HOW TO CHOOSE A PROJECT MANAGER UNDER UNCERTAINTY

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The success of modern construction projects heavily depends on assigned resources, one of the most crucial being the project manager. Project manager selection is a highly critical decision which is complicated because it does not depend on any single attribute but an analysis of several different characteristics of a candidate. This multi-criteria approach which requires the assignment of weights to criteria and candidates introduces uncertainty derived from the subjective judgment of the decision maker(s). This uncertainty amplifies the risk of choosing the wrong person, particularly, when the applicant pool is large and comprised of similarly qualified or experienced candidates. While fuzzy uncertainty has been applied to discriminate among candidates, random uncertainties have been absent from the discourse. Cloud Theory which uses a bell-shaped membership function, and which is an amalgamation of Fuzzy Set Theory and Probability Theory, is used to account for both fuzzy and random uncertainties. A case study on a construction firm illustrates the hiring exercise and details how the preferences of decision makers are applied to the model. This new approach capitalizes on randomness between the fuzzy partitions when the alternatives appear indistinguishable. Such a model can aid human resource managers by simplifying decisions where uncertainty exists.

Keywords: cloud theory, decision-making, human resource, project manager selection

INTRODUCTION

A project manager who lacks the necessary technical, leadership, or managerial skills increases the risk of project failure and can result in overall stakeholder dissatisfaction. The selection of a competent project manager is therefore highly imperative to the accomplishment of a successful project, as they ensure project integration and they also represent the medium between the client and contractor. The associated roles and subsequent importance of the chosen project manager render the decision-making process involved in selecting a project manager as being significant but most complex. The complications manifest themselves as uncertainties in the decision maker(s) thought process when deciding which project manager is most appropriate for a job. There is extensive literature on factors affecting the choice of project managers, but few relating to how one would go about choosing a project manager. In an attempt to reduce this deficiency, academics within the last decade have tried to produce multi-criteria decision models (MCDM) for making this decision. The primary focus of the MCDM's by Afshari and Yusuff (2013), Xing and A-di (2006), and Hadad, Keren, and Laslo (2013) have been related to the application of Fuzzy Set Theory by itself and also as a modification of other models. Fuzzy

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models account for uncertainties that are fuzzy in nature (ambiguous, imprecise, etc.) but does not compensate for random uncertainties. The inclusion of randomness should reduce the risk of choosing the wrong person as low probability outcomes can be accounted for in the modelling process. The suggestion is therefore to move away from Fuzzy Set Theory assignment of a precise value to the membership degree of an element belonging to a qualitative concept (Yang, Yan and Zeng 2013) and the utilization of Cloud theory which overcomes this weakness as it considers the randomness of fuzziness (Cheng et al., 2006).

The Cloud Model first purported by Li, Cheung, and Ng (1998) uses fuzzy set theory integrated with probability theory as the basis for modelling decision making that involves both fuzzy and random uncertainties (Cheng et al., 2006). This model represents a one to many functional mapping. In defining the Cloud model, Li, Cheung, and Ng (1998) acknowledged a stochastic disturbance of the membership degree encircling a determined central value as being more feasible than a precise range of fuzziness. Cloud Theory allows the measurement of the deviation of a random phenomenon from a normal distribution when the phenomenon is not able to wholly satisfy a normal distribution (Wang, Xu and Li 2014). Yang, Yan and Zeng (2013) were of the view that different confidence levels should be used to represent different judgments. Instead of a decision maker expressing a certain confidence level as done by models proposed by Afshari, Yusuff and Derayatifar (2012) and Afshari and Yusuff (2013), the interval judgement will be used to allow the decision maker free reign over their personal confidence level in making a judgment. The Cloud Model along with interval judgement will be used in this paper as a means of modelling uncertainty.

It is debatable whether a purely cognitive decision may suffice for this decision. However, they may become inappropriate even if the premises are true, as often the putative conclusion are not generalizable (Johnson-Laird 1983). Any temporary discrimination between right (good) decisions and wrong (bad) decisions, loses its validity in the chaotic flow of the decision process considered in its wholeness (Dimitrov 1998). Hence, to produce more meaningful results, a more structured approach is required. However, it is contradictory to use models with no account of uncertainty to model a concept which is uncertain (Martin et al., 2016). While fuzzy uncertainties have been accounted for in models developed to select project managers, random uncertainties have been absent from the discourse, as such, the understanding of uncertainty proposed here departs from partial determinism to include variability. To assist with the selection of a project manager, the aim of this research is to develop a computerised model which incorporates both random and fuzzy uncertainties. The objective is therefore to provide the context through which decision-making uncertainty can be incorporated and illustrate the derived approach with a case study. This representation by this work not only provides a wider spectrum of uncertainty that was previously unaccounted for but it also provides a structured, more efficient selection procedure which reduces the risk of poor choice, when recommending the most appropriate person for a project.

