FUZZY ANALYTICAL PROCESSES IN ECONOMIC JUSTIFICATION OF RAPID PROTOTYPING SYSTEMS.

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ABSTRACT

The study examines the fuzzy analytical process involved in providing the economic justification for the rapid growth of prototyping systems. Primarily, it proposes a framework of fuzzy A.N.P (analytic network process) for both qualitative and quantitative attributes for the rapid prototyping system. The study aims to propose a design of a F.A.P. (Fuzzy Analytical Process) Model on various levels, namely, determinants, enablers, and dimensions. Strategic decision-making is based on high-level criteria such as customer perspectives, market affordability, and financial outlook, along with the fulfillment of social responsibility regarding the important usage of the prototyping system. The framework highlights the various level of decision-making involved in making effective decisions. These decisions are based on the requirements set out by the firm, which acts as a source of economic justification. The framework highlighted the preference of the decision-makers using pair-wise comparison as well as extent analysis. It also conducted defuzzification for determining the weights of the attributes. The study uses matrices that are used for the pair-wise comparison of different project phases related to the enterprise function. The findings of the study conclude that the F.A.P. model is based on the structural layout while integrating with the features related to the needs of the market, governmental regulations, firms' capacities, and adaptive strategies. It further analyses that the cost analysis must be done in consideration of project selection through prior economic estimation. It is better to adopt a macro point-of-view in spite of a micro approach in decision-making.

Keywords

Fuzzy analytic network process, rapid prototyping system, framework, economic justification, multi-criteria decision-making.

1. INTRODUCTION

Fuzzy sets of theories were purposely created to adapt mathematical tools providing logical implications for various vague and uncertain decisions. A fuzzy Interference system was introduced to provide a firm understanding of the relationship among different variables that are fuzzy. To reinforce the learning of the virtual world, various controlled policies were introduced under this framework. De Salles et al. [1] regarded significant value in “white-box models,” constructed through the valuable cooperation of various stakeholders and other prototyping systems for fast modeling. The analytic network process performs the functions of eliciting the techniques that are requirements of project attributes. The A.N.P. presents a model that figures out the significance and relevance of different project attributes and techniques for their optimized uses. Subsequently, it adds up the probability of obtaining the required results from which engineers may acquire assistance with reference to techniques that are mandatory. A.N.P. is useful when dependencies are involved and providing feedback is necessary

[2]. In the process of recognition, incorporation, and selection for the maintenance of systems, fuzzy-based systems are used to resolve complex issues. The decision-makers prefer a fuzzy environment over using deterministic scales. In addition to it, Fuzzy Analytic Network Processes (F.A.N.P.) are also efficient in examining the relationships among the different elements involved in the hierarchical structures [3]. Thus, Hemmati et al. [3] have concluded that an F.A.N.P. model is also developed for designing the best maintenance policy that is used in the acid manufacturing plant to make different equipment. F.A.N.P. deals with uncertain data, criteria, and alternatives that are unique in comparison with the other multi-criteria decision-making approaches [3]. Yadav and Singh [4] have examined the fuzzy A.N.P. application in the supply chain via implementing blockchain. Yadav and Singh [4] have asserted that inflationary patterns have badly affected the supply chain (S.C.) globally. Therefore, organizations have been looking to integrate newer technologies to improve their performances via blockchain technology. The study used a comprehensive approach of fuzzy-ISM and fuzzy-MICMAC to figure out common elements for integrating blockchain technologies. Based on the comparative analysis of traditional and blockchain-based supply chains via using fuzzy- A.N.P., the study unveiled that the integration of fuzzy- fuzzy-MICMAC and Fuzzy-ANP along with blockchain technology is more efficient. The study employed five characteristics that were data safety, accessibility, data management, decentralization, documentation, and accessibility [4]. Moiduddin et al. [5] have studied a multitude of rapid prototyping (R.P.) technologies and systems. In the wake of the limited efficiency of these systems, identifying an appropriate prototype for specified conditions is a difficult task. Therefore, it is necessary to consider the element of subjectivity in decision-making and imprecision, along with data uncertainty and vagueness. Grey relational analysis (G.R.A.) and Fuzzy analytical hierarchy process (F.A.H.P.) are the systems that provide a comprehensive dataset for the rapid prototype systems [5].

