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Research Article

Project Duration Risk Transmission and Control based on CCPM

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Abstract: This study advances a project duration risk transmission model based on CCPM and the generalized project risk element transmission theory. By combining the calculation of systemic duration risk of a single process and the transmission of duration delay through an activity chain, this study proposes an modified method of calculating and setting input buffer and project buffer and also distinguishes the bottleneck activities on both the critical chain and non-critical chain, this method can offer a more reliable basis for making a project schedule plan and duration risk control.

Keywords: Bottleneck activities, critical chain project management, duration risk, risk element transmission

INTRODUCTION

A project is an organic whole constituted by a series of unique, complex and interrelated activities. These activities have a clear goal and must be completed at a specific time, within limited budget and resources and in accordance with certain standard and specification. Therefore it needs a detailed schedule. However, due to the distinctive one-time characteristics of the process and the complexity of the environment, coupled with the limited cognitive ability of project managers and project information lag, a wide range of risks emerges constantly as the project progresses and they have complicated relationship. This leads to a variety of uncertainties in the process of implementation of the project and the uncertainty of the project duration is the direct reflection. Duration is one of the three important control objectives during project execution. The delay or compression of duration is probably to result in the loss of manpower, material and financial resources and even affect the quality and safety of the project (Assaf and Al-Hejji, 2006; Kaliba *et al*., 2008). Therefore, the duration risk control and the identification of the schedule delay risk factors become very important. Since 1950s a large number of scholars have worked on the solution of this problem, mainly based on the Gantt chart method (Gantt chart), Program Evaluation and Review Technique (PERT) and Critical Path Method (CPM) (Trietsch and Baker, 2012; Castro-Lacouture *et al*., 2009; Hong *et al*., 2005; Min *et al*., 2005). However, most of these studies are belong to time-cost exchange areas and do not consider the resource constraint (Abbasi and Mukattash, 2001). Although they have solved the prediction and reduction problem of the overall project duration risk, but at the same time, they ignore the transmission of schedule delay risk between each process. Therefore, this study proposes a project duration risk transmission model based on the generalized project risk element transmission theory and critical chain project management technique. Through a combination of systemic risk of single-process duration and the transmission of duration delay through an activity chain, this study proposes an improved method of setting the input buffer and project buffer and also indentifies the bottleneck activities on both the critical chain and non-critical chain, this method can provide a more reliable basis for the formulation of project schedule plan and duration risk control.

MATERIALS AND METHODS

CCPM and traditional critical path technique: Because of not fully taking into account the influence of resource constraint on schedule planning, but solely on the basis of the estimated execution time, so traditional critical path technique often lead to serious gap between planned and actual, reducing the guiding role of schedule plan. Critical Chain Project Management (CCPM) is one of the important progresses achieved in the field of project management following the critical path and Program Evaluation and Review Technique (PERT). In contrast with traditional critical path technique, the main difference of CCPM is that it not only takes into account the process execution time and precedence constraints, but also considers the resource conflicts among processes (Peter *et al*., 2004; Shixin *et al*., 2003). Since the critical chain is a process sequence that determines the project life cycle, it is reasonable to use the length of the critical chain to determine the duration of the project.

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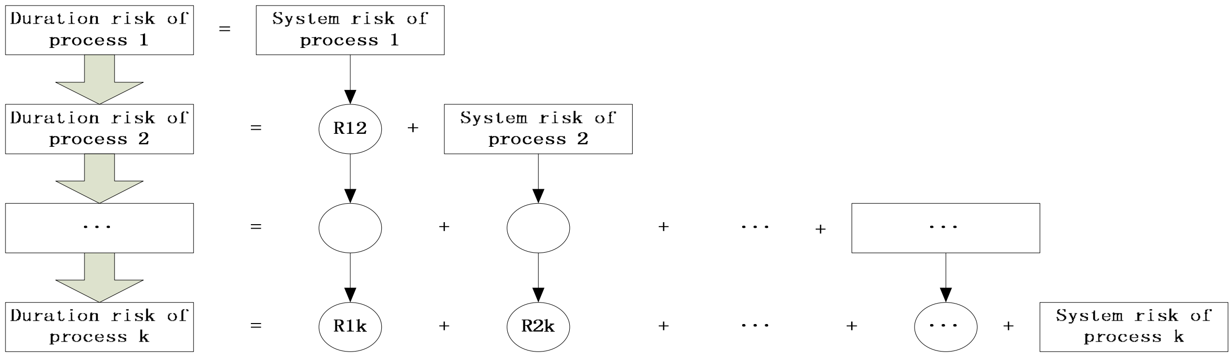

