Artificial Intelligence Model to Assess Project Baseline Plan

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Abstract:
Planning is one of the most important stages in managing construction projects. Most researches focus on developing and improving scheduled techniques. Yet, surveying the literature reveal insufficiency in the area of project planning assessment researches. This research aims at bridging this gap and introduce a model to assess Project Baseline Plan (PBP). The development of the PBP model is achieved in four steps. First, collecting factors affecting the Project Baseline Plan from literature. Second, identifying the most important factor using Delphi technique. Third, assigning relative weights to each factor using the Analytical Hierarchy Process (AHP). Fourth, developing and validating the PBP model. This model helps the user to predict the percentage of matching between the preconstruction program and the actual construction program. Both deterministic model and fuzzy model have been developed where the fuzzy model produces better results than the deterministic model. This research uses project duration as a bench mark to evaluate the model by comparing the model results for two case studies.

Keywords: Project Baseline Plan, Planning Assessment, Delphi rounds, Analytical Hierarchy Process, Fuzzy logic.

1. Introduction

Project planning is the determination of what needs to be done, how, when, and by whom, taking into consideration the required resources and their costs (Laufer and Cohenca 1990). In addition, planning sets the objectives of the project and the course to achieve them, and control ensures that the project remains in alignment with its scope and achieves its targets. The control process involves monitoring and evaluating the project to enable corrective actions to steer the project toward its objectives (Kerzner 1998; Ballard and Tommelein 2016).

Conventional planning practices recognize the relationships between tasks using the critical path method (CPM) but fail to acknowledge the workflow between them, whether it is the flow of trades, space, or resources (Howell et al. 2010). Hence, although CPM may be an efficient tool for developing high-level plans, it is less practical as a communication tool, as a day-to-day operational tool for production planning and control, and as a root-cause analysis tool at the task level (Birrell 1987). CPM observes the big picture and focuses on delivering a master schedule that helps management maintain control over large and complex projects (Hamzeh et al. 2019).

Schedule Delay and cost Overrun can cause serious financial risk to both contractors and owners (Bayraktar et al. 2011). A significant cause for schedule delays and cost overruns in most large-scale projects may be a direct result of unrealistic baseline plans (Flyvbjerg et al. 2003, Sinnette 2004, and Abdelsalam 2018). The lack of efficient baseline plan is surely lead to many failures in the entire construction industry. The first and main stage in project management is the planning stage.

Although, many tools are available to evaluate the Baseline Schedule, there is fewer tools to evaluate the Baseline Plan. Tools utilizing Artificial Intelligence are rare when it comes to evaluating Baseline Plan, which commonly using human judgement an intuition.

The objective of this study is to develop a quantitative tool to evaluate the preconstruction plan which developed immediately after contract award and right before construction starts. This quantitative tool is developed in the form of Artificial Intelligence model to quantitatively evaluating the Project Baseline Plan (PBP). The preconstruction plan, considered in this study as the PBP, is the base or reference plan submitted to the owner prior to construction.

2. Methodology

The methodology of this research can be summarized as follows:

- I) Identify factors affecting PBP from Literature.
- II) Use Delphi technique to obtain a short list of the most effective factors.
- III) Use Analytic Hierarchy Process (AHP) to obtain factors' weights in PBP model.
- IV) Develop three PBP models;
  - 1) Deterministic model,
  - 2) Fuzzy summation model, and
  - 3) Fuzzy-Fuzzy model
- V) Validate the PBP models and select the most reliable model.

3. Literature review

Efficient planning is a disciplined process to ensure that a structured sequence of activities is completed. These activities will ensure that an organization can provide a quality product on time, at the lowest cost and to the customer's custom specifications (Senaratne & Jayarathna, 2012).

Laufer (1987) defined that planning is a process of deciding the following: (1) what activity to be completed; (2) how the activity should be completed; (3) who should complete the activity; and (4) when should the activity be completed (Laufer, 1987; Laufer, 1990). Moreover, The Plumbing-Heating-Cooling Contractors (PHCC) National Association have listed the benefits of preconstruction planning as the following: greater project control, increased project organization, better worker productivity, improved safety record, and increased project profitability. Integration of stakeholders at the preconstruction planning stage ensures project success and cost saving at the early stage of green building projects Son, et al. (2015).

Construction planning is necessary to account for all the variables and situations that may arise during a construction project. In addition, Planning for construction allows a contractor to be proactive rather than reactive to the problems as they arise where that planning helps contractor to controls the direction of the project and minimize the impact of problems. (PHCC National Association, 2002).

Preconstruction planning is a comprehensive set of procedures a contractor do immediately after contract award and right before construction starts (Hanna and Skiffington, 2010). One of the most important tasks in construction planning is to prepare the time plan (Hendrickson, 1998 and Andersson & Rosenberg, 2012). The time plan is an essential part of the planning to assure that the project is completed on time.

4. Factors affecting Project Baseline Plan (PBP)

The initial pool of factors affecting PBP includes twenty-six factors shown in Table 1. Past researches considered project scope definition as one of the factors affecting PBP (Dumont et al., (1997); Cho et al., (1999)). Gibson et al., (2006) mentioned that success during the detailed design, construction, and startup phases of a project depends highly on defining the scope of the project. Son and Rojas (2011) mentioned that “design errors and change orders” is one of the factors affecting project scheduling.

Doloi (2012) stated that accurate project planning and monitoring is one of eight critical factors extracted from a total of 36 selected attributes of cost overruns and project failure. Based on contractors’ point of view, work flow planning is affecting accurate project planning and monitoring.

To make good decisions, both experience from the previous contracts and the knowledge of customers' needs and local conditions must be exploited (Doloi, 2012). A knowledge base containing all the experience gathered by the organization while executing previous projects could be an advantage. Otherwise, the decision process can be based on experience and intuition of the project team members only.

