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A New Method for Estimating Project Weight Values

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Abstract: In this study, an AHP-based method integrated with fuzzy logic is deployed to estimate Project Weight Values (PWVs). Two criteria, namely man-hour and work preference, are used as input in the model to estimate their related weights. Man-hour and work preference are assumed to be deterministic and fuzzy respectively. The fuzzy nature allows deployment of linguistic variables during PWV estimation. The study uses a numerical example for demonstrating the application of the proposed approach. If desired, the model discussed here can be further extended to capture other aspects of interest in the estimation of PWV such as: the required time, budget, etc. A reliable perspective for actual progress of a project is thus provided. It is shown that the proposed approach can be applied to other aspects of a project such as project close up and capital budgeting applications. The approach proposed by this study can be used as an initial step in order to implement an earned value management system.

Key words: Project weight value, AHP analysis, fuzzy logic, progress, project management, payment

INTRODUCTION

The importance of designing a well organized system in order to estimate weight values during project management comes from the fact that progress is measured based on the distribution of weight values and is obtained through multiplying the weight value of each task in the project as shown below:

$$P_T = \sum_{i=1}^{n} W_i \times P_i$$

Where:

$\sum_{i=1}^{n} W_i = 1$

W_i = Weight value of each task
P_i = Progress amount of each task
P_T = Total progress
N = No. of tasks involved in progress measurement

Therefore, weight values must be initialized at the start of a project and then later the total progress must be determined periodically based on the calculated progress of each activity. Depending on the achieved total progress, a client can then make payments to project contractor. Thus, both the progress measurement system and payment are highly dependent on the weight values of each activity. In this respect, Project Weight Values (PWVs) are usually calculated as a percentage of cost. This means that cost percentages (or man-hour percentage) of each task will be set as PWVs. However, there are many factors which may have high impact on PWVs. These include risk, quality and other related factors whose values hat may be assumed by top level managers. This research is looking for such methods in order to yield appropriate weight distributions versus time and consequently to provide more accurate progress curves. This in turn can help clients to pay according to the actual progress made by contractors. Otherwise, due to factors such as bad distribution of PWVs versus time, contractors may receive payments in excess of what they deserve for their actual progress. In such cases, a small percentage of progress may be remaining for completion at the end the project and as a result contractors may be less interested to finalize the remaining work. As a result, the project duration may increase more than it is necessary. Furthermore, the contractors may also release relevant personnel to other projects in order to decrease their overhead costs.

It is common in project control to use graphical charts, such as S-curves, to compare planned schedule with the actual progress of a project. The S-curve can be obtained on the basis of weight value of each task, sub-phases and phases of a project. Indeed, S-curve demonstrates the cumulative progress versus time. If the progress of each element is estimated adequately, a relatively precise curve will be obtained. Since, payments are made with respect to the progress of each element, this approach can be used by both the clients and contractors to determine qualitative as well as subjective

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factors such as risk, quality etc in projects. Therefore, a robust approach to set PWV is highly desirable. By applying fuzzy logic, linguistic terms that cannot be incorporated in a mathematical model may then be included. Another advantage of using fuzzy logic is that it allows appropriate distribution of progress within the project life cycle. Incorporating fuzzy logic in the decision process will allow clients to avoid unnecessary excess payments when no associated physical work exists.

Fuzzy inference systems capable of incorporating numerous rules must be deployed due to the fact that estimating weight value as only a percentage of cost or man-hour is not sufficient to obtain proper PWVs. Two possible applications are presented later on in the study. On the other hand, in fuzzy rule based systems as an effective technique in Fuzzy Logic (FL) is a convenient way for mapping an input space to an output space. It has progressed greatly since its introduction by Zadeh (1965) and has been established as an important branch of human thinking and knowledge representation. FL is based atop human knowledge on possible solutions to existing problems. On the application level, FL can be considered as an efficient tool for transforming and embedding linguistically expressed knowledge into useful workable and operational mathematical algorithms (Kecman, 2001). FL is also used whenever a mathematical model is unknown or impossible to obtain, the process is substantially nonlinear, or there is a lack of precise sensor information. FL is aimed at handling imprecise and approximate concepts that cannot be processed as conveniently by other known modeling techniques. It is applied at the higher levels of hierarchical control systems, in generic decision-making processes and for enabling computers to perform precise, meaningful and reasonable operations on vague concepts (Kecman, 2001).

