A Genetic Algorithm-based Study on the Optimization of Scheduling of Project Development

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Abstract

The thesis is a study on the optimization of scheduling of project development, with the problem stemming from Clash of Clans (COC)– a mobile phone-oriented network game developed by Supercell. Based on COC's game environment, the author, through the analysis and evaluation of optimization tools, proposes the parameters setting that fits the game and provides the game strategy schemes needed by players, i.e. they can define the sequence and time arrangement of performing a game task via the optimization algorithm, so as to significantly reduce "redundant game time", speed up the progress of games and obtain better game experience. The objective of the study is to analyze the needs of different players on the basis of becoming familiar with the game environment and to put forward optimal game strategy schemes in addition to meeting corresponding required conditions according to the game stage each player is in. Apart from establishing an operations research model that meet the goal of optimization on the foundation of game environment, the author adopts the Genetic Algorithm (GA) to undertake guiding search for feasible schemes that meet the required conditions so as to achieve optimal solutions. To explain the practical effects of the method in detail, the thesis will show and use the algorithm with a game case and demonstrate the effects and efficiency of the algorithm with a large quantity of data.

Introduction

Research background and significance

With the continuous development and popularization of mobile Internet technologies, mobile network games have gradually become popular in the field of IT game and an increasing number of people have begun to indulge in the fresh experience brought by the games.

The thesis is a study on the optimization of time sequence of project development, with the problem stemming from Clash of Clans (COC) – a mobile phone-oriented network game developed by Supercell.

In the game environment of COC, each player has a game clan of his own. Meanwhile, all players would be equipped with three construction workers, a Level-1 stronghold, and a certain quantity of "money", "elixir" and "diamonds" ("Diamonds" can be purchased with actual currency and be converted to corresponding quantity of "money" and "elixir") at the initial stage. In the process of the game, players can acquire resources to establish and develop clans through three ways – "attack other clans", "purchase diamonds" and "automatically collect resources". If a player is off the line, his clan may be attacked by other players, which would cost him some "money" and "elixir".

Players need to establish or upgrade different game facilities in their clans, including strongholds, defense facilities, military armies and resources. And they also need to increase resources to upgrade their strongholds which can be upgraded from the initial Level-1 to Level-10. Constructing or upgrading game facilities consumes three kinds of resources: human resources (the establishment or upgrading of each game facility requires a construction worker), money or elixir, and time ("Diamond" can help finish the construction in a second). What deserves attention is that when players are off the line, the construction workers who have been at work would not "stop their work". It means that if players want to complete the construction of all game facilities that meet the resource conditions in the shortest time, they have to constantly appoint all construction workers for the construction work.

With the progress of the game, each player would face the problem on how to arrange the sequence of the construction of tens of hundreds of game facilities. Therefore, how to arrange the construction sequence of these game facilities would directly determine how fast players can increase their speed and how well they can improve their game experience.

Focusing on the problem, the thesis simulates a game situation by establishing an operational research model and using such optimization tools as computer programming language and project management software. Through optimization computing, the author provides a set of scientific and efficient schemes of construction time and sequence for game facilities, so as to significantly promote the playability of the game and enhance the game experience of players.

The study on the problem is not limited to the enhancement of game experience of players, for it is also applicable to the time and sequence arrangement of system engineering like the construction of project engineering. Through the research on the economic value or basic features of sub-projects and through optimization, the author puts forwards a set of rational plans of development time and sequence, thus reducing cost, shortening work period and increasing the exploration of value.

Elements involved in the study

In order to construct game facilities in the most efficient way, players

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must gain resources as quickly as possible and reduce the leisure time of all construction workers as much as possible, i.e. constantly arrange construction tasks for all the construction workers. Due to the fact that the study is about the optimization of construction time and sequence of game facilities, the restrictions on the resources for the construction are not discussed here. Instead, only the restrictions on labor and time of the game facilities are explored.

Restriction on labor means that each game facility can be built by any construction worker, who would be the only one responsible for the facility from the beginning to the end. This means that the largest number of facilities that can be concurrently built by the system is equal to the total number of the construction workers owned by the system. Construction workers can be purchased with "diamonds". According to statistics, 80% of players have 3 to 5 construction workers. In the case analysis in the later part of the thesis, the author analyzes three construction workers.

Restriction on time means that players can only construct each game facility when the game is logged on and that they cannot make construction orders of game facilities beforehand. It is impossible for players to log on the game for 24 hours, so if any game facility is completed while players are off the game, they cannot appoint the construction workers free from previous tasks for the construction of new facilities until they log on the game again. Hence, the game schedule and life routine of each player must be taken into consideration to set "assignment period" and "non-assignment period" in terms of the time and sequence arrangement of game facilities. If construction workers complete their work during the "non-assignment period", they would have to wait until the "assignment period" to get the order for a new construction task; if they complete work during the "assignment period", they would be allowed to begin the construction of a new game facility.

For that reason, the above two kinds of restrictions in addition to the setting of game parameters in the current environment must be taken into consideration for the establishment of the optimization model. Based on the establishment of an objective and rational optimization model, a set of feasible optimization schemes of practical significance will be made.

Tools for the study

Given such a large number of construction tasks and the game schedules of different players, it is apparently impractical and inefficient to make game strategies with the enumeration method. In the search for an optimization solution to a problem like this, the genetic algorithm demonstrates its advantageous efficiency in computing and operability. Judging the advantages and disadvantages of the entire time and sequence scheme to evaluate the value of adaptability in the algorithm is simple in operation and is relatively understandable and receivable. Meanwhile, the intelligent heuristic algorithm, which is represented by the genetic algorithm, is highly efficient in solving complicated problems and can, to some extent, bring a better similar optimum solution.

Framework of the thesis

The structure of the following parts of the thesis is like this: Section 2 is about the current research on the topic; in Section 3, the author describes the background of the optimization of time and sequence arrangement of COC game facilities in detail; Section 4 introduces the optimization framework and relevant optimization components established on the basis of the problem; in Section 5, the author

analyzes and presents the algorithm with a case; Section 6 demonstrates the efficiency and effects of the algorithm with a large quantity of data; the conclusion of the thesis is in Section 7; in Section 8, there is a bibliography.

Related Works

Current situation

At present, the research on the time and sequence optimization based on project development has been highly mature. With regard to the study on the schedule of projects with restriction on classical resources:

Based on the disjunctive arc theory, Bell and Han [1] propose the two-stage method. First, the method creates a feasible solution that meets the restriction on time and sequence; then, it achieves restoration with the resource restrictions; last, it optimizes the ignition solution with the hill-climbing method to get the optimum solution.

Zhang Hong and Li Xiaodong [2] argue that multi-dimensional particles can be used to describe the resource limitation with the optimization goal of achieving the shortest project period, for particles can seek optimization in the constantly updating tracks. The authors establish the operational program with priority on the basis of the sequencing rules and have accomplished satisfactory effects.

Liu Ming [3] analyzes the traditional heuristic algorithm for solving limited resources and achieving the shortest period and points out that there are significant errors in its application. He proposes the branch and bound method whose computing quantity is far less than that of the heuristic algorithm and can reduce errors to an acceptable arrange.