LITERATURE REVIEW

The decision problem of choosing a project manager is hierarchical in nature. This structuring allows for a systematic evaluation of the decision problem (Liqin, Wenming, and Yuexian 2009) where at the lowest tier of the hierarchy are the set of managers to be selected and at the next layers above are the set of factors in which all potential project managers must be compared. At the top of the hierarchy is the most suitable candidate meeting the requirements. Traditional methods for the evaluation and hiring of a new project manager uses an interview panel. In this process, the selection of an individual project leader is based on the panel's perception of the person's competency and their contribution to the success of a similar scale project. The utilization of a group of experts as is conventionally done introduces biases, error, ambiguity, and uncertainty to the process. This fact is supported by Torfi and Rashidi (2011), who stated that the possibility of human error presents itself in every rational decision. Disagreement amongst persons on the choice of a particular individual can also surface in a panel setting (Rashidi, Jazebi and Brilakis 2011). In comparing the qualifications and skills of one Project Manager against another, there exists a vague difference in determining whether one is higher, lower or the same (Liqin, Wenming and Yuexian 2009). They also highlighted that ambiguity between the candidates when weights are assigned to each candidate on each criterion produces vagueness with unclear boundaries especially since all candidates are not exactly alike. The emphasis placed on selecting a suitable project manager and the complicated process involved underscores the need for a system that can simplify and enhance an accurate selection. Where fuzziness exists, it refers to uncertainties about the boundaries of a concept (Yang, Yan and Zeng 2013).

A decision maker's judgment is random, and their knowledge of a candidate may be limited. The variance of these impressions introduces randomness in the decision. Randomness suggests that a concept is perceived differently by different persons or even the same person. It is characterized by repeatability and uncertainty although knowing all possible choices (Li and Du 2007). Ergo, in a case such as the hiring of a project manager where human reasoning takes reign, randomness is inevitably present and contributes to the production of biased decisions. The presence of these elements increases inaccuracies in the decision process (Yang, Yan and Zeng 2013), particularly if they are not accounted for in the decision. A computerized approach to selecting a project manager can aid in simplifying this process. This approach, coupled with an appropriate mathematical principle can eliminate the elements of ambiguity and uncertainty and increase accuracy.

Rashidi, Jazebi, and Brilakis (2011) found that systems using fuzzy set theory as their basis can be used in cases where companies lack experience in selection or the person who possess the necessary expertise are unavailable for the interview. Afshari and Yusuff (2013) modelled the quantitative assessment of project managers through the application of fuzzy linguistic variables. The linguistic judgements were converted into crisp values for the weighting of criteria and the rating of candidates in the form of triangular fuzzy numbers. A fuzzy integral method was used to obtain a final score for candidates. This model was a variation of the one previously done by the same authors, i.e., Afshari, Yusuff, and Derayatifar (2012) in which the evaluation criteria and linguistics were the same, but a simple additive weighting method was used for aggregating the final candidate score.

The type-1 triangular fuzzy model represents a one to one functional mapping of input to output using membership degree between 0 and 1. They, therefore, provide the user with a set confidence level and thus, cannot account for variability in the outcome from the same input data. This approach uses fuzzy set to represent certain and crisp judgments, which is contradictory to the intent of fuzzy set which is to model uncertainty (Saaty and Tran 2007). The type-2 fuzzy set can be applied to solve this deficiency. However, it is equally limited in its account of vagueness as the footprint of uncertainty region is consecutive, and has a clear boundary. The vagueness of human thinking attributes to decision-makers having difficulty in evaluating an entity with corresponding specific numbers (Wang et al., 2014). In the practical sense, these defined triangular fuzzy numbers do not provide a clear relation to human cognition and the degree of confidence and consistency of a decision made by different persons. These models also neglect the inclusion of a person's confidence in making the decision, which is not in keeping with the essence of fuzziness. Because the selection of a project manager involves evaluation of persons on several criteria, the Analytic Hierarchy Process (AHP) has also been employed for gauging the abilities of candidates by Torfi and Rashidi (2011). This method allows for a pairwise comparison of candidates that expressed the degree of preference of one candidate over another. It consists of a nine-point scale corresponding to comparative verbal judgments ranging from "equally preferred" to "extremely preferred" (Saaty 2008). A ratio is used to depict the strength of the dominance of one candidate over the other. Yang et al., (2013) critiqued this method by stating that the numerical values cannot directly correlate to a verbal judgment because of differences in human perception. Thus, randomness still exists. However, it can be deemed as more effective as opposed to giving an assignment of preference based on overall weighting. The ignorance of uncertainty due to randomness in the models reviewed sparks the need for a model that accounts for this element in the selection process.

