Hindawi
Mathematical Problems in Engineering
Volume 2017, Article ID 3271969, 15 pages
https://doi.org/10.1155/2017/3271969

Research Article

Large-Scale Network Plan Optimization Using Improved Particle Swarm Optimization Algorithm

Houxian Zhang[1] and Zhaolan Yang[2]

[1]*School of Architecture and Civil Engineering, Nanjing Institute of Technology, Nanjing 211167, China*
[2]*Industrial Center, Nanjing Institute of Technology, Nanjing 211167, China*

Correspondence should be addressed to Houxian Zhang; houxianzhang@sina.com

Received 21 October 2016; Revised 12 January 2017; Accepted 29 January 2017; Published 27 February 2017

Academic Editor: Shuming Wang

No relevant reports have been reported on the optimization of a large-scale network plan with more than 200 works due to the complexity of the problem and the huge amount of computation. In this paper, an improved particle swarm optimization algorithm via optimization of initial particle swarm (OIPSO) is first explained by the stochastic processes theory. Then two optimization examples are solved using this method which are the optimization of resource-leveling with fixed duration and the optimization of resources constraints with shortest project duration in a large network plan with 223 works. Through these two examples, under the same number of iterations, it is proven that the improved algorithm (OIPSO) can accelerate the optimization speed and improve the optimization effect of particle swarm optimization (PSO).

1. Introduction

A large-scale network plan that is composed of more than 50 works has become an essential tool for managing large-scale engineering project [1, 2]. However, due to the rapidity of solution increase (called the combustion explosion) and the exponential growth of computing time with the complexity of the problem, which far exceeds the processing capacity of computing resources, the optimization of large-scale network plan becomes an unsolvable problem in the mathematics and computer science fields, also called the NP problem [3–7]. Among the existing optimization methods for network plan, accurate algorithm such as the dynamic planning [8], 0-1 planning [9, 10], and branch and bound method [11, 12] can solve the small network plan optimization; various heuristic algorithms [13–18] cannot solve large-scale network plan optimization. An effective way to solve the complex network plan is by using genetic algorithm (GA), but the works numbers of presented examples (86 and 122) are not large enough [19–23].

Proposed in 1995, PSO was applied to optimization, biomedicine, communication, control, plan, prediction, filter, and parameter estimation in rainfall-runoff modeling and so forth [24–30]. It was improved in selecting the parameter, the velocity equation of the particle, uncertainty stimulation, learning abilities, stability, convergence, and more [31–41]. Wang et al. and Chen et al. applied PSO to solve optimization of a nine-work network plan [42, 43]. The initial particle swarm was determined randomly by the improved and the initial PSO.

The Monte Carlo method can be applied to solve equations, integral equations, difference equations, integral, shielding radioactive particles, neutron fission security problems, the random service (queuing theory) of economic service problems, signal detection and system simulation, flow field simulation, life test, and more [44]. As it optimizes initial particle swarm to solve the optimization problem of large-scale network plans, it is PSO's foundation. Zhang and Shi [45] adopted the Monte Carlo method to solve the optimization of the resource-leveling with fixed duration and the resources constraints with shortest project duration of a network plan. But the works number of the presented examples (9) is not large enough. To solve the optimization problem of the resource-leveling with fixed duration in a large network plan, Du et al. [46] proposed partition optimization based on the Monte Carlo method. However, there is not a large enough works number (61), and partition optimization combination may lose the global optimal solution in theory.

Without requiring any advanced knowledge of the reliability function, PSO combining with the Monte Carlo method was used to solve complex network reliability problems, while Monte Carlo method was used to evaluate system reliability, but its motivation is different from this paper [47]. In comparison to the random method, the Monte Carlo method in the Monte Carlo Enhanced PSO can calculate the probability of initial particles' elements and form better initial particles, but there was no analyzation of the improvement mechanism to optimize the initial particle swarm [48]. To solve resource optimization and cost optimization of a large-scale network plan by using PSO, Zhang and Yang used the Monte Carlo method under limited conditions to optimize the initial particle swarm [49, 50]. However, there was no analyzation of the mechanism improvement to optimize the initial particle swarm, and the works number of presented examples (61) is not large enough.

In this paper, an improved particle swarm optimization algorithm via optimization of initial particle swarm (OIPSO) is first explained by the stochastic processes theory. Then two optimization examples of a large-scale network plan are solved using this method, which are the optimization of resource-leveling with fixed duration and the optimization of resources constraints with shortest project duration in a large network plan with 223 works. The optimization effect of the improved algorithm (OIPSO) is proven through these two examples.

