journal of Engineering and Technology* |
| IJPM | *International Journal of Project Management* |
| JAS | *Journal of Applied Sciences* |
| JCEM | *Journal of Construction Engineering and Management* |
| JCCE | *Journal of Computing in Civil Engineering* |
| JCivEM | *Journal of Civil Engineering and Management* |
| JCP | *Journal of Cleaner Production* |
| JLPPI | *Journal of Loss Prevention in the Process Industries* |
| JOMAE | *Journal of Offshore Mechanics and Arctic Engineering* |
| JPSEP | *Journal of Pipeline Systems Engineering and Practice* |
| JRUES | *Journal of Risk and Uncertainty in Engineering Systems, Part A: Civil Engineering* |
| JVC | Joint venture contract |
| KSCE JCE | *KSCE Journal of Civil Engineering* |
| LINMAP | Linear programming technique for multidimensional analysis of preference |
| MCDA | Multiple criteria decision analysis |
| MCDM | Multi-criteria decision making |
| MCS | Monte Carlo simulation |
| PCS | *Procedia Computer Science* |
| PPP | Public private partnership |
| PSBS | *Procedia Social and Behavioral Sciences* |
| RA | *Risk Analysis* |
| RMTTs | Risk management tools and techniques |
| RPN | Risk priority number |
| SEP | *System Engineering Procedia* |
| SIE | *Structure and Infrastructure Engineering* |
| SJR | Scimago Journal & Country Rank |
| SS | *Safety Science* |
| SVM | Support vector machine |
| TUST | *Tunneling and Underground Space Technology* |
| TOPSIS | Techniques for order of preference by similarity to an ideal solution |
| UBC | The University of British Columbia |
| UHV | Ultra high voltage |
| VIKOR | Vise Kriterijumska Optimizacija I Kompromisno Resenje (Multicriteria Optimization and Compromise Solution) |

## 1. Introduction

Project risk can be defined as an uncertain event that leads to failing to achieve at least one project objective [1,2]. The risk management process can improve project performance by controlling the consequences of risky events on project objectives [3]. It is recognised that it is possible to manage risks but not eradicate them [4]. Risk management involves several steps, such as risk identification, analysis, assessment, prioritisation and responding to project risks with the aim of enhancing opportunities and reducing negative consequences [5,6]. Of these, risk assessment is an important aid in decision science for managing uncertain events. Failure to make a timely assessment of risks and their impact on project objectives (e.g., project duration and cost) can hinder project success [7].

Construction risks are complicated, uncertain and subjective by nature due to the unique features of project-based activities [8]. Historical data of similar projects do not always represent the risk status of new projects, which leads to a dependence on expert judgment. Expert judgments are usually uncertain and subjective due to a vague and imprecise understanding of project risks. Many advanced methods exist for assessing the risks of construction projects. These can be broadly categorised into three types, i.e., indexing, matrix and probabilistic methods [3,9]. Indexing methods are the most popular due to their simplicity of application based on expert judgments, but cannot provide accurate results for complex projects, where the risks involve uncertainties. Matrix methods are applicable for analysing expert judgments and providing a better result for complex projects, but are also incapable of capturing subjectivity and uncertainty in the data. Probabilistic methods provide a robust process for risk assessment of complex projects but need a large amount of data from similar, previously constructed, projects. Thus, probabilistic methods are not appropriate for assessing the construction risks of complex projects because of imprecise and insufficient data [10]. In contrast, fuzzy methods are very efficient in modelling the uncertainties encountered in expert judgments and have therefore been frequently and widely used as independent or hybridised methods of construction risk assessment for the last two decades [11].

There has been an increasing number of publications concerning construction project risk-management in recent years using fuzzy logic and hybrid methods. This study responds to the need for a better understanding of the potential applications of fuzzy and hybrid methods for construction risk management. Chan et al. [11] summarised and critiqued research into "fuzzy techniques" in construction management published between 1996 and 2005. They presented a thorough review of the application of fuzzy logic, fuzzy set theory and hybrid fuzzy methods. During this period, fuzzy logic was hybridised mainly by artificial neural networks (ANN), and the genetic algorithm [11]. Recent studies and research trends have revealed the popularity of using multi-criteria decision making (MCDM) methods to hybridise fuzzy techniques for risk assessment [12]. Rezakhani [6] presented another good review of fuzzy logic for project risk management. However, the study did not cluster fuzzy and hybrid methods, and no project specific applications of these methods were provided. There are many risk assessment methods available for a specific project or projects of a similar type. It is within this context and in the context of construction project risk management that this paper aims to provide a detailed review of research into fuzzy and hybrid methods to delineate their application areas, identify research gaps and guide potential research directions. The remainder of this paper is devoted to the research methodology, construction risk-management tools and techniques, fuzzy-based construction risk management methods, applications of fuzzy and hybrid methods, discussion, future research directions and conclusions.

## 2. Research methodology

This study is based on a comprehensive literature review of recently published (2005–2017) relevant papers. The literature is drawn from the top quality journals in the field of construction engineering and project management listed in the *Scimago Journal & Country Rank* (SJR) list. Three additional relevant papers from three journals not listed in the SJR are also included in the review. The most frequently cited journals in this study are: (1) *Expert Systems with Application*, Elsevier; (2) the *Journal of Construction*