The degree of progress achieved in the mathematical theory of fuzzy sets can be clearly demonstrated by many publications in specialized journals. However, practical engineering applications tend to be based on approaches that were developed in the earlier stages. For example, many of the most successful commercial engineering applications of FL, i.e., fuzzy controllers, are still based on the study of Mamdani and Assilian (1975), where symmetric triangular membership functions are used and logical operations for union and intersection are performed using maximum and minimum operations, respectively.

McNeill and Freiberger (1993) found that the absence of a clear procedure for fuzzy modeling had been always emphasized by critics of fuzzy. FL is a precious engineering tool developed to do a good job of trading off precision and significance (Kecman, 2001). Fuzzy models cannot achieve the level of accuracy required by many engineering applications. Although low accuracy can be compromised for faster computation in control applications, this may not be acceptable in the modeling of many other engineering systems. The system theory. must be capable of providing efficient means for model building as well as decision making and control of the system involved. In this sense, fuzzy modeling of engineering systems is lagging behind fuzzy control.

Many issues need to be addressed to construct a new fuzzy model for a given system, such as definition of membership functions, obtaining fuzzy rule base, stating the optimum expressions for performing each particular inference, deciding on the best defuzzification technique for a given problem, reducing computational effort in operating with fuzzy sets and improving computational accuracy of the model (Zimmermann, 2001). In particular, the assumption that membership functions are given and the fact that excessively voluminous computational effort is needed for any large complex problem, have proved to be some of the major challenges for the application of fuzzy theory. Further, neurofuzzy models can improve existing knowledge by learning from data on available examples and by improving the input and output membership functions of the FL model. According to Von Altrock (1995), selection of optimum membership functions and deduction of rules from observed data can be implicitly carried out using artificial neural networks, which can adaptively adjust membership functions and fine-tune rules to achieve better performance. A typical fuzzy application for solving a problem is made up of three major components, namely fuzzifier, fuzzy inference engine (fuzzy rules) and defuzzifier (McNeill and Freiberger, 1993). Effectiveness of the fuzzy approach depends on the successful execution of these steps.

After introducing fuzzy rule based systems it is appropriate to provide an overview of the general methodology of AHP. Readers interested in the mathematical foundation of this technique along with some example applications are referred to Saaty (1980, 1990), Saaty and Vargas (1994) and Nydick and Hill (1992). AHP is a multi-criteria decision-making technique suitable for problems in which several quantitative and qualitative criteria have to be taken into account in order to make a proper decision. The problem environment in AHP is as follows. There are several alternative solutions for a specific problem of which a suitable one should be selected. There are several criteria for qualifying each alternative solution. AHP is a systematic decision-making tool which determines the quality of each solution with respect to all the criteria. The decision-maker creates a hierarchical decomposition representation of the problem in order to employ AHP. At the top of the hierarchy is the overall goal or prime objective that the decision-maker attempts to attain as closely as possible. The possible solutions to the problem take place at the bottom of this hierarchy. The between levels represent the progressive decomposition of the overall goal. The decision-maker does a pair-wise comparison of all elements in each level with respect to the elements of the immediate higher level in the hierarchy. Combination of these comparisons will show the relative quality of solutions in the lowest level with respect to the top-most objective.

