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Collaborative optimization of duration-cost-quality for water conservancy project based on relay chain network

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ABSTRACT

Given the shortcomings of relay technology for managing water conservancy project and the characteristics of duration, cost, and quality being opposite of unity, the optimization equations of relay chain duration target, cost target, quality goal, and multiple targets are constructed, respectively. With the optimal balance among duration, cost, and quality, based on comprehensively reflecting the contribution of each sub-goal to the overall goal, the multi-objective optimization model of planning duration, cost, quality, and synergetic utility of relay chain network has been established, and the multi-objective genetic algorithm been designed to solve the model, and the decision region of the optimal scheme, obtained. Finally, an example is given to verify the feasibility of the model.

Keywords: Relay chain; Duration-Cost-Quality; Collaborative optimization; Genetic algorithms

1. Introduction

As the realities of the project of the transition time between front closely activity and back closely activity have not been taken into consideration of traditional network plan, many scholars, and researchers at home and abroad use relay technology ideas for managing project schedule. Many excellent results have been achieved. However, in most researches, the schedule is just regarded as a single variable, and the comprehensive duration, cost, and quality have been rarely studied. Therefore, they could not satisfy the needs of project management. Duration goals, cost goals, and quality goals are the opposite of unity. How to achieve effective management and make it a coordinated whole has become the focus of research and the urgent problem to be solved [1–7].

In order to achieve satisfactory quality results with less time and expense in project management, a study introduced the concept formulation and evaluation function of value management and proposed a new nonlinear multi-objective model to solve the balance problem of time, cost, and quality [8]. A research proposed to appropriately compress activities at the minimum cost, and considered that project quality was affected by activity compression [9]. Based on this, they developed three pairwise linear programming models related to activity duration, quality level and cost, and studied the balance. Previous study set schedule, cost and quality as variables. They established a comprehensive balanced optimization model of duration-cost-quality by using multi-attribute utility analysis method and overcame the difficulty of giving consideration to the three optimization objectives. Some papers studied the optimization of a

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time limit, cost, and quality under uncertain environment [10,11]. Therefore, defined "objective superior degree" [12]. They set up the optimization model of duration, cost, and quality, based on the fuzzy multi-attribute group decision utility function theory and fuzzy multi-mode network planning technology. After the comparative analysis of the earned value model, quality reliability model, duration-quality curve model, and quality cost model, based on a network system, there proposed the reliability quality model for the comprehensively balanced control of project duration, cost, and quality objectives [13,14].

Based on these previous studies, this paper adopts synergy effects to reflect the contribution of each sub-objective to the overall goal when the three goals reach the optimal level and constructs a multi-objective synergy optimization model for the duration, cost, quality, and synergy utility of relay chain network planning management. Finally, the multi-objective optimal solution with different preferences of decision makers is obtained through providing an example, which verifies the feasibility of the model.

2. Collaborative optimization model construction

2.1. Construction of the relay chain duration target equation

Hypothesis 1: Operation refers to the process that must be coherent and indivisible work. The continuous process cannot be interrupted [15,16] once it started.

Hypothesis 2: Each operation in the relay chain network can only be performed after the tight relay point ends.

Hypothesis 3: When critical work is not adjusted, adjustments to non-critical work do not extend the total duration of the project.

$$\mathrm{Min}T = \max \sum_{L_k \in L} \left(t(h,i) + D_{h-i}(i) \right) \tag{1}$$

$$\text{s.t.} \begin{cases} \mathrm{Max}\left\{ \mathrm{EF}(h,i) \right\} + D_{h-i}(i) = \mathrm{ES}(i,j) \le \mathrm{ST}(i,j) \le \mathrm{LS}(i,j) \\ \mathrm{Max}\left\{ \mathrm{ST}(h,i) + t(h,i) \right\} + D_{h-i}(i) = \mathrm{ST}(i,j) \\ t_{\min}(i,j) \le t(i,j) \le t_{\max}(i,j) \end{cases} \tag{2}$$

