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# Multi-Project Human Resource Constrained Allocation Based on Theory of Constraints

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***Abstract***

*By introducing the theory of cut sets, this paper gives the risk measure of human resource constrained allocation in a multi-project environment based on Theory of Constraints, and it gives a quantitative risk measure method of completion risk of projects depending on constrained human resource in a multi-project environment. Through analyzing the bottleneck of human resource constrained allocation in a multi-Project environment, we set the bottleneck buffer by Theory of Constraints, combined with the characteristics of human resource, and establish human resource constrained allocation model in a multi-project environment based on Theory of Constraints. This paper provides a specific quantitative management method to alleviate the contradiction between supply and demand of constrained human resource in a multi-project environment, and gives the example to prove the feasibility and effectiveness of the approach.*

***Keywords:*** *Multi-project; theory of constraints; cut sets; human resource constrained allocation; genetic algorithm*

## 1. Introduction

Goldratt applies Theory of Constraints(TOC) to project management early, and establishes the method of critical chain project management (CCPM), but he does not discuss in detail how to apply Theory of Constraints to multi-project management in [1]. Leach describes the application of critical chain project management method to the multi-project resource allocation, but Leach doesn't elaborate Theory of Constraints in the multi-project resource allocation in [2-3]. Steyn proposes the application of Theory of Constraints to the parallel multiple projects resource allocation, and expounds the five steps principle of multi-project resource allocation based on Theory of Constraints in [4-5]. But Steyn gives neither qualitative description nor quantitative analysis whether the bottleneck resource conflict in a multi-project environment increases the single project completion risk when he applies Theory of Constraints to parallel multi-project resource allocation. And its essence still cannot break away from the traditional mode of multi-project resource allocation, combining many projects into a single big project, and then finding out the longest task chain in multiple projects to establish it as a critical chain. There is neither effective risk analysis nor attention to the risk that multi-project processes gathering caused by delay of former processes depending on the bottleneck resource brings to project duration. Cascading effect are the main factors that cause project delay and idle resources, which makes that the delay of a project will be completely transferred to follow-up project sharing the bottleneck resources, and make the whole project system delay in [6]. The resource conflicts between multiple projects result in multiple tasks, which namely the same resource at the same time undertakes the various tasks. Multi-task confliction in a project is significant, but it is harmful in multi-project environment. Because the more projects are to perform in the system, the more multiple task conflicts are serious, task time limit for a project with sharing resources in multi-project

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environment can be stretched, and we need extra time to prepare, which leads to delay further. Multiple tasks will be responsible to tardiness of projects because these tasks will extend the time limit for a project during rotation, and the situation is especially serious in multi-project environment.

In the research field of multi-project resource allocation, some experts and scholars at home and abroad have successively put forward some good methods. These methods provide effective approaches for modeling and solving of multi-project resource allocation. Moder established a two layers decision-making model of multi-project resource optimize configuration. The upper model is used to solve the least exceed time limit for a project, while the lower model is used to solve the least practical time limit for a project under the condition of certain resources in [7]. For solving multi-project-resource allocation problem, Lee is to merge multiple projects into a big project. Merging method is to add respectively a virtual task at the beginning and end and connect into a network diagram, of which he gives the multi-project resource allocation model and its algorithm on the basis in [8]. William and others study resources optimizing allocation in multi-project environment to set up mathematical model to minimize the cost of each project, and use genetic algorithm to solve it in [9]. According to the resource optimization problem between multiple projects, Mike points out that the mobilization of internal resources of the enterprise is restricted by the structure of enterprise organization, so appropriate organizational structure will help the enterprise resource optimization work and execution in [10]. However, most of the research on the allocation of these resources is based on the traditional project management technology framework, and has not fundamentally improved the allocation of resources.

