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Project scheduling by FGP to Time-Cost-Quality trade off: construction case study

Najmeh Faregh[1], Saeedeh Ketabi[2], and Mahsa Ghandehari[3]

Abstract: Project managers are responsible to conduct project on time with least amount of costs and the most possible quality with respect to shortage of resources and environmental certainties. They have to make the best decision to reach such conflicting objects. In this study the project scheduling with multi goals- multi modes was planned in fuzzy conditions under resource constraints and expanded by fuzzy goal programing (FGP). The project cost was calculated by the price of renewable resources and the quality criteria were evaluated by the quality function deployment method (QFD). Finally the model was verified by a construction case study with 22 activities along with solving by GAMS. The results showed that this model could provide a systematic framework to facilitate the decision making process and made the project managers to be able to schedule the project closer to reality.

Keywords: project scheduling, time-cost-quality trade off, quality function deployment, fuzzy set, goal programing

I. Introduction

Project scheduling is aimed to provide balance between conflicting objects such as time, cost and quality under resource constraints and environmental uncertainties [1]. In the previous studies this three objectives were not usually considered together and only a specific situation was applied [2].

In scheduling of projects under resource constraints, there are some capitals with confined capacities. Activities not only have priority over each other for being performed but also are restricted in making use of such limited resources. Such resources could be renewable or non-renewable [3]. Considering such limitations along with creating balance between conflicting objectives can make decision making process very difficult [2]. Moreover in real world there are a specific structure. This common property is usually due to vagueness and lack of precision in i defining concepts and phenomenon. Lack of environmental certainty in scheduling would affect projects and would deviate programs. Thus project managers are confronted to fuzzy parameters. Fuzzy theory is used to explain lack of precision in events and it is created based multi value logic.

Considering the mentioned points, it is clear that considering environmental situations, limited resources and creating balance in conflicting objectives simultaneously can push projects scheduling toward reality, although the process becomes so demanding for managers. In the present study regarding different available modes which have individualistic properties for reducing time or cost or increasing quality, a multi modes problem is considered. QFD is used to measure final quality of the project based on the customer`s view. Project cost is calculated by consideration of direct costs of renewable resources in normal and crash time then a mathematical model of multi-mode fuzzy goal programming under resource constraints is designed.

II. Review of the Literature

A significant number of literatures is related to time cost trade off, although quality as the third goal can influence the whole process. Babua and Suresh [4] were the first people considered quality as the third goal. They proposed three different models in each one of these goals is considered as the object and the two others as constraints. They solved three models with three specific objective functions. Iranmanesh et al [1] solved time-cost-quality trade off by making use of goal programing and genetic algorithm. Their case study was a project with thirty activities, each activity can be performed in different modes with specific time, cost and quality. Peng et al. [2] calculated quality criteria by QFD in product development project. They scheduled the project with respect to one the goal while others have been as constraints. Then solved the problem by branch and bound. Ghoddousi et al. [5] considered multi-mode resource constrained project scheduling problem (MRCPSP) discrete time-cost trade off problem (DTCTP) and resource allocation and resource leveling problem (RLP). They solved these problems with non-dodomination based genetic algorithm (NSGA). Peteghem and Vanhouck [6] presented the existing metaheuristic solution to solve the multi-mode resource constrained project scheduling problem on new dataset instances.

[1] MSc graduated, Department of management, Faculty of administrative sciences and economics, University of Isfahan, Tel: +983113915073, E-mail: na.faregh@yahoo.com, (*Corresponding Author)
[2] Assistant professor, Department of management, Faculty of administrative sciences and economics, University of Isfahan
[3] Assistant professor, Department of management, Faculty of administrative sciences and economics, University of Isfahan

Korea Institute of Construction Engineering and Management

Fuzzy set theory was presented by Zadeh [7], consequently has been developed in different fields. Zimmermann [8] introduced fuzzy set theory into linear programing (FLP) for the first time and then fuzzy set theory was entered to other aspects of decision making. Liang [9] designed a FLP approach with fuzzy constraints to minimize total project costs, duration of activities, and total allocated budget. Long and Ohsato [3] designed a critical fuzzy approach in resource constraint models, they scheduled problem under resource constraints then adding a project buffer to the end of the schedule to deal with uncertainty.