Uygun and Dede [6] introduce the notion of cuts to resolve fuzzy numbers into various intervals. In contrast, others involved a similar technique for critical decision-making processes, which is important to change the matrix and ranks providing fuzzy performance. According to some significant industrial examinations, the growth of the rapid prototyping market differs at various intervals. However, a rapid increase is expected in prototyping markets in 2020, providing an estimated value of $3.1 billion in 2015 to $7.7 billion in 2020. Also, the estimated growth rate is expected at 19.9% (CAGR). The entrance of the newly formed prototyping industry has increased the market competition, with 26.6% of the overall market share [7]. Moreover, according to Fortune Business Insights [8], the global rapid prototyping materials market is estimated to accelerate from $491.7 million in 2021 to $1,496.7 million by 2028 at a CAGR of 17.2%. The new competitors in the Industry proved that rapid prototyping is integral due to its timely success and novelty in different product designs.

Rapid prototyping (R.P.) is reckoned as the most advanced manufacturing technique owing to its competency in minimizing the processing time during product development and in fabricating components. Although there is increasing use of the R.P. in engineering and medical applications, in terms of surface roughness, dimensional accuracy, and part strength of the component invented by the R.P. technology, are not up to the mark as compared to the conventional manufacturing process [9]. For microfabrication via the integrated fuzzy analytic hierarchy process (A.H.P.)-technique, Ransikarbum, and Khamhong [10] proposed a system to achieve the order of preference by similarity to the ideal solution (T.O.P.S.I.S.). The study used additive manufacturing (AM) printer selection through the fuzzy analytic hierarchy process (F.A.H.P.) that will be employed in healthcare-related applications [10].

It is used in situations that are highly complex, imprecise, vague, and subjective to environmental changes, where critical decision-making is required for effective solutions. However, the use of qualitative evaluation through fuzzy analytical processes is usually considered to interpret valuable information [11]. The fuzzy analytical process provides a priority scale to evaluate various judgments based on the drawn analysis. To the author's knowledge, no study has proposed a framework or model that is helpful in deriving decisions related to financial risks, managerial decisions, marketing functions, and matters related to technology. However, the levels of uncertainty provided to various economic justifications in a rapid prototyping system is still a matter of interest, given the dearth of knowledge concerning economic justification.

The study, therefore, aims to identify the fuzzy analytical processes involved in providing economic justifications for the rapid growth of prototyping systems. The findings proposed by the study are assumed to be important for the rapidly growing technological world. Furthermore, the process of manufacturing changes with the significant technological developments, where the study helps provide important justifications regarding the economic feasibility provided by the rapid prototyping system. Academics working in the relevant field equally benefit from the study, given the information regarding the economic value of prototyping systems.

Following the introduction, the overall paper is structured into four sections. Such as section two presents a review of the literature concerning the application of the different fuzzy analytical processes. Whereas, in section three, the methods concerning the overall fuzzy analytical process are presented. Section four presents the results following the execution of the proposed methods in a detailed manner, while section five briefly summarizes the overall findings of the research application.

2. LITERATURE REVIEW

The fuzzy analytical process helps remove the barriers to the successful implementation of e-commerce. Valmohammadi and Dashti [12] calculated different levels of important barriers available in the field of e-commerce among industrial groups residing in Iran Khodro. The assessment was proposed through two essential techniques; Fuzzy Analytical Process (F.A.P.) and Interpretive Structural Modeling (I.S.M.). The results, however, provided four crucial factors hindering the successful implementation of the process. The contribution of F.A.P. is to quantify the given relationships while providing relevant significance to individual, technical, environmental, and organizational factors. The results suggested that the low perceived value of e-commerce is the most significant barrier to its successful implementation.

Hu et al. [13] provided Fuzzy clustering procedures in various categorical data. Several difficulties in a similar process have proposed various challenges due to the use of other conventional clustering methods. Various cluster prototypes based on different frequencies were provided for categorical data depending on several distinctive measures. However, the study involved new methods of fuzzy clustering procedures that are useful in getting valuable results for Data Mining tasks followed by the available data on the nominal scale.

The importance of solar stills is understood by utilizing a fuzzy analytical process to improve their productivity. Rufuss et al. [14] suggested that the use of Fuzzy logic is beneficial in providing firm control over the temperature of the upper saline water of multi-stage desalination plants. The process was beneficial in providing input and output criteria. Furthermore, data envelopment analysis provided the total score of efficiency for 20 solar stills. The findings illustrated that solar stills are inefficient when considered from the economic perspective, regardless of providing high productivity.