Resource availability is one of the important constraints to take into account to obtain feasible scheduling (Masmoudi and Hait, 2013). All of those twenty-four factors.

4. Data Collection and Analysis

Factors are identified from previous studies, screened and analyzed in two stages. Stage one, Delphi technique is conducted to produce a short list of factors affecting preconstruction project planning. Stage two, a questionnaire survey has been conducted to collect experts' opinions about factors affecting the Project Baseline Plan and obtain factors' weights in the PBP model using the Analytic Hierarchy Process (AHP).

4.1Delphi technique

The Delphi process involves a series of questionnaire rounds, each followed by iterative analysis and feedback. The process concludes when a predefined level of consensus is reached (Nair et al., 2011). In this research, the consensus reached when experts return questionnaires without adding or eliminating any factor. According to Clayton (1997), only 5 to 10 experts are needed. Here, the surveyed panel consists of 8 experienced engineers. The classification of the surveyed panel experiences is shown in Table 2.

Questionnaires are sent by mail to the surveyed panel in three consecutive rounds. The first round consists of twenty-six factors listed in Table 1. The surveyed experts are asked to:

a) Rate each factor using a five-point Likert scale (1=Extremely Ineffective, 2=Moderately Ineffective, 3 = Neutral, 4=Moderately Effective, 5 = Extremely Effective)
b) Add factors other than listed, if any.
c) Modify factors, if any.

d) Add suggestions, if any.

The result of the first round eliminated 6 factors out of 26. Experts add two new factors; “financial capacity” in company category and “complexity of project” in project category, which increase factors to 22. The result of the second round eliminated 7 factors from the previous 22 factors of the first round and left 15 factors. The consensus is reached in the third round as the experts left the same factors without eliminating or adding as shown in Table 3. Next, AHP is utilized to find weights of these factors and develop the PBP Model.

4.2 AHP

AHP is a set of axioms that carefully delimits the scope of the problem environment (Saaty, 1986). It is based on the well-defined mathematical structure of consistent matrices and their associated right eigenvector's ability to generate true or approximate weights, (Saaty, 1980; Saaty, 1994). The AHP methodology compares criteria, or alternatives with respect to the main criterion, in a natural, and pairwise mode. AHP uses a fundamental scale of absolute numbers. The fundamental scale has been shown to be a scale that captures individual preferences with respect to quantitative and qualitative attributes just as well or better than other scales (Saaty 1980; Saaty 1994).

4.2.1 AHP Questionnaire

The AHP questionnaire aims to determine factors’ in PBP model. 135 questionnaires are sent to the experts. Only 73 responses are received back; 29 are incomplete and 44 are complete. The percentage of completed surveys is 32.6 %. The respondents’ job classification are; 11.1% are Project managers, 66.7% are planning engineers while 22.2% are site engineers. Questionnaires statistics are shown in Table 4, while Table 5 show the distribution of respondents’ experiences.

4.2.2 AHP steps:

Since the research objective is to develop PBP model, the proposed model is depicted as following:

I) Establish objective:

The objective of using AHP is to give weights to each model factor to develop the PBP.

II) Identify factors affecting Project Baseline Plan:

The model starts with identifying all factors affecting Project Baseline Plan, based on the literature review and after determining the most important factors shown in Table 3.

III) Structure the decision hierarchy:

These criteria are then structured into a hierarchy descending from an overall objective to general criteria and sub-criteria in successive levels.

IV) Compute priority weights (using AHP):

After responses are sent back from experts, AHP analysis is applied for the 44 completed questionnaires as the sample pairwise matrix shown in Table 6. Acceptable Consistency Ratio (CR) values for different matrices' sizes are; 0.05 for a 3×3 matrix, 0.08 for a 4×4 matrix, and 0.1 for larger matrices Saaty (1994). A sample of those calculations is shown in Table 7. Summary of priorities of criteria and sub-criteria of the 44 completed questionnaires is shown in Table 8.

As shown in Table 8, the company category is the most effective category in PBP with weight equal (0.34). The "resource capacity" is the most effective factor in this category with weight equal (0.45). On the other hand, the least effective category is "site conditions" with weight equal (0.15). The "late material delivery" is the most effective factor in this category with weight (0.41). "Project" category and "engineering staff" category has almost the same weight equal (0.26) and (0.25), respectively. It is clear that the "project scope definition" is the most effective factor in "project" category with weight equal (0.34). In "engineering staff category", "experience and intuition of the project team members" and "clear understanding of the project scope" represent about 50% of the weight of this category.

After obtaining all weights for main categories and subcategories (factors that affect Project Baseline Plan) as shown in Table 8, the PBP is now ready to be developed.

5. Developing a deterministic PBP model:

The general equation of the PBP model is shown in Equation (1)

$$\text{PBP} = \sum_{i=1}^{n} F_i \times w_i \qquad (1)$$

Where; PBP= Project Baseline Plan Index, f= factor affecting Project Baseline Plan, w= weight of Project Baseline Plan factor, and n=number of Project Baseline Plan factor in the model. Using factors weights developed from AHP, the PBP model is shown in Equation (2) where Equation (2) represents the deterministic model:

$$\begin{aligned}\text{PBP}= &0.34*[(0.26*F1) + (0.29*F2) + (0.45*F3)]\\ &+0.26*[(0.34*F4) + (0.21*F5) + (0.24*F6) + (0.21*F7)]\\ &+0.25*[(0.25*F8) + (0.20*F9) + (0.17*F10) + (0.09*F11) + (0.28*F12)]\\ &+0.15*[(0.30*F13) + (0.41*F14) + (0.29*F15)] \qquad (2)\end{aligned}$$

To convert the value of PBP into the percentage of Error In Plan (EIP %), Equation (3) is utilized taking into consideration that the relation between PBP and EIP in this research is assumed to be linear.

