Chapter 37
The Fuzzy Time-cost-quality-environment Trade-off Analysis of Resource-constrained Multi-mode Construction Systems for Large-scale Hydroelectric Projects

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Abstract This paper studies the fuzzy time-cost-quality-environment trade-off problem of construction project and establishes a decision making model with multiple modes under resource-constrained environment. The objective functions are to minimize the total project time, total resource cost, quality defect of all activities, and the environment impact. Furthermore, a fuzzy based adaptive-hybrid genetic algorithm is developed for finding feasible solutions. More specifically, our approach treats the uncertainty by using fuzzy expected value operator or fuzzy simulation. Finally, Jinping-II hydroelectric project was used as a practical example to demonstrate the practicality and efficiency of the method. Results and sensitivity analysis are presented to highlight the performances of our optimization method, which is very effective and efficient as compared with other algorithms.

Keywords Time-cost-quality-environment trade-off · Multi-mode · Construction project · Fuzzy · Genetic algorithm

37.1 Introduction

Time, cost, quality and environment of project delivery are among the crucial aspects of construction projects [1, 2]. Emergence of new situation that places an increasing pressure on minimizing the environment impact of projects while minimizing its duration, executive cost, and improve quality of all activities, requires the development of models considering environment in addition to time, cost and quality which has been modeled extensively. Nowadays, construction project has been developed so rapidly in quantity and scale in many countries. Construction planners often face the challenges to compromise among different conflicting aspects

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of projects. As the basal construction systems for large-scale hydroelectric projects plays an important role, it often has a great of impaction on our ecological environment. Therefore, construction managers need to develop a project management decision for directing and controlling the duration, budget, quality and environment in a construction projects in order to achieve management objectives. Furthermore, to ensure that these important projects are carried through with maximum efficiency, its efficient project management decision is especially important. Recognition should be given to the fact that in practice one project faces multiple objective to optimize. For instance, when faced with an urgent case, construction managers would increase the allocation of capital under certain limit to shorten the duration or improve quality of the project while minimizing the impaction on environment when it is necessarily. The objective of the project management decision is to find a start time and an executive time for each activity such that the makespan is minimized which may with some other management objectives and the schedule is feasible with respect to the precedence, budget and cost intensity constraints. Four objectives are considered: (1) minimization of the project duration; (2) minimization of the total resource costs; (3) minimization the quality defect of the all activities; (4) minimization of the environment impact. In real-life situations, the duration and environment impact property of each activity are uncertain, the project manager must handle multiple conflicting goals in uncertain environment owing to information is incomplete and unavailable. Therefore, it is necessary to consider uncertainty and multi-objectives in project management practice.

This paper will effectively solve time-cost-quality-environment trade-off problem with fuzzy uncertainty. A multi-objective time-cost-quality-environment trade-off problem under fuzzy environment is described, and assumptions and notation for this problem are presented in Sect. 37.2. A multi-objective fuzzy optimization model is then proposed for this problem. Sect. 37.3 involves a case study regarding the works of construction systems for large-scale hydroelectric projects, sensitivity analysis and the results comparison of (f)a-hGA with other heuristic algorithms are also provided. Finally, concluding remarks are outlined in Sect. 37.4.

37.2 Problem Description and Mathematical Formulation Model

37.2.1 Problem Description

We consider the problem in large construction projects, especially in construction systems for large-scale hydroelectric projects. Assume there are I interrelated activities that must be executed in a certain order before the entire task can be completed. For many uncertain factors and uniqueness of construction project, it is hard to know the exact duration of each activity and difficult to give a strict function of them because of lack of data and strict definition. In real world, there are many non-probabilistic factors that affect a large-scale construction projects and they should not be dealt with probability approaches. And some research have assumed activity duration is characterized by a fuzzy number due to environmental variation [3]. Fuzzy uncertainty is the uncertainty of the states that the event itself are not clear. It leads to different people will have different feeling when they observe the same event, so they could educe different conclusion, so fuzzy uncertainty is subjective uncertainty. Different from the traditional problem, we consider the uncertainty of the environment, so we think the duration of each activity is uncertain when we consider its scheduling under certain resource limit. This study focuses on developing (f)a-hGA technique to optimize activity sequence and executed mode for each activity in the project with the constraints of maximum resource limit. The original fuzzy programme model designed in this study aims to simultaneously minimize total project costs, total completion time, quality defect and environment impact.