Among them, EF(*h,j*) represents homework (*h,j*), the earliest starting time. ST(*i,j*) represents the actual starting time of homework (*i,j*). LS(*i,j*) represents the latest start time of the operation (*i,j*). At the same time, *t*(*h,i*) is the duration of the operation (*h,i*). (*h,i*) represents a collection of tight pre-jobs of (*i,j*). D_{h-j} refers to the influence time of operation (*h,j*) on the force *j*. *L* represents the relay path in the relay chain network. L_k means the *k*th relay path in the chain network.

2.2. Construction of the cost target equation of the relay chain

Hypothesis 4: Contractors pursue their best interests where they conform to the law.

Hypothesis 5: The additional cost of obtaining the construction project by improper means by the contractor is not taken into account.

Hypothesis 6: The resources needed in the project were supplied timely without limitation of its amounts.

Hypothesis 7: The owner has good credit and can pay the progress of the project in a timely manner in accordance with the agreement of the construction contract.

Hypothesis 8: The duration of a compressed critical work cannot be less than the required minimum duration, and it cannot be non-critical work.

If the direct cost of engineering activities (*i,j*) is DC(*i,j*), then

$$\mathrm{DC}(i,j) = \mathrm{DC}_n(i,j) + S_{ij}\left(t_n(i,j) - t(i,j) \right)^2 \tag{3}$$

$$\mathrm{S}_{ij} = \frac{\left(\mathrm{DC}_c(i,j) - \mathrm{DC}_n(i,j) \right)}{\left(t_n(i,j) - t_c(i,j) \right)^2} \tag{4}$$

S(*i,j*) represents the direct cost increase rate when the duration is compressed. $\mathrm{DC}_n(i,j)$ is the normal direct cost of the work (*i,j*). $\mathrm{DC}_c(i,j)$ refers to the maximum direct cost of the work (*i,j*). In addition, $t_n(i,j)$ represents the normal duration of the work (*i,j*). Then, $t_c(i,j)$ means the shortest duration after working (*i,j*) compression.

When the relay point takes more than 0 time, the equipment, capital, personnel, and so on have to be occupied and used, resulting in an increase in project costs. Make the cost of the relay point RC, and then

$$\mathrm{RC}(i) = b \times \sum_{x=1}^{y} \mathrm{SV}(i,x) \times \frac{\mathrm{DC}_x(i,x)}{t_n(i,x)} \times t(i) \tag{5}$$

$$\mathrm{SV}(i,x) = \begin{cases} 0 & (i,x) \in L_c \\ 1 & (i,x) \in L_c \end{cases} \tag{6}$$

$$t(i) = \max\left\{ \mathrm{ST}(h,i) + t(h,i) + D_{h-i}(i) \right\} - \max\left\{ \mathrm{ST}(h,i) + t(h,i) \right\} \tag{7}$$

where *t*(*i*) represents the actual time occupied by relay point *i* in the relay chain network. *b* is the adjustment coefficient of relay cost. (*i,x*) means the set of tight work of relay point *i*. *x* refers to the number of tight work after relay point *i*. The value of SV is 0 or 1 when tight work (*i,x*) of the relay point *i* on the key relay path, SV = 1, when tight work (*i,x*) of the relay point *i* is not on the key relay path, SV = 0.

Total cost is equal to that of direct cost DC, indirect cost IC, and relay point occupancy cost, RC. The uncertainties, such as environment, construction technical complexity, and other uncertainties on total costs are ignored. Project cost targets can be expressed as:

$$\mathrm{Min}C = \min \sum_{(i,j) \in L} \left(\mathrm{DC}(i,j) + \mathrm{RC}(j) \right) + UT \tag{8}$$

$$\text{s.t.} \begin{cases} t(i,j) \ge 0 \\ D(j) \ge 0 \\ t_c(i,j) \le t(i,j) \le t_n(i,j) \end{cases} \tag{9}$$

Where, L represents all paths in the relay chain network. U is the indirect cost coefficient of the project. T refers to the actual construction period of the project. (h,i) represents the tight pre-activity set of the activity (i,j). What is more, (j,h) represents the tight post-activity set of the relay point j.

