Cunbin LI[1], Gongshu LU[1], Pengcheng MA[1], Si WU[1]

School of Economics and Management, North China Electric Power University (1)

System Dynamic Model of Risk Element Transmission in Project Chain

***Abstract**. It is important to realize that the risk of one project will affect other projects as well. Based on risk element transmission theory, firstly, this paper established a risk element transmission model between two projects by using system dynamics methodology. And then this paper stimulated the variations of the risk element transmission impact when the owner and the contractor hold different risk-sharing ratios. The simulation results indicate that the transmission impact of risk element will enjoy an accelerated growth with the increase of the contractor's risk-sharing ratio.*

***Streszczenie.** W artykule analizuje się możliwość przenoszenia ryzyka między różnymi projektami. Wprowadzono pojęcie współczynnika przenoszenia ryzyka. (**Modelowanie dynamiczne możliwości transmisji ryzyka w łańcuchu projektów**)*

Keywords: risk management, risk element transmission, project chain, system dynamics.
Słowa kluczowe: łańcuch projektów, ryzyko, przenoszenie ryzyka.

Introduction

In the past, most enterprises used to manage only one project at a time, however now they can handle several projects simultaneously. Therefore, in order to maximize the enterprise's overall interests, project management needs to integrate the management of multi-project instead of merely pursuing objectives of one project itself. Meanwhile, project risk management should also consider the transmission impact of risk among projects under the condition of multi-project.

In the research field of project risk management, quite a lot of models, tools, techniques and methods appeared and were applied. Kash Barker proposed a framework of quantified risk analysis, which was used to analyze and measure the sensitivity of the uncertainty parameters of the basic probability distribution affected by the extreme events [1]. This approach avoided the impact of human factor in expert evaluating method, which has a good effect in risk decision. Alejandro Balbás transformed risk function into linear programming in infinite-dimension Banach space, and proposed a general simplex solving algorithm [2]. Besides, some other methods, like artificial neutral networks [3], genetic algorithms [4], Monte Carlo stimulation method [5] have also been adopted respectively to solve risk problems in project.

In fact, domestic and foreign scholars have done a lot of work on project risk research, and relevant achievements are mature, but the research on risk transmission among projects is not enough. The reference [6] did some research on risk transmission, while he defined the basic risk variable as risk element and proposed that the project objectives (such as duration, economic benefit) would fluctuate with the random fluctuation of risk element, thus the transmission impact of this kind was defined as risk element transmission.

Based on the risk element transmission theory, this paper considers that some chain structures exist in the multiple projects of one enterprise. And they are defined as project chain, such as project duration chain (life cycle) , cost control chain, resource supply chain and so on, as well as the integration of several chains. When the risk element of one project occurs, it will not only affect its own objectives, but also influence other projects through the project chain transmission. Therefore, project risk management should not only study the impact of risk element transmission on the present project, but more importantly on other projects from the same chain.

From the construction enterprise perspective, this paper studies the transmission impact of risk element in engineering project chain under multi-project environment by using system dynamics methodology. First the system analysis is achieved, which determines the boundary of the system and makes clear of system factors. Second, structural analysis is conducted, in which the casual feedback loop diagram of two interrelated construction projects is constructed based on the system analysis. This paper then establishes the dynamic risk element transmission model in project chain through a variety of visual system dynamics modeling software. Finally, the model stimulation and results analysis are developed.

System analysis

For the risk element transmission of project chain under multi-project environment, author has proposed a four-dimensional structural model, as Figure 1 illustrates [7].