After carefully going through the literature it was found that although there is some research available in the literature on either FL or AHP applications for project management, few papers related to the application of combined AHP and FL for project management were found. Specifically, based on the extensive review of literature, application of this approach for the estimation of PWV in project planning and control has not been attempted. According to Dweiri and Kablan (2006), specific applications of FL in project management are relatively few in comparison to other application areas. They considered project cost, time and quality as project management's internal measures of efficiency and presented an approach that employs Fuzzy Decision Making (FDM) to synthesize these three measures into one measure, namely the Project Management Internal Efficiency (PMIE). The latter represents an overall estimate of how well a project is managed and executed. Estimation of project cost, time and quality have also been obtained through AHP. A Multiple Attribute Decision Making (MADM) tool in the case of fuzzy preference information has been developed by Wang and Parkan (2005). They introduced three optimization models to obtain relative importance weight of attributes in a MADM problem. Wang (2005) presented a MADM model to tackle incompleteness in the preference information.

In terms of applying fuzzy logic for project management, Noori *et al*. (2008) applied a fuzzy control chart through earned value project management. They also provided an illustrative case and presented the related results accordingly.

After a careful examination of the literature as outlined above it appears that there is no closely related research work in this area to allow performing a comparative analysis. However, this research and the technique applied here open up a new direction for further investigation.

THE PROPOSED APPROACH

In the proposed model, man-hour and work preference are considered as two major criteria for estimation of PWV. Man-hour is treated as a deterministic factor through which the planner can estimate the time and cost of the project. Work preference is considered as another criterion that is captured using a fuzzy rule based mechanism. In the proposed model, the required quality and risk are used to estimate work preference value. If each activity is considered as an alternative in AHP analysis, the weight calculation process will be mathematically intractable and time consuming as any real project may contain a large number of activities, e.g., 2000. Therefore, in this study, every major phase of the project is considered as one alternative for AHP. It must be noted that the considered phases in the AHP model should be the same as in the WBS (Work Breakdown Structure) of the project. This makes it possible to calculate project progress using the weights obtained from the AHP based model.

After obtaining the weight of each major phase, the AHP process is continued and the weights associated with sub-phases, activities and so on are calculated. The summation of weights of all alternatives in a particular level in AHP will be equal to one. Figure 1 shows the main structure of the proposed approach.

After setting the required quality and degree of risk, work preference is determined through a fuzzy rule based system and its inferences. Therefore, the work preference is obtained as a linguistic term.

