Chapter 120
The Fuzzy Time-Cost-Quality-Environment Trade-off Analysis of Multi-mode Construction Systems for Large-scale Hydroelectric Projects

Huan Zheng

Abstract This paper studies the time-cost-quality-environment trade-off problem of construction project and establishes a multi-objective decision making model under a fuzzy environment. The objective functions are to minimize the total project time, total executed cost, quality defect of all activities, and the environment impact. Furthermore, a fuzzy based adaptive-hybrid genetic algorithm is developed for finding feasible solutions. Finally, Jinping-II hydroelectric project was used as a practical example to demonstrate the practicality and efficiency of the method.

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

120.1 Introduction

Time, cost, quality and environment of project delivery are among the crucial aspects of construction projects. 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 of projects. 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 executive 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

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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. In Sect. 120.2, a multi-objective time-cost-quality-environ-ment trade-off problem under fuzzy environment is described, and makes assumptions and notation for this problem. A multi-objective fuzzy optimization model is then proposed for this problem. Sect. 120.3 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. 120.4

120.2 Problem Description and Mathematical Formulation Model

120.2.1 Problem Description

Some research have assumed activity duration is characterized by a fuzzy number due to environmental variation [7]. 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 capital 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 which is shown in Fig. 120.1.

120.2.2 Dealing with the Fuzzy Variable

The basic knowledge about fuzzy variable, which includes the definition, the measure and the expected value are introduced in below literatures.

Fuzzy set theory has been well developed and applied in a wide variety of real problems. Here we adopted the definition proposed by Zadeh [9]. The term fuzzy variable was first introduced by Kaufmann [5], then it appeared in Nahmias [6]. Possibility theory was proposed by Zadeh [10], and developed by many researchers such as Dubois and Prade [1]. Membership function of fuzzy variable are introduced in Dubois and Prade [2]. However, the traditional fuzzy measures of fuzzy events

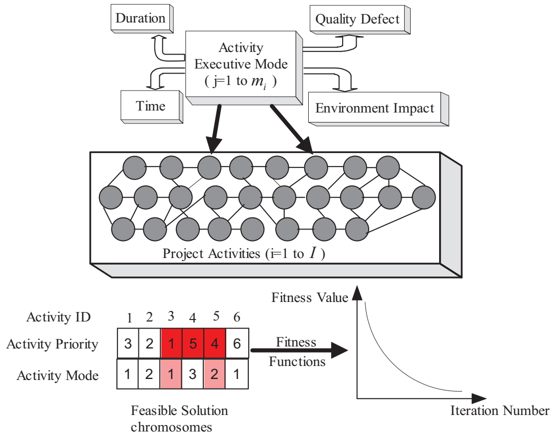

Fig. 120.1 The time-cost-quality-environment trade-off problem

can not express the preference of decision makers. Thus, this paper introduces the fuzzy measure Me [8] which embeds the optimistic-pessimistic parameter to determine the combined attitude of a decision maker.

120.2.3 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, $p = 1, 2, \cdots, P_i$. (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;
B : maximum-limited budget available with the whole project duration availability;
C_{ij} : cost of activity i operating in mode j per unit time, that is cost intensity;
l_t^M : maximum-limited budget 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 about 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_{inr} : the pondering coefficient which is assigned to each positive impact property n for positive environment impact r of activity i;
c_{ifk} : the pondering coefficient which is assigned to each negative impact property f for negative environment impact k of activity i;
$\tilde{p}_{ijnr}$: the positive environment impact property n for positive environment impact r in activity i of selected mode j;
$\tilde{p}_{ijfk}$: 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.

120.2.4 Fuzzy Multi-objective Model

(1) Objective functions

The present optimization model is formulated in order to provide the capability of minimizing construction time, cost, quality defect and environment impact. To this end, the model incorporates four major objective functions as shown in the following four equations to enable the evaluation of project performance in construction time, cost, quality and environment, respectively.