According to the features of projects with limitation on resources, Liu Shixin and Wang Mengguang [4] improve the traditional genetic algorithm. To ensure that no excellent individuals will be missed, the algorithm always directly replicates some excellent individuals from the previous generation for the next one. With the precedence compatibility linked list as the encoding method for individuals, the algorithm uses the serial schedule scheme for decoding. They have achieved satisfactory effects in seeking the solution to the problem of the shortest period with the algorithm.

Wang Hong and Lin Dan [5] improve the encoding of the task linked list and add genes representing decoding rules and directions to the end of the task linked list. The two genes control the decoding rules and directions of chromosomes. The algorithm is of limited significance for seeking solution to the problem of combined optimization with limitation on resources.

Amer Fahmya et al. [6] present a new justification technique, Stacking Justification, for solving RCPSP and for further improvement of generated schedules quality. Meanwhile, the multiple justification particle swarm optimization (MJPSO) algorithm is developed to test the performance of this new justification technique.

José Coelhoa and Mario Vanhoucke [7], adopt a novel approach to solve the multi-mode resource-constrained project scheduling problem (MRCPSP). They design a new algorithm splitting the problem type into a mode assignment and a single mode project scheduling step, and the solution approach use only one priority list, instead of using an activity and a mode list as normally done in literature.

Based on activities which have to be processed without preemptions, Peter and Sigrid [8] develop a new destructive lower bound for the resource-constrained project scheduling problem (RCPSP). The lower

bound calculations are based on two methods for proving infeasibility of a given threshold value T for the makespan. At the same time, a column generation procedure is presented for the linear programming formulation and computational results are reported for an algorithm combining both concepts.

Vicente et al. [9] analyze that justification is a simple technique that can be easily incorporated in diverse algorithms for the resource-constrained project scheduling problem--improving the quality of the schedules generated without generally requiring more computing time. The results of incorporating this technique in 22 different algorithms are shown. Fifteen of the new algorithms that use double justification outperform seven of the best heuristic algorithms that do not use justification.

Liu and Wang [10] have paid attention to the objective of minimizing activities' cost with the resource constraints that is a critical sub-problem in partner selection of construction supply chain management because the capacities of the renewable resources supplied by the partners will effect on the project scheduling.

Filip et al. [11] propose and evaluate a number of dedicated exact reactive scheduling procedures as well as a tabu search heuristic for repairing a disrupted schedule, under the assumption that no activity can be started before its baseline starting time.

Based on priority rule for parallel schedule generation scheme, Bhaskara et al. [12] propose a heuristic method for resource constrained project scheduling problem with fuzzy activity times. Calculation of critical path in this case requires comparison of fuzzy numbers. They also implement a measure to find the non-integer power of a fuzzy number.

Advantages of the study

Most of the above researches on the optimization of similar problems in the academic community emphasize the analysis of restrictions on objective resources, but few of them pay adequate attention to subjective factors like personal preference and individual schedule. Combing objective and subjective factors, the thesis is a optimization study on the time and sequence arrangement of project development of systematic engineering.

Additionally, the thesis is the first optimization study on the time and sequence of COC's game facilities. At present, the results of the optimization are computed and output only in the form of source procedure, but in the future the author will consider packing the optimization program into a mobile APP and bundling it with game systems, so as to provide the large number of COC players with the optimization service and thus promote the development of mobile network games and enhance the experience of players. Also, it is predicted that it will produce certain amount of economic benefits and profits.

Background of the Problem

Description of the research problem

According to the objective of "providing a set of efficient schemes for construction of game facilities" to be realized in the thesis, a targeted function value needs to be set to judge and evaluate the advantages and disadvantages of the schemes. However, the making of the targeted function value needs to be designed according to practical problems. In order to measure the merits and demerits of the optimization schemes, two critical indicators need to be considered: (1) the total time each construction worker spends from the initial moment of the system to the moment he completes the construction of the last game facility; (2) the total time from the initial moment of the system to the moment when the construction of the last game facility is completed.

To reach the objective of achieving the highest efficiency of the schemes, the size of the two indicators must be minimized; thus, the aggregation of the two is used to measure the merits and demerits of the schemes.

To equip the research on the problem with universal adaptability and economic efficiency, the research problem can be transformed, i.e. the two indicators originally representing time are transformed into two cost types symbolizing engineering projects:

Indicator (1) can refer to "the labor cost of engineering projects"; Indicator (2) is compared with a parameter that is set beforehand. If Indicator (2) is higher than the parameter, there would be a margin (the margin is equal to the overstepped value); then Indicator (2) subtracts the margin. In this way, the adjusted Indicator (2) can represent "the delayed cost of engineering projects".

When the time efficiency of the schemes reaches the highest level, the aggregation of the corresponding two items of cost is the lowest.

Therefore, the transformed problem can be regarded as an engineering economic model which evaluates the labor cost and delay cost of construction projects: in the initial stage, the system employs several construction workers, and the adjusted Indicator (1) and Indicator (2) represent the labor cost and the delay cost of construction projects respectively. On the basis of meeting all restrictions, the construction scheme with the lowest aggregation of the two items of cost would be the most economical construction scheme or the most efficient construction scheme of game facilities.

After the adjustment, the description of the problem is as follow:

At present, the system has altogether M items of Task A which consumes Resource X and N items of Task B which consumes Resource Y. The two tasks are numbered A_i and B_j respectively. The time and resources they need to consume respectively are TA_i, RA_i, TB_j and RB_j, and the total resources of the system are X_0 and Y_0.

Suppose that the start time of the project is T_0 and the terminal time T_0. At T_0 the system employs W workers. The employment period of each worker ranges from T_0 to the time the system arranges for him to finish the last task, and the daily employment expense for each worker is C_k. If the system fails to complete the work in T_0, the daily delay cost is DC.

- **Restrictions:**

1) Each task can be completed by any worker;

2) Each worker can only undertake a task at the same time;

3) The daily $[T_s, T_s]$ is "non-assignment period" while the rest "assignment period"; if workers complete their work during the "non-assignment period", they would not receive the next assignment order until the "assignment period"; if they complete their work during the "assignment period", they would be allowed to begin a new task;

4) The number of the resources to be consumed for the appointed work should not exceed the total number of the currently corresponding system resources;

5) The quantity of the appointed work should not exceed the total

number of the tasks of the current system.

- **Objective of seeking solution:** How to assign work so as to achieve a minimum employment combined with delay cost for completing all tasks or systems in the shortest time on the basis of meeting the resource restrictions from $T_{0?}$ (The assignment scheme is shown in Figure 1).

Establishment of problem model

If the model is regarded as one about the cost control of architectural engineering, two parameters–the start time of construction (T_0) and the end time of construction ($T_{0'}$)–need to be set. $T_{0'}$ can be seen as the contract period of construction (it is manually set according to other system parameters and practical operation experience). If the total construction period exceeds T_0, there would be a construction delay cost. $T_{0'}$ serves as a standard to assess the length of the total construction period and then the background of the original problem. The assignment of tasks must meet certain time requirements, so $[T_s, T_{s'}]$ (s represents working day) is set as a daily "non-assignment period". During the period, the system cannot send schedule orders, for which construction workers would not receive task orders until the assignment period. Meanwhile, the time and resources for each task, the total number of resources of the system at the initial moment, and the parameters of the employment cost and the delay cost, all these must be made clear.