2.3. Construction of the quality target equation of the relay chain

The project quality objective function is shown as below:

$$\text{Max}Q = \sum_{i=1}^{n} w_i \times Q_i \tag{10}$$

The constraint is:

$$\text{s.t.}\begin{cases} \sum_{i=1}^{n} w_i = 1 \\ w_i > 0 \\ 0 \le Q_i \le 1 \end{cases} \tag{11}$$

where Q represents the quality of the whole project. w_i represents the weight of activity i in the whole project. Q_i means the quality score of activity i. Although the quality under the compression limit is less than 1, it is still a qualified product that meets the construction requirements, and the number just makes sense in terms of the quantitative aspect.

The weight w_i of task i can be determined by expert estimation, with

$$w_i = \frac{1}{m}\sum_{k=1}^{m} w_{ki}, \left(i = 1,2,\ldots,n; m = 1,2,3,\ldots\right) \tag{12}$$

Among them, m represents the number of experts, and Q_i of quality score of assignment i is expressed in the available range [0,1]. 1 means that the owner is completely satisfied with the quality, and 0 means that the owner is satisfied with the quality level to the minimum extent.

2.4. Multi-objective optimization equation construction

Multi-objective optimization is to achieve the balance of progress objectives, quality objectives, and cost objectives. Also, it aims to achieve the coordination of multi-objective engineering projects. In order to reflect the relationship between constraints and interests of decision-makers in collaborative optimization decisions, and the preference of decision-makers for constraints, the collaborative optimization model is constructed as follows:

$$\text{Max}G = \sum_{i=1}^{n} w_i f\left(x_i\right) = w_1 f\left(x_1\right) + w_2 f\left(x_2\right) + \cdots + w_n f\left(x_n\right) \tag{13}$$

$$\text{s.t.}\begin{cases} a_i \le x_i \le b_i \\ 0 \le w_i \le 1 \sum_{i=1}^{n} w_i = 1 \end{cases} \tag{14}$$

where G represents the total utility value for decision-makers after progress optimization. $w_i f(x_i)$ represents the utility of the ith constraint element to decision-makers. w_i indicates the degree of preference of decision-makers to the ith constraint element. x_i represents the ith constraint element in decision rules for collaborative progress optimization. a_i and b_i, respectively represent upper and lower bounds of constraint factor x_i values.

The degree of collaborative contribution of schedule, cost, and quality to the overall objective system of the project is expressed as G_T, G_C, and G_Q, respectively. According to the concept of synergetic contribution degree, duration and cost target as cost-oriented indicators, target value takes precedence over the small target value. The quality target is taken as an efficiency indicator. The target value is preferred by large. The contribution of the three goals is as follows:

$$G_T = \frac{T_n - T}{T_n - T_C} \tag{15}$$

$$G_C = \frac{C_{\max} - C}{C_{\max} - C_{\min}} \tag{16}$$

$$G_Q = \frac{Q - Q_C}{Q_n - Q_C} \tag{17}$$

Among them, T_n represents the normal duration, T_c means the shortest time limit for a project, $C_{\max}$ is the biggest cost, $C_{\min}$ represents the lowest cost, Q_n refers to the highest quality, and Q_C represents acceptable quality.