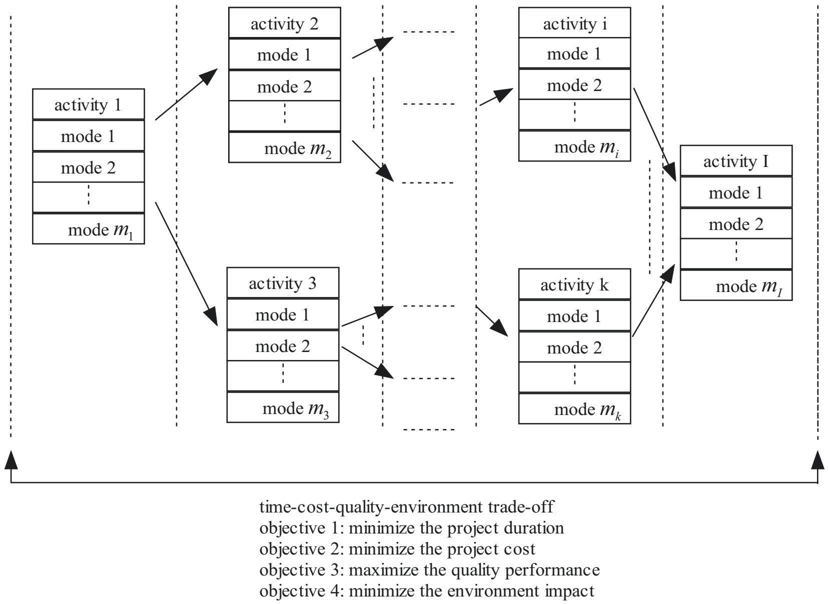

Fig. 37.1 The time-cost-quality-environment trade-off project

37.2.2 Model Formulation

The problem is represented on an activity-on-node (AON) network with a single starting and a single ending node both corresponding to dummy activities.
The following notation is used.

Index

i : the index of activity in a project, $i = 1, 2, \cdots, I$;
j : the mode, $j = 1, 2, \cdots, m_i$, (m_i is the number of possible modes for activity i);
$\lceil\ \rceil$: ceiling operator rounding upward to integer;
t : the period in a project, $t = 1, 2, \cdots, \lceil E[\tilde{T}_{I+1}] \rceil$;
p : the index for weight of quality indicator compared to other indicators in activity i, $p = 1, 2, \cdots, P_i$;
q : renewable resource type index, $q = 1, 2, \cdots, Q$ (P_i is the number of possible indicators for activity i);
r : the index for positive environment impacts of the environment factor, $r = 1, 2, \cdots, R$;
k : the index for negative environment impacts of the environment factor, $k = 1, 2, \cdots, K$;
n : the index for positive environment impact properties, $n = 1, 2, \cdots, N$;
f : the index for negative environment impact properties, $f = 1, 2, \cdots, F$.

Variables

z_1 : total project costs;
z_2 : total project completion time.
z_3 : total project environment performance;
z_4 : total project environment impact;
$\tilde{D}_{ij}$: the duration of activity i operating in mode j, here the duration is fuzzy variable;
$E[\tilde{D}_{ij}]$: the expected duration of activity i operating in mode j;
$\tilde{T}$: specified project completion time;
t_i^{EF} : the earliest finish time of activity i;
t_i^{LF} : the latest finish time of activity i;
$E[\tilde{T}_i]$: the expected start time of activity i;
a_q : the unit price of resource q;
r_{ijq} : Amount renewable resource q required per day when activity i is executed in mode j;
R_q^M : maximum-limited resource q only available in tth period availability;
$Pre(i)$: set of the immediate predecessors of activity i;
$Q_{i,p}^j$: performance of quality indicator p in activity i of selected mode j;
w_i : weight of activity i compared to other activities in the project bout quality assessment;
$w_{i,p}$: weight of quality indicator p in activity i;
y_i : weight of activity i compared to other activities in the project about environment assessment;
$\overline{TV}$: the total environment impact of the project;
$\overline{TV^+}$: the total positive environment impact of the project;
$\overline{TV^-}$: the total negative environment impact of the project;
$\overline{V_{ir}^+}$: the positive environment impact r of activity i;

$\overline{V_{ik}^{-}}$: the negative environment impact k of activity i;
h_{ir} : the pondering coefficient for positive environment impact r of activity i;
h_{ik} : the pondering coefficient for negative environment impact k of activity i;
c_{irn} : the pondering coefficient which is assigned to each positive impact property n for positive environment impact r of activity i;
c_{ikf} : the pondering coefficient which is assigned to each negative impact property f for negative environment impact k of activity i;
$\tilde{p}_{ijrn}$: the positive environment impact property n for positive environment impact r in activity i of selected mode j;
$\tilde{p}_{ijkf}$: the negative environment impact property f for negative environment impact k in activity i of selected mode j.