For the setting of independent variables: the optimization model adopts 0-1 integers planning, with X_{ki} and Y_{kj} representing the assignment orders for A-type and B-type tasks respectively ("0" represents "non-assignment"; "1" "assignment"; "i" "j" and "k" refer to "task index" and "worker index" respectively.) In addition to "task index" and "worker index", two variables –ST_kA_i and ST_kB_j are needed to indicate the start time of each task. Meanwhile, FT_kA_i and FT_kB_j are used to indicate the end time of each task. Last, the end time when each worker finishes his last task is taken as his employment time.

For the setting of dependent variables: the objective is to seek the least total expenses (or the highest efficiency) which consists of the employment cost and the delay cost. The employment cost can be achieved by multiplying and aggregating the employment time (HT_k) and the employment cost coefficient (C_k) while the delay cost is achieved by multiplying and aggregating the delay time (DT) and the delay expense coefficient (b). Meanwhile, the delay time (DT) needs to be determined through the comparison between the total construction period (LT) and the planned construction end time ($T_{0'}$) (Tables 1 and 2).

- Targeted function:

$$\text{Minimize } Z = \sum\nolimits_{k=1}^{w}\left(C_k HT_k k + bDT\right) \tag{1.1}$$

$$\text{OR Minimize } Z = \sum\nolimits_{i=1}^{M}\sum\nolimits_{j=1}^{N}\sum\nolimits_{k=1}^{W}\left(ST_k A_i + ST_k B_j\right) \tag{1.2}$$

- s.t:

$$\sum\nolimits_{i=1}^{M}\sum\nolimits_{k=1}^{W} X_{ki} RA_i \le X_0 \tag{1.3}$$

$$\sum\nolimits_{i=1}^{N}\sum\nolimits_{k=1}^{W} X_{kj} RB_j \le Y_0 \tag{1.4}$$

$$T_{S-1'} \le ST_k A_i \le T_{S'} \qquad \forall i \in M \, \forall k \in W \, S \in N^* \tag{1.5}$$

$$T_{S-1'} \le ST_k B_i \le T_{S'} \qquad \forall j \in N \, \forall k \in W \, S \in N^* \tag{1.6}$$

$$FT_k A_i = ST_k A_i + TA_i \qquad \forall j \in M \, \forall k \in W \tag{1.7}$$

$$FT_k B_j = ST_k B_j + TB_j \qquad \forall i \in M \, \forall k \in W \tag{1.8}$$

$$ST_k A_i \le max\left\{FT_{kx}\right\} \quad \forall i \in M \, \forall k \in W \, \forall x \in P \tag{1.9}$$

$$ST_k B_j \le max\left\{FT_{kx}\right\} \qquad \forall i \in M \, \forall k \in W \, \forall x \in P \tag{1.10}$$

$$HT_k = max\left\{FT_k A_i, \, FT_k B_j\right\} \qquad \forall i \in M \, \forall j \in N \, \forall k \in W \tag{1.11}$$

$$LT = max\left\{HT_k\right\} \qquad \forall k \in W \tag{1.12}$$

$$DT = \left(LT - T_{0'}\right)^+ \tag{1.13}$$

$$\sum\nolimits_{i=1}^{M} x_{ki} \le M \qquad k = 1, 2, \ldots, W \tag{1.14}$$

$$\sum\nolimits_{j=1}^{N} y_{kj} \le N \qquad k = 1, 2, \ldots, W \tag{1.15}$$

$$\sum\nolimits_{k=1}^{w} x_{ki} = 1 \qquad i = 1, 2, \ldots, M \tag{1.16}$$

$$\sum\nolimits_{j=1}^{N} y_{kj} = 1 \qquad j = 1, 2, \ldots, N \tag{1.17}$$

$$x_{ki} \in \{0,1\} \, ; \, y_{kj} \in \{0,1\} \quad \forall i \in M \quad \forall j \in N \, \forall k \in W \tag{1.18}$$

Formula (1.1) defines the targeted function from the perspective of cost while Formula (1.2) defines it from the aspect of time. M, N, W and P represent the amount of A-type tasks, B-type tasks, workers and the preorder task assemblage of the current task respectively. Formula (1.3) and (1.4) refer to the resource restriction of the optimization model, i.e. the aggregation of resources for the assigned tasks is no more than that of the current resources. The thesis is mainly about the time and sequence arrangement of tasks, so if the total resources of the system
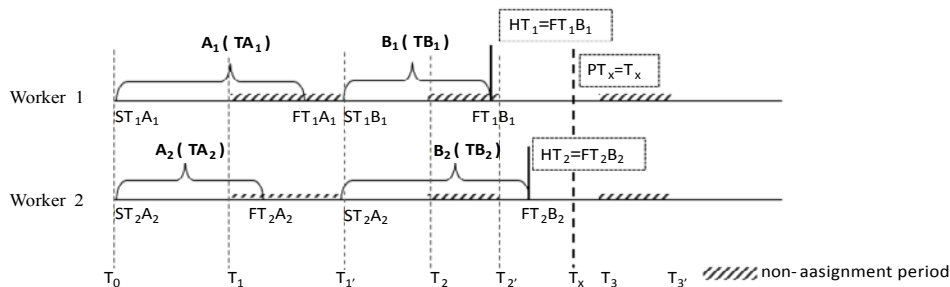

Figure 1: Assignment Scheme.

Parameters Type	Definition	Range
T_0	Start time of construction	
$T_{0'}$	Planed end time of construction	
$T_s \sim T_{s'}$	Non-assignment period	$s = (1, 2, \ldots, t)$, $t \in N^*$
M	The amount of A-type task	$M \in N^*$
N	The amount of B-type task	$N \in N^*$
K	The amount of worker	$K \in N^*$
TA_i	The construction period for No.i A-type task	$\forall i \in M \; \forall j \in N$
TB_j	The construction period for No.j B-type task	
RA_i	The resources for No.i A-type task	
RB_j	The resources for No.j B-type task	
X_0	The total number of the system's resource X at T_0	
Y_0	The total number of the system's resource Y at T_0	
C_k	The employment cost coefficient (the employment expense for each worker a day)	$k \in N^*$
b	The delay cost coefficient (the daily delay cost of the system)	

Table 1: Definition of parameters.

Type of variables	Name of variables	Definition	Range
Independent variables	ST_kA_i	The start time of No.k worker responsible for No.i A-type task	$\forall i \in M \;\; \forall j \in N \;\; \forall k \in W$
	ST_kB_j	The start time of No.k worker responsible for No.j B-type task	
	x_{ki}	The assignment order of No.k worker responsible for No.i A-type task	
	y_{kj}	The assignment order of No.k worker responsible for No.j B-type task	
Dependent variables	FT_kA_i	The end time of No.k worker responsible for No.i A-type task	$\forall i \in M \;\; \forall j \in N \;\; \forall k \in W$
	FT_kB_j	The start time of No.k worker responsible for No.j B-type task	
	HT_k	The employment time of No.k worker	
	LT	The total construction period	
	DT	The delay time of construction	

Table 2: Definition of variables.

match that of all tasks in the process of setting the parameters of the system, the assignment of all tasks would be achieved. Due to the more complicated situation in reality, however, the current resources of the system are inadequate for the assignment of all tasks. Worse still, the resources of the system would change with the passage of time. For that reason, priority is given to the design of corresponding restrictions in the establishment of the model so as to make a preparation for further research in the future. Formula (5)–(1.10) indicate the time restriction of the optimization model and the computing of some dependent variables. Formula (1.11) means the time No.K worker completes his last task is regarded as his employment time. Formula (1.12) means that the longest employment time is taken as the total construction period. Formula (1.13) means that if the total construction period is longer than the contracted construction period, there would be a construction delay, which would result in corresponding delay cost. Formula (1.14) and (1.15) refer to restriction on the quantity of task assignment. Formula (1.16) and (1.17) mean that the same task can only be assigned once. Formula (1.18) refers to the variable of decision-making.

