Automation in Construction 58 (2015) 118–128

Contents lists available at ScienceDirect

Automation in Construction

journal homepage: www.elsevier.com/locate/autcon

Urban stormwater construction method selection using a hybrid multi-criteria approach

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ARTICLE INFO

Article history:
Received 19 November 2014
Received in revised form 17 July 2015
Accepted 21 July 2015
Available online 4 August 2015

Keywords:
Urban stormwater
Construction method selection
Fuzzy Analytical Hierarchy Process (FAHP)
Compromise Programming (CP)
Multi-criteria Decision Making (MCDM)
Hybrid methods

ABSTRACT

Construction of urban stormwater collection systems has inherent complexities in terms of the number of conflicting criteria and stakeholders involved in the process. These conditions make it a must to choose a suitable construction method which considers all the aspects of the problem. In this study, selection of the most suitable construction method in urban stormwater collection systems is performed using a systematic and structured hybrid Multi-criteria Decision Making approach. The approach combines Fuzzy Analytical Hierarchy Process (FAHP) and Compromise Programming (CP). This combination reduces the tedious and time consuming process of pair-wise comparisons needed for conventional AHP, which makes it a more desirable approach for decision makers. A real case-study in the city of Tehran, Iran is used to show the complexities of the problem and the suitability of the approach. Discussing the results, new insights are presented on the parameter p in CP technique. The results reveal that the utilized approach has potential to be applied for method selection in other fields of urban construction.

1. Introduction

Stormwater collection systems are vital for successful urban construction management. Choosing the best alternative has always been a challenge for urban managers/decision makers (DMs) due to the complexity and interrelation of the decision criteria involved. Among which, technical limitations, constructional constraints, legal matters, environmental issues, urban landscape, traffic control related subjects, safety concerns, social problems, and economics can be mentioned.

This paper is aimed at solving the problem of construction method selection in urban stormwater collection systems. There are many construction methods for such projects that from one perspective can be divided into two main categories namely open trench and trenchless methods. Open trench methods are mainly suitable for early stages of urban development and less dense areas but normally they cannot be used in highly populated and dense urban neighborhoods. As for the trenchless methods, there are many alternatives for a given project that result in different outcomes in terms of the criteria that would matter to decision makers. To get the best results, these outcomes need to be scrutinized to justify the selected method. This idea has received much attention not only in stormwater but other construction engineering problems and many studies have been conducted on the matter which is considered in the sequel. This shows that DMs at different sectors need efficient techniques for selecting construction methods. In the presented case study, lack of such method has led to a substantial delay in the detail design and construction of the project.

In this research, a hybrid Multi-criteria Decision Making method based on the combination of analytic hierarchy process (AHP) and compromise programming (CP) is utilized to solve the problem of selecting suitable construction method in urban stormwater collection systems. A fuzzy approach is also utilized to address the vagueness and uncertainty involved in the nature of the encountered problems. To demonstrate the suitability of the method, a real case study of utmost importance for urban managers is dealt with. The case which is the construction method selection of an urban stormwater collection tunnel and the reasons for its importance are discussed in details in Section 3.

To choose the best construction method in a given situation, all the abovementioned criteria should be simultaneously considered which requires a suitable Multi-criteria Decision Making (MCDM) method. Choosing a proper MCDM method is indeed an MCDM problem itself because different methods might yield different results for a given problem [1]. Many researchers have studied the evaluation criteria and recommendations for identifying the proper method for a specific problem, among which Cohon and Marks [15], Szidarovszky et al. [61], Nachtnebel [41], and Ganoulis [21] can be mentioned. A variety of decision making techniques have been used in construction method selection

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http://dx.doi.org/10.1016/j.autcon.2015.07.014
0926-5805/

problems, each based on a different decision and optimization theory, e.g. genetic algorithm [43], artificial neural networks [49], evolutionary fuzzy neural inference systems [14], artificial intelligence techniques [55], multi-attribute utility theory [13], knowledge-based methods [5, 47] and decision tree [50]. AHP based methods are also popular and effective tools in this context for the reasons outlined in the sequel. AHP initially was proposed by Saaty [48] and its potential as a decision making tool in construction problems was discussed by Skibniewski [59]. AHP has been effectively used in construction-related MCDM problems so far by Skibniewski and Chao [60], Ziara et al. [82], Shapira and Goldenberg [51], Lam et al. [32], Al-Barqawi and Zayed [4], Moselhi et al. [40], Shapira and Simcha [52], Moselhi and Roofigari-Esfahan [39], Šiožinytė et al. [57], Gudienė et al. [23], Vodopivec et al. [67], and Khan et al. [29] among others. AHP's popularity arises from its simplicity and robustness. Wang et al. [68] outline three main advantages of AHP method as being 1) measuring consistency in the judgments, 2) Organizing ability in decision procedure and 3) ease of judgment by pair-wise comparisons. However, especially with increasing complexity of the problem, remaining consistent in the pair-wise comparisons has always been an issue. To address this problem, Lin et al. [35] proposed an adaptive AHP approach that provides a function for automatically improving the consistency ratio of pairwise comparisons using genetic algorithm and compared it with traditional AHP in a real case study to show its superiority. Tam et al. [62] have made a comparison between AHP and non-structural fuzzy decision support system to show that the latter has a better performance with regard to resolving inconsistency issues.