Decision variables

$$x_{ijt} = \begin{cases} 1, \text{if activity } i \text{ executed in mode } j \text{ scheduled to be finished in time } t, \\ 0, \text{otherwise.} \end{cases}$$

The decision variable x_{ijt} decides whether the finishing time of current activity with the certain executed mode is scheduled in this certain time or not.

In order to transform these fuzzy variables into crisp numbers, we introduce the expected value operator for fuzzy measure *Me* Xu and Zhou [4] to deal with the uncertainty in the problem.

Due to all fuzzy variables are non-negative triangular fuzzy variable (Fig. 37.1 shows an example), so our problem belongs to the case of $E^{Me}[\xi] = \frac{(1-\lambda)r_1+r_2+\lambda r_3}{2}$.

Since all the fuzzy variables in the problem are triangular fuzzy numbers, the transformations are presented as follows,

$$\tilde{D}_{ij} \longrightarrow E[\tilde{D}_{ij}] = \frac{(1-\lambda)D_{ij1} + D_{ij2} + \lambda D_{ij3}}{2}.$$

37.2.3 Fuzzy Multi-objective Model

(1) Objective functions

The first objective is to minimize the resource cost. And activity cost is determined by the amount of resources consumed by the activity in a special mode. So the first objective is to minimize the total resource costs for the project. That is minimization the sum of the completion cost for all activities.

$$\min z_1 = \sum_{i=1}^{I} \sum_{q=1}^{Q} \sum_{j=1}^{m_i} \sum_{t=t_i^{EF}}^{t_i^{LF}} a_q r_{ijq} x_{ijt} E[\tilde{D}_{ij}]. \tag{37.1}$$

The second objective seeks to minimize the total project time. That is minimization the sum of the completion time for all activities.

$$\min z_2 = \sum_{j=1}^{m_I} \sum_{t=t_I^{EF}}^{t_I^{LF}} t x_{ijt}. \tag{37.2}$$

The third objective aims at minimizing project quality defect that is measured and quantified.

$$\min z_3 = \sum_{i=1}^{I} w_i \sum_{p=1}^{P_i} w_{i,p} \times Q_{i,p}^{j}. \tag{37.3}$$

The fourth objective is designed to minimize project environment impact that is measured and quantified.

The total $\overline{TV}$ is estimated by positive and negative environmental impacts $\overline{TV^+}$ and $\overline{TV^-}$. Pondering coefficients are assigned to each environmental factor to quantify the environmental significance of the factor, which can be estimated by convergence methods. These coefficients have to fulfil Equation (37.9).

$$\begin{aligned}\min z_4 = \quad & \overline{TV} = \overline{TV^+} - \overline{TV^-} = \sum_{i=1}^{I} y_i \left(\sum_{r=1}^{R} h_{ir} \overline{V_{ir}^{+}} - \sum_{k=1}^{K} h_{ik} \overline{V_{ik}^{-}} \right) \\ & = \sum_{i=1}^{I} y_i \left[\sum_{r=1}^{R} h_{ir} \sum_{n=1}^{N} c_{irn} \frac{\tilde{p}_{ijrn}^{2}}{100} - \sum_{k=1}^{K} h_{ik} \sum_{f=1}^{F} c_{ikf} \left(100 - \frac{\tilde{p}_{ijkf}^{2}}{100} \right) \right]. \end{aligned} \tag{37.4}$$

(2) Constraints

In project, precedence is the important basic term ensuring the rationality of the arrangement. Under this term, successive activities must be and can only be started with a certain mode when all the predecessors have already been completed with a certain mode.