Fig. 1: Duration risk transmission on a certain chain

The basic idea of the critical chain technique depends on probability theory and organizational behaviour theory. CCPM is mainly based on "projects must comply with the overall optimization rather than local optimization" and is amended on the basis of the traditional critical path technique. CCPM emphasizes that the main constraints of the project life cycle is the critical chain instead of the critical path and reduces the impact of the uncertainties on the project schedule by setting project buffer, input buffers and resources buffers, to ensure the smooth implementation of project schedule plan in a dynamic environment.

Duration risk transmission: Each project, from the start to the end, is a network structure constituted by a number of processes. Due to the technique, resources and processes correlation, each process is linked closely and become a contradictory system of integrity. The project duration risk transmission means that the duration risk of each process will be passed to the other following processes along the chain in the network structure and finally generates the total duration risk.

This study argues that whether the critical chain or non-critical chain, since each process of the chain is restricted by the risk factors caused by the external socio-political and economic environment, natural environment, science and technology conditions and project themselves, the project duration risk transmission emerges and generates the final project duration risk. Usually a viable project scheduling plan has a unique critical chain. By using heuristic algorithm to identify the critical chain and non-critical chain in the network structure of the project duration, this study simplifies the network structure of the project duration into a geometric structure composed by one critical chain and a number of non-critical chain, so the project duration risk transmission can be divided into two aspects:

- Duration risk transmission on non-critical chain
- Duration risk transmission on critical chain

In terms of the critical chain and one non-critical chain, except the first procedure, the duration risk output of the following procedures consists of two parts:

- Duration risk transmission of adjacent previous process after the risk absorption of current process
- Duration risk infected by the risk environment in which the current process is

Specific to the duration risk transmission on a certain chain, it is shown in Fig. 1, which R_{ij} indicates the duration risk passed from process i to process j, j>i.

During the analysis of the overall duration risk transmission based on CCPM, we need to calculate the duration risk transmission of previous process at the point of time when the previous process ends and current process begins. Since each process has a certain ability to resist risks, the duration risk of the adjacent previous process is partially absorbed and transmitted by the following process.

For the duration delay risk of the adjacent previous process, assuming that the absorption coefficient of each process is ω_i and $0 \leq \omega_i \leq 1$. For example, $\omega_i = 1$ indicates that the anti-risk ability of process i is very weak, process i absorbs all the duration risk that process i-1 passes to it and the duration risk is no longer passed to the next process; $\omega_i = 0$ indicates that process i has a very strong ability to resist the duration risk that process i-1 passes to it and the duration risk will be all passed to the next process; $0 < \omega_i < 1$ indicates that process i has a certain ability to resist the duration risk that process i-1 passes to it but the duration risk can not be completely eliminated, process i will absorb 100 ω_i percent of the duration risk and the remaining 100 $(1- \omega_i)$ percent of the duration risk will be transmitted to next process and then continue to pass to the following processes.

Considering the project duration risk transmission based on CCPM from a global perspective: first, consider a single-process duration risk, the expectations of duration delay of process t must be determined by four variables, the duration delay expectation Y_{t-1} of process t-1, the system risk X_t of process t, the duration delay $t_t - \bar{t}_t$ of process t and the absorption coefficient ω_t of process t towards process t-1; second, consider the transmission of duration risk between processes, except the first process, the duration risk of each process consists of two parts, the duration risk transmission from the adjacent previous process and the system duration risk caused by the current process itself. The duration risk transmission model of each process on the critical chain and non-critical chain is as follows:

- **Calculation of single-process systemic duration risk:** Make that t_t represents the actual duration of process t and $\bar{t}_t$ represents the planned duration of process t, so the systemic duration risk of process t can be expressed as $X_t = P(t_t > \bar{t}_t)$, it is a random variable.