Ouyang et al. [15] studied several economic, environmental, ecological, technical, and management factors relevant to making valuable decisions regarding wastewater treatments. The paper, however, provided optimal alternatives by integrating a fuzzy analytical process along with multidimensional scaling. The methods helped provide alternatives for natural wastewater treatments. The study illustrated that the stabilization pond serves as the most significant water treatment process under the given five treatment systems.

Another similar study by Kumar, et al. [16] provides valuable information regarding the selection of rapid prototyping technology in various educational institutions. The study, however, used a multi-criteria analytical process for decision-making purposes. Furthermore, the qualitative and quantitative frameworks were involved in developing an accurate framework necessary for selecting rapid prototyping machines. The study is significant in providing valuable relationships among given attributes. The research concluded that sensitivity analysis might create an impact on decisions due to the weight, age, and expertise of decision-makers.

The knowledge-Based Fuzzy Analytical Network Process (K.B.F.N.A.P.) was suggested by Aminuddin [17]. The process, however, is useful in creating a valuable impact on decision-making processes regarding the developments of the indicator mechanism. The given system is based on four essential phases, namely, selection, prioritization, initialization, and evaluation. The system, however, is formed through the incorporation of the K.B.F.N.A.P. and Analytical Network Process, providing valuable solutions for making improvements in the manufacturing sector. Mahdiyar et al. [18], in their study, used fuzzy A.N.P. to install a type of green roof (G.R.) through a decision support system (D.S.S.). This system assists in selecting the optimum type of G.R. for the buildings in Kuala Lumpur. This study used the fuzzy Delphi method by creating a database of expert opinions. Along with it, data was analyzed using a cybernetic fuzzy analytic network process that works as a hybrid method. The study concluded that the prototype D.S.S. mechanizes the entire process of G.R. type selection. It is fully capable of taking an effective decision in selecting the most suitable alternative by considering all important financial and non-financial decision criteria [18]. Fung et al. [19] adopted the fuzzy linear programming method for ameliorating the quality function deployment (Q.F.D.), and its application impacted the presence of uncertain data. Yang et al. [20]

established a system that involves decision-making for quantitative buildability assessments. Similarly, Ho et al. [21] projected an integrated group decision system in order to minimalize the inconsistency in group and individual preferences. On account of uncertain quality function deployment (Q.F.D.), it becomes difficult to examine the performance of the design process via accurate quantitative assessment. In order to resolve it, Büyüközkan et al. [22] anticipated a fuzzy group decision-making method for the integration of multiple preference styles that was also designed to respond to customer requirements.

3. MATERIALS AND METHODS

The fuzzy analytical process is used to provide economic justifications regarding the use of rapid prototyping systems. The study will design a F.A.P. Model based on the identified criteria. The model includes various levels, namely, determinants, enablers, and dimensions. The strategic decision-making is based on high-level criteria that include; customer perspectives, market affordability, and financial outlook, along with the fulfillment of social responsibility regarding the important usage of the prototyping system. Other criteria for dimensions involve cost-effectiveness, market feedback, the social responsibility of corporates, and other information drivers. The third category involves enablers that are valuable in supporting the given dimensional criteria. The F.A.P. model derived is adapted from the literature [23]. To achieve a fuzzy synthetic degree, the following equation is used. The hierarchy of this model is shown in figure 1.