$$\begin{aligned} & \sum_{j=1}^{m_e} \sum_{t=t_e^{EF}}^{t_e^{LF}} t x_{ejt} + \sum_{j=1}^{m_i} \sum_{t=t_i^{EF}}^{t_i^{LF}} E[\tilde{D}_{ej}] x_{ijt} \le \sum_{j=1}^{m_i} \sum_{t=t_i^{EF}}^{t_i^{LF}} t x_{ijt}, \\ & i = 1, 2, \cdots, I, \ e \in Pre(i). \end{aligned} \tag{37.5}$$

Each activity must be scheduled and its finish time must be in the range of its early finish time and last finish time to ensure the maturity constraint. Every activity must have a finish time with a certain mode within its earliest finish time and last finish time as in Equation (37.6).

$$\sum_{j=1}^{m_i} \sum_{t=t_i^{EF}}^{t_i^{LF}} x_{ijt} = 1, \ i = 1, 2, \cdots, I. \tag{37.6}$$

To aggregate the estimated quality for all the considered activities, we provide an overall quality at the project level using a simple weighted approach. w_i represents the importance and contribution of the quality of this activity to the overall quality of the project. These coefficients have to fulfil the following condition:

$$\sum_{i=1}^{I} w_i = 1. \tag{37.7}$$

The weight of quality indicators in activity i to indicate the relative importance of this indicator to others is used to measure the quality of the activity, it has to fulfil the following condition:

$$\sum_{p=1}^{P_i} w_{i,p} = 1,\ i = 1,2,\cdots,I. \tag{37.8}$$

To aggregate the estimated environment for all the considered activities, we provide an overall environment at the project level using a simple weighted approach. y_i represents the importance and contribution of the environment of this activity to the overall environment of the project. These coefficients have to fulfil the following condition:

$$\sum_{i=1}^{I} y_i = 1. \tag{37.9}$$

Pondering coefficients have to be assigned to each environmental factor $\overline{V^+}$ or $\overline{V^-}$ to quantify the environmental significance of the factor, which can be estimated by convergence methods. These coefficients have to fulfil the following condition:

$$\sum_{r=1}^{R} h_{ir} + \sum_{k=1}^{K} h_{ik} = 1,\ i = 1,2,\cdots,I. \tag{37.10}$$

Pondering coefficients have to be assigned to each impact property to quantify the influence of each $\overline{v_i}$ on the value of the environmental impact V. They have to fulfil the following conditions:

$$\sum_{n=1}^{N} c_{irn} = 1,\ r = 1,2,\cdots,R,\ i = 1,2,\cdots,I, \tag{37.11}$$

$$\sum_{f=1}^{F} c_{ikf} = 1,\ k = 1,2,\cdots,K,\ i = 1,2,\cdots,I. \tag{37.12}$$

The total cost of all activities scheduled in time t cannot exceed the capital limit per period. In time-cost-quality-environment problem, we think capital used by all activities do not exceed limited quantities in any time period and the execution mode for all activity. The sum of the capital consumptions of all activities which are scheduled in a certain time period during the whole project duration, as well as in a certain mode in Equation (37.14).

$$\sum_{i=1}^{I}\sum_{j=1}^{m_i} r_{ijq} \sum_{s=t}^{t+E[\tilde{D_{ij}}]-1} x_{ijs} \le R_q^M,\ t = 1,2\cdots,\lceil E[\tilde{T}_{I+1}]\rceil,\ q = 1,2\cdots,Q. \tag{37.13}$$

In order to describe some non-negative variables and 0-1 variables in the model for practical situation, the constraints in Equation (37.14) $\sim$ Equation (37.15) are presented. Non-negativity constraints on decision variable and its revelent variable

$$E[\tilde{D}_{ij}],\ E[\tilde{T}],\ t_i^{EF},\ t_i^{LF} \geq 0,\ i=1,2,\cdots,I,\ j=1,2,\cdots,m_i, \tag{37.14}$$

$$x_{ijt}=0 \text{ or } 1,\ i=1,2,\cdots,I,\ j=1,2,\cdots,m_i,\ t=1,2,\cdots,\lceil E[\tilde{T}_{I+1}]\rceil. \tag{37.15}$$

Constraints on project completion time. As is generally known, construction managers confirm an expected duration of the project beforehand to coordinate the whole project or other projects.

$$E[\tilde{T}_{I+1}] \leq E[\tilde{T}]. \tag{37.16}$$

37.3 Case Study: The Time-cost-environment Trade-off for Jinping-II Hydroelectric Project

This section is the practical application to a working procedure at a large-scale hydroelectric construction project. The procedure contains thirteen activities and two dummy activities (start and end activity). Each activity must be performed in one of m_i possible modes, where each activity-mode has fixed duration corresponding quality defect and environment impact, and requires a constant budget.