This study assumes that it follows a normal distribution, that is $X_t \sim N(\mu_t, \sigma^2_t)$, t = 1, 2, 3…, n, μ_t represents the expectation of duration risk of process t; σ_t represents the standard deviation of the duration risk of process t. In terms of tasks of each process, the systemic duration risk is independent, so the systemic duration risk caused by itself can be expressed by formula (1):

$$X_t = P(t_t > \bar{t}_t) = 1 - P(t_t \le \bar{t}_t) \quad (1)$$

- **Calculation of duration risk transmission on the chain:** In the context of the overall project duration, this study considers the Order lag autoregressive discrete system composed by the expectation of schedule delay of current process and the expectation of schedule delay of the adjacent previous process, the dependent variable Y_t is expressed as the function of its endogenous variable Y_{t-1} and its exogenous variable X_t:

$$Y_t = X_t(t_t - \bar{t}_t) + \omega_t Y_{t-1} + \varepsilon_t \quad t = 2, 3, \ldots, n \quad (2)$$

In this formula, Y_t represents the duration delay expectation of current process; Y_{t-1} represents the duration delay of the adjacent previous process; X_t represents the systemic duration risk of current process; $t_t > \bar{t}_t$ represents the duration delay of process t; ω_t represents the risk absorption coefficient process t towards process t-1; ε_t is the random interference term, which represents the impact of other risk factors that can not be predicted and the observational error of the samples.

The recurrence formula of the duration risk transmission on the chain is as follows:

$$Y_1 = X_1(t_1 - \bar{t}_1) + \varepsilon_1 \quad (3)$$

$$Y_t = X_t(t_t - \bar{t}_t) + \omega_t Y_{t-1} + \varepsilon_t \quad t = 2, 3, \ldots, n \quad (4)$$

By the above definition, we know that Y_n represents the duration risk expectation of the last process on the chain. The random interference terms of all the processes on the chain amount to ε, therefore:

$$Y_n = X_n(t_n - \bar{t}_n) + \omega_n X_{n-1}(t_{n-1} - \bar{t}_{n-1}) + \omega_n \omega_{n-1} X_{n-2}(t_{n-2} - \bar{t}_{n-2}) + \cdots + \omega_n \omega_{n-1} \cdots \omega_2 X_1(t_1 - \bar{t}_1) \quad t = 2, 3, \ldots, n \quad (5)$$

This mathematical model describes the duration risk transmission mechanism of each process on the critical chain and non-critical chain. The duration delay caused by a certain process on the duration network structure of the project not only affect the duration of the adjacent next process, but also affect the duration of all the subsequent processes in the law of diminishing, until leads to the total duration risk of the project.

In addition, we can respectively calculate the proportion of duration risk transmission amount of each process on the critical chain to the total duration risk of the project. The calculation method of the proportion of duration risk transmission amount of each process on the critical chain to the total duration risk of the project is as follows:

- The proportion of the duration risk transmission amount of the first process in the total duration risk of the project is:

$$\omega_n \omega_{n-1} \cdots \omega_2 X_1(t_1 - \bar{t}_1) / Y_n \quad (6)$$

- The proportion of the duration risk transmission amount of the second process in the total duration risk of the project is:

$$\omega_n \omega_{n-1} X_{n-2}(t_{n-2} - \bar{t}_{n-2}) / Y_n \quad (7)$$

The proportion of the duration risk transmission amount of the subsequent process in the total duration risk of the project is and so on.

Buffer set of the critical Chain: The application of the critical chain technique to project management is from the overall perspective of project planning and control. The focus of the critical chain technique is the global rather than the local of the project. CCPM arranges the safety time of all the study into the time buffer together. Its starting point is to ensure the entire project to be completed on schedule instead of individual process. The objective of the critical chain technique is to complete the plan of the project schedule and the buffer mechanism provides the project managers with a dial indicator of the real-time status of the implementation of the project. The project managers can see the remaining buffer size of the current implementation of the project clearly and can take measures to control and manage the duration risk when required.

The critical chain technique reduces the impact of uncertainties on the project schedule by setting the project buffer, input buffer and resources buffer, to ensure the smooth implementation in a dynamic environment of the project schedule which prepared in a determined environment. The project buffer is provided at the end of the critical chain, the aim is to ensure the project to be delivered on schedule. The input buffer is set at the confluence of the critical chain and non-critical chain, the aim is to protect the processes on the critical chain from the impact of processes delays on the non-critical chain so that they can be started on schedule.

At present, there are two kinds of methods to determine the buffer size, there are the “cut and paste” method and the “root variance” method (Luong and Ohsato, 2008; Mario, 2012). The advantage of the “cut and paste” method is simple and easy, the drawback is that the buffer size and the cumulative security time are in linear positive correlation, this can easily lead to the phenomenon that the buffer size is either too large or too small. The “root variance” method is based on the premise that the execution time of each process is independent and it can provide an appropriate buffer protection to the critical chain and the entire project. However, these two methods both have ignored the correlation of the technique, resources and process sequence between each process on both the critical chain and non-critical chain and the execution time of each process are not independent variables.

