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Project management model for constructing a renewable energy plant

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Abstract

A project management model is developed for constructing a renewable energy plant in this research. Program evaluation and review technique (PERT) is applied first to find the critical activities when constructing the plant and to calculate the total project cost and total duration time for the project under normal condition. When some activities are crashed, the total duration time can be reduced. The total project cost and the total duration time for crashing various activities are calculated. The fuzzy PERT model is developed by the fuzzy multiple objective linear programming, and the model can devise the project implementation plan to maximize the total degree of satisfaction while minimizing total project cost and total duration time. A case study of a wind turbine construction in Taiwan is presented to show the practicality of the proposed models.

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Keywords: Renewable energy; project management; program evaluation and review technique (PERT); fuzzy.

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1. Introduction

With an enormous investment in time, capital and effort, the development a renewable energy plant is a very complicated task. A good project management for the construction of a plant is necessary. In a large-scale project, the management needs to coordinate numerous activities throughout the organization. Several models, which aim to overcome the disadvantages with critical path method (CPM) and program evaluation and review technique (PERT), have been introduced for the scheduling of construction projects, and some examples are vertical method, linear scheduling method and time scheduling method [1]. PERT, developed in the late 1950's, was first applied for the US Navy to plan and control the Polaris missile program, and its emphasis was to complete the program in the shortest possible time. PERT has the ability to cope with uncertain activity completion times, and it has the potential to reduce both the time and cost required to complete the project [2]. Some recent works on the project scheduling problem include Chrysafis and Papadopoulos [3], Jeang [4], Creemers et al.[5] and Yaghoubi et al.[6].

The rest of this paper is organized as follows. In section 2, two proposed models are introduced: a discrete PERT model and a fuzzy PERT model. In section 3, the proposed models are applied in the construction project of a wind turbine in Taiwan. Some conclusion remarks are made in the last section.

Nomenclature

i	Node number, $i = 1,2,\dots,N$.
j	Node number, $j = 1,2,\dots,N$.
(i, j)	Sequence of nodes, j will be processed after i is processed.
TP	Total duration time for the project
TC	Total cost for the project
R	Total crashing cost for the project.
E_i	Start time for activity i.
ST_{ij}	Slack time for node (i, j).
$K_{D_{ij}}$	Direct cost of node (i, j) under normal time.
D_{ij}	Normal duration time for node (i, j).
d_{ij}	Shortest duration time for node (i, j).
T_{ij}	Duration time for node (i, j).
Y_{ij}	Crash time for node (i, j).
$\tilde{s}_{ij}$	Fuzzy crashing cost per unit time for node (i, j).
s_{ij}	Crashing cost per unit time for node (i, j).
$\tilde{l}$	Fuzzy penalty cost per unit time.

l	Penalty cost per unit time.

2. Proposed models

2.1. Discrete PERT model

In this section, we assume that there is no uncertainty in implementing the project. Thus, the duration time and cost parameters are known and certain. When crashing is considered, the total duration time and cost under various crashing activities can be calculated for the management as a reference. The mathematical model is as follows:

$$Min \quad TC = \sum_i \sum_j K_{D_{ij}} + \sum_i \sum_j Y_{ij} s_{ij} + l \times Max\left\{0, \left(E_N - TP\right)\right\} \tag{1}$$

Subject to:

$$E_i + T_{ij} - E_j \le 0 \quad \forall i, \forall j \tag{2}$$

$$T_{ij} = D_{ij} - Y_{ij} \quad \forall i, \forall j \tag{3}$$

$$Y_{ij} \le D_{ij} - d_{ij} \quad \forall i, \forall j \tag{4}$$

$$E_1 = 0 \tag{5}$$

$$E_i, E_j, T_{ij}, Y_{ij} \ge 0 \quad \forall i, \forall j \tag{6}$$

2.2. Fuzzy PERT model

In this section, we assume that the crashing cost and penalty cost are uncertain. Crashing activities are considered to obtain a compromise solution [7]. The steps of the model are as follows:

Step 1: Consider the fuzziness of crashing cost in each activity.