At present, there are not many studies on the combination of multi project management and human resource allocation, and most of the research is still in qualitative description, while quantitative researches are rarely in [11-12]. From a psychological point of view, Annika analyzes the negative effect of too many projects on human resource allocation in [13]. In a multi-project environment, sharing human resource in all parallel projects becomes the bottleneck of multi-project management. A balanced allocation of sharing human resource becomes the one of key factors of the success of multi-project management in [2-14]. Although resource equilibrium of the human resource constrained process is carried out in multi-project human resources management based on Theory of Constraints, the resource equilibrium is just a relief of the aggregation of these processes. Under the assumption that the resource is limited, there is no complete solution to the competition for limited resources, and there are still multiple tasks. Resource allocation is to be carried out after the resource leveling. Because of the existence of a number of tasks in parallel, the demand for constrained resources is higher than the supply of resources. Therefore, multiple tasks in the scheduled period still can not get enough resources allocation, which means that multiple tasks will be delayed. In view of the impact of multi-project resource constraints on the project completion, this paper introduces the theory of cut sets to measure the risk of multi-project human resource constrained allocation. In the multi-project human resource constrained allocation environment, there is not only the risk of a single project completion, but also the risk of multi-project process aggregation. Therefore, through the discussion of how to use CCPM and TOC to further resolve the conflict of multi-project human resource constrained allocation, this paper establishes the human resource constrained allocation model based on Theory of Constraints, and achieves the optimal allocation of human resources under the multi project environment.

## 2. Risk Measurement of Multi-Project Human Resource Constrained Allocation Based on Cut Sets

Risk is the uncertainty of the actual results relative to the expected results. The risk is the uncertainty of the impact on the actual results in a specific environment and the specific time period. The factors that affect the target may be random factors and fuzzy factors, while the fuzzy factors include policy, economic environment and the subjective intention of the decision makers.

### 2. 1. Definition and Properties of Weighted Probability Mean Value Based on Cut Sets

**Definition 1:**

(The weighted probability mean value of fuzzy variable in [15]) $A$ is assumed to be a fuzzy variable. The $\lambda(\lambda \in (0,1))$ -cut set of $A$ is $A_\lambda = [A_\lambda^-, A_\lambda^+]$, the weighted probability mean value based on the cut set of the fuzzy variable $A$ is

$$E^\omega(A) = \int_0^1 [\omega E(A_\lambda^+) + (1-\omega)E(A_\lambda^-)]d\lambda$$

$E(A_\lambda^+)$ expresses the mean value of the right endpoint of the cut set of the fuzzy variable $A$, $E(A_\lambda^-)$ expresses the mean value of the left endpoint of the cut set of the fuzzy variable $A$. The weight parameter $\lambda \in [0,1]$ indicates the optimistic coefficient of decision makers. The greater the value of $\lambda$, the more likely the weighted probability mean value biases towards the right endpoint of the $\lambda$ -cut set of the fuzzy variable $A$ .The greater the weighted probability mean value, the more optimistic the decision maker. Conversely, the smaller the value of $\lambda$, the more likely the weighted probability mean value tends to the left endpoint of the $\lambda$ -cut set of the fuzzy variable $A$. The smaller the weighted probability mean value, the more pessimistic the decision maker.

**Theorem 1:**

(Properties of the weighted probability mean value in [15]) $A$ and $B$ are assumed to be two fuzzy variables, and the $\lambda$ -cut sets of $A$ and $B$ are respectively $A_\lambda = [A_\lambda^-, A_\lambda^+]$ and $B_\lambda = [B_\lambda^-, B_\lambda^+]$. $k$ is a non negative real number, then the weighted possibility mean value has the following properties.

(1) $E^\omega(kA) = kE^\omega(A)$

(2) $E^\omega(A+B) = E^\omega(A) + E^\omega(B)$

### 2. 2. Definition and Properties of Weighted Probability Variance Based on Cut Sets

**Definition 2:**

(The weighted probability variance of fuzzy variable in [15]) $A$ is assumed to be a fuzzy variable. The $\lambda$ -cut set of $A$ is $A_\lambda = [A_\lambda^-, A_\lambda^+]$, the weighted probability variance based on the cut set of the fuzzy variable $A$ is

$$Var^\omega(A) = \int_0^1 [\omega Var(A_\lambda^+) + (1-\omega)Var(A_\lambda^-)]d\lambda$$

$Var(A_\lambda^+)$ expresses variance of the right endpoint of the cut set of the fuzzy variable $A$, $Var(A_\lambda^-)$ expresses variance of the left endpoint of the cut set of the fuzzy variable $A$.