In addition, through the experimental study of Monte Carlo, Hoel and his partner put forward that: The size of project buffer is determined by the expected probability of the project’s completion on schedule, the size of the input buffer can use the study free time and do not need to be additionally set. However, using the study free time as the size of the input buffer can sometimes result a too large size of the buffer. Taking into account that the critical chain technique uses the “relay” mechanism in the implementation of the project (if the adjacent previous process of a certain process is completed and the resources exactly meet the demand of the current process), this section proposes an improved buffer setting method under the above duration risk transmission model. The process is as follows:

- Indentify the non-critical chain k, k = 1, 2…, K, K is the number of non-critical chains
- Calculate the input buffer size b_k from each non-critical chain to the critical chain according to the duration risk transmission and the free float of the last process from each non-critical chain to the critical chain, k = 1, 2…, K
- Indentify the critical chain
- Calculate the size of the project buffer according to the duration risk transmission model

The above buffer set methods have taken into account the correlation of each process on the critical chain and non-critical chain in techniques, resources and work sequences and use the duration risk of the last process on each non-critical chain which gathers all the duration risk transmission of each process on the non-critical chain as the input buffer and uses the duration risk of the last process on the critical chain which is the result of the duration risk transmission of each process on the critical chain. And it finds a more stable project schedule with a shorter cycle.

RESULTS AND DISCUSSION

Duration risk control: Traditional critical path technique are more concerned about the completion of a certain process and use it to measure the implementation of the entire project. Traditional critical path technique controls the duration of the entire project mainly through the control over the completion of construction period of each process. Therefore, it adds too much safety time into each process in order to ensure the project can be completed with 80 percent probability of completion. Most of these practices advocate an early start to end as soon as possible. They will arrange the processes as early as possible to ensure that it can be completed on time. But in fact, in most cases these practices failed. And because of the effect of “students insert” and “Parkinson’s disease”, it does not make the project complete ahead of time, but frequently leads to project delays. These techniques use the phase control theory, but always use a static view to understand and analyze the duration risk of the project. This makes the duration risk control measures of the various stages lack of necessary and organic links and they do not unify the processes of each stage and the risk factors of each process into an entirety to make a comprehensive consideration. Most of these techniques do not take into account the resources constraint, they are simple management approaches lack of flexibility. The project duration risk has not been effectively controlled.

CCPM is shown in Fig. 2, it has applied the statistical principles of risk aggregation and focus on the security of the overall safety of the project rather than a single process. It aggregates all the safety time of a single process in traditional project management and place it in the end of the process chain. CCPM uses “project buffer” and “input buffer” to protect the project and minimize the impact from the non-critical process to critical process. CCPM is like a “relay race” and everyone completes their study as quickly as possible and then passes the “baton” to the people in next process. This can significantly reduce duration delay and achieve good results to the planning and control of the actual project.

Through the calculation of duration risk transmission in the third section of this study, we can