Step 2: Construct a mathematical model. An optimal project planning and cost reduction alternative can be obtained by balancing the project duration time and cost. The original multiple objective linear programing model is as follows, and the objective function is to minimize the total crashing cost, which includes the crashing cost and the penalty cost, for the project:

$$Min \quad R = \sum_i \sum_j Y_{ij} \tilde{s}_{ij} + \left[\tilde{l} \times Max\left\{0, \left(E_N - TP\right)\right\}\right] \tag{7}$$

Subject to:

Eqs. (2)-(6)

In the objective function, fuzzy crashing cost per unit time for node (i, j), $\tilde{s}_{ij}$, and fuzzy penalty cost per unit time, $\tilde{l}$, are fuzzy in nature and can be represented by triangular fuzzy numbers. $\sum_i \sum_j Y_{ij} \tilde{s}_{ij}$ is the total direct crashing cost, including the personnel cost, machinery cost, outsourcing cost and overtime cost. $\tilde{l} \times Max\{0, (E_N - TP)\}$ is the penalty cost if the project completion time is delayed. Eq. (2) is the constraint for the precedence of activities. Eq. (3) shows that the duration time for a node is the normal duration time for the node minus the crash time for the node. Eq. (4) shows that the crash time for a node must be less than or equal to the normal duration time for the node minus the shortest duration time for the node. Eq. (5)

indicates that the start time for the first activity is 0. Eq. (6) ensures that the decision variables are non-negative

Step 3: Establish fuzzy multiple objective functions.

(1) Based on Lai and Hwang [8], use the triangular fuzzy number to represent the crashing cost for each activity, $\tilde{s}_{ij}$, i.e. ($s_{ij}^{l}, s_{ij}^{m}, s_{ij}^{u}$), as shown in Fig. 1. In addition, a fuzzy membership function, π, is set to have a value between 0 and 1.

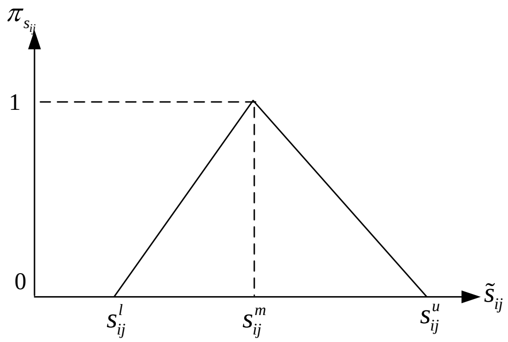

Fig. 1. Fuzzy membership function for the crashing cost, $\tilde{s}_{ij}$

In real practice, the distribution of triangular fuzzy number can contain three values: the most pessimistic value, ($\tilde{s}_{ij}^{u}$), the most optimistic value ($\tilde{s}_{ij}^{l}$), and the most possible value ($\tilde{s}_{ij}^{m}$). The fuzzy multiple objective linear programing model is as follows:

$$Min \quad \sum G_{R_i}\, x \tag{8}$$

Subject to:

$$\tilde{A}x \le \tilde{B} \tag{9}$$

$$x \ge 0 \tag{10}$$

$$\text{where } G_{R_i} \cong (R^{l}, R^{m}, R^{u}) \tag{11}$$

Because G_{R_i} in the objective function is a triangular fuzzy number, its three prominent points, R^{m}, R^{u} and R^{l}, can be used to transform the original fuzzy objective function into three objective functions. They are to minimize the most possible value of the total crashing cost, G_{R_1}, maximize the most optimistic value of the total crashing cost, G_{R_2}, and minimize the most pessimistic value of the total crashing cost, G_{R_3}.

(2) Calculate the positive ideal solution (PIS) and negative ideal solution (NIS) for each objective function based on Hwang and Yoon [9]. The constraints are then added.

(3) Based on the values of PIS and NIS, establish a membership function for each of the three objective functions.

Step 4: Based on the membership function values and the fuzzy programming proposed by Zimmermann [10], auxiliary variable λ is introduced, and the original fuzzy multiple objective linear programming problem can be transformed into a crisp single-goal linear programming problem. By maximizing λ, a compromise solution can be obtained as follows:

$$Max \quad \lambda \tag{12}$$

Subject to:

$$\lambda \le \pi_{11}(G_{R_1}) \tag{13}$$

$$\lambda \le \pi_{12}(G_{R_2}) \tag{14}$$

$$\lambda \le \pi_{13}(G_{R_3}) \tag{15}$$

$$E_1 = 0 \tag{16}$$

$$E_i + T_{ij} - E_j \le 0 \quad \forall i, \forall j \tag{17}$$

$$T_{ij} = D_{ij} - Y_{ij} \quad \forall i, \forall j \tag{18}$$

$$Y_{ij} \le D_{ij} - d_{ij} \quad \forall i, \forall j \tag{19}$$

$$E_i, E_j, T_{ij}, Y_{ij} \ge 0 \quad \forall i, \forall j \tag{20}$$

$$0 \le \lambda \le 1 \tag{21}$$

Step 5: Analyze the results. After solving the model, a compromise solution can be obtained.
(1) Total crashing cost:

$$R = (G_{R_1} - G_{R_3}, G_{R_1}, G_{R_1} + G_{R_2}) \tag{22}$$

(2) Total project duration time: From TP'' in the model, the optimal total project duration time after crashing activities can be obtained.

3. Case study

In this section, the construction project of a wind turbine is used as an example to examine the practicality of the proposed models. The estimated time and costs are shown in Table 1. Under normal condition, the completion time is 245 days. Under uncertain condition, triangular fuzzy number is applied, and the completion time is (170, 245, 255) days. If crashing occurs, a fuzzy crashing cost per unit time for node (*i*, *j*), $\tilde{s}_{ij}$, incurs. In addition, 20 thousand NT dollars or (15.5, 20, 23.5) thousand NT dollars of variable penalty costs incurs for each day under normal condition and fuzzy condition, respectively. The network for the project is as depicted in Fig. 2.

Table 1. Basic information of the wind turbine project.

	Normal condition	Fuzzy condition
Completion time (days)	245	(170, 245, 255)
Penalty cost (,000)	20	(15.5, 20, 23.5)

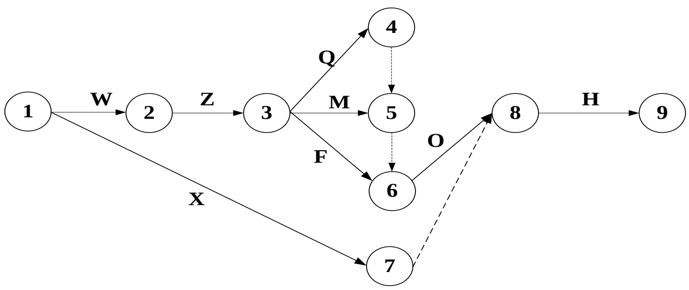

Fig. 2. Network for the wind turbine project.

Table 2. Basic construction data for wind turbine.

Activity Code	Activity	Duration time (day)	Crashing cost per day (,000)	Possible crashed time (day)
W	Foundation	84	$5.05	24
X	Generator system	42	$8.85	12
Z	Power distribution box	40	$4.72	12
Q	Tower	30	$16.32	10
M	Nacelle	56	$9.14	16
F	Rotor blade	84	$5.21	24
O	Wind turbine	7	$68.77	2
H	Trial operation	30	$2.67	10

3.1. Discrete PERT model

The procedure for the discrete PERT model in the case study is as follows:
Step 1 and 2: Calculate the earliest start time (ES), latest start time (LS), earliest finish time (EF), latest finish time (LF), and slack time of each activity, as shown in Table 3.

Table 3. Four different times and slack time for each activity

Activity code	ES	LS	EF	LF	Slack
W	0	0	84	84	0
X	0	173	42	215	173
Z	84	84	124	124	0
Q	124	178	154	208	54
M	124	152	180	208	28
F	124	124	208	208	0
O	208	208	215	215	0
H	215	215	245	245	0

Step 3: Find the critical path, which is shown as the dark path in Fig. 3.

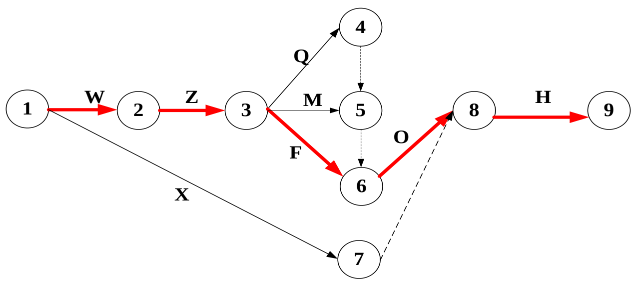

Fig. 3. Critical path of the project.