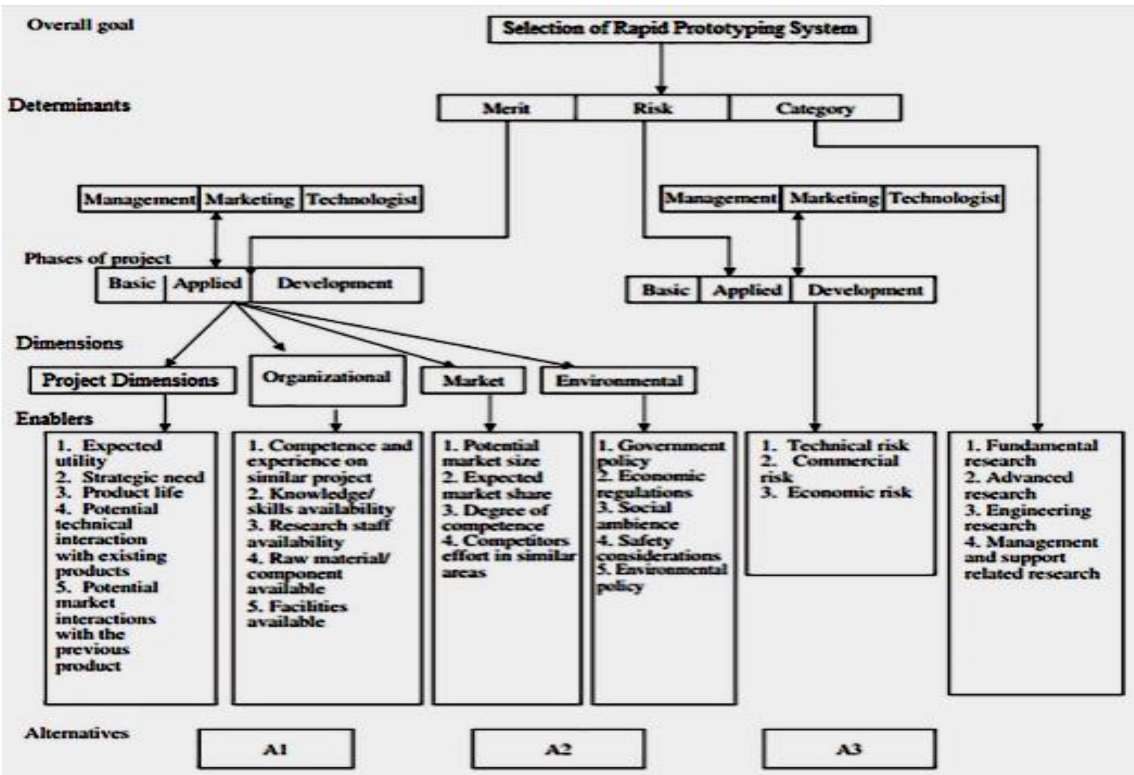

Fig. 1: Hierarchy Structure of Selection of Rapid Prototyping Systems.

$$D_i = \sum_j^m X_{gi}^j \left[\sum_j^n \sum_j^m X_{gi}^j\right]^{-1} \text{ .... (a)}$$

Where,
D_i= represents Fuzzy synthetic degree for the i[th] object
j= represents the end of the year
m = represents project alternative
gi = represents the triangular fuzzy number
n = represents the project life
X_{gi}^{j} = represents the performance of the i[th] alternative with respect to the j[th] criterion

For each hierarchy level, fuzzy synthetic values are obtained for each k level,

$$D_i^k = \sum_{j=1}^{n} a_{ij}^k \otimes \left(\sum_{i=1}^{n} \sum_{j=1}^{n} a_{ij}^k\right)^{-1} \quad \text{.............................. (b)}$$

Where,
D_i^k = represents the fuzzy synthetic degree value for each component i at the k[th] level
$\alpha^k{}_{ij}$ = represents the fuzzy judgment matrix at the k[th] level

Defuzzifying the synthetic degree values using equation (c), provides the weights.

$$w_i = \frac{l_i + 2m_i + n_i}{4} \quad \text{.. (c)}$$

Where,
l_i = represents triangular fuzzy numbers' lowest limit
m_i = represents triangular fuzzy numbers showing Saaty's scale of 1–9
n_i = represents triangular fuzzy numbers' upper limit
$\mathcal{W}_i$ = weight of the i criterion

The proposed model has been designed to assist in organizational decisions that are related to management, marketing and technological matters. The proposed system will be able to derive decisions related to risks, financial matters, and the environment. By developing fuzzy A.N.P., there is a need to define the problem and an anticipated solution. Firstly, the problem has to be defined according to the criteria to derive the relevant decision based on financial, technical, commercial and economic risks. The decisions will be divided into Basic, Applied, Development, Management, Technologies and Marketing. Secondly, based on the data and criteria, a comparison matrix will be built to adopt a consistent framework and to collect other information that may be stipulated for making comparisons. Lastly, the opinions of the decision-makers will be originated. Unlike the F.A.P. model of the study, Anand and Vinodh [24] employed criteria weights by using fuzzy A.H.P. and T.O.P.S.I.S. It dealt with material compatibility, geometrical complexity and minimum feature size. Ransikarbum and Khamhong [10] also used the fuzzy analytic hierarchy process (F.A.H.P.) for assessing AM printer selection while evaluating the product, printer, and material.