From Fig. 1 EIP could be obtained from Equation (3):

$$\text{EIP (\%)} = 20 * (5 - \text{PBP}) \qquad (3)$$

5.1 Determining factors scores:

To evaluate a project plan, the user should substitute F1 to F15 in Equation (2) with relevant scores obtained from Table A-1 (appendix A). The resulted value of PBP should range between 0 and 5. A quick look at Table A-1 reveals that 53.3% and 46.6% of factors having scores ranging between (0-5) and have scores (0 or 5), respectively.

For example, the financial capacity factor's score ranges from 0-5, the user choose the score corresponding to the percentage shown in factor limitation column in Table A-1. Let's assume the company financial capacity will cover 60-80% of project cost, the corresponding factor score =4. Another example, the score of "past experience from the last similar projects" ranges between 0-5. The user should select the score corresponding to the number of similar projects completed in the past. If the number of similar projects equals 7 projects, the corresponding score equals 3.

To more explain the process, consider one more example. The late material delivery factor's score should be selected either 0 or 5 relative to the chosen criteria from factor limitation column. If the user selects to ignore "late material delivery", then the score =0. After substituting all factors in Equation (2) with relevant scores, PBP is easy to calculate using simple math.

5.2 Plan Evaluation

To interpret the PBP value obtained from Equation (2), first use Equation (3) to calculate the percentage of errors in plan (EIP), which defined as the percentage of mismatching between the plan at the preconstruction phase and actual values after project completion. Second, use the calculated EIP in Fig. 2 to obtain the plan evaluation**.**

For example, if PBP equals 1.5 and EIP equals (70%), this plan is evaluated as (poor plan) using Fig. 2. In which case, it is necessary to go back to the plan and try to improve it by focusing on factors that affect Project Baseline Plan.

6. Developing a Fuzzy PBP model

The word "fuzzy" is defined as "blurred, indistinct, vaguely ", according to the dictionary, The term “fuzzy logic” means to the logic of approximation. Zadeh is considered the father of fuzzy set theory where the concept of Fuzzy Logic (FL) was first conceived in Zadeh's proposal of fuzzy set theory (Zadeh, 1965). there are many applications depend on fuzzy logic such as decision-support systems medical applications, instrumentation, industrial process control, and robotics (Idri, et al., 2001). FL provides a simple method to define a conclusion based upon imprecise, vague, ambiguous, noisy, or missing input information, in addition, FL is a mathematical tool for dealing with uncertainty Sivanandam et al. (2007). Moreover, FL approach mimics how a person would make decisions to control problems, only much faster Simon (2003).

6.1 Fuzzy model past practices

(Yasin Karatas and Yasin Karatas, 2016) have developed a reliable fuzzy expert tool for small satellite cost estimation the model consists of three variables where cost is a dependent variable whereas weight, and resolution are independent variables . The input values were from 50 to 500 kg for weight and from 1 m to 20 m for resolution and output values between $1 million and $200 million for cost, this model provides an expert assistance to decision making under uncertainty for small satellite cost estimation. Bhatnagar and Ghose (2012) concluded that fuzzy logic is the best model for predicting early stage effort estimation, where Mamdani FIS was more efficient than neural network models to predict the early stage efforts.

Cheng et al. (2009) have applied the evolutionary fuzzy neural inference for a conceptual cost estimate model, an evolutionary web-based conceptual cost model has been developed which can be used to estimate conceptual construction cost more precisely at the early stages of projects. Adeli and Jiang (2003) have developed a neuro-fuzzy logic model to estimate the freeway work zone capacity that provides a more accurate estimate of the work zone capacity. Al-Sheikh (2013) have developed a parametric fuzzy cost model to predict the conceptual cost of construction building projects in Gaza Strip. The results provided the ability of FL model to predict cost estimate to an acceptable degree of accuracy reached to 88%. Therefore, it is recommended that the fuzzy logic model will provide more accurate estimates, save time, minimize error and provide taking decisions under uncertainty.

6.2 Fuzzy model development

The objective of the fuzzy model is to provide uncertainty concept to PBP and to improve the accuracy of the deterministic model. This study has developed two fuzzy model where both models depend on fuzzy set theory with a different internal design of the proposed model. These modes are a fuzzy summation model and a fuzzy-fuzzy model.

6.2.1 Fuzzy summation model

This model is a fuzzy model that uses the fifteen screened factors of PBP as model's inputs and the output would be a PBP. It is difficult to convert all fifteen factors of PBP to a just one fuzzy model because it requires huge number of fuzzy rules. Therefore, the model design divides the fifteen factors into four groups based on its categories. These categories have been mentioned in Table 8. As a result, four fuzzy sub-models (FSMs) have been developed (FSM C1, FSM C2, FSM C3 and FSM C4) and then have been summed to calculate PBP as illustrated in Table 9.

Fig. 3 shows the input factors and output C1 of the first FSM C1. In this research, the membership values and the membership functions to fuzzy variables were assigned by intuition. It is based on the authors' own intelligence and understanding of the case study attributes. The most common types of membership functions are triangular. As a result, Triangular membership functions have been applied to develop the FSM in this research. As illustrated in Fig. 4, F1 has been divided into six triangular memberships ranging from zero to five. Similarly, F2, F3, F4 and C1 have been created. The next step is to define fuzzy rules as illustrated in Fig. 5. Similarly, (C2, C3 and C4) FSMs can be developed. Once these sub-models have been created, the PBP value can be predicted.

6.2.2 Fuzzy-Fuzzy model

The Fuzzy-Fuzzy model (FFM) consists of two successive fuzzy models, the first model is a just fuzzy summation model, whereas the second model is a fuzzy model that converts the output crisp values of (FSM C1, FSM C2, FSM C3 and FSM C4) to fuzzy values to produce PBP. The objective of this model is to apply more fuzziness to PBP. Fig. 6 shows the structure of the second model of the FFM.