This paper is organized as follows: Section 2 analyzes the improvement mechanism of OIPSO, Section 3 solves large-scale (223 works) network plans by OIPSO, Section 4 introduces the superiority of OIPSO compared with the original and existing PSOs, and Section 5 makes conclusions.

2. Methodology

2.1. OIPSO. The process of the original PSO is as follows [30]:

Step 1. Determining the initial particle swarm

Step 2. Evolving the particle location

Step 3. Determining each particle's best experiencing position and all particles doing

Step 4. Outputting the optimization results when the maximal number of iterations is reached; otherwise return to Step 2

The improved algorithm (OIPSO) in this paper is the same as PSO, except that Step 1 determines the initial particle swarm via optimization of initial particle swarm.

In the optimization of resource-leveling with fixed duration and the optimization of resources constraints with shortest project duration of a network plan, the following expression determines the initial particle swarm:

$$C[j] = d_1[j] + \text{rand}()\,\%\,(F[j] + 1), \quad (1)$$

where $C[j]$ is related to its start time of work j, $d_1[j]$ is the normal duration of the work j, rand()% is the random function, and $F[j]$ is the total float of the work j. The limiting conditions are resource variance in the optimization of resource-leveling with fixed duration, as well as resources and project duration in the optimization of resources constraints with shortest project duration. In the Monte Carlo method, using the random function rang()% is the basic principle.

2.2. The Improvement Mechanism of OIPSO. Markov chains are constituted by the PSO M particles [51]. And then by randomly selecting initial particles and setting them out to a certain point, the stochastic optimization series of particles constitute the Markov chains. The probability for a particle to set out from i is π_i, and the probability $\pi_j^{(n)}$ for a particle to transfer to j after an n time transfer can be determined by the following formula (j represents the optimal position of a limited number of iterations conditions, it can also be the optimization solution, $j \in I$, and I is the state space):

$$\begin{aligned}\pi_j^{(n)} &= P(X_n = j),\\ \pi^{(n)} &= [\pi_1^{(n)}, \pi_2^{(n)}, \ldots],\\ \pi^{(n)} &= \pi^{(0)} P^n,\end{aligned} \quad (2)$$

where X_n represents the arrival state of a particle subsequent to n time transfer; $\pi^{(n)}$ is called the probability distribution of X_n; $\pi^{(0)} = [\pi_1, \pi_2, \ldots]$ and is the initial distribution which is $1\times(n+1)$ matrix of the Markov chains, namely, the probability of the Markov chains starting from i, $\pi_i = P(X_0 = i)$, $i \in I$ (state space), and X_0 is the state for a particle to set out from; P^n is equal to the product of n one-time transfer matrix P ($n+1$ order phalanx), and P is also called matrix of transition probability, expressed as

$$\begin{aligned}P &= (p_{ij}),\\ p_{ij} &= P(X_1 = j \mid X_0 = i), \quad i, j \in I,\end{aligned} \quad (3)$$

where p_{ij} is the probability for a particle to transfer to j in the next time setting out from i [52].

Optimized and unoptimized initial particles comprise the two columns of Markov chains. The probability of particles starting from the location of the initial particle is equal to 100%, while that of particles starting from the locations of other particles is equal to 0. The excellent particle position close to the optimal solution is increased in the n particle positions, which is the position of the excellent initial particle, regardless of the subsequent excellent particle positions that were generated based on the initial particle. There is a higher probability of the excellent particle flying from the position near the optimal solution than it flying away from the optimal solution. Therefore, as shown in (4), j column of one-time