The weighted probability variance is defined as the weighted average of variance of the right endpoint and variance of the left endpoint of the fuzzy variable. The greater the weight parameter $\lambda \in [0,1]$, the more likely the weighted probability variance biases towards the right endpoint of the $\lambda$-cut set of the fuzzy variable $A$. Conversely, the smaller the value of $\lambda$, the more likely the weighted probability variance tends to the left endpoint of the $\lambda$-cut set of the fuzzy variable $A$.

**Definition 3:**

(The weighted probability covariance of fuzzy variable in [15]) $A$ and $B$ are assumed to be two fuzzy variables, and the $\lambda$-cut sets of $A$ and $B$ are respectively $A_\lambda = [A_\lambda^-, A_\lambda^+]$ and $B_\lambda = [B_\lambda^-, B_\lambda^+]$. The weighted probability covariance based on the cut set of the fuzzy variables $A$ and $B$ is

$$Cov^{\omega}(A,B) = \int_0^1 [\omega Cov(A_\lambda^+, B_\lambda^+) + (1-\omega) Cov(A_\lambda^-, B_\lambda^-)] d\lambda$$

$Cov(A_\lambda^+, B_\lambda^+)$ expresses covariance of the right endpoint of the cut set of the fuzzy variable $A$, $Cov(A_\lambda^-, B_\lambda^-)$ expresses covariance of the left endpoint of the cut set of the fuzzy variable $A$. The weighted probability covariance is defined as the weighted average of covariance of the right endpoint and covariance of the left endpoint of the fuzzy variable. The greater the weight parameter $\lambda \in [0,1]$, the more likely the weighted probability covariance biases towards the right endpoint of the $\lambda$-cut set of the fuzzy variable $A$. Conversely, the smaller the value of $\lambda$, the more likely the weighted probability covariance tends to the left endpoint of the $\lambda$-cut set of the fuzzy variable $A$.

**Theorem 2:**

(Properties of the weighted probability variance in [15]) $A$ and $B$ are assumed to be two fuzzy variables, and the $\lambda$-cut sets of $A$ and $B$ are respectively $A_\lambda = [A_\lambda^-, A_\lambda^+]$ and $B_\lambda = [B_\lambda^-, B_\lambda^+]$. $k$ is a non negative real number, then the weighted possibility variance has the following properties.

（1） $Var^{\omega}(kA) = k^2 Var^{\omega}(A)$

（2） $Var^{\omega}(A+B) = Var^{\omega}(A) + Var^{\omega}(B) + 2Cov^{\omega}(A,B)$

**Inference 1:**

(Properties of the weighted probability variance in [15]) $A$ and $B$ are assumed to be two fuzzy variables, and $m, n$ are negative real numbers, then the weighted possibility variance has the following properties.

$$Var^{\omega}(mA+nB) = m^2 Var^{\omega}(A) + n^2 Var^{\omega}(B) + 2mnCov^{\omega}(A,B)$$

### 2. 3. Risk Measurement of Multi-Project Human Resource Constrained Allocation Based on Cut Sets

Parallel projects of which the number is $n$ and a sharing resource pool are assumed, independent resources used in each project activities can be satisfied, and every project has compiled the corresponding critical chain management. Theory of Constraints is applied to parallel projects sharing resource allocation management.

Optimization of single project resource allocation is local optimization but not a system optimum. The parallel projects sharing bottleneck resources can be regarded as a system. According to Theory of Constraints, sharing resource becomes the bottleneck of the system. Assuming that a project process $j$ depends on the bottleneck resource M, we make a risk measure for the project completion risk. The risk measure is completion risk of the entire project team based on the weighted possibility mean and variance of the cut set.