Liqin, Wenming and Yuexian (2009) noted that the process of choosing a project manager is one that involves a significant number of evaluation criteria. Studies (Rashidi, Jazebi and Brilakis 2011; Afshari, Yusuff and Derayatifar 2012) show that the selection factors for choosing a project manager consist of personal attributes which are specifically related to the project manager, his experience, and skills required for managing and leading a team. The literature on project manager selection reveals that the majority of the reviewed studies do not provide a systematic method for criteria selection (Chaghooshi, Arab and Dehshiri 2016). In addition, there is no definitive set of criteria for selecting a project manager, particularly, as each project delivery method assigns different roles to the project manager and hence skills required might vary.

CLOUD theory

Intervals eliminate the uncertainty associated with the use of a point value (Martin et al., 2016). Each decision maker is therefore required to supply interval judgement aij = $[a_{ij}^L, a_{ij}^U]$ for the importance of each factor and project manager on each factor, which is a measure of the certainty of some value between upper a_{ij}^U and lower a_{ij}^L limits. The supply of such judgement is with conviction that the actual value lies within the range supplied; i.e. the uncertainty is small in the cognition of the decision maker (Yang et al., 2013). For this judgement the membership of the median is the largest and the memberships of the values below a_{ij}^L and above a_{ij}^U are quite small. Therefore, the uncertainty is smallest near the expectation Ex (median) and the two endpoints of the "bell shaped" distribution, but the uncertainty in between them is the largest, and the certainty in these regions is low (Yang et al., 2013). See Figure 1. Using the interval judgement supplied by each decision maker, an interval pairwise comparison reciprocal matrix A = [aij], i, j = 1, 2, ..., n, is constructed for the factors compared against each other and for the project managers compared on each factor.

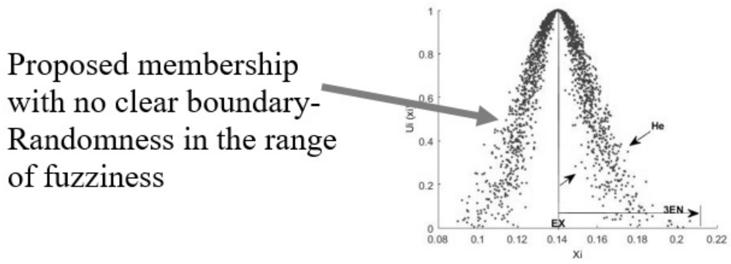

Figure 1: Cloud model characteristics (adopted from Martin et al., 2016)

Since a comparison between two factors is made only once, the symmetrical position, without judgment of the decision makers, are determined as the reciprocal. The diagonal of the matrix a_{ii}, is determined as [1, 1] as each value is compared to itself. The Cloud ratio parameters $\tilde{a}_{ij} = (Ex_{ij}, En_{ij}, He_{ij})$ are defined according to Yang et al., (2013) as follows: Ex expresses the expectation of the interval judgement, the median of the interval can therefore be used to determine its value. See Equation 1.

$$Ex_{ij} = \frac{a_{ij}^L + a_{ij}^U}{2} \quad \text{.... Equation 1}$$

Interval [Ex-3En, Ex +3En] best represents the confidence of a judgment as near certainty (99.74%, 3 Sigma rule) (Grafarend, 2006). Therefore, 6En can be used to reflect the bound and fuzziness of the interval number. Equation 2 illustrates the Entropy (En) determination.

$$En_{ij} = \frac{a_{ij}^U - a_{ij}^L}{6} \quad \text{... .... Equation 2}$$

The computation of uncertainty parameter Hyper-entropy (He) is based on the context of the judgment matrix, see Equation 3.

$$He_{ij} = \frac{Max|En_{ijk} - En_{ij}|}{3} \quad \text{....... Equation 3}$$

Where:

$$En_{ijk} = \frac{(a_{ijk}^U - a_{ijk}^L)}{6} \text{ and } a_{ijk} = [a_{ijk}^L,\ a_{ijk}^U] = a_{ik} \otimes a_{kj},\ \ k = 1,2,\dots,n,\ \ k \neq i, k \neq j$$

