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Reliability-based decision making for selection of ready-mix concrete supply using stochastic superiority and inferiority ranking method

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ABSTRACT

Corporate competitiveness is heavily influenced by the information acquired, processed, utilized and transferred by professional staff involved in the supply chain. This paper develops a decision aid for selecting on-site ready-mix concrete (RMC) unloading type in decision making situations involving multiple stakeholders and evaluation criteria. The uncertainty of criteria weights set by expert judgment can be transformed in random ways based on the probabilistic virtual-scale method within a prioritization matrix. The ranking is performed by grey relational grade systems considering stochastic criteria weight based on individual preference. Application of the decision aiding model in actual RMC case confirms that the method provides a robust and effective tool for facilitating decision making under uncertainty.

1. Introduction

The importance of supply chain management (SCM) is increasingly recognized in the construction industry [1]. The supply chain in many industries encompasses all activities associated with processing, from acquiring raw materials to completion of the end product. Likewise, competitiveness in the construction industry depends on the efficient acquisition, processing, utilization and transfer of information by professional staff when establishing a construction supply chain [2].

Activities associated with SCM include procurement, production scheduling, order processing, inventory management, transport, storage, customer service and all the necessary supporting information systems. Therefore, SCM involves intensive management activity from a central position within the construction coalition or network by either the client organization or by another organization acting as an agent for client. Meanwhile, construction supply chain management (CSCM) which is inspired by manufacturing SCM and which emphasizes volume production modeling, is an emerging research issue. The focus of CSCM is coordinating quantities of materials delivered to specific construction projects.

The process of delivering ready-mix concrete (RMC) to construction projects is a critical CSCM activity. The process depends on the concrete truck mixer, the concrete mobile pump, and the project site environment [3]. The concrete-unloading methods vary and substantially affect on-site project time. However, decision aids (DAs) for evaluating RMC supply chain processes need further development, especially for the RMC unloading type. Particularly, selecting the most appropriate RMC unloading type by considering trade-offs among multiple stakeholders and criteria is actually a highly complex multi-expert multi-criteria decision aid (ME-MCDA) problem.

In practice, multi-expert/group conflict and uncertainty may also occur when decision makers apply their personally preferred structure in the alternative evaluation. The comprehension, analysis and support of the process are even more difficult when deciding how the problem should be handled and what decision should be made [4–6]. Notably, the expert judgments and criteria within the alternatives have great influence when ranking the final alternatives in the DA problem. Thus, this study proposes novel supporting tools for integrating DA strategies to produce robust, reliable, and objective decision making results. The proposed decision aid model helps decision makers (DMs) obtain the best solutions to diverse ME-MCDA problems.

This study is organized as follows: the following section reviews the literature pertaining to current DA on RMC supply chain and the DA method considering uncertainty. The framework of the proposed DA method using virtual-scale method integrated with Monte Carlo simulation (MCS) and individual preference analysis is then

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Nomenclature

$(A_1, A_2, \ldots A_m)$	a set of alternative solutions
$(g_1, g_2, \ldots g_n)$	a set of criteria for assessing each alternative
$g_j(\cdot)$	performance level assigned to each criterion
$\mathbf{D}$	Decision matrix of alternatives under each criterion
$\mathbf{S}$	Superiority matrix (**S**-matrix)
$\mathbf{I}$	Inferiority matrix (**I**-matrix)
$P(A, A')$	level of performance under pair-wise comparison of alternatives between A and A'
$f(d)$	function of preference structure
$S_j(A_i)$	superiority score (dominance of one alternative over others)
$I_j(A_i)$	inferiority score (inadequacy of one alternative when compared with others)
p	preference threshold (the threshold above which one consideration can outrank another)
q	indifference threshold (the threshold below which two consideration do not significantly differ)
d	difference in performance values between alternatives A and A'
$\varphi^{>}(\cdot)$	superiority flow (***S**-Flow*)
$\varphi^{<}(\cdot)$	inferiority flow (***I**-Flow*)
$\varphi_n(A_i)$	complete pre-order net flow (*n-flow*) ranking
$\mathbf{F}_\mathbf{S}^*$	reference score matrix
$\mathbf{D}_\mathbf{S}$	combination matrix
$\mathbf{DC}_\mathbf{S}$	normalized decision matrix
f_{Sj}^{i}	**S**-matrix reference score
f_{Sj}^{*}	**S**-matrix indexes score
C_{Sj}^{i}	normalized **S**-matrix reference score
C_{Sj}^{*}	normalized **S**-matrix indexes score
$\varepsilon_i^{>}(j)$	grey relational grade from superiority of i and j
ω_j	criteria weight value
ρ	distinguishing coefficient with the value of 0.5
ξ	grey relational grade
σ	standard deviation of alternatives criteria
P	preference relation
I	indifference relation
R	incomparability relation
$\mathfrak{R}_{>}$	complete ranking structure from superiority
$\mathfrak{R}_{<}$	complete ranking structure from inferiority
$\mathfrak{R}$	partial ranking structure
X_{ij}	triangular distribution of random virtual-scale variable
(u_{ij}, v_{ij}, y_{ij})	minimum, mode and maximum of virtual-criteria weight values
v	virtual AHP scale criteria weight values
a	actual AHP scale criteria weight values
n	number of alternatives criteria
F_i	strength of the alternative
f_i	weakness of the alternative
α_i	strength of the intensity of preference alternative
x	position of the upper quartile
y	position of the lower quartile