Given the characteristics of different projects and preferences of project decision-makers, weight w_1, w_2, and w_3 are set as the collaborative contribution degree of schedule, cost, and quality objectives.

$$G = G(T,C,Q) = w_1 \times G_T + w_2 \times G_C + w_3 \times G_Q \tag{18}$$

2.5. Relay chain schedule-cost-quality optimization model

In order to avoid unrealistic implementation plan, it is necessary to highlight the integrity of the three goals of duration, cost and quality, while retaining the independent three goals. Therefore, a multi-objective optimization model is established for the four sub-objectives of the relay chain network: duration target, cost target, quality target, and synergistic effect target. Among them, within the allowable scope, the smaller the schedule target and cost target, the better. With the greater goals of quality and synergistic effects, the multi-objective optimization model of relay chain network is more needed to be established.

$$\begin{cases} f_1 = \max G \\ f_2 = \min T \\ f_3 = \min C \\ f_4 = \max Q \end{cases} \tag{19}$$

The above model does not take the unqualified project quality into account. The quality of each process is always higher than the lowest quality level, and the cost of each process cannot lower than the normal cost or higher than the highest cost, and the construction cycle of each process is also within the range between the shortest and the normal period. Each operation in the relay chain network has various execution schemes, each of which has its corresponding time limit, cost, and quality. It is the collaborative optimization goal of relay chain network time limit cost quality to reach scheme combinations of the shortest time limit, the lowest cost, the highest quality, and the maximum degree of coordination.

2.6. Flow design of multi-objective optimization algorithm

When the duration, cost, and quality objectives reach a synergistic optimum state, synergy effects are used to represent the contribution of each objective to the overall goal. At the same time, the multi-objective optimization model of relay chain network is introduced. Fig. 1 shows a multi-objective algorithm flow for relay chain collaboration.

The multi-objective optimization model of a chain network is solved by a genetic algorithm [17–21]. The specific process is as follows:

- Basic parameters required for design operation. Project parameters include the number of processes, inter-process logical relationship, construction period T, cost C, and quality level Q. Genetic parameters include bit string length L, population size M, maximum iteration number G, crossover probability P_c, and mutation probability P_m. The bit string length is determined by the number of operations, and the genetic value is determined by the serial number of the construction scheme.
- Determining the initial population. The M individual was randomly produced by the method of uniform sampling, and the initial population M' was formed.
- Allocation of adaptive values. The duration function is used as the adaptive value function in the optimization, and the total duration T of the relay chain is calculated according to the key relay path. When determining the population in the g generation, the corresponding total project cost and overall quality can be calculated. After N