Two decision-making stages of the problem

The process of solving the problem should be divided into two stages–the stage of task selection and the stage of task assignment.

In the stage of task selection, several "to-be-distributed task assemblages" that meet the "upper limit of the system resource" are selected from the tasks to be distributed according to the current upper limit of system resource. If there is not the restriction on the system resource, all the tasks would be assigned. The thesis aims to explore the time and sequence arrangement of tasks, so it is simplified in the first stage. Nevertheless, the restriction on the system resources must be taken into consideration in terms of its application in practical problems. Meanwhile, according to the requirements of COC's game environment, the constriction scheme of each game facility corresponds with different player strategies and the enhancement of abilities after the construction; hence, the first stage will be enriched and deepened in the future studies.

In the stage of task assignment, all tasks that meet the assignment order are assigned, including task type, task index, worker index and the start time of tasks. Then, the employment time of each worker is evaluated to get two key indicators–the employment cost and the delay cost. For the last step, the two indicators are aggregated to compare the schemes. Meanwhile, the task assignment must meet all the restrictions set for the problem.

Establishment of the Optimization Model

Optimization of components

Genetic algorithm is adopted as the optimization method in the thesis, and the programming tool of Visual C++ is also used for the application of the algorithm. Genetic algorithm is a computing model that simulates the natural selection of Darwin's evolutionary theory and the biological evolution of the genetic mechanism. Also, it is an optimal way for searching through simulating natural evolution. The genetic operators are set as follow:

Chromosome: What the thesis explores is the time and sequence

arrangement, so real encoding is adopted for the design. Based on the programming environment of the VC language, the author finally decides to use embedded structure array to represent chromosome, i.e. the assignment order assemblage and the assignment order of monomial task of the scheme. The definition of the structure array is shown in Tables 3 and 4.

The assignment order assemblage of the scheme consists of monomial task assignment order (embedded), task quantity, total employment time, total construction period and the fitness of the scheme. Monomial task assignment order comprises worker index, task type, task index and the start time of tasks. In the decision-making of the scheme in the later part, emphasis is placed on optimal operation according to the monomial task assignment order.

To avoid the problem that a task is repetitiously assigned after crossover operation, the members in the Job_index of the monomial task assignment order (Structure sch) are sorted.

Initialized population: Two methods are adopted to generate initial solution in the research on the problem: the random generation method and the artificial setting method. The latter can be achieved through observation and the analysis of experience evaluation, with a relatively higher individual fitness. The analysis is based on the comparison about the influence on the optimization efficiency and effects between the two groups of initial solutions generated by the two different methods. The number of each group of initial solutions is 20.

Fitness of chromosome: The fitness of chromosome indicates the merits and demerits of understanding. The targeted function in the mathematical model is adopted in the thesis to evaluate the fitness of chromosome. To realize the goal of the highest efficiency, the author adopts the Formula (1.2) in the problem model as the computing function of chromosome fitness.

Selection: Evaluate and sort the fitness of parent individuals and make it a rule that top 15% of the individuals are directly passed on to the next generation instead of undertaking the evolution of the current generation. Operate the individuals ranking from 15% to 85% in a crossover way. The mutation operation is taken on the last 15%. The selection is done as shown in Figure 2.

Crossover: Adopt the multi-point crossover strategy to undertake the crossover and interchanging operation on the divided sections
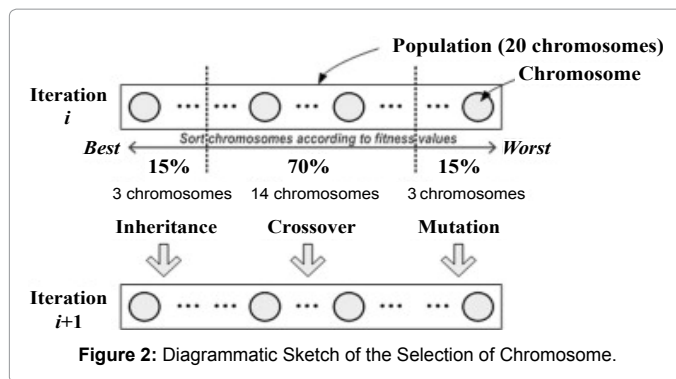

Figure 2: Diagrammatic Sketch of the Selection of Chromosome.
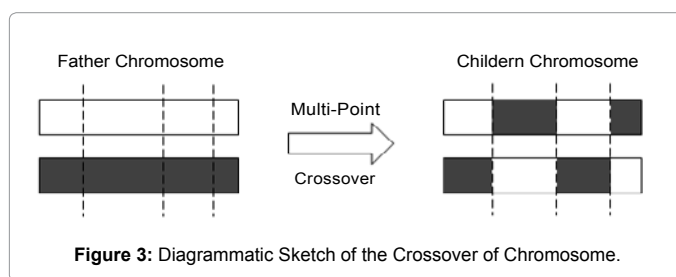

Figure 3: Diagrammatic Sketch of the Crossover of Chromosome.
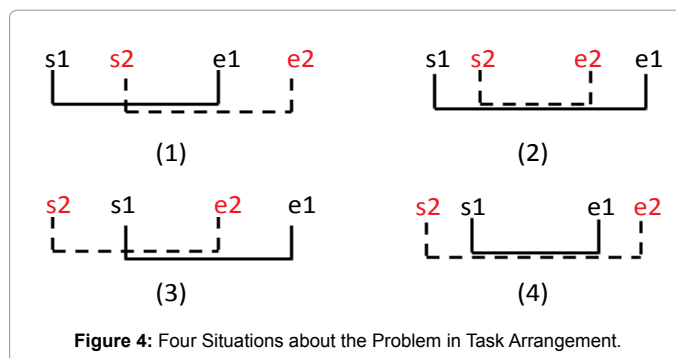

Figure 4: Four Situations about the Problem in Task Arrangement.

of the chromosome. In the model, 14 individuals are involved in the crossover and form 7 crossover pairs. After the operation, 14 new individuals will be generated. The operation of crossover is shown in Figure 3.

Crossover rate: It indicates the frequency of the crossover for individuals. Specifically, if the crossover rate is 0.7, 14 individuals (20*0.7=14) from the colony of 20 individuals are selected for the crossover.

Mutation: Change the genes of some parts of the chromosome according to certain possibility. In the thesis, the parts for mutation are set as "worker index" and the "start time of task". Through the mutation, the start sequence and the start time of the tasks in the scheme would change, which would change the fitness of individuals. There are two objectives for the operation of mutation: one is to equip the genetic algorithm with the ability of random search in some parts. When the genetic algorithm approaches the neighborhood of the optimal solution through the crossover operator, the ability of random search in some parts of the mutated operator quicken the convergence towards the optimal solution; the other is to use the genetic algorithm to maintain the diversity of colony so as to prevent immature convergence.