.... Equation 4

The operator $\otimes$ expresses the fuzzy multiplication of interval numbers, and

$$a_{ijk} = a_{ik} \otimes a_{kj} = [a_{ik}^L, a_{ik}^U] \otimes [a_{kj}^L, a_{kj}^U] = [a_{ik}^L a_{kj}^L, a_{ik}^U a_{kj}^U] \quad \text{....... Equation 5}$$

The Cloud parameters in the symmetrical position of a positive reciprocal matrix, without judgment of experts, are determined as $\tilde{A} = [\tilde{a}_{ij}] = [(Ex_{ij}, En_{ij}, He_{ij})] =$ 1/(Exij,Enij,Heij) (Martin et al., 2016). Where: $\tilde{a}_{ij} = \frac{1}{\tilde{a}_{ji}} \text{ and } \tilde{a}_{ii} = (1,0,0)$ as there is no uncertainty when a value is compared to itself. If He and En are zero a constant is obtained. In this sense, certainty becomes a special case of uncertainty. The cloud weights of matrix Ã for each decision maker is given by the geometric mean, as shown in Equation 6.

$$\widetilde{W}_i = \frac{\left(\prod_{j=1}^{n} \tilde{a}_{ij}\right)^{1/n}}{\sum_{i=1}^{n} \left(\prod_{j=i}^{n} \tilde{a}_{ij}\right)^{1/n}} \quad \text{...Equation 6}$$

Parameter "He" also reflects the consistency of the judgment matrix. Thus, the consistency index (CI) of the Cloud matrix is shown in Equation 7. In practice, CI satisfying less than 0.1 (less than 10%), i.e. a 90% confidence is required (Saaty 2008). To avoid the influence of bad opinions, only decision maker's judgement with consistency greater than 0.1 are considered.

$$\mathrm{CI} = \frac{1}{n(n-1)} \sum_{\substack{i,j=1 \\ i \neq j}}^{n} \left(He_{ij} / Ex_{ij} \right) \dots \dots ..$$
Equation 7

From the equation, individuals with high consistency are rewarded with a high weighting and the converse also holds. See Equation 8.

$$wa_i = (0.1 - \mathrm{CI_i}) / \sum_{i=1}^{m} (0.1 - \mathrm{CI_i}) \dots \dots \dots . \text{Equation 1}$$ Equation 8

If the importance Wp is predefined by seniority etc. of the decision makers, the composite weight vector wc is given by Equation 9.

wc = α^{wa_i} + (1-α)Wp, 0<α<1…… Equation 9

Where: α is the proportion assigned to the consistent weight vector. For two clouds C1 (Ex1, En1, He1) and C2 (Ex2, En2, He2) in the same universe of discourse U, they can be aggregated using one of two methods (Yang et al., 2013): Synthetic Cloud Aggregation Algorithm: This approach treats the cloud contributions equally, see Equation 10; and the Weighted Cloud Aggregation Algorithm: this is the weighted average of n number of Clouds, see Equation 11.

$$\begin{cases} Ex_s = \frac{1}{n} \sum_{i=1}^{n} Ex_i \\ En_s = \frac{1}{6} \left[\max_i \{ Ex_i + 3En_i \} - \min_j \{ Ex_j - 3En_j \} \right] \\ He_s = \frac{1}{n} \sum_{i=1}^{n} He_i \end{cases}$$ … Equation 10

$$\tilde{A}_{wa} = \frac{\sum_{i=1}^{n} wa_i \widetilde{A_i}}{\sum_{i=1}^{n} wa_i}$$ … Equation 11

Where wai = (wa1, wa2, . . ., wan) represents the weight vector, see equation 12.

$$\tilde{A}_{wa} = \sum_{i=1}^{n} wa_i \tilde{A}_i = \left(\sum_{i=1}^{n} wa_i Ex_i, \sqrt{\sum_{i=1}^{n} (wa_i En_i)^2}, \sqrt{\sum_{i=1}^{n} (wa_i He_i)^2} \right)$$ … Equation 12