37.3.1 Presentation of the Case Problem

Jinping-II Hydroelectric Project is located on the large Jinping River Bend, and is the second of the five cascade projects on the river section from Kala down to the estuary. It is designed to cut the 150km river bend by a group of power tunnels to use the natural drop created by the bend. The project primarily consists of a headwork sluice dam, spillway structures, power tunnels and powerhouse complex. The dam is 7.5km downstream of Jinping-I dam. The catchment area upstream of the dam is 103,000 km^2, and the multi-year average inflow at the dam site is 1,220 m^3/s.

Jinping-II reservoir itself only has a capacity of daily regulation, but when jointly operated with Jinping-I, it also has the capacity of yearly regulation. The 4 power tunnels have an average length of 16.6 km and an excavated diameter of 13 m, which are among the world's longest and largest hydraulic tunnels. The powerhouse complex sits underground on the other side of the river bend. The project has a total installed capacity of 4,800 MW (8$\times$600 MW), which gives a multi-year average annual generation of 24.23 TWh.

The detailed corresponding data for each activity is as follows in Table 37.1 and Table 37.2.

Table 37.1 The number, mode, duration, budget, predecessor and two kinds of weight of each activity

I	II	III	IV	V	VI	VII	VIII
1	Dummy activity						
2	1	(2,3,4)	12	8	1	0.06	0.044
	2	(7,9,11)	10	6			
3	1	(0.5,1,1.5)	16	8	1	0.03	0.1
	2	(0.5,1,1.5)	14	6			
	3	(3,5,7)	12	8			
4	1	(2,5,8)	14	8	1	0.06	0.09
	2	(7,8,9)	12	6			
5	1	(3,6,9)	4	10	2	0.07	0.0875
6	1	(1,2,3)	4	4	3	0.15	0.056
	2	(2,6,10)	4	6			
7	1	(1,3,5)	10	10	2,3	0.12	0.11
	2	(7,8,9)	10	8			
8	1	(3,4,5)	12	8	6	0.1	0.0375
	2	(9,10,11)	6	4			
9	1	(1,2,3)	4	8	5	0.04	0.1
	2	(4,7,10)	2	6			
	3	(8,10,12)	2	4			
10	1	(0.5,1,1.5)	8	8	5,7	0.06	0.1
	2	(0.5,1,1.5)	10	4			
	3	(8,9,10)	8	12			
11	1	(4,6,8)	10	4	4,6,7	0.09	0.11
	2	(6,9,12)	6	2			
	3	(8,10,12)	12	2			
12	1	(9,11,13)	12	4	8,10	0.09	0.075
	2	(5,8,11)	14	8			
13	1	(4,5,6)	4	6	8,9,11	0.04	0.05
	2	(3,6,9)	6	6			
	3	(5,7,9)	8	4			
14	1	(2,4,6)	4	8	9	0.09	0.05
	2	(1,3,5)	6	10			
15				Dummy Activity			

Note: I: Activity i; II: Mode j; III: Duration (month) $\tilde{D}_{ij}$; IV: Resources consumption (r_{ij1}); V: Resources consumption (r_{ij2}); VI: Predecessor ($Pre(i)$); VII: Weight activity for quality (w_i); VIII: Weight activity for environment (y_i).

Based on the representation of the case problem, the proposed methods can be used to model it in Equation (37.13) and obtain the project scheduling model for our project.

Table 37.2 Activity mode option, their corresponding quality indicators and quality performance