$p_i \ (i=1,2,\cdots,n)$ is assumed to be the expected completion rate of the project $i$, and it is a fuzzy number. So the fuzzy completion rate vector of the whole project team is $p=(p_1, p_2, \cdots, p_n)$. $x_i \ (0 \le x_i \le 1, i=1,2,\cdots,n)$ is assumed to be the ratio of human resource allocated the project $i$, then the vector of these ratios is $x=(x_1, x_2, \cdots, x_n)$.

So the expected completion rate of the whole project team is $P=(x_1 p_1 + x_2 p_2 + \cdots + x_n p_n) = \sum_{i=1}^{n} x_i p_i$ . $P$ is a fuzzy number. Its vector multiplication is $R = xp^T$.

If the $\lambda \ (\lambda \in [0,1])$ -cut set of the fuzzy expected completion rate $p_i$ is $(p_i)_\lambda = \{x \in X \mid p_i(x) \ge \lambda\} = [p_{i\lambda}^-, p_{i\lambda}^+]$, the $\lambda \ (\lambda \in [0,1])$-cut set of the fuzzy expected completion rate of the whole project team by the rule of interval numbers is

$$(P)_\lambda = \{x \in X \mid P(x) \ge \lambda\} = [P_\lambda^-, P_\lambda^+] = \left[\sum_{i=1}^{n} x_i p_{i\lambda}^-, \sum_{i=1}^{n} x_i p_{i\lambda}^+\right],$$

Namely $P_\lambda^- = \sum_{i=1}^{n} x_i p_{i\lambda}^-$ , $P_\lambda^+ = \sum_{i=1}^{n} x_i p_{i\lambda}^+$

By definition and properties of the weighted probability mean value, the weighted possibility mean value of the expected completion rate $P$ of the whole project team is

$$E^\omega(P) = E^\omega(x_1 p_1 + x_2 p_2 + \cdots + x_n p_n) = \sum_{i=1}^{n} x_i E^\omega(p_i)$$
$$= \sum_{i=1}^{n} x_i \int_0^1 [\omega E(p_{i\lambda}^+) + (1-\omega) E(p_{i\lambda}^-)] d\lambda .$$

The weighted possibility variance of the expected completion rate $P$ of the whole project team is

$$Var^\omega(P) = Var^\omega(x_1 p_1 + x_2 p_2 + \cdots + x_n p_n)$$
$$= \sum_{i=1}^{n} x_i^2 Var^\omega(p_i) + 2 \sum_{i>j=1}^{n} x_i x_j Cov^\omega(p_i, p_j)$$
$$= \sum_{i=1}^{n} x_i^2 \int_0^1 [\omega Var(p_{i\lambda}^+) + (1-\omega) Var(p_{i\lambda}^-)] d\lambda$$
$$+2 \sum_{i>j=1}^{n} x_i x_j \int_0^1 [\omega Cov(p_{i\lambda}^+, p_{j\lambda}^+) + (1-\omega) Cov(p_{i\lambda}^-, p_{j\lambda}^-)] d\lambda.$$

The weight parameter $\omega$ indicates the optimism of decision makers about whether the whole project team completes projects on schedule or not.

Therefore the weighted probability mean value of the expected completion rates measures the expected completion rate of the whole project team, and the weighted probability variance of the expected completion rates measures the completion risk of the whole project team.

# 3. Multi-Project Bottleneck Human Resource Constrained Allocation Model Based on Theory of Constraints

## 3.1. Problem Description

For many engineering projects, usually the key work in a line needs a large number of human resources with a key technology to assist, which can not be replaced by other human resources. Many projects in a certain period of time need this kind of key human resources at the same time, which will produce the conflict and competition on human resource allocation.