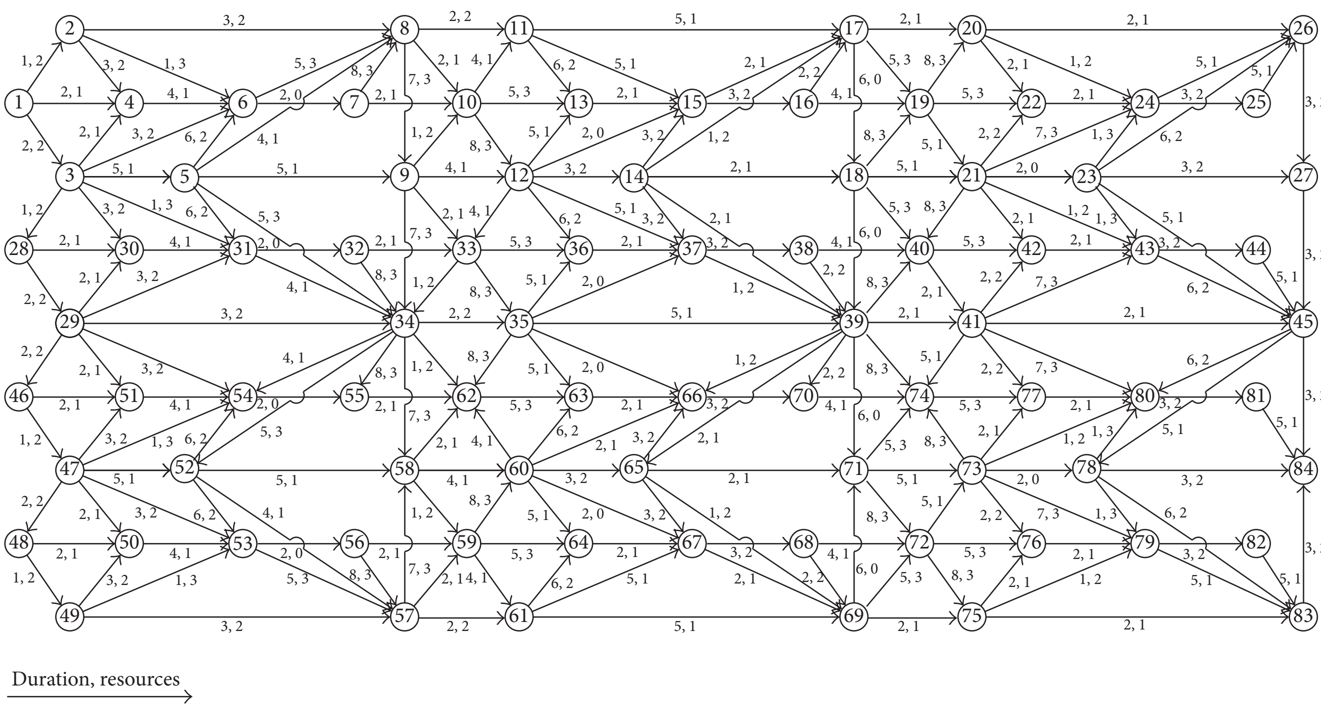

Figure 1: A large-scale network plan (223 works).

transfer matrix P of Markov chains to optimize initial particle is bigger.

$$\begin{pmatrix} 0 & 1 & 2 & 3 & \cdots & j\left(\text{bigger}\right) & \cdots & n \\ 1 & & & & & & & \\ 2 & & & & & & & \\ 3 & & & & & & & \\ \vdots & & & & & & & \\ i & & & & & & & \\ \vdots & & & & & & & \\ n & & & & & & & \end{pmatrix}. \quad (4)$$

As a result, j column of P^n and $\pi^{(0)}P^n$ of Markov chains to optimize initial particle is bigger.

3. Solving Large-Scale Network Plans with 223 Works by OIPSO

As shown in Figure 1, a large-scale network plan has a works number of 223 and a calculated project duration of 135. Table 1 shows each work's resources amount, duration, and earliest start time, corresponding to the resource variance of 37.51. The biggest quantity of resources at one period is 27. The optimization of resource-leveling with fixed duration can be unchanged project duration and resource demand equilibrium of each period. The resources supply capacity limit can be met by the optimization of resources constraints with shortest project duration, and it can have minimal extended project duration.

3.1. Solving the Optimization of Resource-Leveling with Fixed Duration. The variance method can be applied to evaluate the resource leveling, and the calculation formula of the variance is

$$\sigma^2 = \frac{\left(\sum_{i=1}^{J}\left(x_i - \mu\right)^2\right)}{J}, \quad (5)$$

where the total number of the samples x_i is J; the arithmetic average of x_i is μ.

The evolution equation is [49]

$$\begin{aligned} x_{ij}(t+1) = x_{ij}(t) + \operatorname{floor}(w v_{ij}(t) \\ + c_1 \operatorname{rand}_1(t)\left(p_{gj}(t) - x_{ij}(t)\right) \\ + c_2 \operatorname{rand}_2(t)\left(p_g(t) - x_{ij}(t)\right)\Big), \end{aligned} \quad (6)$$

where t is the number of iterations, $x_{ij}(t+1)$ is the j-dimensional space coordinates of the particle i at $(t+1)$ times of iterations, $x_{ij}(t)$ is the j-dimensional space coordinates of the particle i at t times of iterations, w is inertia weight (its general value is 1), $v_{ij}(t)$ is the j-dimensional flight velocity of particle i, c_1 and c_2 are the acceleration constant with a general value of 0–2, rand_1 and rand_2 are the random function with the value in the range of (0, 1), $p_{gj}(t)$ is the best position of particle j experienced, $p_g(t)$ is the best position of all particles, and floor() is the integral function.