The algorithm and power operations for the interaction of cloud C1 and cloud C2 can be obtained from Li and Du (2007) and Martin et al., (2016). The global weights for the project managers are determined by synthesizing the set of local weights. The global weight for the ith alternative delivery method $\tilde{S}_i$ (by considering all attributes is a Cloud number (Exi; Eni; Hei)) using the weighted score method is:

$$\tilde{S}_i = \sum_{k=1}^{k} \widetilde{w_{ik}} \, \widetilde{e_k}$$ …….. Equation 13

Where $\tilde{e}$ is the final cloud weight vector for factors involved in the decision, and $\widetilde{w_k}$ is the final cloud weight vector of the alternatives compared on the factors. The final score $\tilde{S}_i$. Ranking of the project managers can be done by comparing the Cloud numbers parameters (Yang et al., 2013). For example, if Exi ≥ Exj, Eni < Enj, and Hei < Hej, then project manager Ai absolutely dominates project manager Aj; otherwise, if Exi < Exj, and Eni < Enj or Hei < Hej, we say Aj averagely dominates Ai. Consideration of the uncertainty expressed by En and He is done when Exs are approximately equal. The generating algorithm of the one-dimension forward normal Cloud for input of uncertainty characteristic Ex, En, and He, and the number of Cloud drops N, the output will be the certainty degrees μ, i.e., drop (xi , μi), for i=1,2,3,..,N (Li and Du 2007). MATLAB modelling was used to express the content of the information model generated as follows:

Beginning with expectation of En and a standard deviation of He, a normal random number En_i' is generated, En_i' = NORMAND (En, He).

A normal random number xi, with expectation of Ex and a standard deviation of En_i' is produced. xi = NORMAND (Ex, En'1).

Calculate the certainty degree of xi, such that $\mu = e^{-\frac{(x_i - Ex)^2}{2(En')^2}}$

xi is a Cloud drop with the confirmation degree μ_i expressed as drop (xi, μ_i).

i–iv is repeated until the Cloud drops generated are sufficient for N.

Plot each drop (xi, μ_i).

METHOD

The case study was designed to elicit both qualitative information about the topic of study and quantitative information to be used for the model. Data was collected via a structured questionnaire with four main sections. The questionnaire was validated by obtaining a professional opinion on its effectiveness. The first section asked respondents about basic information concerning themselves and their experience in the construction industry. The second section provided the respondent with an exercise involving the interval ranking of candidates based on their curriculum vitae, according to specified criteria. The criteria were chosen and adapted based on previous studies done by Rashidi, Jazebi and Brilakis (2011) and Afshari, Yusuff and Derayatifar (2012). For the purpose of this study, the criteria selected were 1) educational background 2) technical background 3) managerial abilities and 4) project track record.

Participants were then asked to assign a weighting to the respective criteria based on their perceived importance of the criteria to the selection process. Respondents were then asked to give their opinion on the effectiveness and usefulness of the proposed system versus the current system used in the final section of the questionnaire. The survey targeted Project Management/ Engineering firms. However, a small sample size of 3 persons (2 directors and a HR manager) was established based upon the limited availability and willingness of persons and also time constraints. Data was collected by administering the questionnaires to three personnel at a small consultancy firm specializing in civil engineering, construction management and project management. The name of the firm has been omitted for anonymity. Prior to the use of the model, the accuracy of the coding was verified through an experimental reproduction of the relative size of four coins, size being the criteria being evaluated. To ensure the evaluations were not by chance both initial and iterated judgements were compared with Kendall's coefficient. A coefficient of 1 indicates complete agreement and 0 indicates no agreement between both judgements. Significance was set at $p \leq 0.05$.

RESULTS

The participant's best guesses for the relative sizes of the four coins were 93.5% accurate and statically reproducible with significance of $P < 0.001$. A correlation of 1 was attained for the Kendall's-Tau. This indicates that the initial judgement and iteration were identical. The cloud model built is therefore verified as being consistently accurate in measuring the subjective judgement of individuals and a group of individuals incorporating uncertainties of fuzziness and randomness. 4x4 matrices representing the four project management (PM1, PM2, PM3, and PM4) compared against each other were obtained for the three decision-makers (P1, P2, and P3) evaluation of each criteria. For brevity only the pairwise comparison matrix and cloud matrix for decision maker #1 on the factor educational background is provided in table 1. The importance of the criteria compared against each other is obtained in a similar manner. Figure 2 illustrates the final ranking as determined by combining all criteria cloud weighting and the weighing of each candidate.