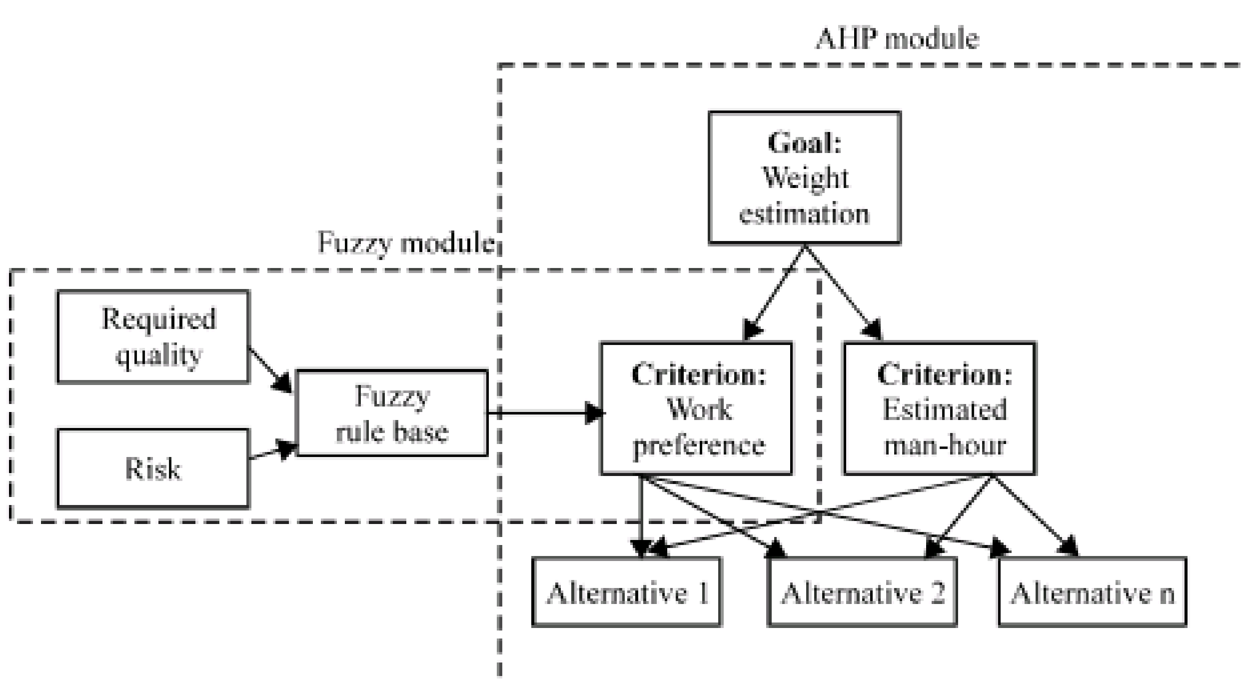

Fig. 1: The main structure of the proposed approach

ILLUSTRATIVE EXAMPLE

The project that is used as an example is assumed to consist of many activities that are to be carried out within a hierarchical process. The client is seeking to confirm a set of logical weight values for payments to contractors based on both quantitative and qualitative variables. Although, the approach would be more applicable in construction type projects, the proposed approach can be conducted in engineering and consultant projects as well. In order to avoid going though many calculations and to provide a better insight the main phases of the project were also taken into account. Moreover, the items in lower levels of WBS may also be used in order to calculate their weight values.

The proposed approach for application of fuzzy rule base for calculation of work preference is composed of three steps. In the first step, a fuzzy membership function is chosen for the required factors: quality and degree of risk. Next, a fuzzy inference system fuzzifies the work preference with respect to these factors. Finally, the work preference value is defuzzified using the selected inference system and Eq. 1-3 as given by Bagherpour *et al*. (2007).

$$y_j = \frac{\sum_{i=1}^{L} y_i}{L} \tag{1}$$

$$p_j(x) = \frac{\prod_{i=1}^{M} \mu_{A_{ij}}(x_i)}{\sum_{j=1}^{L} \prod_{i=1}^{M} \mu_{A_{ij}}(x_i)} \tag{2}$$

$$y = f(x) = \sum_{j=1}^{L} p_j(x) y_j \tag{3}$$

Figure 2 shows application of symmetric Gaussian function selected as the membership function to fuzzify the required quality. As seen in this diagram, the required quality can be expressed as low, medium, or high.

The horizontal and vertical axis in Fig. 2 shows degrees of required quality and membership value, respectively.

Figure 3 shows triangular membership function used to fuzzify degree of risk. Figure 4 shows symmetric Gaussian function chosen as a membership function for work preference. Work preference values are obtained on the basis of quality and risk membership functions shown in Fig. 2 and 3.

In Fig. 3, horizontal and vertical axis indicate degrees of risk and membership value, respectively.

In the Fig. 4, the horizontal and vertical axis indicate degrees of work preference and membership values.