Most of the real world problems have inherent vagueness and uncertainty; hence to address this issue fuzzy AHP (FAHP) methods have been widely developed. The method first appeared in the work of Van Laarhoven and Pedrycz [66], was modified by Boender et al. [9] and continued by Buckley [10]. Later Chang [12], Zhu et al. [81], Leung and Cao [33], Csutora and Buckley [16], Buckley et al. [11], Ota et al. [44] and Wang et al. [70] explored more aspects and possible enhancements of the method. Simultaneously, FAHP was applied in many construction engineering problems, e.g. risk analysis and assessment in construction projects [34,79,80], bridge construction method [45], excavation construction method [46], selection of sustainable materials for building projects [3], intelligent building performance assessment [28], and bridge construction site selection [7].

One downside of AHP method is the fact that in many real cases the decision makers are reluctant to do all the pair-wise comparisons specially when it comes to the alternatives and hence the method is not easy to use. It is widely believed that choosing the best alternative is the consultant engineers' job. So it has been tried to minimize the efforts needed from the decision makers by limiting the pair-wise comparisons to the criteria and using another ranking method for the alternatives. This view point has been recently confirmed in the construction literature by Nassar et al. [42], Mahmoodzadeh et al. [36], Golestanifar et al. [22], Zavadskas et al. [74,75], Bitarafan et al. [8], Aghdaie et al. [2], Marzouk et al. [38], Šiožinytė and Antuchevičienė [56], Turskis et al. [65], Kutut et al. [31], Kildienė et al. [30], Yazdani-Chamzini [71], Taylan et al. [63], and Zavadskas et al. [76] among others. On the other hand, Compromise Programming (CP) method, introduced by Zeleny [77,78], has been proved to be suitable in discrete decision making problems due to its simplicity and efficiency. It has been extensively used in a variety of applications e.g. Duckstein and Opricovic [18], Simonovic [58], Tecle et al. [64], Shih and Lin [54], Ganoulis [21], Abrishamchi et al. [1], Shiau and Wu [53], Zarghaami [73], Hajkowicz et al. [24], Hajkowicz [25], Fattahi and Fayyaz [19], and Diakaki et al. [17].

The downside of CP method is the how of determination of relative weights of the criteria. Many researchers have tried to address this problem with different methods. For instance, sensitivity analysis has been used to address this issue by Simonovic [58] and Abrishamchi et al. [1]. On the other hand, overwhelming number of pair-wise comparisons needed for a conventional FAHP makes it a time consuming and unwelcome method, especially in case of increasing number of criteria and alternatives. So in the current study FAHP has been used to derive the relative weights of the criteria only. Eliminating substantial number of pair-wise comparisons and having the relative weights in hand, the CP method is then utilized for ranking. It is demonstrated herein that this hybrid method can also solve the problem of multiple decision makers. Wang and Yang [69] utilized the AHP and fuzzy CP to the problem of supplier selection with considering quantity discounts. Alptekin [6] has used the fuzzy AHP for determining relative weights of criteria and fuzzy CP for ranking alternatives in digital camera selection. Extensive literature reviews on the application of different single and hybrid Multi-criteria Decision Making methods to the various areas of the construction industry and infrastructure management have been performed by Jato-Espino et al. [26] and Kabir et al. [27], respectively. Also, Mardani et al. [37] presented a literature review on Fuzzy MCDM techniques and their applications based on the papers published from 1994 to 2014. According to the latter studies and the comprehensive review of the literature by the authors, it is concluded that the utilized method in this study has never been used in urban stormwater construction method selection so far. Such methodology is important for two main reasons: 1) it provides a systematic and structured method of decision making for authorities that can be well documented so it helps with the municipal management, and 2) the ease of usage makes the method a handy and applicable tool since it provides a systematic way of finding the relative weights of the criteria and yet reduces the number of pairwise comparisons which is found appealing to the urban managers (DMs).

In the sequel the mentioned hybrid method is first described. Next the method is applied to a real case problem and the results are discussed in the following part.

2. Method

Since the required number of pair-wise comparisons increases drastically for a conventional AHP/FAHP approach with increasing number of criteria and alternatives, which is normally the case in urban areas, most decision makers are reluctant to do all the comparisons and the method seems annoying to them. Furthermore, they normally believe that evaluating the alternatives is mostly the consultant's job and not theirs. So the present method focuses on determining the relative weights of criteria from FAHP and performing rest of the calculations using CP. Urban construction problems normally involve several stakeholders and so it is imperative for the method to be able to address problems of multiple decision makers.

The solution procedure in this paper consists of four main steps as follows:

Step 1: Studying the nature of problem to identify the most pertaining criteria and alternatives.
Step 2: Creating the hierarchy model of the problem.
Step 3: Determining the relative weights of criteria applying FAHP.
Step 4: Using CP method to achieve the final ranking of alternatives utilizing the weights obtained in step 3.

Table 1
Fuzzy importance scale. The utilized fuzzy numbers represent relative importance of criteria.

Linguistic judgment	Explanation	Fuzzy number
Very unimportant (VU)	A criterion is strongly inferior to another	(0,0,1,2)
Less important (LI)	A criterion is slightly inferior to another	(1,2.5,4)
Equally important (EI)	Two criteria contribute equally to the object	(3,5,7)
More important (MI)	Judgment slightly favors one criterion over another	(6,7.5,9)
Very important (VI)	Judgment strongly favors one criterion over another	(8,9,10,10)