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Multi-Project Sharing Human Resource Leveling Based on the Theory of Risk Element Transmission

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Abstract

By introducing the theory of risk element transmission, this paper analyzes the risk of human resource allocation in a multi-project environment based on Theory of Constraints, and it analyzes qualitatively completion risk of processes depending on the bottleneck resource in a multi-project environment. Through analyzing the bottleneck of resource allocation in a multi-Project environment, we set the bottleneck buffer based on the Theory of Constraints, combined with the characteristics of human resource, and establish sharing human resource equilibrium model in a multi-project environment based on the theory of risk element transmission, providing a specific quantitative management method to alleviate the contradiction between supply and demand of sharing human resource in a multi-project environment, and give the example to prove the feasibility and effectiveness of the approach.

Keywords: *Multi-project; sharing human resource leveling; the theory of risk element transmission; theory of constraints; bottleneck buffer*

1. Introduction

Goldratt applys Theory of Constraints (TOC) to project management early, and establishes 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]. 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 [3]. Compared with Goldratt and Leach, Steyn introduces Theory of Constraints into the multi-project resource allocation more deeply, and he has made a more detailed explanation for setting buffer and finally how to remove constraints. 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. And in the five steps principle of the theory of constraints, setting buffer is only in order to prevent the delay former tasks depending on bottleneck resource to wait, so the buffer only plays the role of resource buffer. Yet, there is a cascade effect in multi-project system. This makes the delay of a project fully transfer to the follow-up project sharing the bottleneck resource, and leads the whole multi-project system delay in [4]. At present,

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there are many researches on resource leveling in single project environment, but little researches on resource leveling in a multi -project environment. The people gradually realize competition and contest of resources between multiple projects, and some scholars study resource allocation in a multi -project environment in [5-12]. Based on Dantzig-Wolfe decomposition method, Wiley gives a more feasible resource allocation plan in a multi-project environment in [6]. Hendriks studies human resource allocation in a multi -project environment under the environment of long term, medium term, short term and R& D, and puts forward a conceptual framework in [7]. Fatemi Ghomi builds a simulation model of multi-project resource allocation based on GPSS simulation language, and through the model can predict the project completion time and resource distribution in [8]. Isakow and Golany think about system capacity, and put forward CONTIP (Constant time in Process) model in [9]. Andrés L proposes a new evolutionary method to study selection problems of the multi-objective projects in [10]. The method of research on the multi-project resource leveling problem is the initial network graph plus virtual operation, and changes the multi-project problem into a single project to solve the problem in [11. But if the difference of each project network diagram is larger, the number of virtual operation will increase sharply, so it increases the difficulty to solve it, And the flexible management method ,which a number of projects will be integrated into a large project, has been proved to be of low efficiency in [12]. The essence of multi-project resource allocation is to satisfy the resource constraints and the timing constraints of each task of each item, as well as multi-project resource constraints, optimizing all the project schedules to minimize the total project duration. Parallel multi-project resource competition makes project management more complex. How to allocate the resources effectively to avoid resource conflicts among projects and improve the utilization rate of resources becomes the key to the successful implementation of the project.

At present, there is not many researches of multi-project management and allocation of human resources in combination, and most of them are the qualitative description, while quantitative researches are rarely in [13]. Annika Zika-Viktorsson, from a psychological point of view, analyzes the influence of too many projects on human resource allocation. 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]. According to this problem whether the bottleneck resource conflict in a multi -project environment based on Theory of Constraints increases the single project completion risk or not, this paper gives a risk analysis of multi-project resource allocation by introducing the theory of risk element transmission. In a multi -project environment, processes sharing bottleneck resource exist both single project completion risk and a risk of multi-project process aggregation. Therefore, through the discussion of how to use CCPM and TOC to further resolve the conflict of sharing human resource, this paper establishes the sharing human resource leveling model based on the theory of risk element transmission, and achieves a leveling optimization of sharing human resource in a multi-project environment.