According to the different importance and scarcity degree human resources in a multi-project environment can also be required as the key resources and non critical resources. This paper focuses on bottleneck human resource allocation in a multi-project environment. In addition, each project still needs some non critical independent human resources. In order to simplify the problem, assuming independent resources used in each project activities can be satisfied. Each project has been compiled the corresponding key chain, so the single item does not exist resource leveling problem. We assume that there is a sharing resource pool and the number of parallel projects is $n$. We suppose the projects involves only a key human resource M, which cause resource allocation conflicts between parallel projects. Supply of the key human resource M in a certain period of time is limited, and it can not be obtained by other means. In addition to sharing human resource M, projects are independent to each other, so the competition of the limited sharing human resource M is the only connection between the parallel projects. Therefore, how to balance the bottleneck human resource among many projects, and ease the resource conflicts among projects, which will become an important research topic. We assume that the resource leveling problem has been solved in multi-project environment. The resource allocation problem is assumed to be the maximum amount of resources, and the goal is to seek the shortest project duration. Therefore, how to allocate human resources among multiple projects based on Theory of Constraints is to solve the resource conflicts among projects, which is to further improve the management of multi-project human resource constrained allocation based on Theory of Constraints.

## 3.2. Model Assumptions

Firstly, it assumes that the system bottleneck resource M is limited in a multi-project environment. We assume these projects are in a the multi-project resource allocation environment based on Theory of Constraints, and have been implemented the critical chain project management. According to the multi-project resource management method based on Theory of Constraints, human resource M becomes the system bottleneck resource of parallel multiple projects, and bottleneck buffer is set in each task $i_k$ sharing the bottleneck resource M. In front of the configuration of the bottleneck resource M of the multi project system, it is assumed that the multi-project equilibrium adjustment based on Theory of Constraints has been carried out. The bottleneck buffer is composed of two parts, and one part is used to protect the process aggregation, used to say $T_{AN}\left(i_k\right)$. In order to avoid occupying the project buffer of follow-up process by the bottleneck buffer, we assume the adjusted time of the task $i_k$ for this part of the buffer. When this part of the bottleneck buffer is used more than two thirds to take remedial measures, we assume that the adjustable time of the task is two thirds of its bottleneck buffer time.

After the multi-project resource leveling, we must carry out the allocation of resources to the project, and can not postpone the time of allocation. Because the amount of resources is limited, it can not be configured according to the needs of the project. If the allocation of resources for each project is set, then there will be projects not to be configured, which means that the individual projects will have to wait. But the results will lead to more serious resource conflicts between the post projects, and are more disadvantage to the allocation of resources. We assume that the adjustment of the bottleneck resource among projects will not affect the work efficiency.

In order to more explicitly discuss and analyze the background of the problem, we should do the following hypothesis to establish the mathematical model.

First, the multi-project resource allocation problem involves independent projects of which the number is $n$ . $A_i$ is used to represent the project $i$ ($i = 1, 2, \cdots, n$). These projects are independent in addition to sharing the key human resources $M$ .

Second, the priority weight factors for multiple projects have been determined, which are respectively $\omega_1, \omega_2, \cdots, \omega_n$ .

Third, the total amount of key human resources is R.

Fourth, $r_i$ indicates the number of human resources $M$ allocated to the project $A_i$ .

Fifth, because the object of the study is the case of multiple projects competing for a kind of resource at the same time, it is assumed that a lot of projects at a certain time start to compete for resources, remembering this moment for the zero moment, from which we start time. $t_i$ is the expected completion time after increasing the buffer that a task of the project $i$ needs the key human resource. In the case of the assumption that the human resources can be satisfied, the schedule plan should work out the time which uses to complete the task. After resource contention among multiple projects, the task of the project $i$ still needs to be completed at the moment $t_i$ of which the actual completion time is $t_s$ .

Sixth, according to the fifth hypothesis, the time interval between the actual completion time and the expected completion time of a task is to be $\Delta t = t_s - t_i$ . Due to the scarcity of resources leading to resource contention allocation, this time interval must be greater than zero. Since each single project adopts key chain project management, time is the main consideration of the allocation of resources. Delay of the process depending on system bottleneck resources will make the follow-up process schedule change. More serious situation will result in change of the key chain, which is not conducive to project management, and brings the risk of project delay. The more such a project, the greater the loss of the whole system. So the system bottleneck resource allocation considers from the delay-time minimum. Resource allocation is carried out by the weighted total delay-time minimum of each item.