7. Results and Discussion

7.1 Model Validation

Two case studies are applied to validate model results. A planning engineer with experience exceeds 15 years is asked to score each factor in Table (A-1) (appendix A). Then, PBP is calculated using Equation (2) for a deterministic model and by fuzzy summation model and FFM for fuzzy models. EIP % is calculated using Equation (3). The results of case studies according to this model are compared with the actual values for the completed project. In this research, project duration is used to compare result.

Case study 1:

The project is in (Malls and Mega government buildings) group. The estimated duration of this project is 885 days and the actual duration is 1125 days. Table 10 illustrates the score values of the first case study and the results of fuzzy models.

7.1.1 Case study 2:

The project is in (Residential and administrative buildings) group. The estimated duration of this project is 240 days and the actual duration is 326 days. The detailed information that is used for the model is given as shown in Table 9.

$$\text{Actual error in project } = \frac{\text{Estimated duration} - \text{Actual duration}}{\text{Estimated duration}} \qquad (4)$$

$$\text{comparison error} = \text{Model EIP} - \text{Atual EIP} \qquad (5)$$

$$\text{Overall comparison error} = \frac{\left|\sum_{0}^{n} \text{ comparison error}\right|}{n} \qquad (6)$$

Where; EIP: error in plan , and n: number of cases.

Overall comparison error: the absolute average of all cases' errors to select the most accurate model.

7.2.1 Deterministic model results (model 1)

As illustrated in Table 10, according to the case study (1), by applying the deterministic model to this case, using Equation (2), the result is 3.78, this value is between the ranges 3:4 in a zone called very good plan. In this zone, the error in the plan is ranged from 20:40%. The EIP equals 24.40% compared with the actual error in project plan "percentage" which is measured from the difference between the estimated duration and actual duration, it is 27.1% Equation (4). The model results and the case study results have the same range (very good plan). Based on Equation (5), the comparison error is -2.70 %.

According to the case study (2) shown in Table 11, by applying the deterministic model to this case, using Equation (2), the result is 3.42, this value is between the ranges 3:4 in a zone called a very good plan. In this zone, the error in the plan ranged from 20%:40%. The EIP of the model is equal 31.6% compared with the actual error in project plan, it is 35.8% Equation (4). Both the model and the case study results have the same range (very good plan). Based on Equation (5), the comparison error is -4.20 %.

7.2.2 Fuzzy summation model results (model 2)

According to the case study (1), by applying the Fuzzy summation model to this case, the result is 3.43, as a result the decision would be a very good plan. In this zone, the EIP of the model result equals 31.50% compared with the actual error in project plan, it is 27.1% by Equation (4). The model results and the case study results have the same range (very good plan). Based on Equation (5), the comparison error is 4.40 %.

According to the case study (2), by applying the Fuzzy summation model to this case, the result is 3.30, as a result the decision would be a very good plan. In this zone, the EIP of the model result equals 34.00% compared with the actual error in project plan, it is 35.80% by Equation (4). The model results and the case study results have the same range (very good plan). Based on Equation (5), the comparison error is -1.80 %.

7.2.3 FFM results (model 3)

According to the case study (1), by applying the FFM to this case, the result is 3.75, as a result the decision would be a very good plan. In this zone, the EIP of the model result equals 25.00 % compared with the actual error in project plan, it is 27.1%

Equation (4). The model results and the case study results have the same range (very good plan). Based on Equation (5), the comparison error is -2.10%.

According to the case study (2), by applying the FFM to this case, the result is 2.50, as a result the decision would be a very good plan. In this zone, the EIP of the model result equals 50.00 % compared with the actual error in project plan, it is 35.80% by Equation (4). The model results and the case study results have different ranges (very good plan) for the actual case study and (good plan) for FFM. Based on Equation (5), the comparison error is 14.20%.

7.2.4 Select the most precise model

As illustrated in Table.12, based on Equation (6), the overall comparison error for each model has been calculated, the worst precise model is FFM with overall error (12.10%) due to overuse of fuzziness concept that leads to a low precise model performance. However, the Fuzzy summation model produces the best precise results (2.60%) more than the deterministic model (6.90%). Therefore, the correct use of fuzzy theory will develop the most accurate, realistic and reliable model than a deterministic one. As a result, the Fuzzy summation model is the most precise model to predict PBP.

8. Conclusions and Recommendation

The aim of this research is to develop a model to precisely predict the Project Baseline Plan Index to predict if the plan is good or not. This model is created by collecting factors that affect Project Baseline Plan. Some filtrations are made for them in order to find the most important factors using the Delphi technique then has been applied AHP technique to find their weights. The company has the most important category with the value of (0.34) while, the most effective factor in this category is the resource capacity with the value of (0.45). It is also clear that, the most important factor in project category is the project scope definition with the value of (0.34) while the most important factor in the engineering staff category is the experience and intuition of the project team members with value of (0.28). Finally, the most important factor in the site condition category is the late material delivery with value of (0.41).

Moreover, three models have been developed based on both deterministic and fuzzy concepts, and the results shows that fuzzy model is more accurate and realistic than the deterministic one. Therefore, the correct use of fuzzy theory will develop the most accurate, realistic and reliable models than deterministic ones. Finally, Fuzzy summation model is selected to be the most accurate model of PBP with overall error (2.60%).