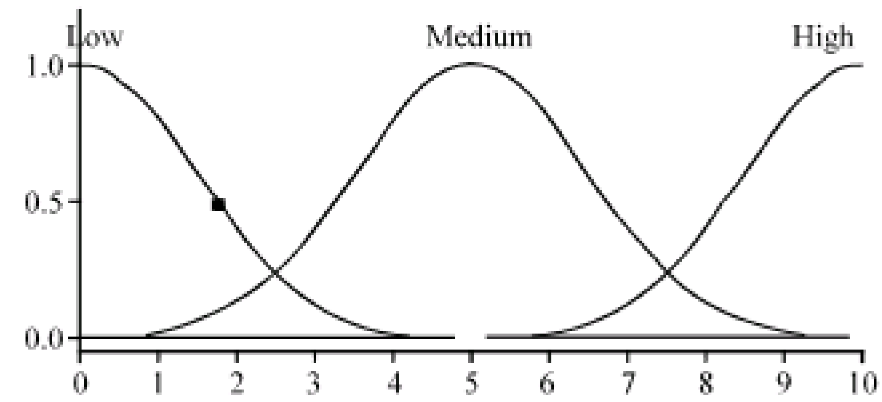

Fig. 2: Membership function for the required quality

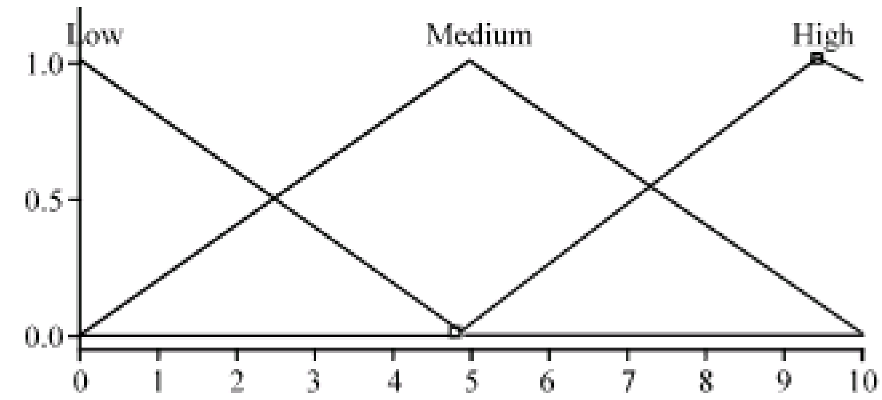

Fig. 3: Membership function for risk

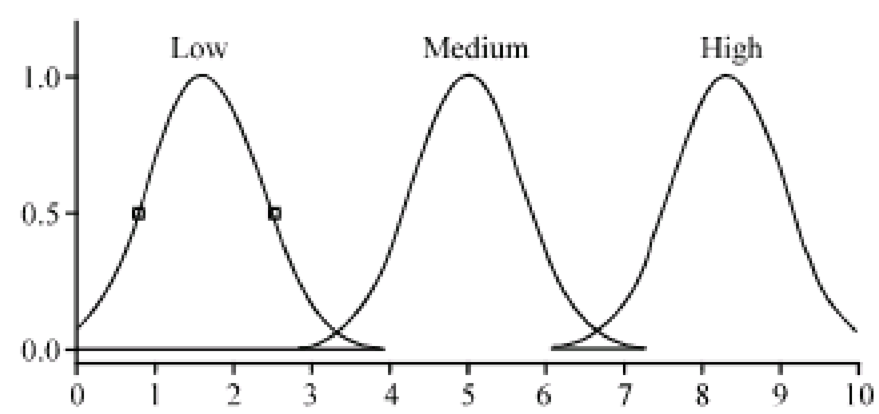

Fig. 4: Membership function for work preference

In order to perform fuzzy inference system, many fuzzy rules can be established in a real project according to the circumstances within which the project is carried out. Without loss of generality, the following fuzzy rules are considered for the illustrative example.

- **Rule 1:** If the required quality is high and degree of risk is medium then work preference is high
- **Rule 2:** If the required quality is low and degree of risk is low then work preference is low
- **Rule 3:** If the required quality is high and degree of risk is low then work preference is medium

As mentioned so far, two factors, namely the required quality and degree of risk are considered in the proposed approach to estimate work preference. In this example, these factors have been formulated as shown in Fig. 2 and 3. Table 1 shows work preference values obtained based on these factors, which are calculated on the basis of Eq. 1-3. In Table 1, each row and column indicate the

Table 1: Work preference obtained based on the required quality and degree of risk

Required quality	Degree of risk VL	L	M	H	VH
VL	1.68	1.69	7.00	7.00	7.00
L	1.70	1.73	7.40	7.47	7.47
M	5.00	5.00	8.00	8.00	8.00
H	6.60	6.60	8.30	8.30	8.30
VH	6.00	6.80	8.32	8.31	8.29