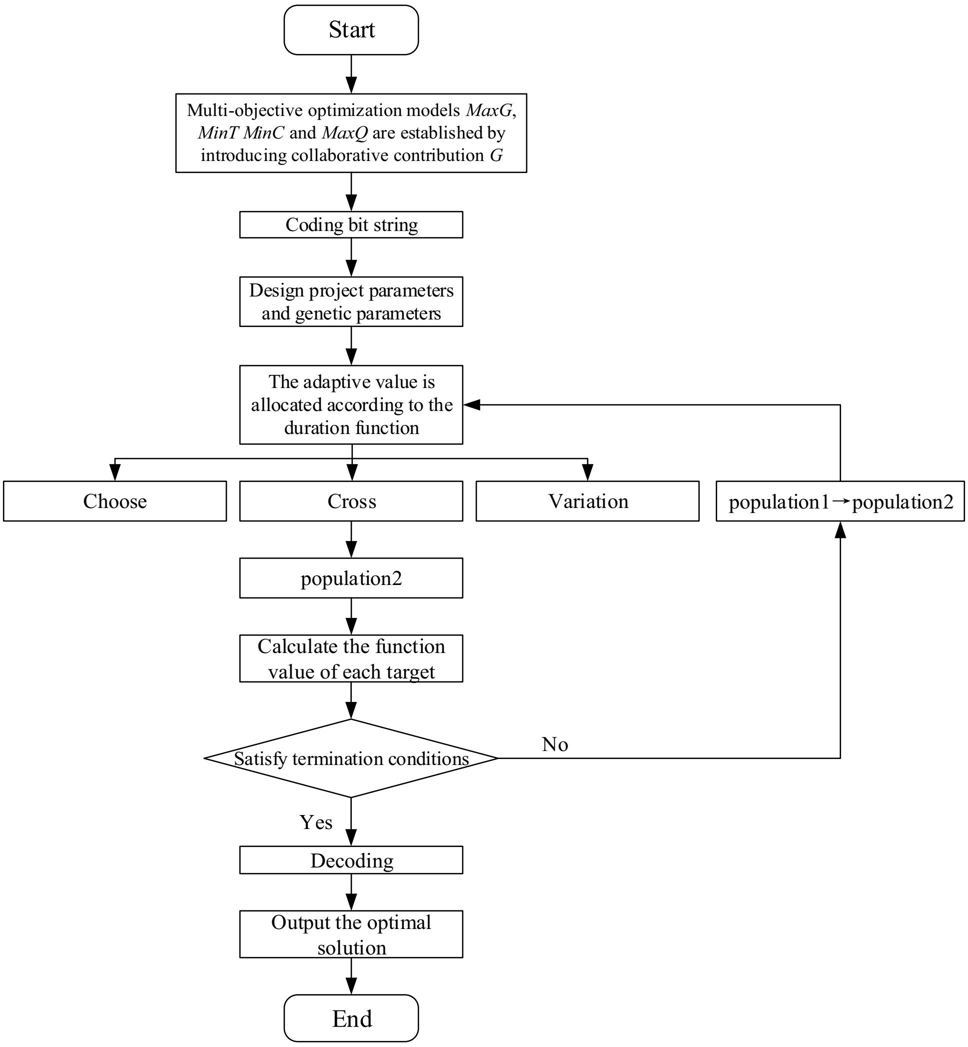

Fig. 1. Relay chain collaboration multi-objective algorithm flow.

iterations, the target value of all solutions in the population in the *g* generation is finally obtained.

- Genetic operator operation. Random traversal sampling method is used for determining the individual population, and then the crossover operation is carried out on the selected replicated population to ensure the diversity of the population. Finally, mutation operation is carried out on the population according to the probability designed in the genetic parameters, so as to obtain the new population.
- Terminate operation. Once the new population is obtained, the target value and iteration can be calculated successively. When the pre-specified generation times are reached, or when the individual in the population no longer has any obvious change, the operation satisfies the termination condition, which is the optimal solution set.

3. Example analysis

Take a project as an example. The feasibility and effectiveness of the relay chain multi-objective optimization model in practical application are verified. The relay chain network is shown in Fig. 2, and the operating parameters of the relay chain network are shown in Table 1.

This project contains 11 activities and 8 relay points. In Table 1 is the normal construction period and 3 means the shortest construction period. The normal duration of the process is determined by the technical properties of the process. The overhead cost of the project of the project is RMB 2.3 thousand yuan/day, and the adjustment coefficient of the relay cost is 0.3. The parameters of the genetic algorithm are set as follows: bitstring length is 11, group size, 50, maximum iteration number, 100, crossover probability, 0.5, and mutation probability, 0.01. Matlab programming was used to carry out the genetic operation in accordance with the 2.6 programs, and iteration was carried out in turn. When the number of iterations reaches 100 or the individual in the population does not change significantly, the operation is terminated, and the optimal solution set is decoded.

When the decision-maker decides to prioritize the cost target and takes the construction period as the second, ω_2 can be set as the maximum value and ω_3 as the minimum value. In this case, the weight of the construction period, cost and quality target is set as 0.3, 0.5, and 0.2 respectively, so the distribution of the minimum optimal solution of different construction period schemes can be obtained. For the first 20 construction period schemes with the lowest cost under different construction period schemes combinations, their corresponding construction period, quality score, and synergistic utility are shown in Table 2. The decision-maker can determine the appropriate combination of process plans according to the realities of the project.

Table 3 shows the optimal solution distribution of synergetic effects under the preference of decision-makers.