2. Risk Analysis of Multi-Project Resource Allocation Based on the Theory of Risk Element Transmission

2.1. The Theory of Risk Element Transmission

Risk is uncertainty of the actual results relative to the expected results. And the risk element is uncertainty affecting the actual results in a particular environment and the specific period of time. Because factors affecting the target may be random factors, fuzzy factors and so on, types of risk elements may be different in different environments. For a specific problem, we often list the main risk elements which are the main factors affecting the target, but some secondary risk factors will not be considered because of the risk of the constantly changing.

By the understanding of The theory of risk element transmission, risk element transmission can be regarded as change of some risk areas caused by other risk domains. In general, the domain is denoted as $U = \{x_1, x_2, \cdots, x_n\}$, while x_i represents research object which is an unexpected value in [15].

2.2. Risk Analysis of Multi-Project Resource Allocation Based on the Theory of Risk Element Transmission

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 a parallel projects sharing resource allocation management.

Optimization of single project resource allocation is local optimization but not a system optimum. The n parallel projects sharing bottleneck resources can be regarded as a system. According to the 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 analysis for the project by the theory of risk element transmission.

In practical application, the dependency relations of two processes will lead the maximum deviation of a process as the starting point of the next procedure. If a project has many processes, dependencies between different processes cause great differences between the production planning and results of implementation. Because durations of the processes in front of the process j are uncertainty factors that effect on the actual duration of process, according to the definition of the risk element, the time limit for $j-1$ processes in front of j process can be regarded as $j-1$ risk elements of j process, and suppose they are $x_1, x_2, \cdots, x_{j-1}$. But the delay of $j-1$ processes in front of j process may increase the finish risk of j process. According to the theory of risk element transmission, the domain is denoted as $U = \{x_1, x_2, \cdots, x_{j-1}\}$. Risk changes of the target object j are caused by risk changes of domain U. Risk of the j process in single project environment is set for x_j. Risk of the j process in a multi-project environment is set for Z, and random changes of each risk element will directly affect the volatility of Z, and according to basic structure analysis of the risk element transmission, risk transfer of risk element $x_1, x_2, \cdots, x_{j-1}$ belongs to the relational risk element transmission. Because of the complexity of risk transfer, considering the relational risk element nonlinear, we design nonlinear general function $Z_1 = f(x_1, x_2, \cdots, x_{j-1})$, and risk elements $x_1, x_2, \cdots, x_{j-1}$ are risk variables influencing Z_1 in [15]. We set that mathematical expectations of $x_1, x_2, \cdots, x_{j-1}$ are respectively $Q_1, Q_2, \cdots, Q_{j-1}$. We assume that the function $Z_1 = f(x_1, x_2, \cdots, x_{j-1})$ exists every order derivative at $Z_0 = f(Q_1, Q_2, \cdots, Q_{j-1})$, So it can be approximately expanded into Taylor series.

$$Z_1 = f(Q_1, Q_2, \cdots, Q_{j-1}) = \sum_{k=1}^{j-1} \left(\frac{\partial f}{\partial x_k}\right)_Q (x_k - Q_k) + \frac{1}{2}\sum_{k=1}^{j-1} \left(\frac{\partial^2 f}{\partial x_k^2}\right)_Q (x_k - Q_k)^2 + \sum_{1 \le k \prec s \le j-1} \left(\frac{\partial^2 f}{\partial x_k \partial x_s}\right)_Q (x_k - Q_k)(x_s - Q_s)$$

x_k is risk transfer coefficient. Because the risk elements x_k and x_s are independent each other, $\rho_{ks} = 0$.

According to the numerical characteristic relevant theorems of the random variable function in probability theory ,there is

$$E(Z_1) = Z_0 + \frac{1}{2}\sum_{k=1}^{j-1}\left(\frac{\partial^2 f}{\partial x_k^2}\right)_Q \sigma_k^2$$

$\sigma_k^2 = E(x_k - Q_k)^2$ is variance of x_k ;

$$D(Z_1) = \sigma_{Z_1}^2 = \sum_{k=1}^{j-1}\left(\frac{\partial^2 f}{\partial x_k^2}\right)_Q \sigma_k^2$$

σ_{Z_1} and σ_k are the mean variance of Z_1 and x_k , and $\frac{\partial f}{\partial x_k}$ is risk transfer coefficient x_k .