DISCUSSION

The Synthetic weight was used to aggregate all decision makers view on a project manager compared against another on a factor, as this weighting represents an assignment of importance to each decision maker by consistency. The weighted average of all Synthetic weights obtained for each factor was then determined yielding the final cloud weights. This weighted average weight treats each factor as being equally important, as at this stage no importance is given to any of the factors by the group. To determine the importance of the factors against each other the synthetic weight was used; the importance of each decision maker was to consistency of their judgement supplied.

Table 1: Comparison of decision makers on factor Educational Background

	Interval comparison matrix			
Candidates	PM1	PM2	PM3	PM4
PM1	[1,1]	[1.125,1.143]	[1.125,1.143]	[1.500,1.600]
PM2	[0.875,0.889]	[1,1]	[1,1]	[1.333,1.400]
PM3	[0.875,0.889]	[1,1]	[1,1]	[1.333,1.400]
PM4	[0.625,0.667]	[0.714,0.750]	[0.714,0.750]	[1,1]
	Cloud Matrix - CI -0.003			
PM1	[1,0,0]	[1.176,0.009,0.003]	[1.008,0.001,0.007]	[1.374,0.015,0.001]
PM2	[0.856,0.008,0.002]	[1,0,0]	[0.859,0.008,0.002]	[1.178,0.005,0.007]
PM3	[1.003,0.002,0.009]	[1.179,0.011,0.003]	[1,0,0]	[1.365,0.017,0.001]
PM4	[0.734,0.009,0.001]	[0.863,0.003,0.005]	[0.733,0.009,0.001]	[1,0,0]
Weight	[0.279,0.002,0.001]	[0.238,0.002,0.001]	[0.279,0.002,0.001]	[0.204,0.002,0.001]

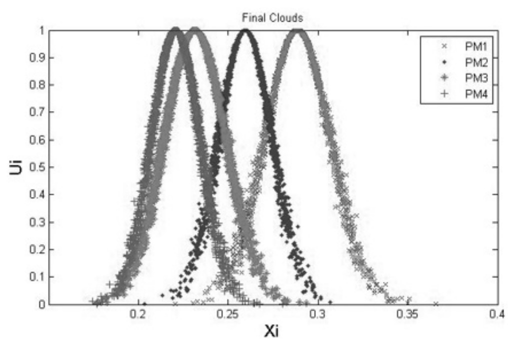

Figure 2: Final Cloud Weights

In combining the weighted average cloud for the comparison of the decision makers and the synthetic weight of each factor the final ranks of candidates was obtained. Using the cloud numbers corresponding to the uncertainty parameters (Ex_{ij}, En_{ij} and He_{ij}) a dominance of the "i" element overpowering the "j." was determined as Exi ≥ Exj, Eni < Enj, and Hei < Hej. As such, PM1 turned out as the highest ranking candidate. The overall ranking in descending order was PM1, PM2, PM3 and PM4. In ranking criteria, Managerial Abilities (MA) was the most important criteria among the four, while Technical Background (TB) was ranked the lowest. In comparing the usefulness, and practical use of the proposed evaluation system to that which currently exists, two out of three practitioners partaking in the questionnaire exercise indicated that the proposed system is more effective at eliminating an undesirable candidate from the process. They also agreed that the system would be a beneficial tool for use in the future. All participants strongly agreed that the system was able to reflect a high degree of certainty in their judgment which was the ultimate aim of this research. One limitation to this research is that there was no existing system for the proposed system to be compared with. Also, the model does not address interpersonal uncertainties which could have been achieved by involving an iteration process, which involves two separate judgments by the same group of persons and improving the consensus on the first judgment. Time constraints and willingness of persons prevented the use of such procedures. The computational process has also shown itself to be quite time consuming, but further exploit in MATLAB computer program may be able to provide further simplification.

CONCLUSIONS

Uncertainty presents itself within most every day and professional decision-making processes due to innate human cognitive processes. Extant models have successfully automated the procedure, but have failed to capture the essence of uncertainty in the form of randomness which exists in the intrapersonal realm and only treat with fuzziness. This research recognized that interpersonal uncertainties are often neglected and this may produce less accurate decisions. Cloud model was shown to be accurate in the representation of a person's judgement with reality. The model built can prove to be quite effective and beneficial to the construction industry, especially in cases where a panel of experts is difficult to conglomerate or when alternatives are indistinguishable. Further work can incorporate the one-iteration Delphi method to improve the judgments of decision-makers, a sensitivity evaluation of the judgement supplied, and an ease of use graphic user interface. This research enlightens a new path for professionals within the construction industry for improving decision-making skills that will ultimately aid in reaping rewards through successful projects supervised by competent project managers.

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