Mutation rate: It indicates the frequency of mutated operation

Plan	scheduels [Ichrom]	Task Count	Hiring Time	Total Time	Fitness
plan[0]		18	2891	600	2109
plan[1]		18	1490	450	3510
plan[2]	Nested Structure For sch[Ichrom]	18	1570	520	3430
......		......	......	......	......
plan[popsize]		18	2000	400	4600

Table 3: Definition of Structure Array of Assignment Order Assemblage of the Scheme.

Member Name	Worker Id	Task Type	Task Index	Start Time
sch[0]	0	1	0	20
sch[1]	1	1	1	20
sch[1]	2	1	2	20
......	......	......	......	......
sch[Ichrom]	2	2	17	300
Member Note:	Worker Code	0=Type A 1=Type B	0=Task No.1	

Table 4: Definition of Structure Array of Monomial Task Assignment Order.

for individuals. Specifically, if the crossover rate is 0.1, 2 individuals (20*0.1=2) from the colony of 20 individuals are selected for the mutation.

Adjustment: Test individuals each time they have undertaken the crossover and the mutation operation. If any one does not meet the restriction, it would be adjusted until it meets the restriction. In the study, the design of the chromosome makes it impossible that a task would be assigned more than once. However, due to the evaluation operation of crossover and mutation, it is possible that a task would start during the "non-assignment period" and that a worker concurrently engages in two tasks. The adjustment can be divided into two steps: (1) Adjustment of the start time during the non-assignment period; (2) adjustment of a worker's engaging in two tasks at the same time.

There are two situations in Step (1). If there isn't any other task at the start time of the non-assignment period when the current task is being done, the current task is ordered to be equal to the start time. Otherwise, the start time of the current task is ordered to be equal to its terminal time. (According to the setting of the problem, tasks can be assigned on the boundary between the start time and the terminal time of the non-assignment period.)

There are roughly four situations in Step (2), as is shown in Figure 4.

Situation (1) and (2) are under the problem type of $s_1<s_2<s_3$, and the adjustment strategy is to achieve $s_2=s_1$. Meanwhile, if e_1 is in the "non-assignment period", s_2 is equal to the start time of the "assignment period". Situation (3) and (4) are under the problem type of $s_2<s_1<e_2$, and the adjustment strategy is to achieve $s_1=e_2$. Meanwhile, if e_2 is in the "non-assignment period", s_1 moves backwards to the start time of the "assignment period". To avoid new problems after adjustment, the adjusted parts would be marked and the marked parts would be re-checked after the current round of adjustment. If there is any new problem, the adjustment will be made again until there isn't any new problem, which means that all problems have been solved and that the adjustment has come to an end.

After the adjustment, it should be ensured that all the solutions obtained from the process of the genetic operation are workable ones, so that the results of the optimization are in the range of the workable solution assemblage, thus avoiding the reduction in the effect and efficiency of the algorithm search. The procedure of the adjustment is shown in Figure 5.

Elite statistics: Evaluate the fitness of all generated individuals and record the individuals with an fitness of 5. This is beneficial for the data analysis experiment in the later period to reflect the information about the individuals.
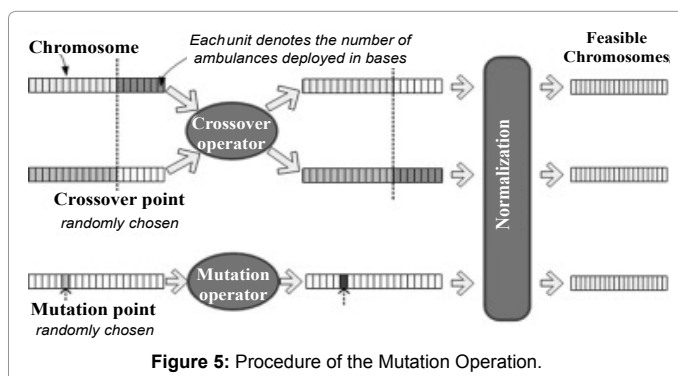

Figure 5: Procedure of the Mutation Operation.

Framework of the optimization procedure

The GA will be achieved with the Visual C++ programming language. The framework of the optimization procedure is as follow:

Initialization generates 20 initial chromosomes to form an initial population;

// Transfer the initialized function to generate initial chromosomes; every chromosome is a structure array consists of some parameters and variables in question such as "schedules" (embedded), "Hiring Time" and "Total Time" of each plan.

Evaluate each chromosome's fitness by a defined function Fit(x) wrote according to the Targeted function mentioned in the section 3.2.

DO (Run genetic evolution and inheritance among iterations)

{

Generate (evolution and inheritance operation function) "Select", "Crossover" and "Mutation" the parent individuals to get child individuals and pass them to the next iteration.

DO (evolution in the current iteration)

{

Directly select top 15% of parent individuals in terms of fitness to the next generation.

Undertake the crossover operation with the method of multi-point crossover. The individuals for the crossover are parent individuals ranking from 15% to 85% in terms of fitness.

Undertake the mutation operation between the worker index and the start time of task according to certain possibility. The mutated individuals are the parent individuals ranking from 85% to 100% in terms of fitness.

Evaluate the employment time of the scheme, the total time of the scheme, the fitness of the scheme, and the average fitness of contemporary population.

Standardize the individuals that do not meet the restriction after the crossover and the mutation through adjustment, so that they can meet the restriction and become feasible solutions.

}

While (Termination conditions for the evolution and inheritance of the current iteration)//All operations traverse all the chromosomes.

Evaluate the fitness of the child chromosomes generated in the current generation and sort them in an ascending way.

Calculate and record top five individuals in terms of fitness.

}

While (Termination conditions for the evolution and inheritance among iterations)//The iterations reach to the biggest evolutionary generation or the highest fitness will remain unchanged for 500 consecutive generations.

Output the results of the optimization algorithm.

Case Study

With a specific game for a case study, the thesis shows the optimization of time and sequence and presents the algorithm, with the

aim of demonstrating the practical effect and optimization efficiency by solving practical problems.

Setting of model parameters

According to the description of the background of the problem environment, the parameters that need to be set include the start time of construction, the planned terminal time of construction, the non-assignment period, the time and resources for A-type and B-type tasks, the total quantity of resources of the system at T_0, the coefficient of the employment cost, and the coefficient of the delay cost. The setting of all parameters is shown in Tables 5-7.

The "Start Time of Construction=20" in Table 3 means that the start time of the optimization scheme is at 8 pm on the evening of the Day 0; the "n" in the "start time of the non-assignment period" and the "start time of the assignment period" refers to the "n"th day since the Day 0.

Convergence of the optimization algorithm

The genetic algorithm is an intelligent and heuristic one. Through such internal operators like selection, crossover and inheritance, it

Parameter Type	Parameter Value
Number of Workers (w)	3
Start Time of Construction (T_0)	20
Planned Terminal Time of Construction ($T_{0'}$)	240
Start Time of the Non-Assignment Period (T_s)	{24,48,72,……,24n}
Terminal Time of the Assignment Period ($T_{s'}$)	{32,56,80,……,24n+8}
Maximum of X-Type Resource (X_0)	1000
Maximum of Y-Type Resource (Y_0)	1000
Coefficient of the Employment Cost (a_k)	1
Coefficient of the Delay Cost (b)	1

Table 5: Parameter Value List.