So $Z = x_j + Z_1$, then

$$D(Z) = D\left(x_j + Z_1\right) = D\left(x_j\right) + D(Z_1) + 2\operatorname{cov}\left(x_j, Z_1\right)$$

$$= \sigma_j^2 + \sum_{k=1}^{j-1}\left(\frac{\partial^2 f}{\partial x_k^2}\right)_Q \sigma_k^2 + 2\rho_{jZ_1}\sigma_j\sqrt{\sum_{k=1}^{j-1}\left(\frac{\partial^2 f}{\partial x_k^2}\right)_Q \sigma_k^2}$$

the risk elements $x_1, x_2, \cdots, x_{j-1}$ increase the risk of Z , so $0 \le \rho_{jZ_1} \le 1$ and $D(Z) \ge \sigma_j^2$.

Thus, the j process completion risk increases in a multi-project environment, namely processes sharing the bottleneck resource not only undertake process completion risk, but also bear multi-project process aggregation risk caused the bottleneck resource.

3. Multi-Project Bottleneck Human Resource Leveling Model Based on the Theory of Risk Element Transmission

Under the conditions of fixed duration, Objective of resources leveling is not to minimize the need for resources by optimization method, but the rational allocation of resources in the premise conditions of meeting the schedule, to avoid resource "peak" and "Valley" of demand, reduce project cost, and improve resource efficiency.

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 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, not by external or other means to obtain. 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.

3.2. Model Assumptions

When a particular resource demand occurs the frequent changes, resource leveling is a method of resource demand fluctuation minimization, and is also used to reduce resource utilization fluctuation. On the premise of ensuring the quality of projects and the duration of projects, the balanced use of resources as much as possible, which reduces resource fluctuations in demand, and strives to make each time the resource allocation more balanced, so high peak and low trough does not appear in the whole duration, and meet the project requirements to complete the schedule. A manifestation of excessive resources is in fact resource conflicts. In the multi-project plan, one-sided pursuit of the shortest construction period and the lowest cost, which makes resource overload, and affects the project quality, so reworks occur frequently, not considering resource constrained problem, but assuming that resources required by the project are available. In a multi-project environment, this assumption is not established. Therefore, first assume that the system bottleneck resource M is limited in a multi-project environment.

We assume n projects is in the multi-project resource allocation environment based on the theory of constraints, and implement the critical chain project management for each project. According to the multi-project resource management method based on the 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.

To balance the multi-project system bottleneck resource M and adjust the task i_k start time, we must use the bottleneck buffer. The bottleneck buffer is composed of two parts, and one part is used to protect the process aggregation, used to say $T_{AN}(i_k)$. 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. We assume the gathered buffer of the first project process is zero, because only the front of the project will bring the risk of process aggregation into the back project.

3.3. Model Establishment

We assume there are n parallel projects, the maximum value of the project durations is T . Only one task i_k uses the sharing human resource of M in project i ($i = 1, 2, \cdots, n$), and the supply of it(limited unit time demand)is R . We assume that the whole demand of resource M is R_t in the t th working day for all projects, and that the demand of tasks i_k for resource M per unit time is $R(i_k)$.

Because human resource can be updated, a measure of equilibrium problems of multi project system bottleneck resource M is balanced degree of resource supply and resource demand. By using variance to measure the degree of balance, and expectations of resource demand is the supply of resource,

that is $\sigma^2 = \frac{1}{T}\sum_{t=1}^{T}(R_t - R)^2$

There is a positive deviation and negative deviation in variance. Positive deviation represents that supply of multi-project system bottleneck resource is greater than demand, which causes waste of the multi-project system bottleneck resource. Negative deviation represents that demand of multiple project system bottleneck resource is greater than supply, which causes inadequate supply for multi-project system bottleneck resource. Therefore, the positive and negative deviation will cause the unbalance of supply and demand of resource, and increase the cost and waste.