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Appendix (A)

1. Factors scores for PBP

Table A-1 Factors score

Category	Code	Factor	Measure Unit	Factor Limitation		Score
Company	F1	1. The financial capacity		Lower limit	Upper limit	
			Cash flow of company as a percentage from the estimating step	0		0
				› 0	< 20 %	1
				20	< 40 %	2
				40	< 60 %	3
				60	< 80 %	4
				80	100 % or more	5
	F2	2. Select team members	Availability of project manager, site engineers and labor before starting the project as a percentage from the estimating step	Lower limit	Upper limit	
				0		0
				0	< 20 %	1
				20 %	< 40 %	2
				40 %	< 60 %	3
				60 %	< 80 %	4
				80 %	100 % or more	5
	F3	3. Resource capacity	The company resource availability as a percentage from the estimating step	Lower limit	Upper limit	
				0		0
				0 %	< 20 %	1
				20 %	< 40 %	2
				40 %	< 60 %	3
				60 %	< 80 %	4
				80 %	100 % or more	5
Project	F4	4. Project scope definition	Availability of a complete drawing and specification	Incomplete drawings and specifications.		0
				Complete drawings and specifications.		5
	F5	5. Project Complexity .		Project constructed in country under a state of war		0
				Tunnel under seas and bridges over seas.		1
				Road tunnels and bridges.		2
				Malls and Mega government buildings.		3
				Roads.		4

				Residential and administrative buildings.		5
	F6	6. Past experience from last similar projects.		0 projects		0
				≤ 2 projects.		1
				2-5 projects.		2
				5-10 projects.		3
				10-15 projects.		4
				≥ 15 projects.		5
	F7	7. Financial analysis	project financial analysis as a percentage of company financial capacity	Lower limit	Upper limit	
				› 100 %		0
				80 %	≤100 %	1
				60 %	<80 %	2
				40 %	<60 %	3
				20 %	<40 %	4
				< 20 %		5
Engineer staff	F8	8. Clear understanding of the project scope.	The percentage depends on engineer understanding.	Lower limit	Upper limit	
				0		0
				› 0	< 20 %	1
				20 %	< 40 %	2
				40 %	< 60 %	3
				60 %	< 80 %	4
				80%	100 %	5
	F9	9. Accurate work flow planning	complete work breakdown structure	Incomplete work breakdown structure		0
				Complete work breakdown structure		5
	F10	10. Clear process of project control	Availability of agreements to apply project control	Unavailability of agreements to apply project control.		0
				Availability of agreements to apply project control.		5
	F11	11. Clear change request protocol	Availability of agreements to apply change requests	Unavailability of agreements to apply change requests.		0
				Availability of agreements to apply change requests.		5
	F12	12. Experience and intuition of the project team members	planning engineer years of experience	Lower limit	Upper limit	
				0		0
				› 0	<1year	1
				1 years	<5 years	2
				5 years	<10 years	3
				10 years	<20 years	4
				≥ 20 years.		5
Site conditions	F13	13. Resource availability	Ensuring that the assumption of estimated amount of resources is available in company resource pool	Didn't make check to confirm that the assumptions are correct.		0
				Made check to confirm that the assumptions are correct.		5
	F14	14. Late material delivery.		Ignoring late material delivery.		0
				Considering late material delivery.		5

	F15	15.	Bad weather conditions.	Ignoring bad weather conditions.	0
				Considering bad weather conditions.	5

Table 1 Factors collected from previous studies.

Categories		Factor	AACE 1990	Dumon et al., 1997	Hanna and Skiffington 2010	Smith and Tucker 1983	PMBOK 2004	Nowak and Nowak 2011	Son and Rojas 2011	Doloi, (2012)	Elkhayari, 2003	Masmoudi and Hait ,2013.
Company	1	The financial capacity	√									
	2	Resource capacity.	√									
	3	Human resource capacity.	√									
Project	4	Availability of basic and preliminary designs.				√						
	5	Knowledge of project requirement.					√					
	6	Past experience from last similar projects.						√				
	7	Financial analysis.						√				
	8	Design errors and change orders.							√	√		
	9	Project scope definition.		√		√	√			√		
Engineer Staff	10	Clear understanding of the project scope.								√		
	11	Accurate work flow planning.					√			√		
	12	Buildability and specialized resources.								√		
	13	Agreement on project budget and duration.								√		
	14	Clear process of project control.								√		
	15	Clear change request protocol.								√		
	16	Monitoring and status reporting protocols.								√		
	17	Clear understanding of the project scope.								√		
	18	Knowledge of customers' needs.						√				

	19	Understanding the design.								√		
	20	Construction methods and techniques.								√		
	21	Experience and intuition of the project team.						√		√		
Site Conditions	22	Resource availability.									√	√
	23	Late material delivery.							√			
	24	Shortage of labor and unskilled labor.							√			
	25	Bad weather conditions.							√			
	26	Complexity of on-site construction activities.								√		

Table 2 Classification of the surveyed experts based on their experience.

Years of experience	Project Managers	Planning Engineer	Site Engineer	Total	%
<10 years	-	1	1	2	25.0
≥ 10 years and > 15	-	2	1	3	37.5
≥15 years	1	2	-	3	37.5

Table 3 Factors after the Third round.

Category	Factor
1. Company (C1)	1.1 The financial capacity (Assets, cash flow, etc.).
	1.2 Resource capacity.
	1.3 1.3 Human resource capacity..
2. Project (C2)	2.1 Project scope definition.
	2.2 Project Complexity.
	2.3 Past experience from last similar projects.
	2.4 Financial analysis.
3. Engineer Staff (C3)	3.1 Clear understanding of the project scope.
	3.2 Accurate work flow planning.
	3.3 Clear process of project control.
	3.4 Clear change request protocol.
	3.5 Experience and intuition of the project team members.
4. Site conditions (C4)	4.1 Resource availability.
	4.2 Late material delivery.
	4.3 Bad weather conditions.

T

able 4 AHP Questionnaire and statistics.

Construction projects experts	Distributed questionnaires	Returned questionnaires	uncompleted questionnaires	completed questionnaires	% completed questionnaires
Project managers	15	10	5	5	33.3
Planning engineer	90	42	16	26	28.9
Site engineer	30	21	8	13	43.3
Total	135	73	29	44	32.6

Table 5 AHP Questionnaire and classification of respondents' experiences.

Years of Experience	Project Managers	Planning Engineer	Site Engineer	Total	%
< 10 years	2	14	9	25	34.25
≥ 10 years and < 20)	5	21	7	33	45.21
≥ 20 years	3	7	5	15	20.55

Table 6 Example of pairwise comparison scale of main category.