Task Index	Consumption of Work Time	Consumption of X-Type Resource
a1	6	12
a2	8	18
a3	12	20
a4	24	40
a5	24	35
a6	48	50
a7	48	55
a8	72	70
a9	60	60
a10	45	45
Total	347	405

Table 6: A-Type Task List.

Task Index	Consumption of Work Time	Consumption of X-Type Resource
b1	6	12
b2	8	18
b3	12	20
b4	24	40
b5	24	35
b6	48	50
b7	48	55
b8	72	70
Total	242	300

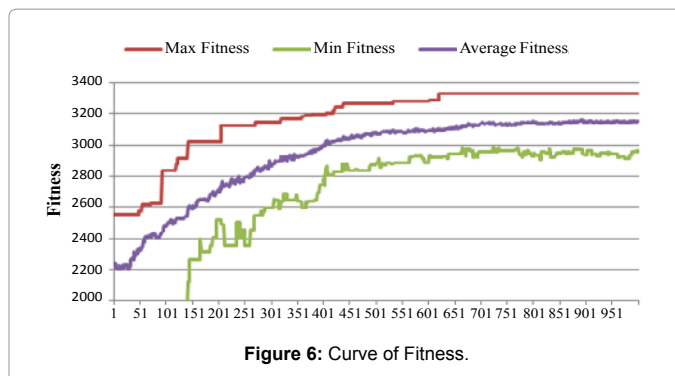**Table 7:** B-Type Task List.

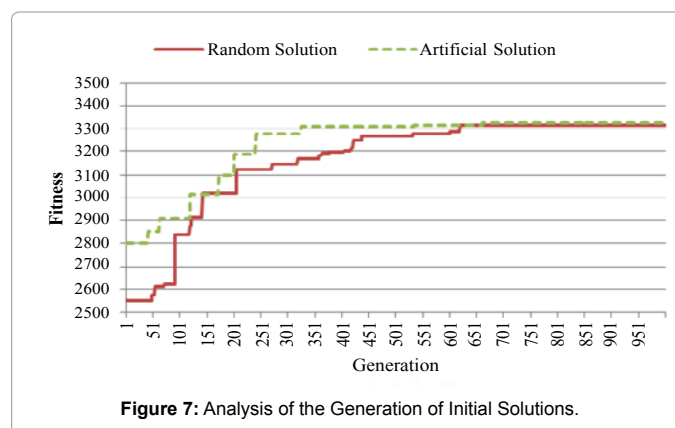**Figure 6:** Curve of Fitness.

Figure 7: Analysis of the Generation of Initial Solutions.

undertakes an intelligent search for workable solutions, so as to find out the optimal solutions of the scheme via the evaluation on fitness. Hence, the algorithm itself has a high level of convergence. However, if the setting of genetic operators is inappropriate, the algorithm would easily fall into partial convergence, which would hinder the enhancement of the efficiency of the algorithm. In the next step, a series of data experiments would be conducted to determine a set of relatively rational standards for setting genetic operators. The convergence curve of the algorithm is shown in Figure 6, and the parameter reference list of the model is shown in Tables 5-7.
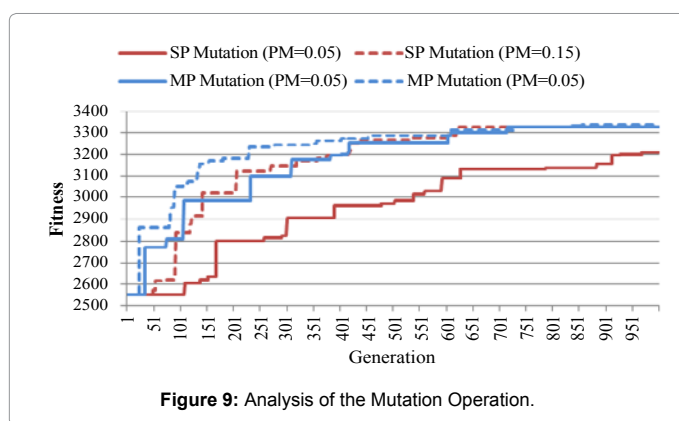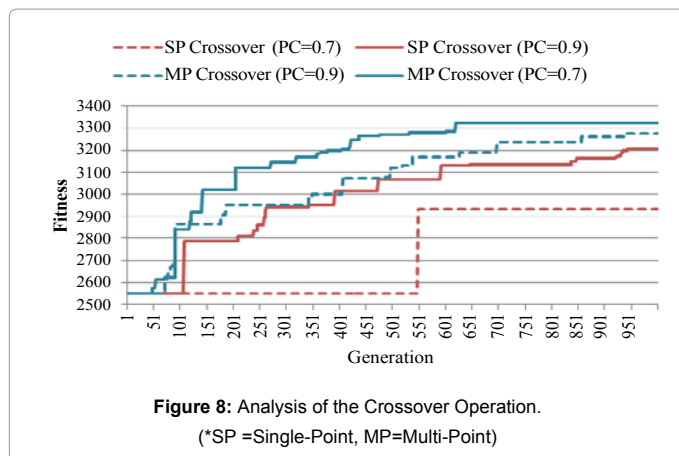
Parameter setting of the genetic algorithm

Through a series of data experiments in this part, the author changes the method and relevant parameters of the generation, crossover and inheritance of the initial solutions of the genetic algorithm, so as to make a set of relatively efficient parameter standards of the genetic algorithm. The results of the experiments are shown in Figures 7-9.

Figure 7 reflects the influence of different generation strategies of initial solutions on fitness. The artificially set average fitness of initial solutions is higher than the randomly generated initial solutions, so the artificial value is better than the random value in terms of search efficiency and the fitness in stability. It can be seen that a rational initial solution plays a significant role in promoting the efficiency of the algorithm.

Figure 8 shows the influence of the crossover strategy and the crossover rate on the algorithm. It can be learned from the Fig. that the effect and efficiency of the algorithm reaches the highest level when the multi-point crossover is adopted and the slightly equal to 0.7.

Figure 9 demonstrates the influence of the mutation rate and the

Figure 8: Analysis of the Crossover Operation.
(*SP =Single-Point, MP=Multi-Point)

Figure 9: Analysis of the Mutation Operation.

Total Cost of the Scheme	670
Employment Cost of the Scheme	662
Deployment Cost of the Scheme	8
Number of Generation Appears in Satisfactory Solution	637 Generations
Evaluation Time	8 Seconds

Table 8: Statistics of the Optimization Results.

way of mutation on the algorithm. Except for the single-point mutation whose mutation rate is 0.05, the other three kinds of setting has little influence on the algorithm. Therefore, the author finally decides to use the multi-point mutation strategy whose mutation rate is 0.15.

Based on the above three experiments, the author considers the convergence speed and the maximum value of fitness of the algorithm and then decides to use the artificially set initial value, the multi-point crossover (crossover rate=0.7) and multi-point mutation (mutation rate=0.7) to seek solution of the algorithm.

Optimization scheme

According to the setting of optimization components proposed above, the author takes the data in Tables 5-7 as the parameters of the system. The final results of the procedure optimization and the time and sequence scheme are shown in Table 8 and Figure 10.