If the value of variance σ^2 is least, equilibrium degree of multi-project system bottleneck resource M is the best. Because T is constant, the minimum value of variance can be obtained by calculating $S^2 = \sum_{t=1}^{T} (R_t - R)^2$.

The objective function $\min S^2 = \sum_{t=1}^{T} (R_t - R)^2$

Constraint equations

$$R_t = \sum_{i=1}^{n} R_t(i_k) \text{,} \quad t = 1, 2, \cdots, T \tag{1}$$

$$R_t(i_k) = \begin{cases} R(i_k), & T_a(i_k) \le t \le T_a(i_k) + T(i_k) \\ 0, & else \end{cases} \text{,} \quad i = 1, 2, \cdots, n \tag{2}$$

$$T_s(i_k) \le T_a(i_k) \le T_s(i_k) + T_c(i_k) \text{,} \quad i = 1, 2, \cdots, n \tag{3}$$

$T_a(i_k)$ 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.

In the model, the expectation of resource requirement is the supply of resource. The minimum value required variance makes the requirement of resource supply more close to the supply of resource. If human resource is idle, it will create waste, which is different from physical resources, and increases the cost. From the angle of view of microeconomics, the equilibrium of supply and demand of resource not only avoids the waste of resource that the supply is greater than demand, but also eases the resource overload that the demand is greater than supply, thus it can improve the allocation of sharing resource in a multi-project environment.

3.4. Example Verification and Analysis based on the Genetic Algorithm

Based on the traditional algorithm and heuristic methods, a new algorithm -- genetic algorithm can overcome the defects and deficiencies of these algorithm in [16]. Sou-Sen Leu gives a genetic algorithm to solve the equilibrium problem of single resource and multiple resources, and points out that the genetic algorithm can give optimal or approximate optimal solution of project actual commencement and completion time in the condition of multi -project resource equilibrium in [17].

3.4.1. Examples Description

Suppose there are four parallel projects sharing human resource M, and the quantity of supply R is equal to 16 . The project parameters are shown in Table1, which the planning start time is the time considered the former processes delay.

Table 1. Item Parameters of Human Resource Leveling

projects	tasks	$R(i_k)$	$T_s(i_k)$	$T(i_k)$	$T_{AN}(i_k)$	$T_c(i_k)$
1	A	10	1	10	0	1
2	B	10	4	12	6	3
3	C	10	5	10	5	4
4	D	10	8	8	4	4

The mathematical model of this problem follows as:

$$\min S^2 = \sum_{t=1}^{19} (R_t - R)^2$$

$$s.t. \quad \begin{cases} 0 \le T_a(B) - 4 \le 3 \\ 0 \le T_a(C) - 5 \le 4 \\ 0 \le T_a(D) - 8 \le 4 \end{cases}$$

3.4.2. Algorithm Simulation

First, chromosome structure and coding scheme.

The key of the realization of genetic algorithm lies in the coding method and genetic operation. Because of the multi-project system bottleneck resource used by only one task each item, we will carry out the resource equilibrium so as long as the start time of the task depending on the system bottleneck resource can be adjusted. Therefore, we regard the actual start time of the task using the system bottleneck resource as coding object, then calculation will be more simple, which $T_a(i_k)$ is to be encoded as chromosomes.

Second, constraint conditions

$T_s(i_k)$ and $T_c(i_k)$ are constants in constraints (3). We can change such constraints into $0 \le T_a(i_k) - T_s(i_k) \le T_c(i_k)$ through the linear transformation, and constraints of the objective function can be achieved by the code of $T_a(i_k) - T_s(i_k)$ (the length of code determined by $T_c(i_k)$).

suppose $\begin{cases} T_a(B) = x_1 + 4 \\ T_a(C) = x_2 + 5 \\ T_a(D) = x_3 + 8 \end{cases}$

A six bit long binary number represents chromosomes, its structure is shown in Table 2.

Table 2. Chromosome Structures of Human Resource Leveling

x_1		x_2		x_3	
1	2	3	4	5	6

Third, genetic operator and the termination condition of algorithm.

Select the roulette selection operator, and reserve the best individual in each generation; Choose the single point crossover operator, and adopt a consistent mutation operator. The maximum population number and minimum variance value are regarded as the termination condition.