Factor	C1	C2	C3	C4
C1 (company)	1.00	0.33	3.00	3.00
C2 (project)	3.00	1.00	5.00	5.00
C3 (engineering staff)	0.33	0.20	1.00	1.00
C4 (site)	0.33	0.20	1.00	1.00
Total	4.77	1.73	10.00	10.00

Table 7 Calculation of priority weights of main category.

Factor	C1	C2	C3	C4	Total	Weight	C MEASURE
C1 (company)	0.21	0.19	0.30	0.30	1.01	0.25	4.04
C2 (project)	0.64	0.58	0.50	0.50	2.22	0.55	4.10
C3 (engineering staff)	0.07	0.12	0.10	0.10	0.39	0.10	4.02
C4 (site)	0.07	0.12	0.10	0.10	0.39	0.10	4.02
Total	1.00	1.00	1.00	1.00	4.00	1.00	
Consistency Index (CI)							0.01
Random Index (RI)							0.90
Consistency Ratio (CR)							0.02
CR < 0.1 OK							

Table 8 Summary of weights of main category and sub-category.

Categories and Factors	Category weight	Factor weight
C1 (Company)	0.34	
F1 (Financial capacity)		0.26
F2 (Select team members)		0.29
F3 (Resource capacity)		0.45
C2 (Project)	0.26	
F4 (Scope definition)		0.34
F5 (Complexity)		0.21
F6 (Past experience from last similar projects)		0.24
F7 (Financial analysis)		0.21
C3 (Engineering staff)	0.25	
F8 (Clear understanding of the project scope)		0.25
F9 (Accurate work flow planning)		0.20
F10 (Clear process of project control)		0.17
F11 (Clear change request protocol)		0.09
F12 (Experience and intuition of the project team members)		0.28
C4 (Site)	0.15	
F13 (Resource availability)		0.30
F14 (Late material delivery)		0.41
F15 (Bad weather conditions)		0.29

Table 9 Factors used in each model.

Serial	Model	Factors used in each model
1	FSM C1	0.34*[(0.26*F1)+(0.29*F2)+(0.45*F3)]
2	FSM C2	0.26*[(0.34*F4)+(0.21*F5)+(0.24*F6)+ (0.21*F7)]
3	FSM C3	0.25*[(0.25*F8)+(0.20*F9)+(0.17*F10)+(0.09*F11)+(0.28*F12)]
4	FSM C4	0.15*[(0.30*F13) +(0.41*F14)+(0.29*F15)]
5	PBP	[FSM C1 + FSM C2 + FSM C3 + FSM C4]

Table 10 Case 1 fuzzy models results.

Case 1 inputs ‘scores		Category of FSMs	Crisp Values of FSMs		Crisp Value of FFM
F1	3	FSM C1	1.28	**FFM**	**3.75**
F2	4				
F3	4				
F4	5	FSM C2	0.65		
F5	3				
F6	4				
F7	0				
F8	4	FSM C3	1.12		
F9	5				
F10	5				
F11	5				
F12	4				
F13	5	FSM C4	0.37		
F14	5				
F15	0				
		Fuzzy summation model	**3.42**		

Table 11 Case 2 fuzzy models results.

Case 2 inputs ‘scores		Category of FSMs	Crisp Values of FSMs		Crisp Value of FFM
F1	5	FSM C1	1.50	**FFM**	**2.50**
F2	5				
F3	4				
F4	5	FSM C2	1.04		
F5	5				
F6	5				
F7	1				
F8	4	FSM C3	0.70		
F9	5				
F10	0				
F11	0				
F12	4				
F13	0	FSM C4	0.06		
F14	0				
F15	0				
		Fuzzy summation model	3.30		

Table 12 Models comparisons

			Model 1	Model 2	Model 3
		Actual Error in Project	deterministic model	Fuzzy Summation model	FFM
Case 1	PBP	3.65	3.78	3.43	3.75
	EIP	27.10	24.40	31.50	25.00
	Decision	very good plan	very good plan	very good plan	very good plan
	Comparison error	0.00	-2.70	4.40	-2.10
Case 2	PBP	3.21	3.42	3.30	2.50
	EIP	35.80	31.60	34.00	50.00
	Decision	very good plan	very good plan	very good plan	good plan
	Comparison Error	0.00	-4.20	-1.80	14.20
	Overall Error	0.00	6.90	2.60	12.10