VL: Very Low, L: Low, M: Medium, H: High, VH: Very High

Table 2: Specification of phases

Phases	Degree of risk	Quality	Man-hour
1	Medium	Low	500
2	Very low	Very high	200
3	High	Medium	400
4	Low	Very low	300

Table 3: Work preference of each phase

Phases	Values
1	7.40
2	6.00
3	8.00
4	1.69

Table 4: The relative priority of work preference

	Work preference	Man-hour
Work preference	1	2
Man-hour	1/2	1

Table 5: Comparison of phases with respect to work preference

	Phases			
Phases	1	2	3	4
1	1	2	1/2	7
2	1/2	1	1/3	5
3	2	3	1	8
4	1/7	1/5	1/8	1

required quality and degree of risk, respectively. The data in Table 1 belongs to the interval (0, 10) and indicates work preference obtained through software coded with MATLAB™ Toolbox.

In order to implement AHP for the problem under consideration in this study, we consider one level including the main phases of project and assume the hierarchy shown in Fig. 5 to be true. Table 2 and 4 show the input data. Table 3-7 show the results obtained through the proposed approach. Table 7 also shows the final results of the AHP as reported by Expert Choice® software.

As shown in Table 7, phase 3 has attained the highest weight and phases 1, 2 and 4 are in the subsequent decreasing order, respectively. Although, according to man-hour data shown in Table 2, phase 1 has the maximum weight value, phase 3 has gained the maximum weight value in total. This is because of the fact that phase 3 has a high work preference value due to a high degree of risk and a medium level for the required quality. Since, the consistency index is 0.00 in this problem, validation of the results is strongly satisfied.

Table 6: Comparison of phases with respect to man-hour

	Phases			
Phases	1	2	3	4
1	1	5	4	3
2	1/5	1	1/4	1/2
3	1/4	4	1	3
4	1/3	2	1/3	1

Table 7: Obtained PWV of each phase

Phases	Values
1	0.373
2	0.144
3	0.413
4	0.071

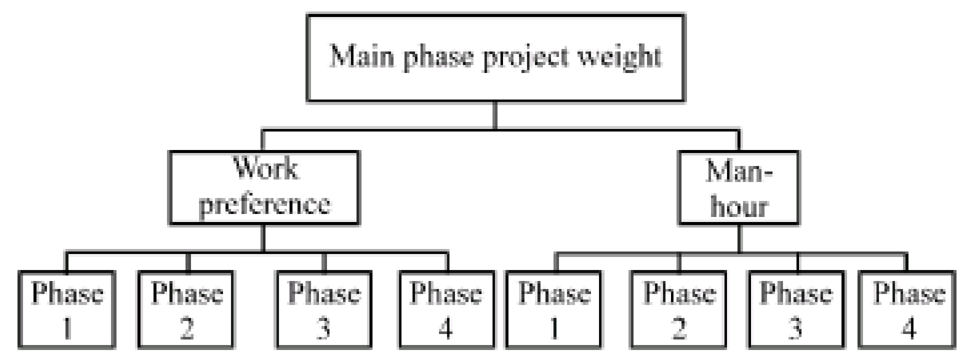

Fig. 5: Sample hierarchy structure of the project

As indicated, although phase 1 had the maximum amount of man-hour, phase 3 obtained the maximum amount of weight value amongst all the phases. That is why phase 3 had a high degree of risk and medium degree of quality. Therefore, the proposed model improves on its predecessors for estimating PWV in which the weights would be estimated as a percentage. Thus the proposed approach not only considers the man-hour factor (as a commonly used approach for estimating the PWV), but it also takes into account other important factors influencing the PWV. Of course, its results are highly dependent on project conditions and can vary form one project to another.

FURTHER APPLICATIONS

The approach proposed in this study has other possible practical applications as outlined below.