Goal programing (GP) is one of the oldest widely used methods in multi objective linear programing (MOLP). GP is proposed in problems with conflicting objects and its aim is to minimize unfavorable deviations. Zimmermann [10] first extended FLP to a MOLP problem. Subsequent investigations on FGP included those of Dubois and Fortemps, Hannan, Kuwano, Leberling, Luhandjula [11-15]. The main differences among their methods are resulted from the types of aggregation operators and membership functions that they applied. Liang [16] proposed a multi-phase fuzzy goal programing for solving multi object problems which aim is to minimize total costs, total time and crash costs.

III. PROBLEM FORMULATION

This study considers three objectives time, cost and quality in resource constrained project planning with different possible modes, therefore the problem is MRCPSP.

V is set of development activities and i is the activity index of the members. E represents relation between the activities, E (i,j) shows the precedence of activity i to activity j. there is a set of renewable resources denoted by K, in which Rk is amount of resource type k. Each activity is performed with a mode m∊ M; M is the set of available modes. The project is modeled by activity on node network (AON). The start time of project is set 0 and the project duration is shown by fn; n is the end activity. The parameter and decision variables are as following:

- dn_{im} : normal time of doing activity *i* in mode *m*
- dov_{im} : crash time of doing activity *i* in mode *m*
- ed_{im} : overtime of activity *i* in mode *m* if done in crash time
- q_{im} : quality of doing activity *i* in mode *m* based on the project manager points of view
- cn_k : normal cost of unite time for resource type *k*
- cov_k : crash cost of unite time for resource type *k*
- Er_i : earliest doing time of activity *i*
- La_i : latest doing time of activity *i*
- rr_{imk} : renewable resource requirement of type *k* for activity *i* in mode *m*
- T_{max} : maximum execution time
- C_{max} : maximum available cost
- Q_{min} : minimum expected quality

$$x_{itm} = \begin{cases} 1 & \text{If activity i in mode m ended in time t} \\ 0 & \text{Otherwise} \end{cases}$$

$$y_i = \begin{cases} 1 & \text{If activity i performed in crash time} \\ 0 & \text{Otherwise} \end{cases}$$

3.1 Calculation of project cost:

Cost occurs from the consumption of resources. Most practical project manager decisions have considered minimizing total project cost. In this study the total direct cost consist of normal and crash costs of resources consumption. The direct normal costs of resource is calculated as follows:

$$\sum_k \sum_i \sum_m \sum_t (rr_{imk} . Cn_k . X_{itm} . dn_{im}) \quad (1)$$

The crash costs are related to shorting the duration of activities and is calculated as follows:

$$\sum_i \sum_m \sum_t \left(X_{imt} . y_i . \sum_k rr_{imk} . e\,\mathrm{d_{im}} . Cov_K \right) \quad (2)$$

Thus the total cost of project by consideration of (1) and (2) is:

$$F_c = \sum_k \sum_i \sum_m \sum_t (rr_{imk} . Cn_k . X_{itm} . dn_{im}) + \sum_i \sum_m \sum_t \left(X_{imt} . y_i . \sum_k rr_{imk} . e\,\mathrm{d_{im}} . Cov_K \right) \quad (3)$$

3.2 Calculation of project quality:

QFD is a method that divides customer needs layer by layer into product features and process technical requirements. It can be understood as an analytical tool that quantifies the relationship between the purpose and means of assessment in the form of the house of quality matrix [17].

This study uses the approach proposed by Peng et al. [2]. They used QFD to present a model for identification of final quality of project with respect to quality of each activity separately. Since the project activities affect differently on the whole project quality, it is necessary to interfere the weights of the activity's quality in the project quality. These weights are calculated by QFD. To do this, first the view of customer quality index for each activity is obtained and then total quality will be calculated.

QFD is an important management method on product quality [18]. A basic QFD house of quality matrix is shown as Table 1 in which quality indicators (1, 2,…l) is represented in the first column and importance of quality indicators (k1, k2,…,kl) is presented in the second column. On the roof, the integers 1, 2… n -1, n represent the project activities n. In the relationship matrix, zij indicates the correlation between the quality indicator (customer demand) i and activity j. Then the weight of each project activity can be formulated as:

$$h_i = \sum_{j=1}^{l} K_j Z_{ji} \tag{4}$$

TABLE I
EXAMPLE OF QUALITY HOUSE

Quality indicators	importance	Project activities				
		1	2	…	n-1	n
1	K_1	Z_{11}		…	Z_{1n-1}	Z_{1n}
2	K_2	Z_{21}		…		
…	…			…		
l-1	K_{l-1}			…		
l	k_l	Z_{l1}		…	Z_{ln-1}	z_{ln}