Step 4: Based on the critical path depicted in Fig. 3, the total project cost and duration time can be calculated under the normal condition. The total project cost is 149276.9 thousand dollars, and the total duration time is 245 days, as shown in Table 4. Next, based on Eqs. (1)-(6), the total project cost and duration time with crashing activities can be obtained, as shown in Table 4. For example, if the activity H is crashed for one day or two days, the total project cost will increase to 149303.6 and 149330.6, respectively.

Table 4. Project duration and cost

Project duration (day)	Crashing activity and crashing days	Total project cost (,000)
245	—	149276.9
244	H_1	149303.6
243	H_2	149330.6
240	H_5	149410.4
230	Z_5、H_{10}	149779.9
220	W_3、Z_{12}、H_{10}	150261.8
210	W_{13}、Z_{12}、H_{10}	150766.8
200	W_{23}、Z_{12}、H_{10}	151271.8
190	W_{24}、Z_{12}、F_9、H_{10}	151791.2
180	W_{24}、Z_{12}、F_{19}、H_{10}	152312.2
175	W_{24}、Z_{12}、F_{24}、H_{10}	152572.7
174	W_{24}、Z_{12}、F_{24}、O_1、H_{10}	153260.4
173	W_{24}、Z_{12}、F_{24}、O_2、H_{10}	153948.1

3.2. Fuzzy PERT model

The procedure for the fuzzy PERT model in the case study is as follows:
Step 1: Consider the fuzziness of crashing costs.

Table 5. Project activity durations and costs

Activity Code	Activity	Crashing cost per day (,000) (l,m,u)
W	Foundation	(0.64,5.05,6.14)
X	Generator system	(7.38,8.85,12.38)
Z	Power distribution box	(4.23,4.72,8.48)
Q	Tower	(15.36,16.32,25.5)
M	Nacelle	(8.5,9.14,13.2)
F	Rotor blade	(4.52,5.21,8)
O	Wind turbine	(63.05,68.77,92.33)
H	Trial operation	(1.17,2.67,5.47)

Step 2：Establish an objective function for the project by applying Eq. (7).

$$\begin{aligned} Min \quad R = \{ & (0.64, 5.05, 6.14 * Y_{12} + (7.38, 8.85, 12.38) * Y_{17} + (4.23, 4.72, 8.48) * Y_{23} + (15.36, 16.32, 25.5) * Y_{34} \\ & + (8.5, 9.14, 13.2) * Y_{35} + (4.52, 5.21, 8) * Y_{36} + (63.05, 68.77, 92.33) * Y_{68} \\ & + (1.17, 2.67, 5.47) * Y_{89} + ((15.5, 20, 23.5) * Max\{0, (\mathrm{E}_9 - 173)\})\} \end{aligned}$$

Step 3: Establish fuzzy multiple objective functions.

(1) List three objective functions

$$Min \quad G_{R_1} = 5.05*Y_{12} + 8.85*Y_{17} + 4.72*Y_{23} + 16.32*Y_{34} + 9.14*Y_{35}$$
$$+5.21*Y_{36} + 68.77*Y_{68} + 2.67*Y_{89} + (20*Max\ \{0, (E_9 - 173$$
$$Min \quad G_{R_2} = 1.09*Y_{12} + 3.53*Y_{17} + 3.76*Y_{23} + 9.18*Y_{34} + 4.06*Y_{35}$$
$$+23.56*Y_{68} + 2.8*Y_{89} + 3.5*(E_9 - 17$$
$$Max \quad G_{R_3} = 4.41*Y_{12} + 1.47*Y_{17} + 0.49*Y_{23} + 0.96*Y_{34} + 0.64*Y_{35}$$
$$+0.69*Y_{36} + 5.72*Y_{68} + 1.5*Y_{89} + 4.5*(E_9 - 17$$

(2) Calculate the positive ideal solution (PIS) and negative ideal solution (NIS) for each objective function. The results are shown in Table 6.

Table 6. The PIS and NIS for each objective function.