Construction managers aim at achieving option of executing mode for minimum cost to complete the project. So the first objective is to minimize the executed cost.

$$\min z_1 = \sum_{i=1}^{I} \sum_{j=1}^{m_i} \sum_{t=t_i^{EF}}^{t_i^{LF}} C_{ij} x_{ijt} E[\tilde{D}_{ij}]. \tag{120.1}$$

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

$$\min z_2 = \sum_{j=1}^{m_I} \sum_{t=t_I^{EF}}^{t_I^{LF}} t x_{ijt}. \tag{120.2}$$

The third objective aims at minimizing project quality defect that is measured and quantified. It enables the aggregation of the estimated quality for all the considered activities to provide an overall quality performance at the project level using a simple weighted approach.

$$\min z_3 = \sum_{i=1}^{I} w_i \sum_{p=1}^{P_i} w_{i,p} \times Q_{i,p}^{j}. \tag{120.3}$$

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

$$\begin{aligned} \min z_4 &= \overline{TV} = \overline{TV}^{+} - \overline{TV}^{-} = \sum_{i=1}^{I} y_i \left(\sum_{r=1}^{R} h_{ir} \overline{V}_{ir}^{+} - \sum_{k=1}^{K} h_{ik} \overline{V}_{ik}^{-} \right) \\ &= \sum_{i=1}^{I} y_i \left[\sum_{r=1}^{R} h_{ir} \sum_{n=1}^{N} c_{inr} \frac{\tilde{p}_{ijnr}^{2}}{100} - \sum_{k=1}^{K} h_{ik} \sum_{f=1}^{F} c_{ifk} \left(100 - \frac{\tilde{p}_{ijfk}^{2}}{100} \right) \right]. \end{aligned} \tag{120.4}$$

(2) Constraints

In project, precedence is the important basic term ensuring the rationality of the arrangement. That is to ensure that none of the precedence constraints.

$$\sum_{j=1}^{m_e} \sum_{t=t_e^{EF}}^{t_e^{LF}} t x_{ejt} + \sum_{j=1}^{m_i} \sum_{t=t_i^{EF}}^{t_i^{LF}} E[\tilde{D}_{ej}] x_{ijt} \le \sum_{j=1}^{m_i} \sum_{t=t_i^{EF}}^{t_i^{LF}} t x_{ijt}, \tag{120.5}$$

$$i = 1,2,\cdots,I,\ e \in Pre(i). \tag{120.6}$$

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.

$$\sum_{j=1}^{m_i} \sum_{t=t_i^{EF}}^{t_i^{LF}} x_{ijt} = 1,\ i = 1,2,\cdots,I. \tag{120.7}$$

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:

$$\sum_{i=1}^{I} w_i = 1. \tag{120.8}$$

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:

$$\sum_{p=1}^{P_i} w_{i,p} = 1,\ i = 1,2,\cdots,I. \tag{120.9}$$

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:

$$\sum_{i=1}^{I} y_i = 1. \tag{120.10}$$

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:

$$\sum_{r=1}^{R} h_{ir} + \sum_{k=1}^{K} h_{ik} = 1,\ i = 1,2,\cdots,I. \tag{120.11}$$

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

$$\sum_{n=1}^{N} c_{inr} = 1,\ r = 1,2,\cdots,R,\ i = 1,2,\cdots,I, \tag{120.12}$$

$$\sum_{f=1}^{F} c_{ifk} = 1,\ k = 1,2,\cdots,K,\ i = 1,2,\cdots,I. \tag{120.13}$$

Firstly, cost planning is constrained according to activity breaking down. Constraint limits the total capital consumption to the available amount, so we consider the total budget for the project. It is basic and important in project to limit the total capital consumption used by all activities. It has a maximum limit B during the whole project duration.

$$z_1 \leq B. \tag{120.14}$$

Secondly, cost planning is constrained according to time. The total cost of all activities scheduled in time t cannot exceed the capital limit per period.

$$\sum_{i=1}^{I}\sum_{j=1}^{m_i} C_{ij} \sum_{s=t}^{t+E[\tilde{D}_{ij}]-1} x_{ijt} \leq l_t^M,\ t = 1,2\cdots,\lceil E[\tilde{T}_{I+1}]\rceil. \tag{120.15}$$

In order to describe some non-negative variables and 0-1 variables in the model for practical situation are presented. Non-negativity constraints on decision variable and its revelent variable

$$E[\tilde{D}_{ij}], E[\tilde{T}], t_i^{EF}, t_i^{LF} \geq 0,\ i = 1,2,\cdots,I,\ j = 1,2,\cdots,m_i, \tag{120.16}$$

$$x_{ijt} = 0 \text{ or } 1,\ i=1,2,\cdots,I,\ j=1,2,\cdots,m_i, t=1,2,\cdots,\lceil E[\tilde{T}_{I+1}]\rceil. \tag{120.17}$$

Constraints on project completion time.

$$E[\tilde{T}_{I+1}] \leq E[\tilde{T}]. \tag{120.18}$$

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

120.3.1 Presentation of the Case Problem

The project has 13 activities from preliminary work to clearing up and finishing work. Each of these has certain predecessors, successors, and fixed finishing time. Here, the company traditionally uses the month as a time unit (i.e. 1 month per unit). Two dummy activities were set up to help for the convenience of the model. The detailed corresponding data for each activity is as follows in Table 120.1, Table 120.2 and Table 120.3.