Seventh, activity duration is a calculation of activity workload divided by resource quantity, which can be expressed by $t_s = \frac{w_i}{r_i}$ , the workload of project $i$ in a period of time is expressed by $w_i$ . The paper assumes that the workload is fixed, and it is determined by the project plan. $r_i$ represents the number of key human resources $M$ actually allocated to the project $i$ . According to the assumption, the value of $r_i$ is changed. Because of resource competition, the resource requirements of the higher priority projects can be guaranteed, and ones of the lower priority projects may be less. Due to a certain amount of work, the amount of reduced resources will increase the activity of the work, increase the completion time of the project tasks.

### 3.3. Model Establishment

Based on the above assumptions and the description of the problem, we can establish the following multi-project resource allocation model.

Objective function $$F = \min Z = \min \sum_{i=1}^{n} \sum_{i=1}^{n} \omega_i \Delta t_i$$

$$= \min \sum_{i=1}^{n} \sum_{i=1}^{n} \omega_i \left( \frac{w_i}{r_i} - t_i \right)$$

Constraint equation $0 \le \sum_{i=1}^{n} r_i \le R$

The objective function is to minimize the weighted tardiness of tasks depending on the bottleneck resource. Tardiness of project of which degree of importance is the highest is the shortest. If the high priority project is tardiness, it is necessary to compensate for the loss, and which influences the enterprise's strategy, the future of the market development and corporate reputation. Because each project uses the key chain management technology, the pre-order task of the delay will bring great impact on the whole project. If tasks of non-critical chains occupy the import buffer too much, the same will lead to the risk of the whole project. Therefore, we should ensure that the high degree of importance of the project will not be delayed because of resource competition

### 3.4. Example Verification and Analysis Based on the Genetic Algorithm

**3.4.1. Examples Description:**Suppose there are four parallel projects sharing human resource M, and the quantity of supply $R$ is equal to $10$. The project parameters are shown in table 1, which the planning start time is the time considered the former processes delay.

**Table 1. Item Parameters of Human Resource Allocation**

| projects | tasks | $R(i_k)$ | $T_s(i_k)$ | $T_a(i_k)$ | $T(i_k)$ | $T_{AN}(i_k)$ | $T_c(i_k)$ | $T_d(i_k)$ | $\omega_i$ |
|---|---|---|---|---|---|---|---|---|---|
| 1 | A | 10 | 1 | 1 | 10 | 5 | 3 | 3 | 0.32 |
| 2 | B | 10 | 4 | 4 | 12 | 6 | 4 | 5 | 0.26 |
| 3 | C | 10 | 5 | 9 | 10 | 5 | 3 | 2 | 0.22 |
| 4 | D | 10 | 8 | 12 | 8 | 4 | 3 | 1 | 0.20 |

$R(i_k)$ represents the amount of human resources M in the task $i_k$; $T_a(i_k)$ represents the actual start time of task $i_k$; $T(i_k)$ indicates the completion duration of the task $i_k$; $T_s(i_k)$ represents the planning start time of task $i_k$; $T_c(i_k)$ represents the adjusted time of task $i_k$; $T_{AN}(i_k)$ represents the bottleneck buffer time of task $i_k$ undertaking processes gathering risk; $T_d(i_k)$ represents the delay adjustment time of the task $i_k$.

Objective function $F = \min Z = \min\left(0.32\Delta t_1 + 0.26\Delta t_2 + 0.22\Delta t_3 + 0.20\Delta t_4\right)$

Constraint equation $r_1 + r_2 + r_3 + r_4 = 16$

**3.4.2. Algorithm Simulation:** We have steps as follows to solve the model based on genetic algorithm.

The chromosome is a group of the number of resources allocated tasks assigned as the gene value of chromosome. The serial number sequence of tasks is to be arranged in a row to form a chromosome string, as shown in Table 2.