I	II	IX	X	I	II	IX	X
2	1	43.5,38.54	0.63,0.37	9	1	71,76.97	0.33,0.67
	2	31,14.785	0.63,0.37		2	49,50.49	0.33,0.67
					3	41,35.775	0.33,0.67
3	1	77.5,85.605	0.28,0.72	10	1	34,33.022	0.32,0.68
	2	70.5,65.175	0.28,0.72		2	47.5,51.1765	0.32,0.68
	3	49,50.39	0.28,0.72		3	24,25.47	0.32,0.68
4	1	19,13.695	0.56,0.44	11	1	26,20.6	0.3,0.7
	2	43,39.965	0.56,0.44		2	18,16.07	0.3,0.7
					3	34.5,32.835	0.3,0.7
5	1	31.5,24.525	0.58,0.42	12	1	19.5,13.595	0.52,0.48
					2	29.5,26.01	0.52,0.48
6	1	28.5,25.54	0.38,0.62	13	1	59,82.335	0.85,0.15
	2	26,21.7	0.38,0.62		2	48.5,58.5	0.85,0.15
					3	43.5,3.5	0.85,0.15
7	1	44,40.41	0.35,0.65	14	1	21,10.16	0.6,0.4
	2	29.5,28.985	0.35,0.65		2	14,6.775	0.6,0.4
8	1	36,29.335	0.85,0.15				
	2	56,16	0.85,0.15				

Note: I: Activity i; II: Mode j; IX: Quality Performance $Q^j_{i,p}$; X: Weight of quality indicator $w_{i,p}$.

Other relevant data are as follows: total budget is 110000, maximum limited of resource is 30 unite for each period, project completion duration under normal condition 28 months and decision maker expected project completion duration below 30 months.

37.3.2 Result of the Case Problem

The parameters of the environment for the problem was set as follows:

Based on the above model, we uses the proposed (f)a-hGA [5, 6] using Visual C++ language and run on Pentium 4, 2.40 GHz clock pulse with 1024 MB memory, and tested the performance of this method with the actual data obtained from the above project.

The evolutionary environment for the problem was set as follows: pop_size was 20, the rate of crossover and mutation is 0.6 and 0.1 respectively, max_generation was 200, the optimistic-pessimistic parameter is $\lambda = 0.5$.

After a run of a genetic algorithm computer program, the following satisfactory solution was obtained: the optimal value of the objective function is:

$$z_1 = 100100,\ z_2 = 27,\ z_3 = 33.5,\ z_4 = 35.5,$$

using the objective weights 0.1, 0.5, 0.1, and 0.3 respectively, The optimal fitness is 0.57.

Using the chromosome illustrated above, we obtain the following schedule:

$$\begin{aligned} S = & \ 1,2,3,6,5,4,8,9,14,7,10,11,12,13,15 \\ = & \ a_1(0):0-0, a_2(1):0-3, a_3(2):3-4, a_6(1):4-6, a_5(1):4-10, a_4(1): \\ & 6-11, a_8(1):6-10, a_9(1):10-12, a_{14}(1):12-16, a_7(1):12-15, \\ & a_{10}(2):15-16, a_{11}(1):16-22, a_{12}(1):16-27, a_{13}(1):22-27, \\ & a_{15}(1):27-27. \end{aligned}$$

The detailed results was shown in Table 37.3. The above strategy is offered for the project, that is: arrange the activities in the order proposed in Table 37.3, and choose the corresponding crash time in accordance with the required certain processing time and given budget which results in the decision-maker satisfied.

Table 37.3: Environmental impacts, impact properties and their pondering coefficients for each activity-mode

Activity i	Mode j	h_{ir}	c_{inr}	$p_{\tilde{ij}nr}$	h_{ik}	c_{ifk}	$p_{\tilde{ij}fk}$
2	1	0.2	0.7,0.3	99.5,86.9885	0.04	0.4,0.6	77.46,92.195
		0.5	0.55,0.45	99.5,98.38			
		0.2	0.72,0.28	94.34,56.45	0.06	0.8,0.2	90.55,94.154
	2	0.2	0.7,0.3	92.736,87.178	0.04	0.4,0.6	89.44,91.285
		0.5	0.55,0.45	90.55,85.5			
		0.2	0.72,0.28	88.32,96.06	0.06	0.8,0.2	60.83,96.77
3	1	0.2	0.7,0.3	85.44,40.41	0.04	0.4,0.6	91.1,94.69
		0.5	0.55,0.45	72.11,65.66			
		0.2	0.72,0.28	74.83,55.68	0.06	0.8,0.2	46.9,62.169
	2	0.2	0.7,0.3	85.44,40.41	0.04	0.4,0.6	91.1,94.69
		0.5	0.55,0.45	72.11,65.66			
		0.2	0.72,0.28	74.83,55.68	0.06	0.8,0.2	46.9,62.169
	3	0.2	0.7,0.3	76.16,64.29	0.04	0.4,0.6	76.16,86.41
		0.5	0.55,0.45	64.81,57.52			
		0.2	0.72,0.28	36.06,22.36	0.06	0.8,0.2	48.99,32.63
4	1	0.2	0.7,0.3	72.11.46.9	0.04	0.4,0.6	66.33,77.89
		0.5	0.55,0.45	69.282,66			
		0.2	0.72,0.28	56.57,37.6	0.06	0.8,0.2	84.85,77.14
	2	0.2	0.7,0.3	75.5,51.96	0.04	0.4,0.6	69.282,79.37
		0.5	0.55,0.45	76.16,70.08			
		0.2	0.72,0.28	56.57,37.6	0.06	0.8,0.2	85.44,96
5	1	0.2	0.7,0.3	85.44,40.41	0.04	0.4,0.6	91.1,94.69
		0.5	0.55,0.45	72.11,65.66			
		0.2	0.72,0.28	74.83,55.68	0.06	0.8,0.2	46.9,62.169