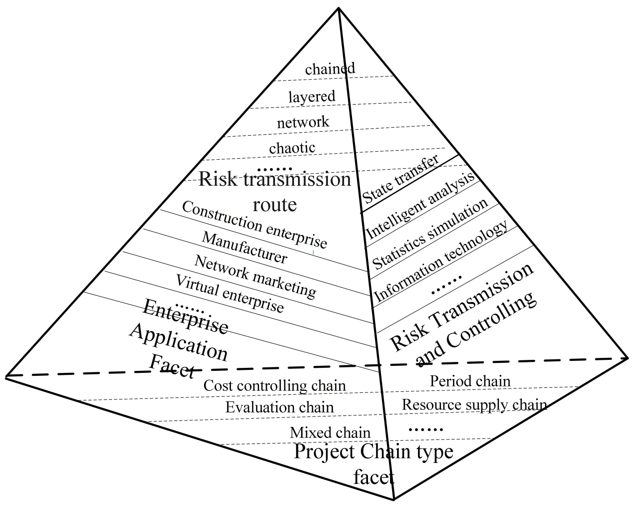

Fig.1. Model of project chain risk element transmission and controlling mechanism

In the enterprise application facet, this paper selects construction enterprises as the research object; and system dynamics methodology will be chosen in risk transmission and controlling method facet; while in project chain facet, this paper chooses the impact of resource transfer on project objective among two interactive projects, which is to say that the project chain of this paper is the "resource supply chain"; correspondingly, the chain transmission of risk is selected in risk transmission route facet.

For construction enterprise, the fundamental factor leading to the risk of project duration and cost is the changes of engineering quantities. Therefore, this paper regards the factor, which leads to the changes of engineering quantities, as the basic risk element (BRE). And this paper studies when a project has BRE, how it affects the duration and the cost of the project and other projects through the project chain. Besides, considering the clarity of research process, here we just study the impact of risk element transmission between two interrelated projects (project 1 and project 2), while supposing that the two projects resources, such as workforce, material, equipment, are shared and the resources quantities are limited. In this way, resources from project 2 may be seconded to project 1 to compensate its shortage, and vice versa, which matches the actual situation that the overall resource quantities are limited.

Casual feedback loop diagram is a kind of directed graph, which is often used to analyze complex relationship of inner system variables in system dynamics. It is composed of casual chains, which consist of factors and arrows, while the arrows represent influences between different factors. There are two kinds of casual chains: reinforce chain and balance chain. Reinforce chain is represented by an arrow headed line with a symbol "R+", meanwhile balance chain is with a symbol "B-". The loop composed of casual chains is called as casual feedback loop, and the feedback loop is divided into two kinds according to the number of the balance chains in the feedback loop. If the number is an even figure or equals to zero, then the feedback loop is called balance loop and represented by symbol "B-". On the contrary, it is called reinforce loop and represented by symbol "R+". Reinforce loop can enhance the variables' fluctuations existing in loop, and balance loop can limit the variables' fluctuations existing in loop.

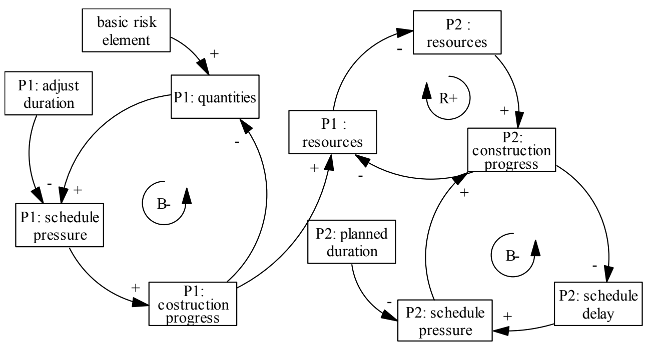

Fig.2. Casual loop diagram of two interrelated projects

In the process of project construction, the BRE of project 1 will lead to present engineering quantities to increase, which results in schedule pressure as the planned duration remains unchanged. Then according to the sharing-risk ratio of the owner, the contractor can negotiate to relieve the schedule pressure by extending planned duration. The more extension of planned duration, the less schedule pressure. To eliminate the schedule pressure, project 1 has to accelerate construction progress, which needs much more resources. Due to the limits of total resources, providing resources to project 1 from project 2 will limit the construction progress of project 2. As a result, although the construction progress reduction of project 2 guarantees the adequate resources supply of project 1, it leads to construction schedule of project 2 as well. Contrary to project 1 which may adjust its duration as risk occurs, project 2 has to be completed on time. Therefore, the construction enterprise needs to concentrate resource to accelerate construction progress of project 2 after the completion of project 1, for which will relieve the schedule pressure of project 2. All these casual relationships can be illustrated in Figure 2, in which P1 and P2 are the abbreviations of project1 and project 2 respectively.