When the decision-maker prioritizes quality objectives and takes the construction period in second place, the weight ω_3 of quality objectives can be set as the maximum value and ω_2 of cost objectives as the minimum value. For example, the weight of the construction period, cost, and quality objectives is set as 0.3, 0.2, and 0.3 respectively. At this time, when the quality score reaches the highest, the optimal solution distribution is shown in Table 4.

The optimal solution distribution of synergetic effects under the preference of decision-makers is shown in Table 5.

For the decision preference, decision-makers can choose the implementation plan that conforms to their preferences based on the optimal solution. Therefore, decision-makers, to some extent, can make a decision in a smaller scope, and reduce the workload of decision-makers.

The multi-objective optimization problem is to provide the common non-inferior solution to the four objective functions and treat it as two norms. Then the space distance between the objective function and the zero vector in the four-dimensional space is obtained by taking it as the final optimization target value. The results of the population evolution iteration are shown in Fig. 3. With the continuous evolution of the population, the target value decreases rapidly and tends to be stable after about 30 generations. The target values converge around 285.

4. Conclusion

In this paper, based on the basic model of the relay chain network, time limit, cost, and quality in relay chain network are expressed. Synergetic utility is applied to multi-objective optimization of relay chain network in engineering projects. Also, the paper sets up a multi-objective cooperative optimization model for relay chain network. Given the characteristics of optimal subject preference, multi-objective, system, and complexity of engineering relay chain, a reasonable optimization method has been adopted to develop multi-preference and multi-objective cooperative optimization schemes. Only in this way, have the three goals for the project relay chain network been fulfilled. This paper not only provides a new research content and research topic for multi-objective optimization of relay chain network management, but also reduces the complexity of multi-objective optimization of relay chain network planning and improves the satisfaction towards the project.

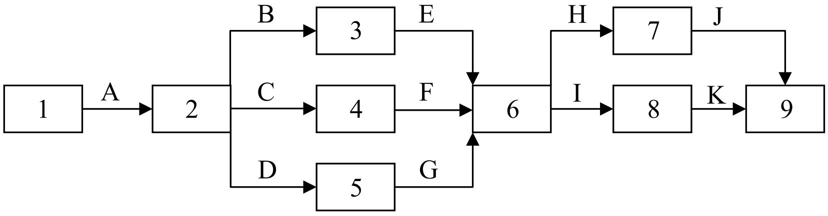

Fig. 2. Relay chain network.

Table 1
Operation parameters of relay chain network

Serial number	Name of the project	Tight after work	Process weight (%)	Relay point	Duration scenarios	$t(i,j)$	$D_{i-j}(j)$	DC(i,j)	Q	Direct cost increase rate, S_{ij}	Relay point occupancy cost (10 thousand yuan/day)
1–2	*A*	*B*, *C*, *D*	0.05	2	1	20	2	12.2	1	0.21	0.70
					2	17	4	14.09	0.49		
2–3	*B*	*E*	0.11	3	1	24	3	20.8	1	0.17	0.24
					2	20	5	23.52	0.81333		
					3	18	6	26.92	0.72		
2–4	*C*	*F*	0.03	4	1	22	2	18.4	1	0.13	0.36
					2	18	4	20.48	0.76		
					3	15	5	24.77	0.58		
2–5	*D*	*G*	0.16	5	1	26	2	16.7	1	0.1	0.38
					2	18	5	23.1	0.48		
3–6	*E*	*H*, *I*	0.06	6	1	24	1	18.9	1	0.11	0.58
					2	17	3	24.29	0.7		
4–6	*F*	*H*, *I*	0.05	6	1	28	2	33.5	1	0.19	0.58
					2	25	5	35.21	0.718		
					3	23	7	38.25	0.53		
5–6	*G*	*H*, *I*	0.14	6	1	21	1	26.4	1	0.15	0.58
					2	18	4	27.75	0.778		
					3	16	6	30.15	0.63		
6–7	*H*	*J*	0.18	7	1	36	2	37.1	1	0.14	0.24
					2	32	5	39.34	0.64571		
					3	29	7	43.96	0.38		
6–8	*I*	*K*	0.1	8	1	14	2	12.6	1	0.16	0.30
					2	12	3	13.24	0.872		
					3	9	4	16.6	0.68		
7–9	*J*		0.02	9	1	17	2	8.9	1	0.19	
					2	12	5	13.65	0.49		
8–9	*K*		0.1	9	1	15	2	14.8	1	0.13	
					2	13	3	15.32	0.84		
					3	9	5	19.48	0.52		