Table 37.3: Continued

6	1	0.2	0.7,0.3	70,50.67	0.04	0.4,0.6	89.44,93
		0.5	0.55,0.45	74.16,67.9			
		0.2	0.72,0.28	53.85,40.62	0.06	0.8,0.2	73.48,79.47
	2	0.2	0.7,0.3	44.72,31.62	0.04	0.4,0.6	88.3,91.1
		0.5	0.55,0.45	37.42,42.94			
		0.2	0.72,0.28	30,23.3	0.06	0.8,0.2	64.8,74.9
7	1	0.2	0.7,0.3	60,47.61	0.04	0.4,0.6	84.85,90.55
		0.5	0.55,0.45	52.9,50.77			
		0.2	0.72,0.28	61.64,33.48	0.06	0.8,0.2	80,66.96
	2	0.2	0.7,0.3	76.16,64.29	0.04	0.4,0.6	84.26,86.21
		0.5	0.55,0.45	78.74,71.33			
		0.2	0.72,0.28	64.81,82.9	0.06	0.8,0.2	73.48,88.4
8	1	0.2	0.7,0.3	55.68,42	0.04	0.4,0.6	74.83,77
		0.5	0.55,0.45	45,83,40.69			
		0.2	0.72,0.28	34.64,25.768	0.06	0.8,0.2	78.74,92.82
	2	0.2	0.7,0.3	85.44,40.41	0.04	0.4,0.6	91.1,94.69
		0.5	0.55,0.45	72.11,65.66			
		0.2	0.72,0.28	74.83,55.68	0.06	0.8,0.2	46.9,62.169
9	1	0.2	0.7,0.3	76.16,64.29	0.04	0.4,0.6	76.16,86.41
		0.5	0.55,0.45	64.81,57.52			
		0.2	0.72,0.28	36.06,22.36	0.06	0.8,0.2	48.99,32.63
	2	0.2	0.7,0.3	85.44,40.41	0.04	0.4,0.6	91.1,94.69
		0.5	0.55,0.45	72.11,65.66			
		0.2	0.72,0.28	74.83,55.68	0.06	0.8,0.2	46.9,62.169
	3	0.2	0.7,0.3	69.28,64.29	0.04	0.4,0.6	77.49,79.58
		0.5	0.55,0.45	64.03,69.04			
		0.2	0.72,0.28	64.81,70.1	0.06	0.8,0.2	64.03,67.82
10	1	0.2	0.7,0.3	69.28,52.92	0.04	0.4,0.6	42.43,38.3
		0.5	0.55,0.45	65.57,70.48			
		0.2	0.72,0.28	84.85,96.66	0.06	0.8,0.2	26.46,14.14
	2	0.2	0.7,0.3	85.44,40.41	0.04	0.4,0.6	91.1,94.69
		0.5	0.55,0.45	72.11,65.66			
		0.2	0.72,0.28	74.83,55.68	0.06	0.8,0.2	46.9,62.169
	3	0.2	0.7,0.3	76.16,64.29	0.04	0.4,0.6	76.16,86.41
		0.5	0.55,0.45	64.81,57.52			
		0.2	0.72,0.28	36.06,22.36	0.06	0.8,0.2	48.99,32.63
11	1	0.2	0.7,0.3	76.16,64.29	0.04	0.4,0.6	84.26,86.21
		0.5	0.55,0.45	78.74,71.33			
		0.2	0.72,0.28	64.81,82.9	0.06	0.8,0.2	73.48,88.4
	2	0.2	0.7,0.3	72.8,62.98	0.04	0.4,0.6	46.9,50.33
		0.5	0.55,0.45	76.16,66.84			
		0.2	0.72,0.28	66.56,79.28	0.06	0.8,0.2	78.74,90.09
	3	0.2	0.7,0.3	64.81,53.54	0.04	0.4,0.6	42.43,49.67
		0.5	0.55,0.45	67.82,57.16			
		0.2	0.72,0.28	64.03,66.76	0.06	0.8,0.2	88.88,97.8