System dynamic model

According to the casual relationship feedback loop of two interrelated projects, we can establish the model of it by using system dynamics methodology, and quantitatively analyze how project 1 affects project 2 through the resource supply relationship between them. In this paper, the software of iThink is used to establish risk element transmission model in multi-project resource supply chain. The model is illustrated in Figure 3, where CP is the abbreviation of construction progress.

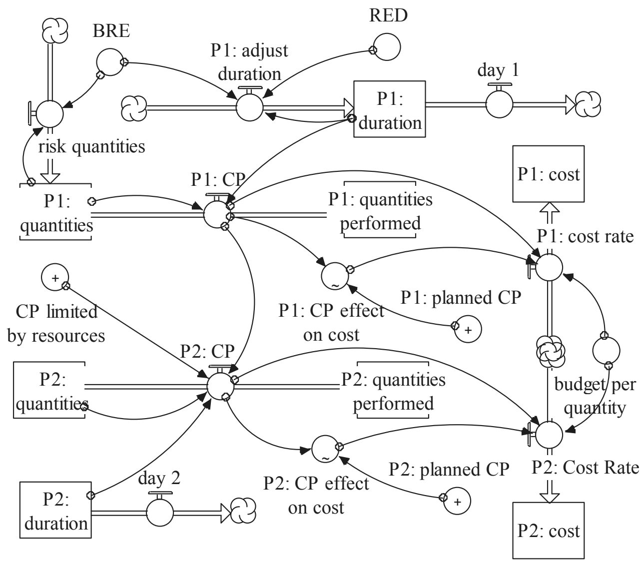

Fig.3. System dynamic model of risk element transmission in multi-project resource supply chain

The variable of risk quantities is calculated by the ratio of project 1's planed quantities when the project progresses to a certain period, in which the ratio is reflected by BRE. It is obvious that the more serious the risk is, the larger the value of BRE and risk quantities is. Then risk quantities will be:

(1) $$Risk\ quantities = init\left(P1 : quantities\right) * BRE$$

In which init represents the initial value of variable. When the BRE causes the increase of project 1 engineering quantities, the contractor can negotiate with the owner to adjust planned duration for relieving schedule pressure. Based on the size of BRE, the adjusting ratio of the planned duration are determined according to the ratio of the planned duration. The ratio is the consequence of negotiation between the contractor and the owner, which is a kind of decision dealing with risk according to mutual sharing-risk ratio. Therefore, we call it risk element decision (RED). For instance, if the BRE is 0.1, the risk quantities will be 10% of the planned quantities; if all the risk quantities are in owner's charge, then the value of RED is 1 and the adjusting quantities of the duration will be 10% (10%*1) of the planned duration; and the adjusting quantities will be 6% (10%*60%) of the planned duration, while 60% of the risk quantities are in owner's charge. So P1: adjust duration will be:

(2) $$P1 : adjust\ duration = init\left(P1 : duration\right) * BRE * RED$$

Besides, the variable CP limited by resources represents the engineering construction capability of two projects, and it is limited by the overall quantities of resources. The expression is:

(3) $$CP\ limited\ by\ resources = init(P1:quantities)/init(P1:duration) + init(P2:quantities)/init(P2:duration)$$

In fact, the acceleration of construction progress on the one hand leads to an increase of direct cost due to the resource increase, and on the other hand of indirect cost due to the increase of coordination management. In this paper, we use P1: CP effect on cost to express the impact of the increase of the indirect cost on the project cost leaded by schedule acceleration, and the specific value varies from project to project. The same to P2: CP effect on cost. Then P1: cost rate can be expressed as:

(4) $$P1:cost\ rate = P1:CP * budget\ per\ quantity * P1:CP\ effect\ on\ cost$$

Model stimulation and analysis

With the instance of a construction enterprise managing two earthwork excavation projects, the model valuates for corresponding parameters of project 1 and project 2, the initial values are shown in Table 1:

Table. 1. Parameter Values

Parameters	Projects		Unit
	Project 1	Project 2	
quantities	25000	45000	m^3
duration	100	150	days
planed CP	250	300	m^3/day
budget per quantity	200		yuan/m^3
CP limited by resources	550		m^3/day
total budget	14000000		yuan

In addition, on the basis of interview with the project managers and workers, the variable P1: CP effect on cost can be illustrated as a lookup function in Figure 4: S-shaped curve represents that if the extent of CP acceleration is not high, it has a little effect on cost; while the CP keeps accelerating, its impact on cost has a rapid growth due to a significant increase of coordination management; and as the schedule accelerates to a certain extent, its impact on cost will not increase anymore but tend to be steady for coordination management has no increase.

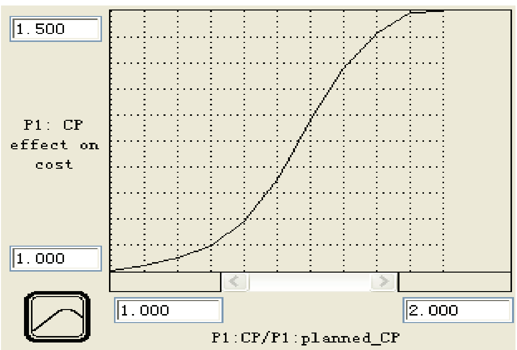

Fig.4. Lookup function: P1: CP effect on cost

Then, we set the initial value of each variable in the model. At the beginning, the value of BRE is set at 0, which means there is no variation of engineering quantities. The simulated result is illustrated in Figure 5: both project 1 and project 2 are in accordance with planned construction progress, expressed as P1: quantities (curve1) and P2: quantities (curve2) reducing in uniform. And they reduce to zero respectively on the day of 100 and 150, which means the engineering is completed in planned duration. The corresponding costs reach 5 (curve3) million and 9 million (curve4) at last, and the overall cost is 14 million, equaling to budget.

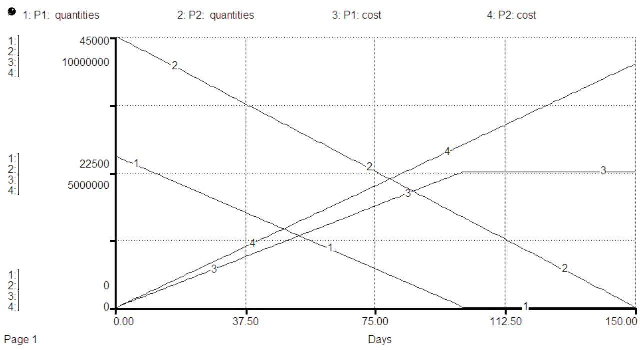

Fig.5. Simulated results: BRE=0

After that, we suppose the BRE is 0.3 as project 1 carried out to the 50th day, the ratio of adjusting planned duration is 0.4 negotiated by the contractor and the owner, namely modeling parameters BRE=0.3, RED=0.4. Running the model again, the result is illustrated in Figure 6:

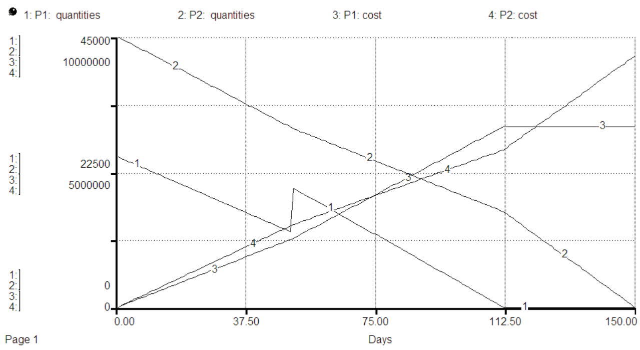

Fig.6. Simulated results: BRE=0.3 in day 50, RED=0.4

Contrasting Figure 5 and Figure 6, it is obvious that curve1 (P1: quantities) rises at 50th day and the reducing speed increases after that, meanwhile the reducing speed of curve2 (P2: quantities) decreases. This is because the occurrence of risk element of project 1 extends the planned duration, but the extended duration is just only 12% (BRE*RED=30%*40%=12%) of the planned duration compared with risk engineering quantities' 30% of the planned quantities. Thus project 1 still has to second resources from project 2 to accelerate construction process, which leads to the construction progress of project 2 decreases. After all quantities of project1 are completed until day 112, all resources are reused to complete project 2. Then project 1 won't generate cost (curve 3) anymore, but the cost increasing speed of project 2 (curve4) rises obviously. Finally, project 1 is completed at day 112 with the cost of 6.68 million, and project 2 is completed as planned at day 150 with the cost of 9.29 million. The total cost of two projects overruns the budget of 19.75million, which is the final result of risk element transmission.

Furthermore, when the BRE has no variation and the risk responsibility of the owner varies with the different reasons of the risk, the corresponding RED will also be different. The Figure 7 illustrates the transmission impacts of different RED on projects when project 1 has a BRE of 0.3 on 50 day.

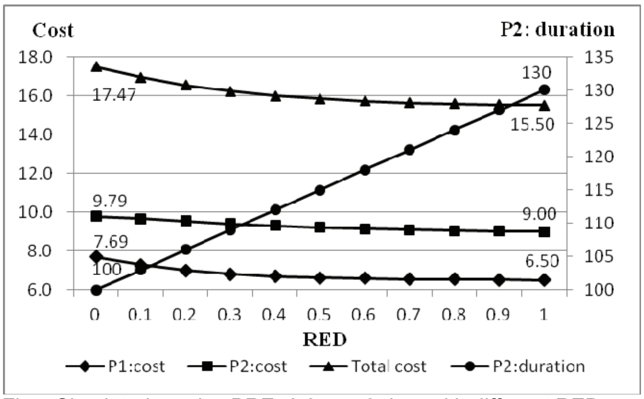

Fig.7 Simulated results: BRE=0.3 on 50 day with different RED

For the duration of project 2 has no adjustment, the actual completion time of project 2 is planned duration (150 day), it is not illustrated in Figure 7. It can be seen from the Figure 7, when the owner undertakes all risk responsibilities (RED=1), the cost of project 2 equals to its budget (9 million), the completion time of project 1 is 130 days and the cost overruns the budget of 1.5million 30% of it, equaling to completing the risk quantities at the budget price. When more risk responsibilities are undertaken by the contractor, the RED and adjusting duration will be less. The completion time of project 1 decrease uniformly, but the cost of project 1 and project 2 increases rapidly. As RED=0, the completion time of project 1 is 100 days, the cost is 7.69 million overrunning the budget 53.7%, which means the finished risk engineering quantities are only 30% of the planned quantities at the cost of overrunning budget 53.7%, and the cost of project 2 is 9.79 overrunning budget 8.75%.

BRE leads to the variations of project 1's quantities, if the contractor has to undertake risk responsibility (RED≠0), the risk not only leads to the cost overruns of project 1, but also the cost overruns of project 2 through transmitting in resource supply chain. And the risk transmission impact of this kind has an accelerated increase with the contractor's risk-sharing ratio increases.

Conclusion

As for the multiple projects of an enterprise, there are various project chains among the interacted projects. When the risk of one project occurs, it will transmit to other projects along with the project chain; hence affect their objectives, which is called risk element transmission of project chain. Based on system dynamics, this paper established a risk element transmission model in project resource supply chain, the model stimulation results proved that the transmission impact of risk element on project objectives had an accelerated growth as the contractor risk-sharing ratio increased. The establishment of the model provides a theoretical basis for effective evaluation of project chain risk element transmission impact, and a support to apply system dynamics to the research on project chain risk element transmission.

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***Authors**: Cunbin Li, prof.; Gongshu Lu, Ph. D.; Pengcheng Ma, M. D.; Si Wu, M. D.. School of Economics and Management, North China Electric Power University, Box 611, No.2, Beinong Road, Changping District, Beijing, 102206, China, E-mail: lcb999@263.net (Cunbin Li); ybzs1997@yahoo.com.cn (Gongshu Lu); mpchyx521@126.com (Pengcheng Ma); sabrinawithhot@yahoo.com.cn (Si Wu).*