Table 2
Optimal solution distribution when costs are lowest

Serial number	Duration, *T*	Total cost, *C*	Quality score, *Q*	Synergy, *G*	Duration scenarios
1	136	252.5632	0.9712	0.649259	11,111,111,212
2	135	258.5417	0.886895	0.628366	12,111,112,212
3	135	264.8937	0.868895	0.579742	12,112,112,212
4	131	266.8056	0.9826	0.718375	11,211,111,121
5	134	266.9053	0.805756	0.56366	12,111,213,113
6	131	268.0502	0.854	0.652917	21,221,211,112
7	136	269.1553	0.850387	0.519242	12,112,121,313
8	134	270.7665	0.770787	0.523352	12,112,123,113
9	131	271.749	0.805829	0.607748	11,312,132,113
10	128	273.3062	0.819329	0.678838	23,311,112,113
11	134	274.2815	0.7861	0.507748	11,112,313,213
12	135	274.7603	0.761049	0.468485	11,122,222,212
13	128	274.8492	0.795695	0.658412	22,311,232,112
14	133	274.9015	0.8358	0.551014	21,121,311,311
15	131	275.0745	0.849687	0.60612	22,212,121,312
16	128	276.0541	0.888567	0.69225	22,211,111,123
17	133	276.1638	0.804167	0.528804	22,112,131,313
18	129	276.6131	0.839349	0.641668	21,111,222,122
19	129	276.6783	0.8788	0.658895	23,311,311,212
20	132	277.0516	0.844315	0.566088	12,111,222,122

Table 3
Optimal solution distribution of synergistic utility

Serial number	Duration, *T*	Total cost, *C*	Quality score, *Q*	Synergy, *G*	Duration scenarios
1	131	266.8065	0.9826	0.718375	11,211,111,121
2	128	276.0541	0.888567	0.69225	22,211,111,123
3	136	252.5632	0.9712	0.679259	11,111,111,212
4	128	273.3062	0.819329	0.678838	23,311,112,113
5	129	276.6783	0.8788	0.658895	23,311,311,212
6	128	274.8492	0.795695	0.658412	22,311,232,112
7	131	268.0502	0.854	0.652917	21,221,211,112
8	129	276.6131	0.839349	0.641668	21,111,222,122
9	135	258.5417	0.886895	0.628366	12,111,112,212
10	131	271.749	0.805829	0.607748	11,312,132,113
11	131	275.0745	0.849687	0.60612	22,212,121,312
12	135	264.8937	0.868895	0.579742	12,112,112,212
13	132	277.0516	0.844315	0.566088	12,111,222,122
14	134	266.9053	0.805767	0.56366	12,111,213,113
15	133	274.9015	0.8358	0.551014	21,121,311,311
16	133	276.1638	0.804167	0.528804	22,112,131,313
17	134	270.7665	0.770787	0.523352	12,112,123,113
18	136	269.1553	0.850387	0.519242	12,112,121,313
19	134	274.2815	0.7861	0.507748	11,112,313,213
20	135	274.7603	0.761049	0.468485	11,122,222,212