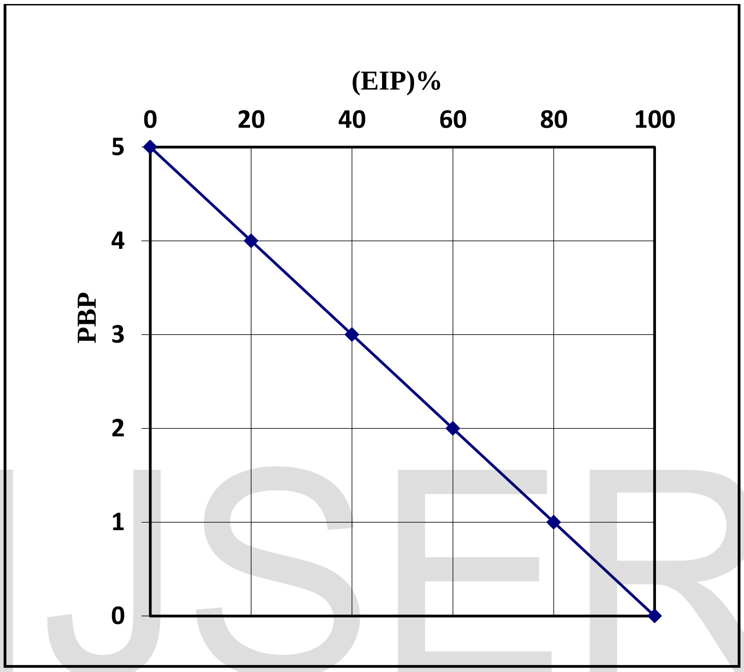


Fig. 1 Relation between PBP and EIP %

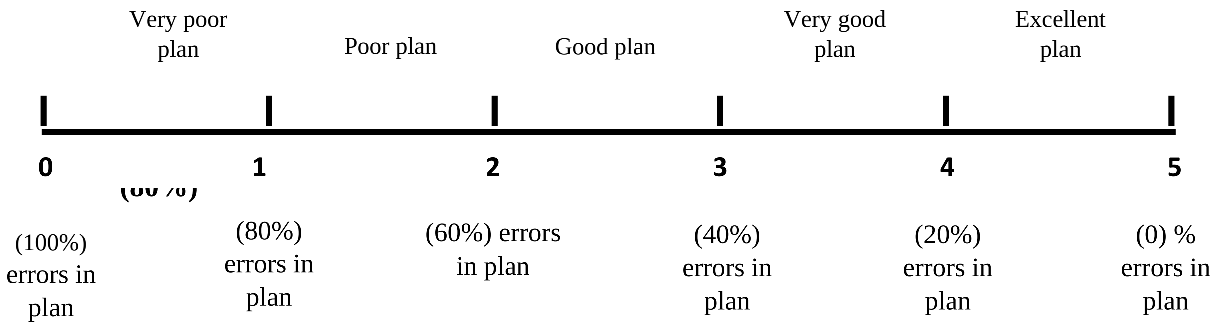


Fig. 2 The Preconstruction Project Plan Index.

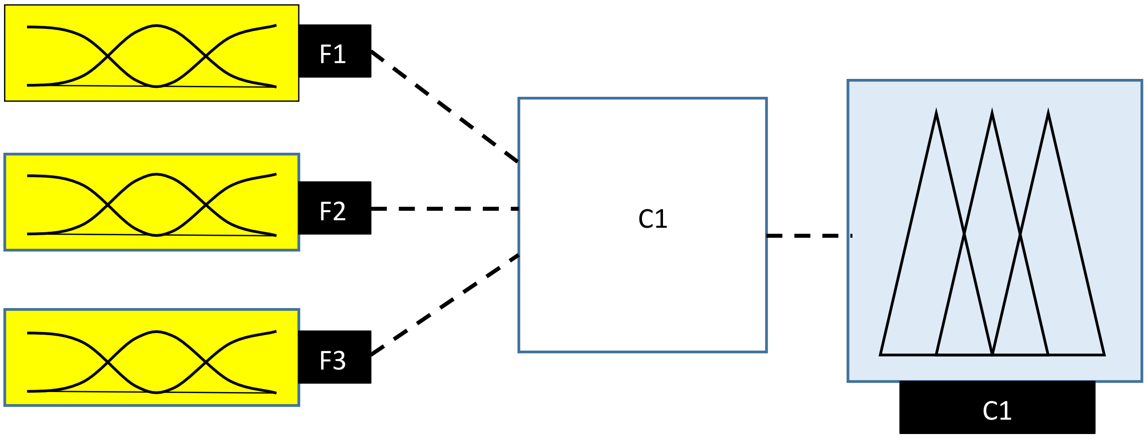


Fig. 3 FSM C1 components.

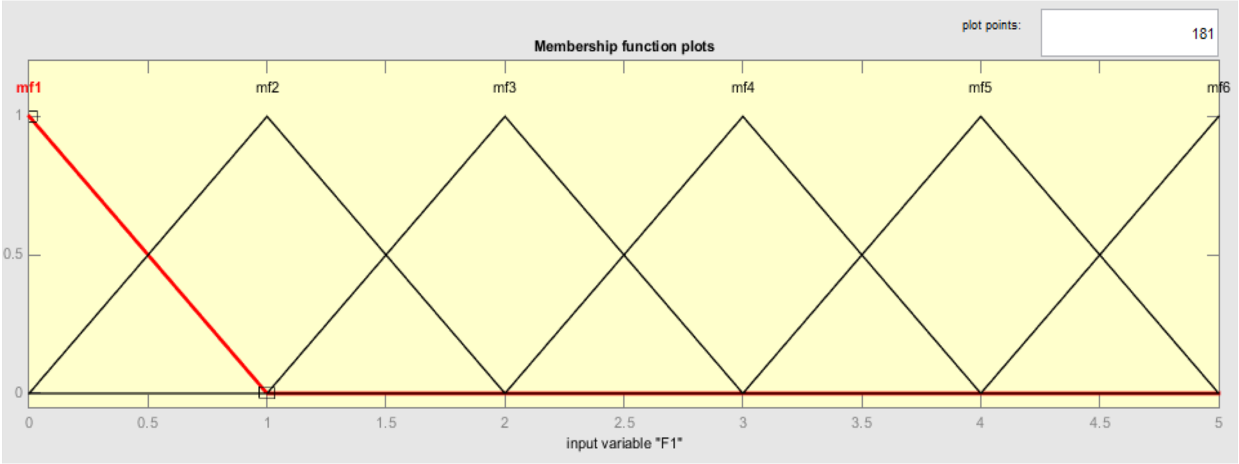
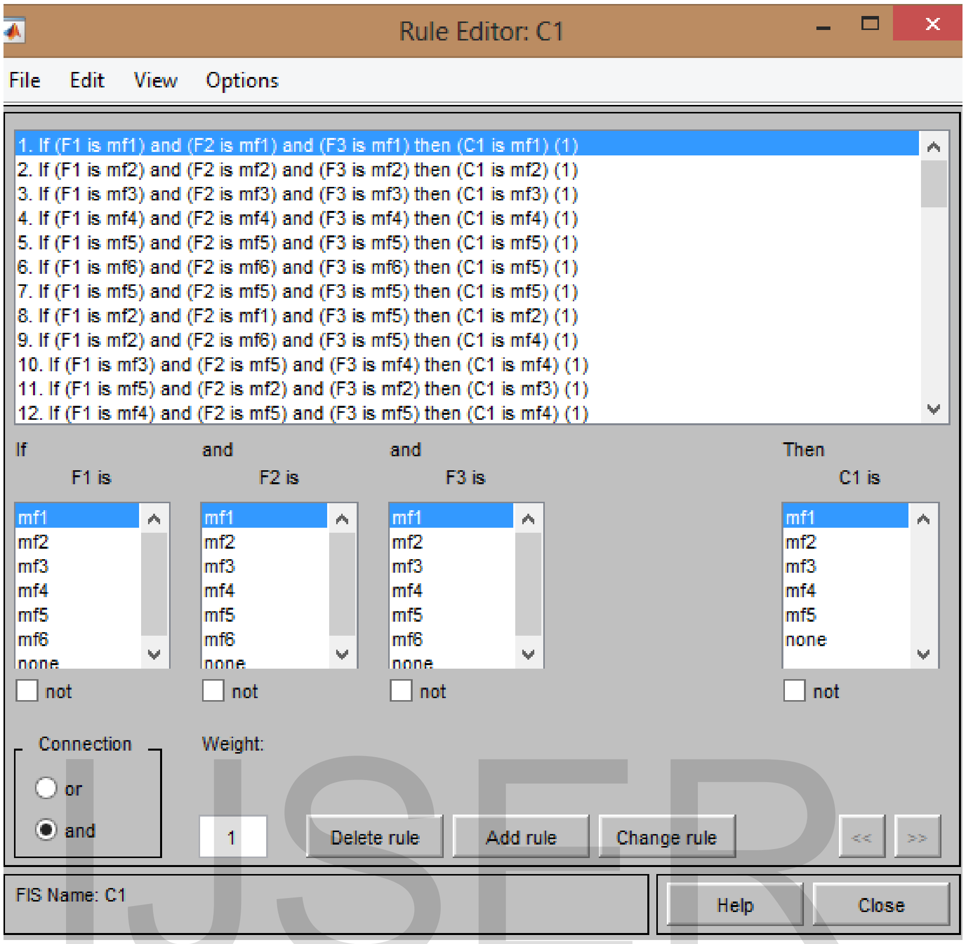