Table 1 also shows the start time of each work for resource-leveling optimization with fixed duration solution,

Table 1: The parameters and their optimization solution for the optimization example of the resource-leveling with fixed duration.

Number	Work	Duration	Resources quantity	ES	Optimized ES
1	1–3	2	2	0	0
2	1–4	2	1	0	0
3	3-4	2	1	2	2
4	1-2	1	2	0	0
5	4–6	4	1	4	4
6	5–8	4	1	7	7
7	5–9	5	1	7	7
8	6–8	5	3	13	13
9	7-8	8	3	15	15
10	3–6	3	2	2	2
11	2–4	3	2	1	1
12	3–5	5	1	2	2
13	2–8	3	2	1	1
14	5-6	6	2	7	7
15	2–6	1	3	1	1
16	6-7	2	0	13	13
17	8-9	7	3	23	23
18	8–11	2	2	23	23
19	8–10	2	1	23	23
20	7–10	2	1	15	15
21	9-10	1	2	30	30
22	9–12	4	1	30	30
23	18-19	8	3	57	58
24	17–20	2	1	51	51
25	16–19	4	1	49	49
26	18–21	5	1	57	71
27	17–19	5	3	51	51
28	16-17	2	2	49	49
29	15–17	2	1	46	46
30	14–18	2	1	42	42
31	14–17	1	2	42	42
32	13–15	2	1	44	44
33	10-11	4	1	31	31
34	12-13	5	1	39	39
35	10–13	5	3	31	31
36	10–12	8	3	31	31
37	17-18	6	0	51	51
38	15-16	3	2	46	46
39	11–15	5	1	35	35
40	14-15	3	2	42	42
41	11–17	5	1	35	35
42	12–14	3	2	39	39
43	11–13	6	2	35	35
44	12–15	2	0	39	39
45	21-22	2	2	70	86
46	22–24	2	1	75	88
47	20–22	2	1	73	74
48	20–24	1	2	73	74
49	20–26	2	1	73	74
50	19–21	5	1	65	81
51	19–22	5	3	65	66
52	19-20	8	3	65	66

Table 1: Continued.

Number	Work	Duration	Resources quantity	ES	Optimized ES
53	24-25	3	2	77	96
54	24–26	5	1	77	96
55	26-27	3	2	85	104
56	25-26	5	1	80	99
57	23–27	3	2	72	88
58	23–26	6	2	72	88
59	23-24	1	3	72	88
60	21–23	2	0	70	86
61	21–24	7	3	70	89
62	3–28	1	2	2	2
63	3–30	3	2	2	2
64	3–31	1	3	2	2
65	28–30	2	1	3	3
66	28-29	2	2	3	3
67	29-30	2	1	5	5
68	29–31	3	2	5	5
69	29–34	3	2	5	5
70	30-31	4	1	7	7
71	5–31	6	2	7	7
72	5–34	5	3	7	7
73	31-32	2	0	13	13
74	31–34	4	1	13	13
75	32-33	2	1	15	15
76	32–34	8	3	15	15
77	9–34	7	3	30	30
78	9–33	2	1	30	30
79	34-35	2	2	44	44
80	33-34	1	2	43	43
81	33–35	8	3	43	43
82	33–36	5	3	43	43
83	12–33	4	1	39	39
84	12–36	6	2	39	39
85	12–37	5	1	39	39
86	35-36	5	1	51	51
87	35–37	2	0	51	51
88	35–39	5	1	51	51
89	36-37	2	1	56	56
90	14–37	3	2	42	42
91	14–39	2	1	42	42
92	37-38	3	2	58	58
93	37–39	1	2	58	58
94	38-39	2	2	61	76
95	18–39	6	0	57	57
96	18–40	5	3	57	57
97	39-40	8	3	63	76
98	39–41	2	1	63	63
99	40-41	5	1	78	98
100	40–42	5	3	78	98
101	21–40	8	3	70	90
102	21–42	2	1	70	86
103	21–43	1	2	70	86
104	41-42	2	2	83	103

Table 1: Continued.