If activity j is closely related to quality indicators and these quality indicators with large weights, the hj becomes large, and this activity is more important. Based on the quality weight (hi) and the quality value of each activity (qim), the quality value of the whole project; Fq can be calculated as:

$$F_q = \left[\frac{\sum_i \sum_m \sum_t \left(X_{itm} . q_{im} . h_i \right)}{\sum_i \left(10 \times h_i \right)} \right] \times 10 \tag{5}$$

- q_{im} is the real number from 1 to 10 and is identified by the manager of the project where 1 is the best quality and 0 is the worst quality.

3.3 Calculation of project duration time

In most projects, minimizing duration time is the most important criteria. Assuming the start time as 0, end time of the project can be calculated as follow:

$$F_t = \sum_m \sum_t t x_{ntm} \tag{6}$$

IV. MATHEMATICAL MODEL

4.1 goal programing approach

This multi-mode multi objective resource constrained project scheduling problem is formulated as an integer programing problem. The mathematical model is as follows:

$$\min \ Z_t = \sum_m \sum_t t x_{ntm} \tag{7}$$

$$\max \quad Z_q = \left[\frac{\sum \sum \sum \left(X_{itm} . q_{im} . h_i \right)}{\sum_i \left(10 . h_i \right)} \right] \times 10 \tag{8}$$

$$\min \quad Z_c = \sum_k \sum_i \sum_m \sum_t (rr_{imk} . Cn_k . X_{imt} . dn_{im}) + \sum_i \sum_m \sum_t \left(X_{imt} . y_i . \sum_k rr_{imk} . e\,\mathrm{d}_{im} . Cov_K \right) \tag{9}$$

$$S.t$$
$$-\sum_m \sum_{t=Eri}^{lai} t . x_{itm} + \sum_m \sum_{t=Erj}^{laj} (t - dn_{jm}) X_{jtm} . \left(1 - y_j\right)$$
$$+ \sum_m \sum_{t=Eri}^{lai} (t - dov_{jm}) x_{jtm} . y_j \geq 0 \qquad (i, j) \in E \tag{10}$$

$$\sum_i \sum_m \sum_t^{t+dn_{im}-1} rr_{imk} . x_{itm} \leq R_k \qquad k \in K \tag{11}$$

$$\sum_m \sum_t x_{itm} = 1 \qquad i \in V$$
$$x, y \rightarrow binary \tag{12}$$

In which functions (7), (8), (9), show project objectives. Constraints (10) express that all activities need to satisfy the preceding relationship. Constraints (11) of renewable resources ensure that the quantity of resources allocated to specific activities must be less or equal to the available amount of the resources. Constraints (12) allocate a special time and specific mode for performing each activity. The resource constraints have been modeled using the concept of Talbot [19].

4.2 Fuzzy goal programing approach

Many applied problems need to be formulated with uncertainty. Fuzzy programing approach is used to consider problem under uncertainty. Thus the fuzzy version of the above problem can be shown as follow:

$$\min \ z_t \cong \sum \sum t x_{ntm}$$

$$\max \ z_q \cong \left[\frac{\sum_i \sum_t \sum_m \left(x_{itm} . q_{im} . h_i \right)}{\sum_i \left(10 \times h_i \right)} \right] \times 10$$

$$\min \ z_c \cong \sum_k \sum_i \sum_m \sum_t (rr_{imk} . Cn_k . X_{imt} . dn_{im}) + \sum_i \sum_m \sum_t \left(X_{imt} . y_i . \sum_k rr_{imk} . e\,\mathrm{d}_{im} . Cov_K \right) \tag{13}$$

Subject to Eqs. (10- 12)

The above model can be solved using the concept of

Zadeh and Bellman [20] together with fuzzy programing method of Zimmerman. First the positive ideal solution (PIS) and the negative ideal solution (NIS) is obtained for each fuzzy objective function:

$$z_g^{PIS} = \min z_g, z_g^{NIS} = \max z_g \quad \text{For minimizing functions}$$
$$g = 1, 2, ..., k$$

$$z_g^{PIS} = \max z_g, z_g^{NIS} = \min z_g \quad \text{For maximizing functions}$$
$$g = 1, 2, ..., k$$

(14)

Then to represent the fuzzy objective functions, the linear membership function is used. The linear membership function can be defined to imposing the DM to select the goal value interval.