Based on the representation of the case problem, the proposed methods can be used to obtain the project scheduling model for our project.

Table 120.1 The number, mode, duration, budget, predecessor and two kinds of weight of each activity

I	II	III	IV	V	VI	VII
1	Dummy Activity					
2	1 2	(1,3,5) (5,9,13)	4 3	1	0.07	0.1
3	1 2 3	(0.5,1,1.5) (0.5,1,1.5) (2,5,8)	4 3 4	1	0.06	0.11
4	1 2	(3,5,7) (6,8,10)	4 3	1	0.03	0.08
5	1	(3,6,9)	5	2	0.06	0.1
6	1 2	(1,2,3) (3,6,9)	2 3	3	0.12	0.056
7	1 2	(1,3,5) (6,8,10)	5 4	2,3	0.15	0.07
8	1 2	(2,4,6) (8,10,12)	4 2	6	0.1	0.014
9	1 2 3	(1,2,3) (5,7,9) (7,10,13)	4 3 2	5	0.09	0.07
10	1 2 3	(0.5,1,1.5) (0.5,1,1.5) (7,9,11)	4 2 6	5,7	0.09	0.11
11	1 2 3	(3,6,9) (7,9,11) (7,10,13)	2 1 1	4,6,7	0.06	0.14
12	1 2	(9,11,13) (6,8,10)	2 4	8,10	0.04	0.028
13	1 2 3	(3,5,7) (4,6,8) (5,7,9)	3 3 2	8,9,11	0.07	0.056
14	1 2	(1,4,7) (1,3,5)	4 5	9	0.04	0.056
15			Dummy Activity			

Note: I: Activity i; II: Mode j; III: Duration $(\tilde{D_{ij}})$ (month); IV: Cost intensity (C_{ij} (billion)); V: Predecessor $(Pre(i))$; VI: Weight of activity for quality (w_i); VII: Weight of activity for environment (y_i).

Other relevant data are as follows: total budget is 180, maximum limited of cost intensity is 15 unite for each period, project completion duration under normal con-

Table 120.2 Activity mode option, their corresponding quality indicators and quality performance

I	II	IX	X	I	II	IX	X
2	1	72,71.14	0.3,0.7	9	1	66.7,66,7	0.5,0.5
	2	42,43.14	0.3,0.7		2	44.4,44.4	0.5,0.5
					3	33.3,33.3	0.5,0.5
3	1	87,82.35	0.2,0.8	10	1	42,58	0.85,0.15
	2	68,66.357	0.2,0.8		2	72,36.7	0.85,0.15
	3	56,48.5	0.2,0.8		3	38,6.7	0.85,0.15
4	1	70,61.75	0.6,0.4	11	1	60,67.44	0.1,0.9
	2	155,184.25	0.6,0.4		2	40,51.11	0.1,0.9
					3	103,99.7	0.1,0.9
5	1	66.7	0.5,0.5	12	1	82,73.76	0.15,0.85
					2	131,123.94	0.15,0.85
6	1	70,65.6	0.25,0.75	13	1	73,65.72	0.78,0.22
	2	58,58.4	0.25,0.75		2	58,53.9	0.78,0.22
					3	44,38.54	0.78,0.22
7	1	72,64.64	0.28,0.72	14	1	78,74.67	0.1,0.9
	2	55,43.47	0.28,0.72		2	52,49.78	0.1,0.9
8	1	63,101.89	0.82,0.18				
	2	98,109.11	0.82,0.18				

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

dition 28 months and decision maker expected project completion duration below 30 months.

Table 120.3: Environmental impacts, impact properties and their pondering coefficients for each activity-mode