Number	Work	Duration	Resources quantity	ES	Optimized ES
105	41–43	7	3	83	103
106	41–45	2	1	83	103
107	42-43	2	1	85	105
108	23–43	1	3	72	88
109	23–45	5	1	72	88
110	43-44	3	2	90	110
111	43–45	6	2	90	110
112	44-45	5	1	93	113
113	27–45	3	2	88	107
114	38–40	4	1	61	61
115	47-48	2	2	8	8
116	48–50	2	1	10	10
117	47–50	2	1	8	8
118	48-49	1	2	10	10
119	50–53	4	1	14	14
120	52–57	4	1	49	49
121	52–58	5	1	49	49
122	53–57	5	3	55	55
123	56-57	8	3	57	57
124	47–53	3	2	8	8
125	49-50	3	2	11	11
126	47–52	5	1	8	8
127	49–57	3	2	11	11
128	52-53	6	2	49	49
129	49–53	1	3	11	11
130	53–56	2	0	55	55
131	57-58	7	3	65	65
132	57–61	2	2	65	65
133	57–59	2	1	65	65
134	56–59	2	1	57	57
135	58-59	1	2	72	72
136	58–60	4	1	72	72
137	71-72	8	3	99	99
138	69–75	2	1	93	93
139	68–72	4	1	91	91
140	71–73	5	1	99	99
141	69–72	5	3	93	93
142	68-69	2	2	91	91
143	67–69	2	1	88	88
144	65–71	2	1	84	84
145	65–69	1	2	84	84
146	64–67	2	1	86	86
147	59–61	4	1	73	73
148	60–64	5	1	81	81
149	59–64	5	3	73	73
150	59-60	8	3	73	73
151	69–71	6	0	93	93
152	67-68	3	2	88	88
153	61–67	5	1	77	77
154	65–67	3	2	84	84
155	61–69	5	1	77	77
156	60–65	3	2	81	81

Table 1: Continued.

Number	Work	Duration	Resources quantity	ES	Optimized ES
157	61–64	6	2	77	77
158	60–67	2	0	81	81
159	73–76	2	2	112	112
160	76–79	2	1	117	117
161	75-76	2	1	115	115
162	75–79	1	2	115	115
163	75–83	2	1	115	115
164	72-73	5	1	107	107
165	72–76	5	3	107	107
166	72–75	8	3	107	107
167	79–82	3	2	119	124
168	79–83	5	1	119	124
169	83-84	3	2	127	132
170	82-83	5	1	122	127
171	78–84	3	2	114	123
172	78–83	6	2	114	123
173	78-79	1	3	114	123
174	73–78	2	0	112	112
175	73–79	7	3	112	112
176	46-47	1	2	7	7
177	47–51	3	2	8	8
178	47–54	1	3	8	8
179	46–51	2	1	7	7
180	29–46	2	2	5	5
181	29–51	2	1	5	5
182	29–54	3	2	5	5
183	51–54	4	1	11	11
184	52–54	6	2	49	49
185	34–52	5	3	44	44
186	54-55	2	0	55	55
187	34–54	4	1	44	44
188	55–62	2	1	57	57
189	34–55	8	3	44	44
190	34–58	7	3	44	44
191	58–62	2	1	72	72
192	34–62	1	2	44	44
193	35–62	8	3	51	51
194	62-63	5	3	85	85
195	60–62	4	1	81	81
196	60–63	6	2	81	81
197	60–66	2	1	81	81
198	35–63	5	1	51	51
199	35–66	2	0	51	51
200	63–66	2	1	90	90
201	65-66	3	2	84	84
202	39–65	2	1	63	63
203	66–70	3	2	92	92
204	39–66	1	2	63	63
205	39–70	2	2	63	63
206	39–71	6	0	63	63
207	71–74	5	3	99	99
208	39–74	8	3	63	63

Table 1: Continued.

Number	Work	Duration	Resources quantity	ES	Optimized ES
209	41–74	5	1	83	103
210	74–77	5	3	120	120
211	73-74	8	3	112	112
212	73–77	2	1	112	112
213	73–80	1	2	112	112
214	41–77	2	2	83	103
215	41–80	7	3	83	103
216	77–80	2	1	125	125
217	78–80	1	3	114	123
218	45–78	5	1	98	118
219	80-81	3	2	127	127
220	45–80	6	2	98	118
221	81–84	5	1	130	130
222	45–84	3	2	98	118
223	70–74	4	1	95	95

"ES" is the early start time of each work. "Optimized ES" is the optimized start time.

corresponding to the resource variance of 22.41. The parameters applied in the OIPSO are the following: the inertia weight $w = 1$ (empirical value), the acceleration constant $c_1 = 3.5$ (empirical value), $c_2 = 4.0$ (empirical value), the particle number $M = 50$ (experimental value), the initial particle variance <30 (experimental value), and the number of iterations $G = 100$ (experimental value). It is obvious that the optimized resource variance (22.41) is much less than the original one (37.51).