At the first, the problem is solved only for one single goal model and the PIS and NIS for each of the objective function will be determined. ZgNIS for objective function can be selected by DM. Cmax (total available cost), Cmax (maximum execution time) and Qmin (minimum expected quality) can be selected by DM for zgNIS. According for each function Fg (zg) is calculated as follows:

For minimizing functions

$$f_g(z_g) = \begin{cases} 1 & z_g \le z_g^{PIS} \\ \dfrac{z_g^{NIS} - z_g}{z_g^{NIS} - z_g^{PIS}} & z_g^{PIS} \prec z_g \prec z_g^{NIS} \quad g = 1, 2, ...k \\ 0 & z_g \ge z_g^{NIS} \end{cases}$$

For maximizing functions:

$$f_g(z_g) = \begin{cases} 0 & z_g \le z_g^{NIS} \\ \dfrac{z_g^{PIS} - z_g}{z_g^{PIS} - z_g^{NIS}} & z_g^{NIS} \prec z_g \prec z_g^{PIS} \quad g = 1, 2, ..., k \\ 1 & z_g \ge z_g^{PIS} \end{cases}$$

(15)

By introducing the auxiliary variable λ g the fuzzy problem can be converted into an equivalent ordinary single goal model:

$$\max \quad w_t\lambda_t + w_q\lambda_q + w_c\lambda_c$$
$$s.t$$

$$Z_t + P_t\lambda_t \le T_{\min} + P_t$$

$$Z_c + P_c\lambda_c \le C_{\min} + P_c \qquad (16)$$

$$Z_q - P_q\lambda_q \ge Q_{\min} - P_q$$

Subject to Eqs. (10- 12)

Therefore our problem can be formulated as:

$$man \quad w_t\lambda_t + w_q\lambda_q + w_c\lambda_c + w_k\lambda_k \qquad k \in K$$
$$s.t \quad \sum_m \sum_t tx_{nmt} + P_t\lambda_t \le T_{\min} + P_t$$

$$\left[\frac{\sum_i \sum_t \sum_m (x_{itm}.q_{im}.h_i)}{\sum_i (10 \times h_i)}\right] \times 10 - \mathrm{P}_q\lambda_q \ge Q_{man} - P_q$$

$$\sum_k \sum_i \sum_m \sum_t (rr_{imk}.Cn_k.X_{imt}.dn_{im}) +$$
$$\sum_i \sum_m \sum_t \left(X_{imt}.y_i \sum_k rr_{imk}.e\,\mathrm{d}_{im}.Cov_K\right)$$
$$+P_cC_c \le C_{\min} + P_c$$

Eqs. (10-12)

(17)

Where w_q is the corresponding weight of gth fuzzy objective function chosen by DM. these values can be obtained by DM experience and preferences.

V. CASE STUDY

In order to evaluate the proposed model, data from Kimia Bana Gostar, Construction Company has been collected. This company was established in 2008 and its main activity is consultation, designing, supervision and performing construction projects. In this case study, it was decided to focus on only the elaborate work of construction for a building consisting of 22 activities. These activities are performed in tow modes: classic and modern, and in normal and crash time. To conduct the project, besides engineers, five types of workers are also needed: simple construction workers, semi-skilled construction workers, skilled construction workers, simple installation workers, semi-skilled installation workers and skilled installation workers. All these are considered as human resource of the project. Due to very limit roll of the engineers in this project they are not considered as limited resource. Table 2 and 4 have listed the basic data of the case and in Table 3 has been shown the quality house of the case that obtained by customers' view and project manager. The precedence relationship network is shown in fig. 1.

TABLE II
Resource requirement of the project

Resource type	Cost of daily work	Cost of over time	R_k
simple workers	20	3.75	5
semi-skilled construction workers	30	5.5	2
skilled construction workers	35	6.5	2
semi-skilled installation workers	45	8.4	1
skilled installation workers	60	10	1

Because in the proposed model for quality criteria, customers' view has great importance, the quality of the project is first identified by QFD. Customer demand and its importance have been shown in Table 2. The quality matrix of the project is corresponding to the customers' view and then total quality of project is determined.