Project close up: Project close up is the last phase of a project during the implementation phase of project management process. Usually due to the low number of required man-hours in comparison with other phases such as the execution phase, the estimated man-hour is usually low. However, this is the most important phase in which contractors wish to deliver the project to their clients. Therefore, for example during the pre-commissioning stage, some problems related to the previously completed phases of the project may be encountered. The client then tries to resolve these issues. On the other hand, contractors may unduly receive more that 95% of the expected total payment according to the approved project progress which is based on the weight value system. In this scenario, due to the relatively low amount of the remaining progress and consequently inadequate incentive associated with the remaining payment, contractors may not be not interested enough to continue and finalize the project that has been agreed. One logical result is the delaying of project finish date. However, by implementing the proposed approach, a client will be able to increase the weight value of the close up phase of the project by incorporating some linguistic and verbal terms in the contract in addition to the usual quantitative terms. By involving both quantitative and qualitative terms the client can ensure that the project will be implemented safely and its progress gets distributed correctly.

Capital budgeting applications: Project cost estimation approaches may be designed from two different points of view. The first is a top-down hierarchical process in which usually mangers need to know how much money must be assigned in each phase of the project. In the second approach, usually cost estimation is done based on a bottom-up hierarchical process. However, in large scale projects, due to unanticipated problems and a lack of completion of numerous items and components, costs cannot be always estimated using bottom-up approaches. For instance, the material transportation costs depend on the raw material quantity required in the project which can only be calculated later on in the project when the corresponding drawings are prepared. In that case, a weighted linear programming method as outlined below must be used instead:

$$\begin{aligned} &\text{MaxZ} = \sum_{i=1}^{n} W_i \times X_i \\ &\text{S. To:} \\ &L_i \le X_i \le U_i \\ &\sum_{i=1}^{n} X_i \le B \end{aligned}$$

Where:

I	=	No. of phases available in the project
W_i	=	Obtained weight value based on proposed approach
X_i	=	Amount of budget for each phase
L_i	=	Lower bound of assigned budget for each phase
U_i	=	Upper bound of assigned budget for each phase
B	=	Pre-specified budget for the project

The objective function ensures that the assigned budget for each phase depends on the level of importance of the relevant phase. Thus, if one phase is more important, higher amounts of budget will be assigned to that phase resulting from its importance. Therefore, if in one phase of a project either too many qualitative risks are involved or contingency activities need to be adopted, the proposed linear programming approach can deal efficiently with such cases and treat them mathematically. The emphasis of the first set of constraints (bounded ones) on the budget of each phase must be estimated within an interval. The lower bound and upper bound of such constraints are assumed to be estimated roughly (by applying a bottom-up approach) or can be determined by top level managers (by applying a top-down approach). The last constraint ensures that the total estimated budget for all phases of a project must be less than B, the pre-assigned budget, for implementing the project. The pre-budget B is obtained from the total price of a project signed in the contract less the sum of the marginal profits and overhead costs.

To the bests of our knowledge no related research found in which helps us to run comparative analysis accordingly. However, the study can generate open field in project management systems for the other researchers as well.

CONCLUSION

In this study, an AHP based approach for estimating the weight value of each main-phase, phase and activity in a project was presented. Two factors, i.e., man-hour and work preference, were considered as the major criteria which determine the weight of each element. Without loss of generality, two factors, namely the required quality and degree of risk were considered for estimating the work preference value using a fuzzy rule based system. However, the approach proposed in this paper can be easily used to consider other factors (such as resource requirements and work importance) affecting work preference. The hierarchy of the proposed AHP is the same as the WBS of the project. The study used a numerical example for demonstrating the application of the proposed approach. If desired, the model discussed here can be further extended to capture other aspects of interest in the estimation of PWV such as: the required time, budget, etc. A reliable perspective for actual progress of a project was thus provided. It was shown that the proposed approach can be applied to other aspects of a project such as project close up and capital budgeting applications. The model can be further investigated by considering the probabilistic nature of the events that affect the actual progress of a project. The approach proposed by this study can be used an as initial step in order to implement an earned value management system.

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