**Table 2. Chromosome Structures of Human Resource Allocation**

| | | | |
|---|---|---|---|
| $x_1$ | $x_2$ | $x_3$ | $x_4$ |

According to the actual start time of each task and available resource allocation time, we segment the time of the task to obtain the resources, as shown in the following table 3.

**Table 3. Resource Allocation Time**

| task | A | B | C | D |
|---|---|---|---|---|
| time | 1-13 | 4-19 | 9-21 | 12-22 |

When the task B on the fourth day to be allocated the resource, the amount of resources obtained by the task A changes. When the task C was performed on the ninth day to be allocated the resource, the amount of resources obtained by B and A changes. When the task D on the twelfth day to be allocated the resource, the amount of resources acquired by C, B, and A changes. Between the fourteenth day and the nineteenth day, the task A lost access to resources, and some of the resources are released, so the amount of resources obtained by the task B and A changes. Between the twentieth day and the twenty-first day, the task B lost access to resources, and some of the resources are released, so the amount of resources obtained by the task C and D changes. On the twenty-second day, the task C lost access to resources, and some of the resources are released, the amount of resources obtained by the task D has changed. Therefore, the time points of resource allocation changed are the fourth, ninth, twelfth, fourteenth, twentieth and twenty-second day.

Objective function $F = \min Z = \min\left(0.32\Delta t_1 + 0.26\Delta t_2 + 0.22\Delta t_3 + 0.20\Delta t_4\right)$.

Constraint equation $r_1 + r_2 + r_3 + r_4 = 16$.

The fitness function follows as:

$$F_1 = \min Z_1 = \min\left(0.32\Delta t_1 + 0.26\Delta t_2 + 0.22\Delta t_3 + 0.20\Delta t_4\right) + \alpha f\left(x\right),$$

$\alpha$ is the punishment factor, $f\left(x\right) = \left(r_1 + r_2 + r_3 + r_4 - 16\right)^2$.

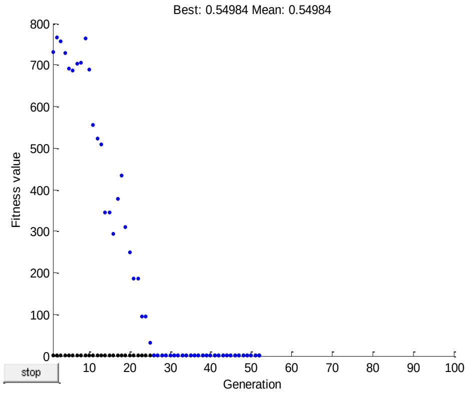
Genetic parameters selected follows as:

$\alpha$ is equal to $200$; the crossover probability is equal to $200$; population size is equal to; $0.600000$; mutation probability is equal to $0.40000$.

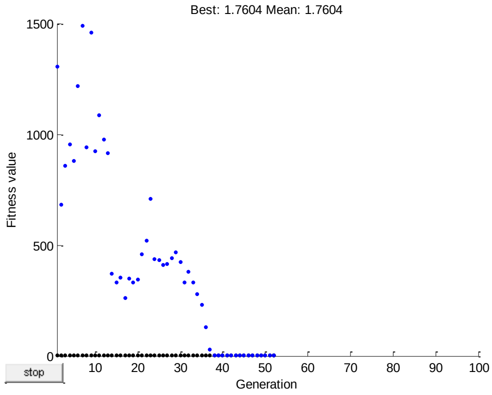
**3.4.3. Simulation Results:** In this paper, the results of the model are solved by computer simulation, and the results are shown in Table 4. The results of genetic algorithm are shown in figure 1.