The genetic algorithm is a heuristic one, so there is often partial convergence in the process of search in the optimization evaluation of practical problems. As a result, a satisfactory solution rather than an optimal solution can be evaluated. Apparently, it can be further optimized according to the scheme arrangement in Figure 10, as is shown in Table 9 and Figure 11.

After the second optimization, Task b6 which originally leads to delay cost is arranged for No.2 worker, which can not only reduce the employment cost (eliminate the non-assignment gap between the original b3 and b6) but also ensure that all tasks are completed in the planned construction period, thus further reducing the total cost of the scheme.

Sometimes the genetic algorithm cannot lead to the optimal solution, but it can bring a satisfactory solution within a short time and thus greatly reduce the work of people and enhance work efficiency.

Additionally, the operation workers can optimize and improve the satisfactory solution according to practical needs, and the process would not cost too much time and energy. For that reason, the genetic algorithm is of great significance in enhancing the efficiency of optimization.

Parameter Experiment

In this part, the author explores the influence of some parameters of the system on the final results, so as to provide some suggestions for game players or the managers of engineering projects in their actual work.

Influence of parameters on the solution of targeted value

According to the setting of the parameters of the problem, the author decides to analyze and explore three parameters of the system, namely "number of worker", "non-assignment period" and "planned terminal time of construction". The experiment data are shown in Figures 12-14.
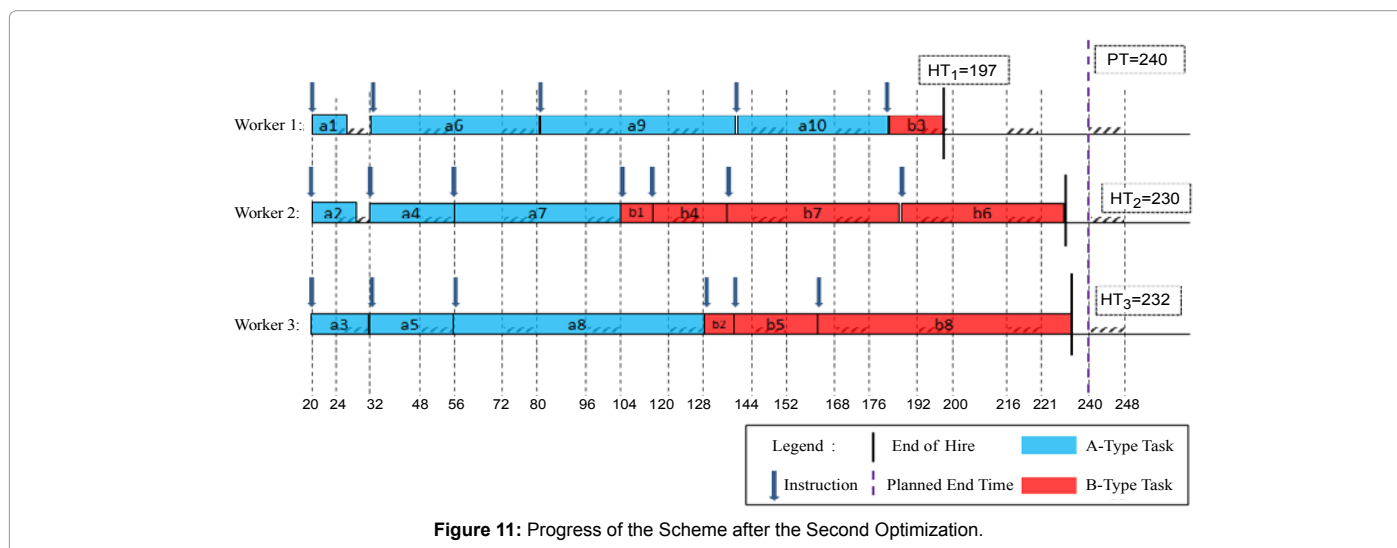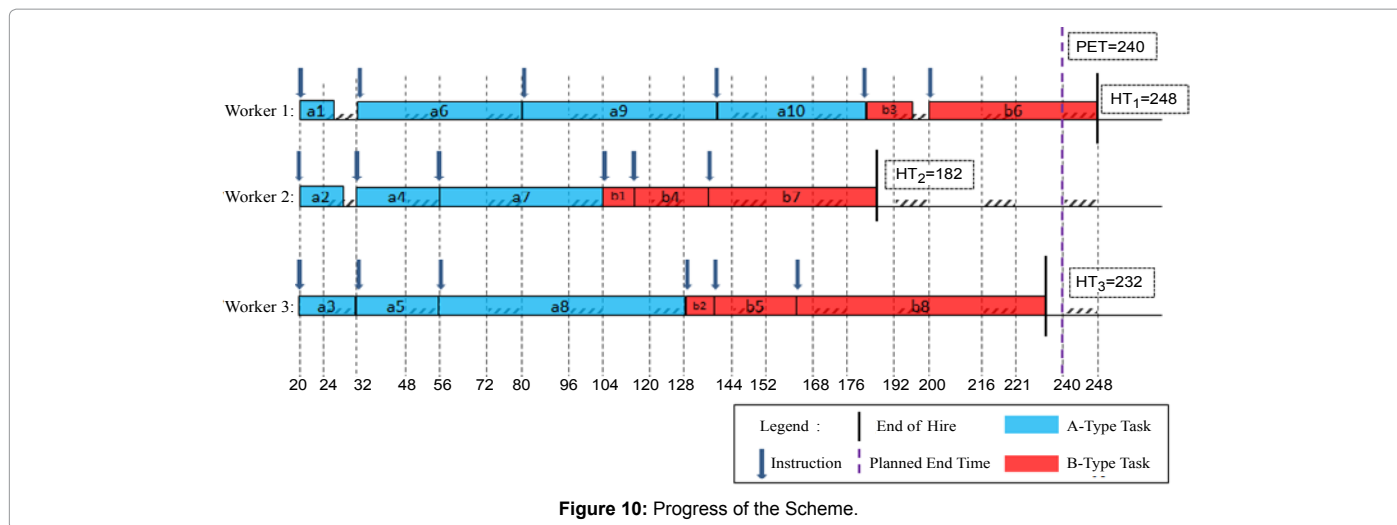
Figure 12 indicates the influence of the number of construction worker on the fitness of scheme. It can be seen from the development trend of fitness in the figure, that the growth trend of fitness will gradually slow down with the increase in the number of workers. Under the parameter environment of the problem, the growth of fitness is significant when the number of construction workers ranges from 0 to 3. When the number exceeds 6, the growth will slow down. Obviously, the most economical number of construction workers ranges from 3 to 4 in this case.

Figure 13 demonstrates the influence of the total length of the non-assignment period on fitness. As is shown in the Figure, fitness would decline with the increase in the length of the non-assignment period. As far as the problem is concerned, the length of the non-assignment period which ranges from o to 4 has the least influence on fitness. When the length rises over 10 hours, the influence on fitness will be significant.