Activity i	Mode j	h_{ir}	c_{inr}	$\tilde{p}_{ijnr}$	h_{ik}	c_{ifk}	$\tilde{p}_{ijfk}$
2	1	0.3	0.4,0.6	99.5,97.81	0.07	0.8,0.2	63.25,77.46
		0.5	0.42,0.58	97.98,87.37			
		0.05	0.37,0.63	92.74,97.34	0.08	0.82,0.18	83.67,96.02
	2	0.3	0.4,0.6	99.5,98.64	0.07	0.8,0.2	51.96,95.92
		0.5	0.42,0.58	97.98,75.06			
		0.5	0.37,0.63	52.92,42.99	0.08	0.82,0.18	83.67,64.96
3	1	0.3	0.4,0.6	99.5,98.66	0.07	0.8,0.2	72.11,90.55
		0.5	0.42,0.58	97.468,98.35			
		0.05	0.37,0.63	46.90,24.76	0.08	0.82,0.18	88.32,61.42
	2	0.3	0.4,0.6	99.5,98.66	0.07	0.8,0.2	72.11,90.55
		0.5	0.42,0.58	97.468,98.35			
		0.05	0.37,0.63	46.90,24.76	0.08	0.82,0.18	88.32,61.42
	3	0.3	0.4,0.6	89.44,85.63	0.07	0.8,0.2	36.06,69.28
		0.5	0.42,0.58	90.55,66.385			
		0.05	0.37,0.63	77.46,58.82	0.08	0.82,0.18	69.28,79.09

Table 120.3: Continued

4	1	0.3	0.4,0.6	99.5,96.95	0.07	0.8,0.2	76.16,85.44
		0.5	0.42,0.58	98.99,96.35			
		0.05	0.37,0.63	61.64,56.26	0.08	0.82,0.18	97.88,99.73
	2	0.3	0.4,0.6	97.98,99.65	0.07	0.8,0.2	86.02,96.95
		0.5	0.42,0.58	99.75,99.32			
		0.05	0.37,0.63	81.85,76.85	0.08	0.82,0.18	97.98,92.89
5	1	0.3	0.4,0.6	98.49,97.64	0.07	0.8,0.2	69.28,65.57
		0.5	0.42,0.58	94.34,95.25			
		0.05	0.37,0.63	73.48,61.75	0.08	0.82,0.18	82.46,93.14
6	1	0.3	0.4,0.6	97.98,99.65	0.07	0.8,0.2	65.57,61.64
		0.5	0.42,0.58	95.92,94.10			
		0.05	0.37,0.63	88.32,82.75	0.08	0.82,0.18	78.74,99.40
	2	0.3	0.4,0.6	74.83,57.16	0.07	0.8,0.2	65.57,82.46
		0.5	0.42,0.58	36.06,46.50			
		0.05	0.37,0.63	57.45,50.06	0.08	0.82,0.18	88.32,98.01
7	1	0.3	0.4,0.6	97.98,99.65	0.07	0.8,0.2	65.57,61.64
		0.5	0.42,0.58	95.92,94.10			
		0.05	0.37,0.63	88.32,82.75	0.08	0.82,0.18	78.74,99.40
	2	0.3	0.4,0.6	97.88,99.65	0.07	0.8,0.2	86.02,96.95
		0.5	0.42,0.58	99.75,99.32			
		0.05	0.37,0.63	81.85,76.85	0.08	0.82,0.18	97.88,92.89
8	1	0.3	0.4,0.6	97.98,99.65	0.07	0.8,0.2	65.57,61.64
		0.5	0.42,0.58	95.92,94.10			
		0.05	0.37,0.63	88.32,82.75	0.08	0.82,0.18	78.74,99.40
	2	0.3	0.4,0.6	97.88,99.65	0.07	0.8,0.2	86.02,96.95
		0.5	0.42,0.58	99.75,99.32			
		0.05	0.37,0.63	81.85,76.85	0.08	0.82,0.18	97.88,92.89
9	1	0.3	0.4,0.6	97.98,99.65	0.07	0.8,0.2	65.57,61.64
		0.5	0.42,0.58	95.92,94.10			
		0.05	0.37,0.63	88.32,82.75	0.08	0.82,0.18	78.74,99.40
	2	0.3	0.4,0.6	97.88,99.65	0.07	0.8,0.2	86.02,96.95
		0.5	0.42,0.58	99.75,99.32			
		0.05	0.37,0.63	81.85,76.85	0.08	0.82,0.18	97.88,92.89
	3	0.3	0.4,0.6	97.88,99.65	0.07	0.8,0.2	86.02,96.95
		0.5	0.42,0.58	99.75,99.32			
		0.05	0.37,0.63	81.85,76.85	0.08	0.82,0.18	97.88,92.89
10	1	0.3	0.4,0.6	98.49,94.16	0.07	0.8,0.2	64.81,46.90
		0.5	0.42,0.58	92.20,82.32			
		0.05	0.37,0.63	47.96,38.81	0.08	0.82,0.18	26.46,54.06
	2	0.3	0.4,0.6	95.92,90.55	0.07	0.8,0.2	64.81,81.85
		0.5	0.42,0.58	99.00,97.24			
		0.05	0.37,0.63	85.44,76.62	0.08	0.82,0.18	95.52.98.77
	3	0.3	0.4,0.6	89.44,85.63	0.07	0.8,0.2	36.06,69.28
		0.5	0.42,0.58	90.55,66.385			
		0.05	0.37,0.63	77.46,58.82	0.08	0.82,0.18	69.28,79.09