**Table 4. Resource Allocation**

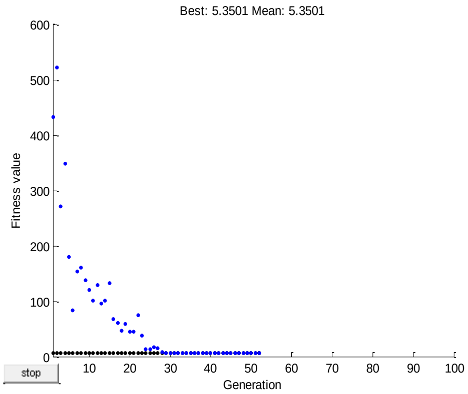
| Time<br>Task | 1-3 | 4-8 | 9-11 | 12-13 | 14-19 | 20-21 | 22 | Delay time |
|---|---|---|---|---|---|---|---|---|
| A | 16 | 6 | 4 | 2 | 0 | 0 | 0 | 0.6 |
| B | 0 | 10 | 5 | 4 | 6 | 0 | 0 | 1.1 |
| C | 0 | 0 | 7 | 5 | 5 | 10 | 0 | 1.9 |
| D | 0 | 0 | 0 | 5 | 5 | 6 | 16 | 1.2 |



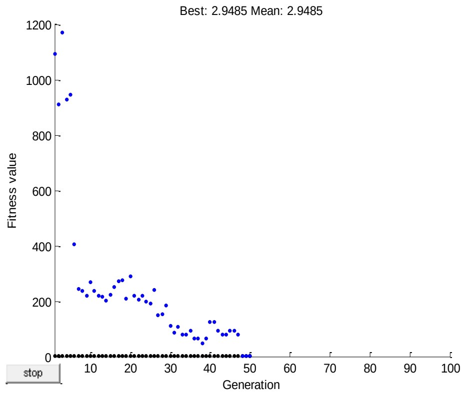

(a) 4-8



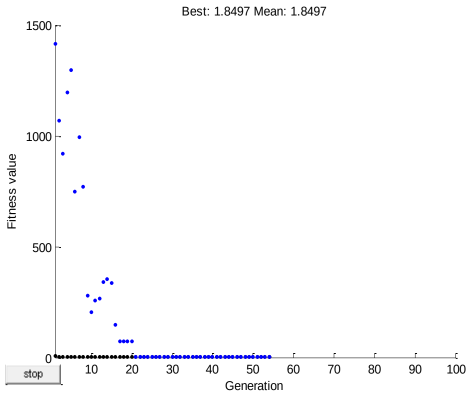

(b)9-11




(c)12-13




(d)14-19




(e)20-21

**Figure 1. Genetic Algorithm Running Results of Human Resource Allocation**

By the multi-project resource management method based on Theory of Constraints, this paper assumes that the bottleneck resource is limited, and the processes depending on the bottleneck resource are allocated. Adjustment resource allocation and the case of delay are shown in table 5.

**Table 5. Adjustment Resource Allocation**

| Time<br>Task | 1-3 | 4-8 | 9-11 | 12-16 | 17-20 | 21-23 | 24 | 25 | Delay time |
|---|---|---|---|---|---|---|---|---|---|
| A | 16 | 6 | 4 | 2 | 0 | 0 | 0 | 0 | 0 |
| B | 0 | 10 | 5 | 4 | 4 | 4 | 7 | 0 | 0 |
| C | 0 | 0 | 7 | 5 | 6 | 7 | 7 | 0 | 1 |
| D | 0 | 0 | 0 | 5 | 6 | 5 | 2 | 16 | 2 |

## 4. Conclusion

According to the data of Table 5, the delay time of task C is one day, and the delay time of task D is two days, which indicates that the method of multi-project management based on Theory of Constraints has alleviated the cascade effect. According to the task delay time of table 5, the method of multi-project management based on Theory of Constraints is implemented in this paper. The task A and task B are not postponed, and the delay time of the task C and D is respectively. one day and two days. The result is in accordance with the weight factor of table 1. By the multi-project resource management approach based on Theory of Constraints and the analysis of the multi-project human resource allocation, we establish a multi-project human resource constrained allocation model based on Theory of Constraints, and find out the appropriate method to solve the case, finally through an example to verify it. Therefore, according to the delay data of table 5, this paper shows that the buffer setting is reasonable, and it is preferable to organize procedure by the resource leveling rather than to sequence processes to ease the aggregation of processes.

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