Figure 14 reflects the influence of the planned end time on fitness. According to the conditions of the problem, the total cost consists of the total employment cost and the delay cost. Apparently, the length of the planned end time directly influences the delay cost of the scheme. It can be seen from the data in the figure that the curve of fitness of the scheme begins to slow down when its length is over 250 hours. This means that a rational planned terminal time for the problem is about

Total Cost of the Scheme	659
Employment Cost of the Scheme	659
Delay Cost of the Scheme	0
Reduced Value of the Total Cost of the Scheme	11= (670-659)

Table 9: Statistics of the Further Optimization Results.

Figure 10: Progress of the Scheme.

Figure 11: Progress of the Scheme after the Second Optimization.

250 hours. Based on the critical value, the manager can roughly define the range of the total construction period of the scheme.

Enlightenment on management

According to the above three parameter experiments, the efficiency of the scheme will change significantly when the number of construction workers ranges from 4 to 5 and the non-assignment period is less than 4 hours. Meanwhile, it can be roughly estimated that the total construction period of the scheme ranges from 240 to 260 hours. This will provide a relatively macroscopic understanding for the operators and thus offer some help for the control over the progress of the scheme.
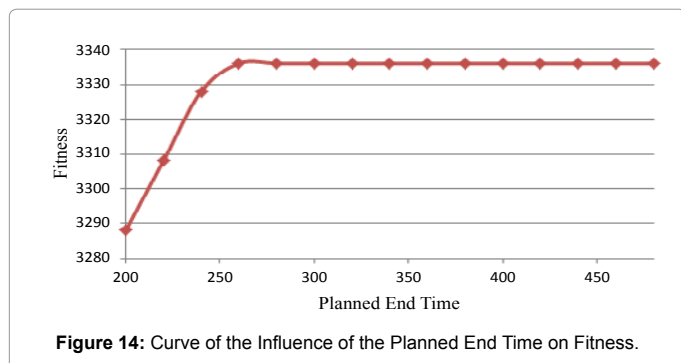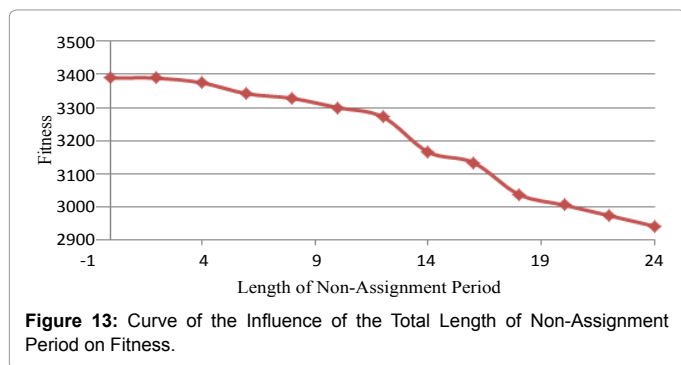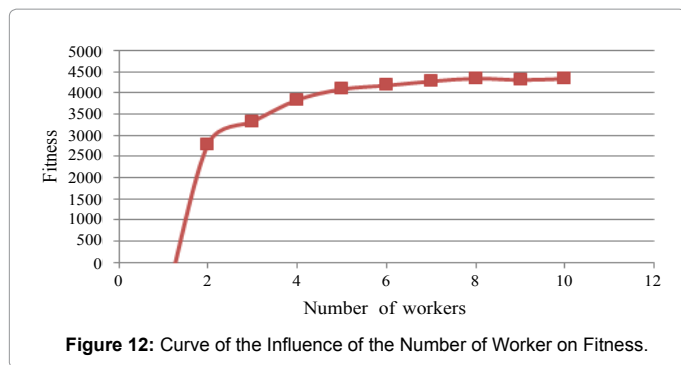
But one thing deserves attention. The above experiments are based on the satisfactory solution of the scheme, so the satisfactory scheme might need to be optimized again to get a relatively accurate curve of fitness according to different needs of the actual operators. Meanwhile, the different settings of the parameters of the scheme would lead to change to the critical value of fitness curve, which needs different analysis according to different problems.

The experiment is about the influence of parameters on fitness,

so some "parameter cost" variables can be added in the evaluation on fitness when the cost of engineering management is studied. Obviously, the increase in the number of construction workers and the decrease in the length of the non-assignment period would cause corresponding cost. In this case, balance should be obtained between the increase in cost and the enhancement of efficiency. If the growth of the former is higher than that of the latter, the optimization of the scheme would not be an economical one. Additionally, different managers would have different understanding of the effect of the enhance efficiency of the scheme; hence, analysis varies according to different situations. Centering on the problem, the thesis has provided a research method and a research tool.

Conclusion

With the genetic algorithm and the VC language, the author has managed to optimize the time and sequence arrangement of the construction of game facilities with the background of COC's game environment. In the process, the author undertakes the application and presentation of the algorithm with a case study and analyzes the setting of the internal parameters of the genetic algorithm. Apart from

Figure 12: Curve of the Influence of the Number of Worker on Fitness.

Figure 13: Curve of the Influence of the Total Length of Non-Assignment Period on Fitness.

Figure 14: Curve of the Influence of the Planned End Time on Fitness.

ensuring the efficiency of the algorithm, the author has optimized the problem.

Significance of the thesis

The thesis is a study on the optimization of the time and sequence of the scheme based on COC's game environment. Through a successful application of the genetic algorithm, the author has promoted the efficiency in making the construction sequence of game facilities, which will enable the vast number of players to greatly improve their game experience.

Moreover, the thesis is the first study on the optimization of the time and sequence arrangement of the construction of COC's game facilities. By far, none of relevant optimization tools and software can be found in the market. In addition to the optimization of the COC game, the research achievement of the thesis is applicable to other games involving construction of facilities, which provides the large quantity of players with an essential supporting game tool.

Last but not least, the research method of the thesis can be adopted in the optimization of the time and sequence arrangement of the construction of engineering projects, which will play a positive role in the development of social economy and the enhancement of work efficiency of enterprises.

Limitations of the thesis

In the making of optimization strategies, the author merely focuses on the time and sequence arrangement and pay inadequate attention to some subjective factors, for which there is still some gap between the optimization model and the reality. Plus, the optimization scheme uses the heuristic algorithm for seeking solutions, so there are still some limitations in the calculation of the optimal solution.

First, as far as the optimization model is concerned, the thesis arranges the construction of all tasks with the hypothesis that there are adequate system resources. But in reality, the total resources of the system cannot meet the construction needs of all tasks. In this case, the system needs to select and combine all tasks before the assignment. Meanwhile, the total resources of the system would change with the passage of time in the actual operation. If there is any change to the resources of the system, the task portfolio needs to be rearranged and adjusted. It is a dynamic process of planning. The clocked updating and calculation of the environment parameters will equip the model with more practical significance and increase the complexity of the research on the problem.

Second, the author does not take the factors of priority among tasks into consideration; instead, the optimization sequencing is merely done from the perspective of the length of time. But in reality, the priority of each task needs to be set so as to make it more targeted and practical.

Thirdly, the proposal of the optimization scheme is based on the support of the heuristic algorithm since the genetic algorithm merely leads to a satisfactory solution. So, for scheme makers with stricter requirements, other optimization tools are needed to optimize the satisfactory solution brought by the genetic algorithm to get an optimal solution. To this end, scheme makers need to seek more sophisticated algorithms and tools for the optimization.

Based on the above three limitations, the author will have deeper and more comprehensive analysis of the problem in the future studies to break these limitations and ultimately increase the practical and academic significance of the research achievements.

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