3.2. Solving the Optimization of Resources Constraints with Shortest Project Duration. As shown above, the methods of the optimization of resources constraints with shortest project duration in a large-scale network plan and the optimization of resource-leveling with fixed duration are similar. Besides, the initial particle swarm constraint is applied with resources constraints and as small as possible duration. The optimal solutions criteria are different; the constraint range of the feasible solution $C[i][j] + V[i][j]$ is also different, where the spatial coordinates of particles $C[i][j] + V[i][j]$ are the N-dimension variables related to the work start time; their initial values are the coordinates of the initial particle swarm $c[i][j]$; $V[i][j]$ is the flight speed of particles.

The example is as shown in Figure 1, and Table 2 lists the start time of each work for resources constraints with shortest project duration optimization, where 25 is the resource constraint, 199 is the project duration, and 22 is the biggest resources quantity. The applied parameters of the resources constraints with shortest construction period optimization of the OIPSO are the following: the inertia weight $w = 1$ (empirical value), the acceleration constant $c_1 = 3.5$ (empirical value), $c_2 = 0.4$ (empirical value), the quantity of particle $M = 10$ (experimental value), the number of iterations $G = 1000$ (experimental value), the resource constraint of the initial particle swarm is 25 (experimental value), and the constrained duration is 300 (experimental value). The range of $C[i][j] + V[i][j]$ is $d_1[j]$ and $2 * d_1[j]$ (the meaning of $C[i][j]$, $V[i][j]$, and $d_1[j]$ is the same as the previous). The resource constraint (25) is met, and the corresponding project duration (199) is not too long after optimization.

4. The Superiority of OIPSO Compared with the Original and the Existing PSOs

After changing optimization parameters, the superiority of OIPSO in optimization of resource-leveling with fixed duration and resources constraints with shortest project duration of a large-scale network plan in Figure 1 is shown in Tables 3 and 4.

Case 3 in Table 3 and case 8 in Table 4 are obtained by the original and existing PSOs in which the initial particles are randomly decided. Case 1 in Table 3 and case 5 in Table 4 are obtained by the improved algorithm (OIPSO) in which optimization is used to decide the initial particles. For the optimization of resource-leveling with fixed duration or resources constraints with shortest project duration of a large-scale network, it can be found that the improved algorithm (OIPSO) can accelerate the optimization speed and improve the optimization effect of particle swarm optimization under the same number of iterations by adding proper optimization constraints of the initial particle swarm, such as the variance restriction or resources limitation and project duration constraint. The optimization constraints of the initial particle swarm are decided gradually through the experiment such as case 2 (the resource variance corresponding to the initial particle is 50) and case 4 (the resource variance corresponding to the initial particle is 25) in Table 3 and case 6 (the constrained resources of the initial particle are 25 and there is no constrained project duration of the initial particle), case 7 (there are no constrained resources of the initial particle and the constrained project duration of the

Table 2: The parameters and their optimal solution of resources constraints with shortest project duration.

Number	Work	Duration	Resources quantity	ES	Optimized ES
1	1–3	2	2	0	1
2	1–4	2	1	0	7
3	3-4	2	1	2	4
4	1-2	1	2	0	0
5	4–6	4	1	4	10
6	5–8	4	1	7	9
7	5–9	5	1	7	15
8	6–8	5	3	13	18
9	7-8	8	3	15	20
10	3–6	3	2	2	5
11	2–4	3	2	1	2
12	3–5	5	1	2	3
13	2–8	3	2	1	2
14	5-6	6	2	7	9
15	2–6	1	3	1	1
16	6-7	2	0	13	16
17	8-9	7	3	23	33
18	8–11	2	2	23	28
19	8–10	2	1	23	28
20	7–10	2	1	15	19
21	9-10	1	2	30	40
22	9–12	4	1	30	43
23	18-19	8	3	57	84
24	17–20	2	1	51	82
25	16–19	4	1	49	81
26	18–21	5	1	57	97
27	17–19	5	3	51	77
28	16-17	2	2	49	72
29	15–17	2	1	46	69
30	14–18	2	1	42	76
31	14–17	1	2	42	61
32	13–15	2	1	44	64
33	10-11	4	1	31	44
34	12-13	5	1	39	58
35	10–13	5	3	31	41
36	10–12	8	3	31	45
37	17-18	6	0	51	74
38	15-16	3	2	46	68
39	11–15	5	1	35	49
40	14-15	3	2	42	63
41	11–17	5	1	35	51
42	12–14	3	2	39	58
43	11–13	6	2	35	48
44	12–15	2	0	39	53
45	21-22	2	2	70	104
46	22–24	2	1	75	126
47	20–22	2	1	73	107
48	20–24	1	2	73	112
49	20–26	2	1	73	122
50	19–21	5	1	65	96
51	19–22	5	3	65	95
52	19-20	8	3	65	99

Table 2: Continued.