Table 37.3: Continued

12	1	0.2 0.5 0.2	0.7,0.3 0.55,0.45 0.72,0.28	55.68,42 45,83,40.69 34.64,25.768	0.04 0.06	0.4,0.6 0.8,0.2	74.83,77 78.74,92.82
	2	0.2	0.7,0.3	85.44,40.41	0.04	0.4,0.6	91.1,94.69
		0.5	0.55,0.45	72.11,65.66			
		0.2	0.72,0.28	74.83,55.68	0.06	0.8,0.2	46.9,62.169
13	1	0.2	0.7,0.3	85.44,40.41	0.04	0.4,0.6	91.1,94.69
		0.5	0.55,0.45	72.11,65.66			
		0.2	0.72,0.28	74.83,55.68	0.06	0.8,0.2	46.9,62.169
	2	0.2	0.7,0.3	69.28,52.92	0.04	0.4,0.6	42.43,38.3
		0.5	0.55,0.45	65.57,70.48			
		0.2	0.72,0.28	84.85,96.66	0.06	0.8,0.2	26.46,14.14
	3	0.2	0.7,0.3	85.44,40.41	0.04	0.4,0.6	91.1,94.69
		0.5	0.55,0.45	72.11,65.66			
		0.2	0.72,0.28	74.83,55.68	0.06	0.8,0.2	46.9,62.169
14	1	0.2	0.7,0.3	85.44,40.41	0.04	0.4,0.6	91.1,94.69
		0.5	0.55,0.45	72.11,65.66			
		0.2	0.72,0.28	74.83,55.68	0.06	0.8,0.2	46.9,62.169
	2	0.2	0.7,0.3	69.28,52.92	0.04	0.4,0.6	42.43,38.3
		0.5	0.55,0.45	65.57,70.48			
		0.2	0.72,0.28	84.85,96.66	0.06	0.8,0.2	26.46,14.14

Considering a given budget, with regard to the number of activities and the corresponding executive mode and the project duration, total executive cost, quality and environment performance are often conflicting. The best way to handle multi-objective optimization is to keep dependent on the decision-maker's objective. Generally, the solution to this problem is a balance of multiple objectives.

37.4 Conclusion

The main advantage of the proposed method is that it provides a systematic workable method for the problem that facilitates the decision-making process, enabling decision maker to control the schedule according to his optimistic-pessimistic parameter, and the fuzzy logic is a suitable tool for environment impact assessment for project. We have applied the model to construction systems for large-scale hydroelectric projects (Jinping-II) in the southwest region of China. The application

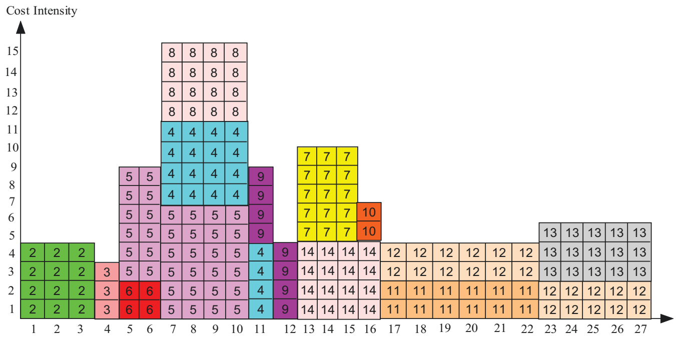

Fig. 37.2 Gantt chart for the construction project schedule

of fuzzy variables makes the proposed multiple objective model more suitable for describing the vague situation in the real world. This work is original, and we develop fuzzy-based adaptive hybrid genetic algorithm to enhance the optimization quality and stability. Practical results indicate that both the proposed model and the (f)a-hGA are viable and efficient in handling such complex problems.

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