	G_{R_1}	G_{R_2}	G_{R_3}
PIS	369.58	152.28	646.98
NIS	2222.76	493.70	173.24

(3) Based on the values of PIS and NIS, establish a membership function for each of the three objective functions. They are as follows:

$$\pi_{11}(G_{R_1}) = \begin{cases} 1, & G_{R_1} \le 369.58 \\ \dfrac{2222.76 - G_{R_1}}{2222.76 - 369.58}, & 369.58 < G_{R_1} < 2222.76 \\ 0, & G_{R_1} \ge 2222.76 \end{cases}$$

$$\pi_{12}(G_{R_2}) = \begin{cases} 1, & G_{R_2} \le 152.28 \\ \dfrac{493.70 - G_{R_2}}{493.70 - 152.28}, & 152.28 < G_{R_2} < 493.70 \\ 0, & G_{R_2} \ge 493.70 \end{cases}$$

$$\pi_{13}(G_{R_3}) = \begin{cases} 1, & G_{R_3} \ge 646.98 \\ \dfrac{G_{R_3} - 173.24}{646.98 - 173.24}, & 173.24 < G_{R_3} < 646.98 \\ 0, & G_{R_3} \le 173.24 \end{cases}$$

Step 4: The fuzzy multiple objective linear programming problem can be transformed into a crisp single-goal linear programming problem using Eqs. (12)-(21). By maximizing λ , a compromise solution can be obtained.

$$Max \quad \lambda$$
$$Subject \quad to$$
$$\lambda \le \frac{2222.76 - G_{R_1}}{2222.76 - 369.58}$$
$$\lambda \le \frac{493.70 - G_{R_2}}{493.70 - 152.28}$$

$$\lambda \le \frac{G_{R_3} - 173.24}{646.98 - 173.24}$$
$$E_1 = 0$$
$$E_1 + T_{12} - E_2 = 0$$
$$E_1 + T_{17} - E_7 = 0$$
$$E_2 + T_{23} - E_3 <= 0$$
$$E_3 + T_{34} - E_4 <= 0$$
$$E_3 + T_{35} - E_5 <= 0$$
$$E_4 + T_{45} - E_5 <= 0$$
$$E_3 + T_{36} - E_6 <= 0$$
$$E_5 + T_{56} - E_6 <= 0$$
$$E_6 + T_{68} - E_8 <= 0$$
$$E_7 + T_{78} - E_8 <= 0$$
$$E_8 + T_{89} - E_9 <= 0$$
$$T_{12} = 84 - Y_{12}$$
$$T_{17} = 42 - Y_{17}$$
$$T_{23} = 40 - Y_{23}$$
$$T_{34} = 30 - Y_{34}$$
$$T_{35} = 56 - Y_{35}$$
$$T_{36} = 84 - Y_{36}$$
$$T_{68} = 7 - Y_{68}$$
$$T_{89} = 30 - Y_{89}$$
$$Y_{12} <= 24$$
$$Y_{17} <= 12$$
$$Y_{23} <= 12$$
$$Y_{34} <= 10$$
$$Y_{35} <= 16$$
$$Y_{36} <= 24$$
$$Y_{68} <= 2$$
$$Y_{89} <= 10$$
$$E_9 <= 240$$
$$T_{ij}, Y_{ij}, E_i \ge 0 \quad \forall i, \forall j$$
$$0 \le \lambda \le 1$$

Step 5: Analyze the results. They are as follows.

(1) Total project cost: We can obtain $G_{R_1} = 1122.68$ thousand dollars, $G_{R_2} = 246.18$ thousand dollars, and $G_{R_3} = 454.46$ thousand dollars. By applying Eq. (22), the total project cost is

R =(668.22, 1122.68, 1368.86) thousand dollars.

(2) Total project duration time: With crashing activities, the optimal duration time is $TP = 184.99$ days.

4. Conclusions

In this research, program evaluation and review technique (PERT) is adopted to find the critical activities when constructing the plant. The total project cost and total duration time for the project under normal condition are calculated first. When some activities are crashed, the total duration time can be reduced. Thus, the total project cost and the total duration time for crashing various activities are obtained for reference. Because the crash time of each activity is usually uncertain, the fuzzy set theory is incorporated with the PERT next. A fuzzy multiple objective linear programming is constructed to solve the fuzzy PERT model. By maximizing the total degree of satisfaction through minimizing total project cost and total duration time, a compromise solution can be obtained. The practicality of the proposed models is examined by carrying out a case study of a wind turbine construction in Taiwan. The proposed model can help the management consider relevant information in the construction process systematically so that resources can be best utilized and costs can be minimized.

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