Number	Work	Duration	Resources quantity	ES	Optimized ES
53	24-25	3	2	77	129
54	24–26	5	1	77	131
55	26-27	3	2	85	148
56	25-26	5	1	80	142
57	23–27	3	2	72	108
58	23–26	6	2	72	109
59	23-24	1	3	72	112
60	21–23	2	0	70	102
61	21–24	7	3	70	107
62	3–28	1	2	2	3
63	3–30	3	2	2	10
64	3–31	1	3	2	29
65	28–30	2	1	3	30
66	28-29	2	2	3	5
67	29-30	2	1	5	7
68	29–31	3	2	5	8
69	29–34	3	2	5	9
70	30-31	4	1	7	35
71	5–31	6	2	7	12
72	5–34	5	3	7	43
73	31-32	2	0	13	42
74	31–34	4	1	13	44
75	32-33	2	1	15	61
76	32–34	8	3	15	49
77	9–34	7	3	30	46
78	9–33	2	1	30	41
79	34-35	2	2	44	76
80	33-34	1	2	43	63
81	33–35	8	3	43	67
82	33–36	5	3	43	79
83	12–33	4	1	39	53
84	12–36	6	2	39	57
85	12–37	5	1	39	57
86	35-36	5	1	51	81
87	35–37	2	0	51	79
88	35–39	5	1	51	88
89	36-37	2	1	56	87
90	14–37	3	2	42	63
91	14–39	2	1	42	62
92	37-38	3	2	58	91
93	37–39	1	2	58	94
94	38-39	2	2	61	94
95	18–39	6	0	57	82
96	18–40	5	3	57	83
97	39-40	8	3	63	97
98	39–41	2	1	63	97
99	40-41	5	1	78	118
100	40–42	5	3	78	116
101	21–40	8	3	70	107
102	21–42	2	1	70	121
103	21–43	1	2	70	120
104	41-42	2	2	83	123

Table 2: Continued.

Number	Work	Duration	Resources quantity	ES	Optimized ES
105	41–43	7	3	83	127
106	41–45	2	1	83	130
107	42-43	2	1	85	126
108	23–43	1	3	72	129
109	23–45	5	1	72	108
110	43-44	3	2	90	134
111	43–45	6	2	90	139
112	44-45	5	1	93	141
113	27–45	3	2	88	151
114	38–40	4	1	61	96
115	47-48	2	2	8	31
116	48–50	2	1	10	48
117	47–50	2	1	8	32
118	48-49	1	2	10	43
119	50–53	4	1	14	70
120	52–57	4	1	49	74
121	52–58	5	1	49	73
122	53–57	5	3	55	87
123	56-57	8	3	57	86
124	47–53	3	2	8	32
125	49-50	3	2	11	67
126	47–52	5	1	8	33
127	49–57	3	2	11	49
128	52-53	6	2	49	69
129	49–53	1	3	11	82
130	53–56	2	0	55	84
131	57-58	7	3	65	94
132	57–61	2	2	65	103
133	57–59	2	1	65	95
134	56–59	2	1	57	100
135	58-59	1	2	72	101
136	58–60	4	1	72	104
137	71-72	8	3	99	138
138	69–75	2	1	93	130
139	68–72	4	1	91	127
140	71–73	5	1	99	138
141	69–72	5	3	93	131
142	68-69	2	2	91	126
143	67–69	2	1	88	123
144	65–71	2	1	84	118
145	65–69	1	2	84	128
146	64–67	2	1	86	119
147	59–61	4	1	73	104
148	60–64	5	1	81	113
149	59–64	5	3	73	106
150	59-60	8	3	73	105
151	69–71	6	0	93	129
152	67-68	3	2	88	122
153	61–67	5	1	77	111
154	65–67	3	2	84	119
155	61–69	5	1	77	112
156	60–65	3	2	81	114

Table 2: Continued.