4. RESULTS

To achieve the determined objective, the research considered a case of rapid prototyping systems. This study conducted a pair-wise comparison of the components for the determining criteria. The comparison of the criteria highlighted three potential alternatives. For economic justification, effective decisions are required with careful evaluation to meet the requirements outlined by the organization. Table 1 presents the decision-makers opinions concerning the fuzzy numbers (i.e., from 1 to 9). The opinions of the decision-makers which emerge in the initial phase are depicted in table 1. The same matric level is computed for the other decision-making levels using the suggested scale of Saaty [25] ranging from 1 to 9 for quantifying the decision-maker's preferences.

Table (1): Attributes of Pair-Wise Comparison.

Basic Attribute	Project	Firm	Market	Environment
Project	(1,1,1)	(5,6,6)	(1,2,3)	(1,2,4)
Firm	(1/6, 1/6, 1/8)	(1,1,1)	(1/4,1/3,1/2)	(1/3, 1/6, 1/8)
Market	(1/3, 1/2, 1)	(2,3,4)	(1,1,1)	(1,6,8)

Synthetic evaluation of Saaty [25] hierarchy is presented, where the value for the degree of the fuzzy synthetic degree is achieved. Table 2 presents synthetic degree weights, which are derived using equations a to c.

Table (2): Weight of Attributes.

W1	W2	W3	W4
0.457	0.189	0.3249	0.048

Following the determination of the hierarchical weights at all levels, among or within; an analysis is conducted to achieve the levels of interdependencies of the hierarchy. In this particular case, interdependency is observed across different project phases as well as functions. The matrices are listed in tables 3 and 4, which exhibit the association across the different hierarchical levels.

Table (3): Matrix Weight in relation to Enterprise Function.

	Basic	Applied	Development
Management	0.0702	0.0749	0.0687
Technologies	0.3902	0.5908	0.5789
Marketing	0.5678	0.2990	0.3459

Table (4): Matrix weight in relation to project phases.

	Management	Marketing	Technologist
Basic	0.0691	0.0675	0.5854
Applied	0.3546	0.3534	0.3356
Development	0.5687	0.5879	0.089

Accordingly, the formation of the supermatrix takes place to even out the interdependencies outcomes among the project ‘project life cycle phase’ and ‘functions of the enterprise.' In order to assess the effect of the function on the project phases, six pair-wise comparison matrices are needed.

The matrices are used for the pair-wise comparison of different project phases in relation to the enterprise function. Table 5 shows the weight vector for every matrix, which was computed and positioned in the supermatrix.

Table (5): Matrix Weight in relation to Project Phases.

	Basic	Applied	Development	Management	Technologies	Marketing
Management	0.0723	0.0767	0.0768	0	0	0
Technologies	0.2908	0.7609	0.5184	0	0	0
Marketing	0.5347	0.3617	0.3054	0	0	0
Basic	0	0	0	0.0691	0.0675	0.5742
Applied	0	0	0	0.3654	0.3254	0.3709
Development	0	0	0	0.5676	0.5819	0.3776

Table (6): Converged Super Matrix for weights (long-term).

	Basic	Applied	Development	Management	Technologies	Marketing
Management	0.0712	0.0754	0.0790	0	0	0
Technologies	0.4908	0.6785	0.5789	0	0	0
Marketing	0.4643	0.3345	0.3345	0	0	0
Basic	0	0	0	0.2391	0.2543	0.2435
Applied	0	0	0	0.4254	0.3465	0.3096
Development	0	0	0	0.2465	0.2457	0.2543

The converged weight is attained following the power increase of the supermatrix (table 6). The present study shows that the convergence in the original matrix takes place at the 16th power. The desirability index (DAi) for every alternative is achieved using the equation (d):

$$Desirability\ Index = \sum\sum\sum\sum B_i A_{ji} E_{kji} S_{mkji} \quad \text{.....................} \ (d)$$

Where,
B_i= Relative impact weight of criterion i
A_{ji}= Relative priority weight for attribute j of criterion i
E_{kji}= Relative importance weight for sub-attribute k of attribute j of criterion i
S_{mkji}= Relative impact of alternative m on sub-attribute k of attribute j of criterion i