TABLE III
THE QUALITY HOUSE OF THE PROJECT

		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
View	2	8	10	6										5	5				6	6			8
Ficxibility	1	9	4	3	5	4	3	5	4						2	4	3	5		3	5	5	
Sound Issulator	1	7	5							5					3								
Non Conductor	8	8	7	2		5				7	7				5					6			
Anti-earth Quick	6	9	7							8					4			2			2	2	
Anti-fire	6	7	6			4	5											5			5	5	
Duarbility	4	8	6	5		6	4	4	4	4	5		7	5	7	6		3	5	4	3		4
Delicacy	3	4	7	4	3	3	5	2	4	1		3	6	7	3	4	4	6	7	5	6	6	7
Customer Qualitu index		236	199	63	14	101	64	27	32	128	76	9	46	51	116	40	15	77	53	95	77	65	53

TABLE IV
TASK LIST OF THE PROJECT (ANNUAL REPORT OF KIMIA BANA GOSTAR 2012)

		CLASSIC MODE				MODERN MODE			
Activity ID	activities	quality	Requsite workers	Crash time(day)	Normal time(day)	quality	Requsite workers	Crash time(day)	Normal time(day)
1	To wall in	8	(2,0,1,0)	5	7	9.5	(2,0,0,1,0)	2	3
2	View laying	9	(3,0,0,1,0)	7	10	7	(3,0,0,1,0)	6	8
3	Cement laying	8	(1,0,0,1,0)	6	8	7.5	(1,0,0,1,0)	2	3
4	To install flour1	9	(1,0,0,1,0)	1	1	9	(1,0,0,1,0)	1	1
5	Mechanical installation	7	(1,0,0,0,2)	5	6	8.5	(1,0,0,0,2)	1	2
6	To lay electrical pipes	8.5	(1,0,0,0,2)	2	3	9	(1,0,0,0,2)	1	1
7	To install cooler	8.5	(1,0,0,1,0)	2	3	8.5	(1,0,0,1,0)	2	3
8	Rabbits	9	(1,0,0,1,0)	1	2	9.5	(1,0,0,1,0)	1	2
9	Flour installation2	7.5	(2,0,0,1,0)	3	5	9	(2,0,0,1,0)	1	2
10	Insulation	9.5	(1,0,0,1,0)	1	1	9.5	(1,0,0,1,0)	1	1
11	Gornice	8	(1,0,0,1,0)	1	2	8	(1,0,0,1,0)	1	2
12	To lay tile	8	(1,0,0,1,0)	2	4	8	(1,0,0,1,0)	2	4
13	Stucco work	7.5	(2,0,0,1,0)	5	8	8.5	(2,0,0,1,0)	2	3
14	To cover flour	8.5	(2,0,0,1,0)	2	5	9	(2,0,0,1,0)	3	5
15	Stairs	8	(1,0,0,1,0)	1	2	8	(1,0,0,1,0)	1	2
16	To cover labia	9	(1,0,0,1,0)	1	2	8.5	(1,0,0,1,0)	1	2
17	To cover wire	9	(1,0,0,0,2)	1	2	9.2	(1,0,0,02)	1	2
18	Stucco work2	8.5	(1,0,0,1,0)	4	6	9	(1,0,0,1,0)	2	3
19	To install windows	8	(1,0,0,1,0)	1	2	8.5	(1,0,0,1,0)	1	2
20	Mechanical installation2	9	(0,0,0,0,1)	1	1	9	(0,0,0,0,1)	1	1
21	Electrical installation2	9	(0,0,0,0,1)	1	2	9	(0,0,0,0,1)	1	2
22	To paint	8	(1,0,0,2,0)	3	4	7	(1,0,0,2,0)	5	7