Number	Work	Duration	Resources quantity	ES	Optimized ES
157	61–64	6	2	77	112
158	60–67	2	0	81	114
159	73–76	2	2	112	152
160	76–79	2	1	117	162
161	75-76	2	1	115	159
162	75–79	1	2	115	168
163	75–83	2	1	115	160
164	72-73	5	1	107	146
165	72–76	5	3	107	150
166	72–75	8	3	107	151
167	79–82	3	2	119	171
168	79–83	5	1	119	174
169	83-84	3	2	127	181
170	82-83	5	1	122	175
171	78–84	3	2	114	163
172	78–83	6	2	114	162
173	78-79	1	3	114	161
174	73–78	2	0	112	151
175	73–79	7	3	112	155
176	46-47	1	2	7	30
177	47–51	3	2	8	33
178	47–54	1	3	8	101
179	46–51	2	1	7	37
180	29–46	2	2	5	25
181	29–51	2	1	5	9
182	29–54	3	2	5	98
183	51–54	4	1	11	130
184	52–54	6	2	49	69
185	34–52	5	3	44	64
186	54-55	2	0	55	134
187	34–54	4	1	44	110
188	55–62	2	1	57	138
189	34–55	8	3	44	71
190	34–58	7	3	44	70
191	58–62	2	1	72	132
192	34–62	1	2	44	123
193	35–62	8	3	51	83
194	62-63	5	3	85	142
195	60–62	4	1	81	115
196	60–63	6	2	81	118
197	60–66	2	1	81	118
198	35–63	5	1	51	81
199	35–66	2	0	51	83
200	63–66	2	1	90	148
201	65-66	3	2	84	130
202	39–65	2	1	63	98
203	66–70	3	2	92	152
204	39–66	1	2	63	100
205	39–70	2	2	63	129
206	39–71	6	0	63	101
207	71–74	5	3	99	148
208	39–74	8	3	63	105

Table 2: Continued.

Number	Work	Duration	Resources quantity	ES	Optimized ES
209	41–74	5	1	83	140
210	74–77	5	3	120	164
211	73-74	8	3	112	155
212	73–77	2	1	112	154
213	73–80	1	2	112	168
214	41–77	2	2	83	123
215	41–80	7	3	83	123
216	77–80	2	1	125	170
217	78–80	1	3	114	161
218	45–78	5	1	98	156
219	80-81	3	2	127	174
220	45–80	6	2	98	159
221	81–84	5	1	130	177
222	45–84	3	2	98	155
223	70–74	4	1	95	158

"ES" is the early start time of each work. "Optimized ES" is the optimized start time.

Table 3: The superiority of OIPSO in optimization of resource-leveling with fixed duration.

Optimization parameters	Case 1	Case 2	Case 3	Case 4
w	1	1	1	1
c_1	3.5	3.5	3.5	3.5
c_2	0.4	0.4	0.4	0.4
M	50	50	50	50
G	100	100	100	100
The project duration of the network plan	135	135	135	135
The project duration of the initial particle	135	135	135	135
The resource variance corresponding to the initial particle	30	50	—	25
The resource variance corresponding to the optimization results	22.41	22.99	22.99	—

"—" denotes "no restrictions" or "no solution in a limited amount of computing time." The other symbols' meanings are the same as the previous.

Table 4: The superiority of OIPSO in optimization of resources constraints with shortest project duration.

Optimization parameters	Case 5	Case 6	Case 7	Case 8	Case 9
w	1	1	1	1	1
c_1	3.5	3.5	3.5	3.5	3.5
c_2	0.4	0.4	0.4	0.4	0.4
M	10	10	10	10	10
G	1000	1000	1000	1000	1000
The constrained resources of the network plan	25	25	25	25	25
The constrained resources of the initial particle	25	25	—	—	25
The constrained project duration of the initial particle	300	—	300	—	200
The biggest resources quantity after optimization	22	21	22	19	—
The calculated project duration after optimization	199	206	199	206	—

Annotation is the same as Table 3.

initial particle is 300), and case 9 (the constrained resources and the constrained project duration of the initial particle are, respectively, 25 and 200) in Table 4.

5. Conclusion

In this paper, the improved particle swarm optimization algorithm via optimization of initial particle swarm (OIPSO) has been proven to improve the solution probability of optimal solution or by the theory of Markov chains in random process and the optimization examples accelerates the optimization speed and improves optimization effect of particle swarm optimization under the same number of iterations. In existing publications on the larger-scale network plan optimization, the optimization examples of the resource-leveling with fixed duration and the resources constraints with shortest project duration on the large-scale network plan with 223 works have the largest work quantity.

Competing Interests

The authors declare that there is no conflict of interests regarding the publication of this paper.

Acknowledgments

This research is a part of the results of Methods Research on Resource Optimization of Large-scale Network Plan (2014-K3-039), which is the Science and Technology Plan Project from Housing and Urban-Rural Development of China.

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