Using the desirability index equation (d), DA1, DA2, and DA3 achieved values are 0.3526, 0.3301, and 0.291. The present alternative value can be computed with the use of equations e and f, which for alternative 1 is 181 890, 189 276, 210 532, for alternative 2, these are 243 299, 265 000, 265 565 and for alternative 3, 185 345, 196 218, 237 345.

$$C_{mj} = \left(R_{mj} - O_{mj}\right) - \left(R_{mj} - O_{mj} - D_{mj}\right)T_{mj} - I_{mj} + P_{mj} \quad \text{................} \ (e)$$

$$NPV_{Ai} = \sum \frac{C_{mj}}{(1+\beta)^n} \quad \text{..} \ (f)$$

Here N.P.V. is the net present value and β is the discount rate.

The evaluation of the weights occurred subsequent to the defuzzification of the alternative present net values. The weight achieved for alternative 1 (WA1 ¼) is 0.301, for alternative 2 (WA2 ¼) is 0.387 and for alternative 3 (WA3 ¼) is 0.312. Table 7 presents the final alternative weights, which are attained using the following equation:

$$OD_{Ai} = D_{Ai} * OW_{Ai} \quad \text{(g)}$$

Where,
D_{Ai} = the alternative desirability index of alternative
Ai = the subjective attribute and W_{Ai} is the weight in terms of monetary aspect.

Among the three alternatives, an alternative one is found to be comparatively better, which is derived using equations a and b.

Table (7): Alternative Final Weight.

OD_A1	OD_A2	OD_A3
0.11214	0.09823	0.11123

In contrast to the study, Khamhong et al. [26] examined the criteria for selecting the best 3D printers via an analysis of two types of decision-makers, such as experts and users, through Fuzzy A.H.P. It assessed the criteria weights for 3D printers' printer selection-related factors, printers' characteristics, and properties of materials. Another study by Wang et al. [27] reviewed required critical factors that are used in the applicability of advanced 3D printing technologies to the aircraft industry via using a fuzzy systematic approach while combining a fuzzy analytical hierarchy process and fuzzy geometric mean. The study concluded that the usefulness of the approaches is determined through a reduction in cycle times, production costs, and with the lighter weight of parts. Resultantly, employing fuzzy A.H.P. was economically beneficial for the aircraft industry [27].

5. CONCLUSION

The determination of an effective decision is a challenging task, particularly for the selected case. The study addresses the ways in which the project uncertainty, as well as ambiguity linked with different variables, can be subsided. In order to implement effective and economically justified decisions, the study presented an effective method in the form of F.A.P. It showed the decision-maker's preferences using the fuzzy analytical theory along with attributes pair-wise comparison.

The F.A.P. approach gives the structural layout for the integration of all the calculated opposition regarding the selection of the project, which includes the needs of the market, regulation from the government, the capacity of a firm, its strategies, and many other aspects. The analysis of cost must be integrated with these calculations in the project selection. Without having any economic estimation, the practicality cannot be forecasted, and therefore the cost analysis is conducted with the use of the indistinct and unclear method of cash flow. The methodology used for the problem of the project selection is the macro point of view rather than the micro, which is the approach of decision-making in an organization rather than the approach of an individual's decision-making. The selected methodology is used for the creation of a smooth framework for rapid prototyping systems.

Following are the core contributions to the research; firstly, the goal of expanding the latest literature in the field with respect to the rapid prototyping systems and for the selection of the project, the A.N.P. framework was initiated. This framework had a model method based on the groups, which promotes the rapid prototyping systems process and a communicating A.N.P. structure that helps and assists with the tasks of decision-making groups. Secondly, this paper provides the framework which can be applied to the real process of project selection. The research is unique in a way that it provides those methods and approaches which are distinguished from the existing methodologies. It addresses the assistance and support which is available for the group's decision-making of an organization in the process of rapid prototyping systems. Concluding, the qualitative and quantitative evaluation of features of projects' relationships among the different interdependent levels was provided by this model. A significant contribution of this research is to provide an approach for the evaluation of the uncertainties that represent partiality in the process of decision-making.

Though, the model does not examine all the certain elements and the circumstances which are linked with the selection of the project. The features, the circumstances, and the interconnection between those features are represented in the structure as specified by the particular organization. The approaches can be applied to various circumstances by adjusting different levels of structural standards and the associated features. The extent of this work in the future is likely to increase the effectiveness of the suggested approach.

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