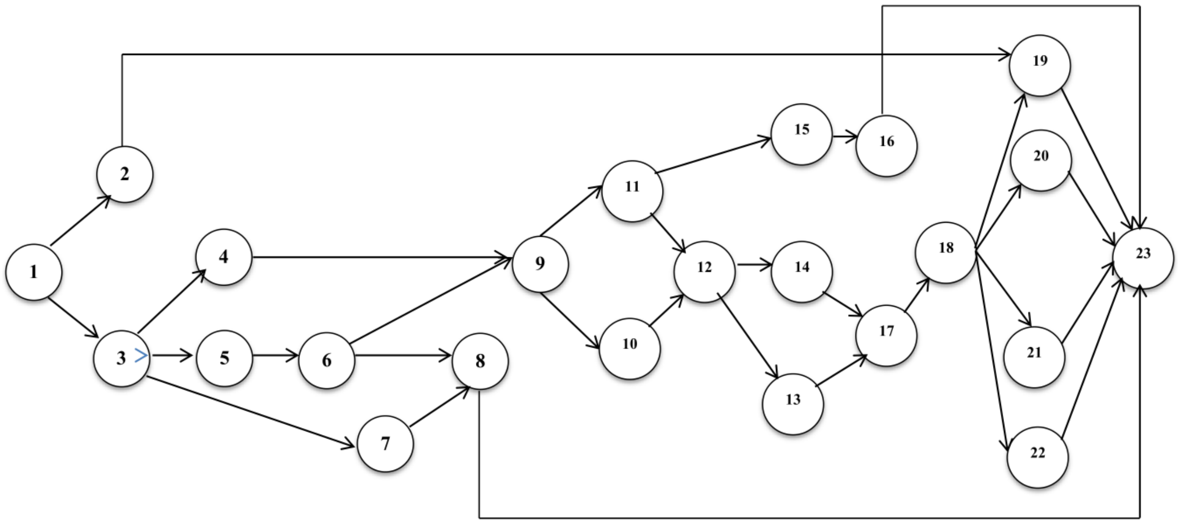

FIGURE I
THE PRECEDENCE RELATIONSHIP NETWORK OF THE PROJECT

The computational result:

The proposed model for the case study has been solved by GAMS. For each objective function, PIS can be determined by considering it as a single goal and the others objectives as constraints. The results are given in Table 5.

Tmax, Cmax and Qmin as NIS for each objective function, were determined by DM. using the collected information and projects data, the fuzzy goal programming model has been solved; the optimal solution has been shown in Table 6.

TABLE V
THE PIS FOR OBJECTIVE FUNCTION BY SOLVING SINGLE GOAL MODEL

item	1	2	3
Objective function	Min Z_q	Min Z_c	Max Z_q
Z_t	33	60	60
Z_c	6498	6095	6473
Z_q	9	9.1	9.5

The symbols m1 and m2 correspond to the classic and modern modes. According to the optimal solution, modern mode has been selected for the first activity. This is reasonable as the modern pre-fabricated walls are anti-earth quick, anti-fire and non-conductor and is conformed to the customer demands and the effect of first activity on the whole quality of project. Due to the concern of customers to the view of building and effect of second activity, view laying, on this factor, classic mode has been selected. Classic view has been considered due to delicacy and beauty.

TABLE VI
OPTIMAL SOLUTION FOR THE PROJECT SCHEDULING

X_{itm}				y_i	Optimal solution
i	t	m_1	m_2		
1	t3	0	1	0	
2	t13	1	0	0	
3	t6	0	1	0	
4	t7	0	1	0	Total time
5	t8	0	1	0	35
6	t9	0	1	0	
7	t9	1	0	0	Total cost
8	t11	0	1	0	6095
9	t11	0	1	0	
10	t13	0	1	0	Total quality
11	t13	0	1	0	9.35
12	t17	0	1	0	
13	t20	0	1	0	
14	t23	0	1	0	
15	t15	0	1	0	
16	t17	1	0	0	
17	t25	0	1	0	
18	t28	0	1	0	
19	t30	0	1	0	
20	t29	1	0	0	
21	t30	1	0	0	
22	t35	0	1	0	
23	t35	1	0	0	

VI. CONCLUSIONS

In practical decision problem, the DM must handle conflicting goals in resource constraints and uncertain situations. This paper has presented a model for project scheduling problem with the tradeoff between time, cost and quality. Also by considering resource constraints and uncertain conditions, it has been tried to make the model closer to reality. The proposed model has attempted to minimize total project costs with reference to crash and normal costs under renewable resources and the duration of activities. Also it has tried to maximize the whole project quality by considering the customers' view. It has used QFD to calculate the quality criteria. The main advantage of this model is that it provides a systematic framework to facilitate the decision making process. It makes project managers to be able to schedule projects closer to reality. The model has been verified for a real world project by showing the capability to achieve an optimal trade-off between conflicting goals. The optimal solution verifies that demands of customers can effect on selective mode and scheduling. Therefore by considering customers' view, fuzzy conditions and resources constraints, project managers can be able to satisfy customers. The model has been solved by GAMS. It is recommended to develop a heuristic method to solve the model efficiently.

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