Fig. 4 Triangular membership functions of F1.



1. If (F1 is mf1) and (F2 is mf1) and (F3 is mf1) then (C1 is mf1) (1)
2. If (F1 is mf2) and (F2 is mf2) and (F3 is mf2) then (C1 is mf2) (1)
3. If (F1 is mf3) and (F2 is mf3) and (F3 is mf3) then (C1 is mf3) (1)
4. If (F1 is mf4) and (F2 is mf4) and (F3 is mf4) then (C1 is mf4) (1)
5. If (F1 is mf5) and (F2 is mf5) and (F3 is mf5) then (C1 is mf5) (1)
6. If (F1 is mf6) and (F2 is mf6) and (F3 is mf6) then (C1 is mf5) (1)
7. If (F1 is mf5) and (F2 is mf5) and (F3 is mf5) then (C1 is mf5) (1)
8. If (F1 is mf2) and (F2 is mf1) and (F3 is mf5) then (C1 is mf2) (1)
9. If (F1 is mf2) and (F2 is mf6) and (F3 is mf5) then (C1 is mf4) (1)
10. If (F1 is mf3) and (F2 is mf5) and (F3 is mf4) then (C1 is mf4) (1)
11. If (F1 is mf5) and (F2 is mf2) and (F3 is mf2) then (C1 is mf3) (1)
12. If (F1 is mf4) and (F2 is mf5) and (F3 is mf5) then (C1 is mf4) (1)

Fig.5 fuzzy rules of FSM C1.

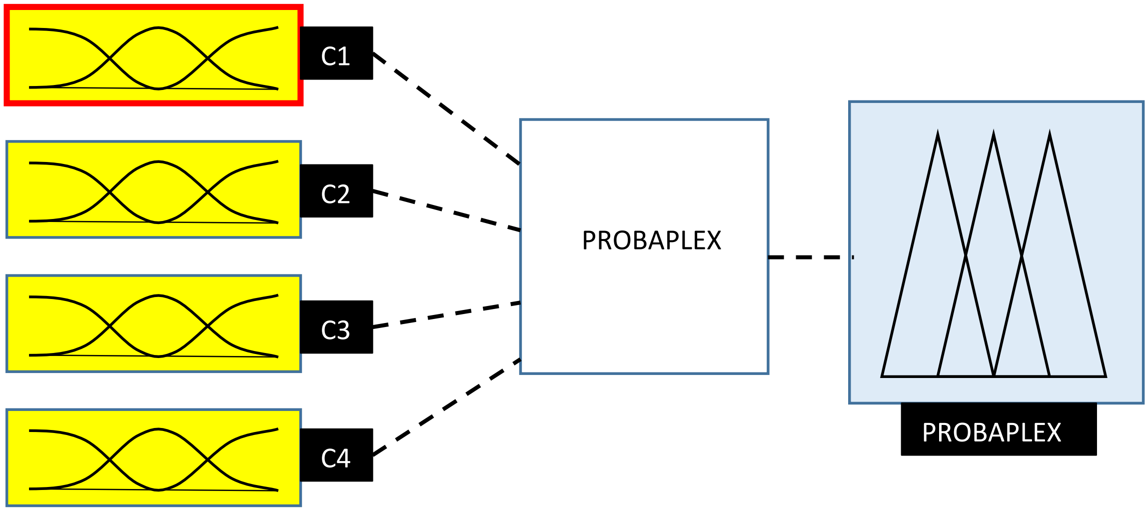


Fig. 6 The structure of the FFM.

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