demonstrated by replicating uncertainty information and by achieving a global consensus by different DMs. The applicability of the proposed method is demonstrated in examples of RMC case studies. The experimental results are presented and discussed. Finally, conclusions and directions for future study are given.

2. Literature survey

Ready-mix concrete is a widely used structural material in commercial and industrial buildings, bridges, roadways, sidewalks, houses, dams and other structures [7]. Of all manufactured products, RMC is among the most vulnerable to transport barriers. Coordinating of just-in-time production and transportation in a network of partially independent facilities to guarantee timely delivery to the distributed customers is one of the most challenging aspects of CSCM [8].

Effective production scheduling and efficient truck dispatching are the major concerns of carriers for an RMC plant and for construction site managers. The carrier delivering RMC must be timely, flexible, and able to operate within construction site constraints [3,9]. These challenges arise from the value-to-weight ratio of RMC and its highly perishable condition such that it must be discharged from the truck before it hardens [7]. Hence, RMC supply chain management, and especially the DA problem pertaining to support of supply chain process of RMC suppliers in complex and uncertain environments, are crucial issues in the construction industry.

2.1. Developing an RMC supply chain

The literature includes many studies of RMC supply chains in construction projects. Yan et al. developed an integrated model combining RMC production scheduling and truck dispatching [9]. The model includes a mathematical programming solver to evaluate and solve real-world problems such as mixed integer network flow with side constraint. Park et al. developed a dynamic simulation model to analyze the RMC supply process by focusing on the tradeoff between the truck mixer dispatching interval and on-site queuing time [3]. The model-generated information helps engineers to achieve an economical RMC supply by maintaining the number of queuing truck mixers at the desired level while also satisfying the contractor requirements.

Further, Lin et al. formulated the dispatching operations of RMC trucks as a job shop problem including time windows and demand postponement in a multi-objective programming model [7]. By applying optimization tools, the results could help small and medium-sized enterprises to determine a cost effective and reliable day-to-day RMC distribution schemes. Naso et al. proposed a novel meta-heuristic approach based on a hybrid genetic algorithm combined with constructive heuristics for use in a case study of RMC distribution. The approach obtained a feasible schedule for any given set of requests and reduced the complexity of the just-in-time production and transportation problem [8].

Applying DA in RMC supply chain processes involves two important considerations. First, suppliers always focus on productivity issues. One example of time and cost efficiency is minimizing on-site truck mixer idling to reduce operational losses. Meanwhile, the supplier is concerned about maintaining a good reputation. Secondly, contractors as the client representatives are most concerned about timely delivery to ensure no interruptions in concrete placing. However, automated decision tools for supporting RMC supply planning from the supplier perspective such as decisions tools for maintaining service quality are rarely reported in the literature [3].

Although past studies have confirmed the importance and the major role of the RMC supply chain in construction projects, DAs for RMC supply chain processes are rarely studied and need further development. Considering the complexity of construction project from planning until commencement phase, DAs cannot be