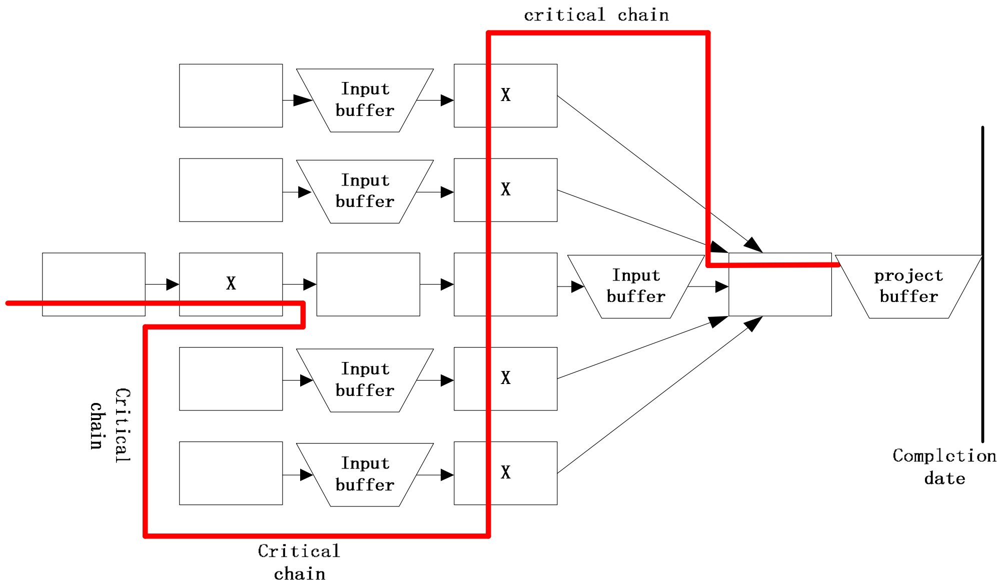

Fig. 2: Duration risk control based on CCPM

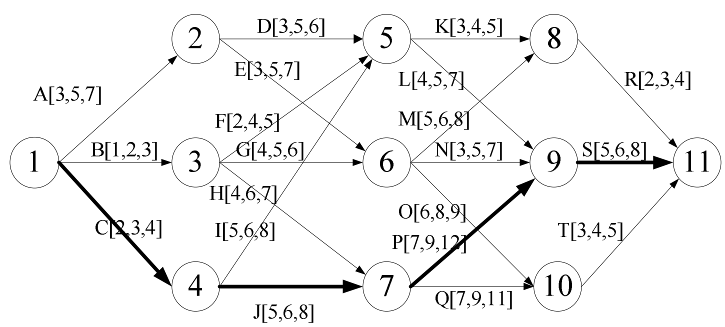

Fig. 3: Duration network diagram of the project

obtain the total duration risk amount of the critical chain as well as all the non-critical chains. If the total duration risk amount is significantly abnormal and beyond the scope of the project can withstand, we need to indentify the bottleneck activities on the chain. Bottleneck activities refer to those activities that their duration risk transmission amount has a large proportion in the total duration risk amount of the project and they have a great impact on the total duration risk. If we can adjust and optimize these bottleneck activities appropriately and reduce the duration risk transmission amount of the bottleneck activities, the total duration risk of the project can be greatly reduced and the total duration delay of the project will be in the range which the project can withstand. The project managers can achieve effective plan and control to both the overall and the local of the project by using duration risk transmission to indentify the bottleneck activities on the critical chain and non-critical chain.

Example analysis: The following is a simple example about the process of duration risk transmission based on the Critical Chain Project Management (CCPM) and how to calculate the size of project buffer, input buffer and resource buffer. Figure 3 is a study network diagram of a project and it includes the resource nodes.

Table 1: Basic information of the critical chain

Process /parameter	Planned duration $\bar{t}_t$	Risk absorption coefficient ω_t
C	2	—
J	5	0.7
P	7	0.4
S	5	0.8

The critical chain we get by heuristic algorithm is: 1 → 4 → 7 → 9 → 11, that is the study sequence C → J → P → S, Table 1 is the basic information of the critical chain.

Assume that the systemic duration risk of each process is $R_t = P(t_t > \bar{t}_t)$ which follows a normal distribution and R_C ~N(0.6,0.25); R_J ~N(0.4,0.25); R_P ~N(0.8, 0.25); R_S ~N(0.3,0.25). The result of calculation is:

$$Y_C = 0.6t_C - 1.2$$
$$Y_J = 0.4t_J + 0.42t_C - 2.84$$
$$Y_P = 0.8t_P + 0.16t_J + 0.168t_C - 1.696$$
$$Y_S = 0.3t_S + 0.64t_P + 0.128t_J + 0.1344t_C - 2.8568$$

Y_s is the project buffer. Secondly it can be seen that the duration delay of process P has the greatest impact on the total duration of the critical chain per unit of time. Therefore, process P is the bottleneck activity on the critical chain and so the project management personnel need to focus on process P during the control of the duration risk. It is the same to use this method to calculate the input buffer from each non-critical chain to the critical chain and it only need to subtract the free float of the last process from the non-critical chain to the critical chain eventually.

CONCLUSION

The project schedule management based on Critical Chain Project Management (CCPM) has overcome many problems existing in the traditional schedule management and it is more in line with the practical application. This study has applied the project risk element transmission theory into the calculation of the size of project buffer, input buffer in critical chain project management. It has avoided the isolated consideration of the execution time of each process. This study has also proposed the method to indentify the bottleneck activities on the critical chain and the non-critical chains by comparing the proportion of the duration risk transmission amount of each process in the total duration risk amount of the entire project and this has enabled the project manager to plan and control the project more effectively both as a whole and partial.

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