Table 4
Optimal solution distribution at the highest quality score

Serial number	Duration, *T*	Total cost, *C*	Quality score, *Q*	Synergy, *G*	Duration scenarios
1	129	285.054	0.9284	0.708785	133,312,111,121
2	129	281.6523	0.902087	0.688057	122,311,321,121
3	126	296.5845	0.8666	0.685228	233,312,311,221
4	126	292.3916	0.855187	0.68318	222,312,221,221
5	129	287.596	0.9037	0.674674	111,312,311,321
6	127	283.0248	0.845029	0.670755	211,311,212,222
7	131	283.0049	0.920567	0.655263	122,212,311,121
8	127	285.0628	0.832429	0.65146	211,212,212,222
9	128	280.3818	0.836095	0.64252	222,312,312,111
10	128	287.9464	0.832349	0.619003	111,312,122,321
11	132	273.7971	0.88602	0.615164	111,312,321,212
12	134	265.445	0.910167	0.613502	122,211,211,312
13	129	287.8606	0.84932	0.613198	133,312,121,123
14	129	282.5986	0.8355	0.611191	111,311,213,122
15	131	274.0133	0.847595	0.59665	122,311,312,311
16	136	263.5269	0.9263	0.586441	133,111,211,212
17	130	284.6592	0.828495	0.573094	122,212,132,121
18	133	270.1101	0.859867	0.570343	222,111,211,313
19	132	284.1111	0.837449	0.534505	111,112,322,122
20	136	269.3244	0.8834	0.523663	133,112,131,112

Table 5
Optimal solution distribution of synergistic utility

Serial number	Duration, *T*	Total cost, *C*	Quality score, *Q*	Synergy, *G*	Duration scenarios
1	129	285.054	0.9284	0.708785	133,312,111,121
2	136	263.5269	0.9263	0.586441	133,111,211,212
3	131	283.0049	0.920567	0.655263	122,212,311,121
4	134	265.445	0.910167	0.613502	122,211,211,312
5	129	287.596	0.9037	0.674674	111,312,311,321
6	129	281.6523	0.902087	0.688057	122,311,321,121
7	132	273.7971	0.88602	0.615164	111,312,321,212
8	136	269.3244	0.8834	0.523663	133,112,131,112
9	126	296.5845	0.8666	0.685228	233,312,311,221
10	133	270.1101	0.859867	0.570343	222,111,211,313
11	126	292.3916	0.855187	0.68318	222,312,221,221
12	129	287.8606	0.84932	0.613198	133,312,121,123
13	131	274.0133	0.847595	0.59665	122,311,312,311
14	127	283.0248	0.845029	0.670755	211,311,212,222
15	132	284.1111	0.837449	0.534505	111,112,322,122
16	128	280.3818	0.836095	0.64252	222,312,312,111
17	129	282.5986	0.8355	0.611191	111,311,213,122
18	127	285.0628	0.832429	0.65146	211212212222
19	128	287.9464	0.832349	0.619003	111,312,122,321
20	130	284.6592	0.828495	0.573094	122,212,132,121

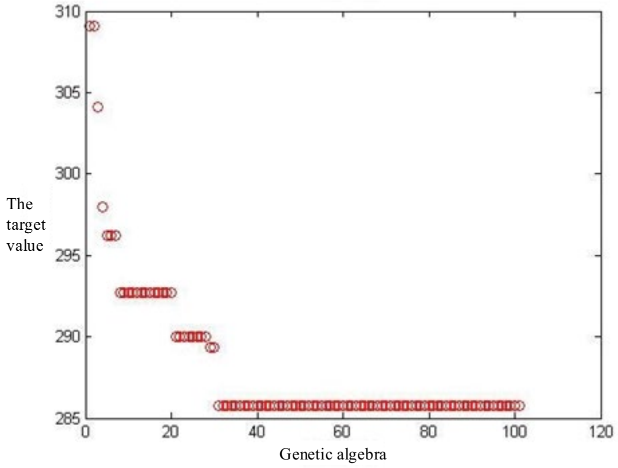

Fig. 3. Population evolution iteration run results.

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