Table 120.3: Continued

11	1	0.3	0.4,0.6	97.98,99.65	0.07	0.8,0.2	65.57,61.64
		0.5	0.42,0.58	95.92,94.10			
		0.05	0.37,0.63	88.32,82.75	0.08	0.82,0.18	78.74,99.40
	2	0.3	0.4,0.6	95.92,90.55	0.07	0.8,0.2	65.57,79.37
		0.5	0.42,0.58	88.32,92.14			
		0.05	0.37,0.63	78.74,57.82	0.08	0.82,0.18	92.20,98.61
	3	0.3	0.4,0.6	98.49,94.16	0.07	0.8,0.2	64.81,87.75
		0.5	0.42,0.58	90.55,66.39			
		0.05	0.37,0.63	44.72,9.75	0.08	0.82,0.18	61.64,86.49
12	1	0.3	0.4,0.6	97.98,99.65	0.07	0.8,0.2	65.57,61.64
		0.5	0.42,0.58	95.92,94.10			
		0.05	0.37,0.63	88.32,82.75	0.08	0.82,0.18	78.74,99.40
	2	0.3	0.4,0.6	97.98,99.65	0.07	0.8,0.2	86.02,96.95
		0.5	0.42,0.58	99.75,99.32			
		0.05	0.37,0.63	81.85,76.85	0.08	0.82,0.18	97.98,92.89
13	1	0.3	0.4,0.6	97.98,99.65	0.07	0.8,0.2	65.57,61.64
		0.5	0.42,0.58	95.92,94.10			
		0.05	0.37,0.63	88.32,82.75	0.08	0.82,0.18	78.74,99.40
	2	0.3	0.4,0.6	98.49,94.16	0.07	0.8,0.2	68.56,84.85
		0.5	0.42,0.58	90.55,66.39			
		0.05	0.37,0.63	44.72,9.75	0.08	0.82,0.18	93.81,89.64
	3	0.3	0.4,0.6	97.98,99.65	0.07	0.8,0.2	65.57,61.64
		0.5	0.42,0.58	95.92,94.10			
		0.05	0.37,0.63	88.32,82.75	0.08	0.82,0.18	78.74,99.40
14	1	0.3	0.4,0.6	97.98,99.65	0.07	0.8,0.2	65.57,61.64
		0.5	0.42,0.58	95.92,94.10			
		0.05	0.37,0.63	88.32,82.75	0.08	0.82,0.18	78.74,99.40
	2	0.3	0.4,0.6	98.49,94.16	0.07	0.8,0.2	68.56.37,84.85
		0.5	0.42,0.58	90.55,66.39			
		0.05	0.37,0.63	44.72,9.75	0.08	0.82,0.18	93.81,89.64

120.3.2 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 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:

$$z_1 = 175,\ z_2 = 27,\ z_3 = 67,\ z_4 = 71,$$

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 Gantt chart for the construction is shown in Fig. 120.2.

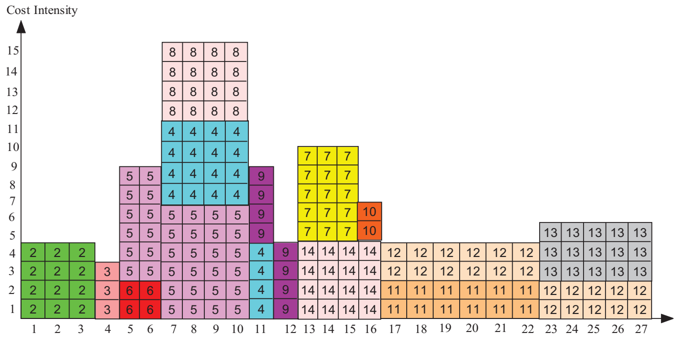

Fig. 120.2 Gantt chart for the construction project schedule

120.4 Conclusion

In this paper, the proposed fuzzy time-cost-quality-environment trade-off model attempts to minimize total project costs, total completion time, quality and the environment impact with reference to cost intensity, duration of activities, the constraint of precedence, total budget, weight and pondering coefficients. 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 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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