Fourth, the choice of the fitness function and genetic parameters .

The fitness function follows as:

$$F = \sum_{t=1}^{19} (R_t - R)^2 + \alpha f(x),$$

α is the punishment factor, $f(x) = \sum_{j=1}^{6} \left[\min\left(0, h_j(x)\right)\right]^2$, and

$h_1(x) = x_1$, $h_2(x) = x_2$, $h_3(x) = x_3$, $h_4(x) = 3 - x_1$, $h_5(x) = 4 - x_2$, $h_6(x) = 4 - x_3$ 。

Genetic parameters selected follows as:

α 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 .

3.4.5. Simulation Results

Based on GA toolbox of MATLAB, we get $T_a(B) = 4$, $T_a(C) = 9$, $T_a(D) = 12$. The variances optimized by leveling before and after are respectively $s_1^2 = 3374$, $s_2^2 = 1629$.

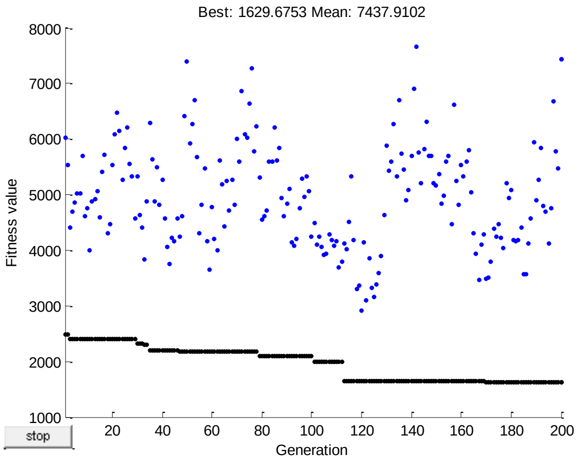

Figure 1. Genetic Algorithm Running Results of Human Resource Leveling

Results of the genetic algorithm operation are shown in Figure 1. The variances optimized by leveling before and after are respectively $s_1^2 = 3374$, $s_2^2 = 1629$, and this shows that the resource demand variance before equilibrium optimization is far greater than the resource demand variance after equilibrium optimization. There are positive deviation and negative deviation in variance. The positive deviation indicates that the supply of resource is greater than demand, which causes the waste of resource. The negative deviation indicates that the demand of resource is greater than supply, which means insufficient supply of resource. Therefore the positive deviation and negative deviation will cause the imbalance of supply and demand of resource, and increase the cost and waste.

From the risk perspective, the unbalanced supply and demand risks after equilibrium optimization of resource are significantly less than unbalanced supply and demand risks before equilibrium optimization of resource. There is a large deviation of supply and demand at different times of resource requirements before equilibrium optimization of resource, which exists not only a large number of waste of resources, but also serious shortage of supply of resource. Equilibrium optimization alleviates the unbalanced supply and demand of resource, improving the relationship between supply and demand of sharing resources in a multi-project environment.

4. Conclusion

In this paper, by introducing the theory of risk element transmission, we analysis systematically process completion risk, which shares bottleneck resource in a multi-project environment, depending on variance. In a multi-project environment, processes sharing the bottleneck resource not only undertake process completion risk, but also bear processes gathering risks which cause by other processes of projects sharing the bottleneck resource. Introducing the Theory of Constraints into the multi-project management, we set bottleneck buffer in the multi-project system, which can reduce general completion risk under the condition of the constant time limit for a project. Based on Theory of Constraints, combined with the characteristics of human resource, through the analysis of the multi-project constrained human resource equilibrium problem, we establish the equilibrium model of multi-project constrained human resource by the theory of risk element transmission, and find the appropriate solving method, finally through an example to verify it. Genetic algorithm running results show that bottleneck resource equilibrium method in a multi-project environment based on the theory of risk element transmission more effectively alleviates the conflict of multi-project resource allocation in this paper. Therefore the method not only improves the imbalance of supply and demand of resource, but also alleviates aggregation of processes because of delays of the former processes.

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