Research Journal of Applied Sciences, Engineering and Technology 6(6): 1111-1115, 2013
ISSN: 2040-7459; e-ISSN: 2040-7467

Submitted: November 08, 2012 Accepted: January 01, 2013 Published: June 30, 2013

Risk Early Warning Model of Grid Engineering Project Based on System Dynamics

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Abstract: Timely and effective risk early warning helps managers to take relative measures in time, therefore to control risk factors as well as reduce risk occurrence probability or loss. As for the risk management of grid engineering projects in China, system dynamics method was used to establish the cost and schedule risk early warning model at first and then the construction process of one transmission line project in western China was simulated. The results indicated that the risk occurrence was effectively prevented due to the timely adjustment of construction progress after risk warning signals being sent out. Furthermore, corresponding analogue-control and result-display interface to the established model was set up, which can simulate the risk early warning values of grid engineering projects under different circumstances.

Keywords: Cost, duration, grid engineering project, risk early warning, system dynamics

INTRODUCTION

The risk management for grid engineering mainly consists of risk identification, assessment, response and monitoring, which not includes Risk Early Warning (REW). Given that effective REW helps managers to take relative measures in time so as to reduce risk occurrence probability or loss, therefore scholars has been putting increasing emphasis on the engineering REW. There exist two sorts of research directions in this field. One is qualitative research, which mainly studies the concepts of REW (Ming-Qin, 2011), the basic framework (Wei-Qing and Nai-Juan, 2012; Jian-Bin, 2011), along with operating mechanism (Ming-Yuan and Di, 2011). The other is quantitative research, which uses different methods to build project REW model. For example, Tang proposed an engineering project risk warning method based on entropy optimal model (Bao-Jun *et al*., 2008); Zhang combined the analytic hierarchy process, Delphi method and fuzzy theory to set up an engineering project REW model (Hui and Jian-Bin, 2009); Li adopted the matter element analytical method to establish a REW model of subjects' behavior (Juan-Fang and Xing, 2012). Besides, the decision tree method (Tie-Xin *et al*., 2010) and the DEA method (Feng-Shan *et al*., 2011) are also utilized in building the risk warning model of engineering project.

There is rarely any particular REW for grid engineering project and those quantitative studies depend on experts' judgment, which makes the REW be in a stationary state and fail to reveal the dynamic change process of potential risk. Thus, this study will utilize system dynamics method to establish a grid engineering REW model for monitoring the status of potential risk dynamically.

REW SYSTEM OF GRID ENGINEERING PROJECT

Cost, duration, quality and safety serve as four key objectives of grid engineering projects and from the viewpoint of REW for these four objectives, former two goals rely more on construction technology and construction methods while the later two depend more on management methods and tools. Hence, we only consider the REW for duration and cost in this study.

In the construction process, the quantities and duration determine the Construction Progress (CP), while labors and materials that are invested to ensure the CP determine the cost. Once the cost overruns the budget, relevant cost warning signals should be sent out as so. Then the actual CP needs to be slowed down to prevent the occurrence of cost risk. When actual CP leads to the anticipated duration going beyond the planned duration, relevant schedule warning signals should be given. In the meantime, the actual CP needs to be speeded up to prevent the occurrence of duration risk. Therefore, under the constraints of duration and cost, the actual CP does not always equal to the anticipated CP. It is worth noting that the change of construction progress, especially the acceleration of schedule can exerts evident influence on project quality. Above analysis can be illustrated by a causal relationship loop diagram of system dynamics as in Fig. 1.

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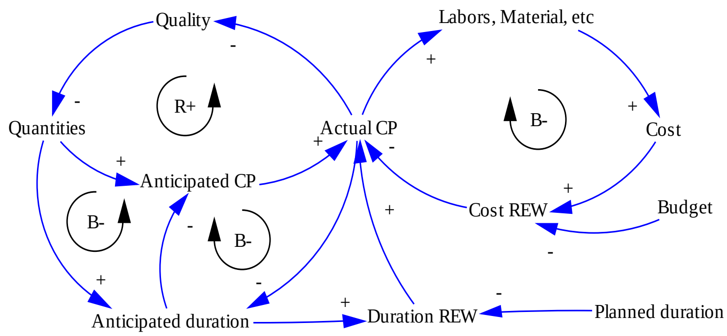

Fig. 1: Causal relationship loop diagram of REW for grid engineering

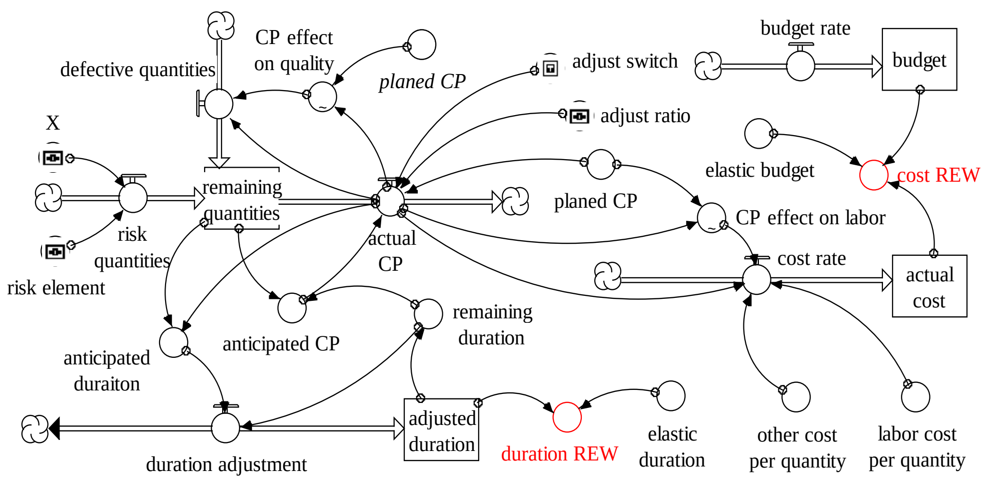

Fig. 2: System dynamics model of REW system for grid engineering project

SYSTEM DYNAMIC MODEL OF REW

After determining the feedback loop, the system dynamics software of i Think is adopted in this study to construct a model of REW system for grid engineering project, therefore to quantitatively estimate the dynamic impacts between factors. The model is depicted in Fig. 2.

If the grid engineering carries on entirely according to the plan, the quality will be ensured, while the cost will not overrun the budget and the duration will not be extended. Nevertheless, deviation from the plan always happens in reality, so the model uses *X* and risk element to express the generated risk quantities that are deviated from the plan at day *X* of the project, as presented in Eq. (1):

$$\textit{risk quantities} = \textit{if time} = X \ \textit{then risk element else } 0 \tag{1}$$

As to the duration, when project quantities deviate from the plan, anticipated duration is also likely to deviate from the planned duration. So the planned duration should be adjusted then, which can be represented as adjusted duration. Within the limited elastic range of duration (denoted as elastic duration), when adjusted duration deviates in a certain degree, duration REW information should be given. In the model, the different values of variable duration REW represent duration risk warning signal, while the button of duration REW in Fig. 3 would show corresponding colors. This can be illustrated as in Eq. (2):

$$\textit{duration REW} = \frac{(\textit{adjusted duration} - \textit{INIT}(\textit{adjusted duration}))}{\textit{elastic duration}} \tag{2}$$

As to the cost, when project quantities deviate from the plan, actual CP is also likely to deviate from the planned CP which would impact the cost as well. For one thing, labor cost would be influenced, which is presented as variable CP effect on labor. It reveals the effect of schedule's accelerating degree on labor efficiency, particularly the higher the ratio of actual CP

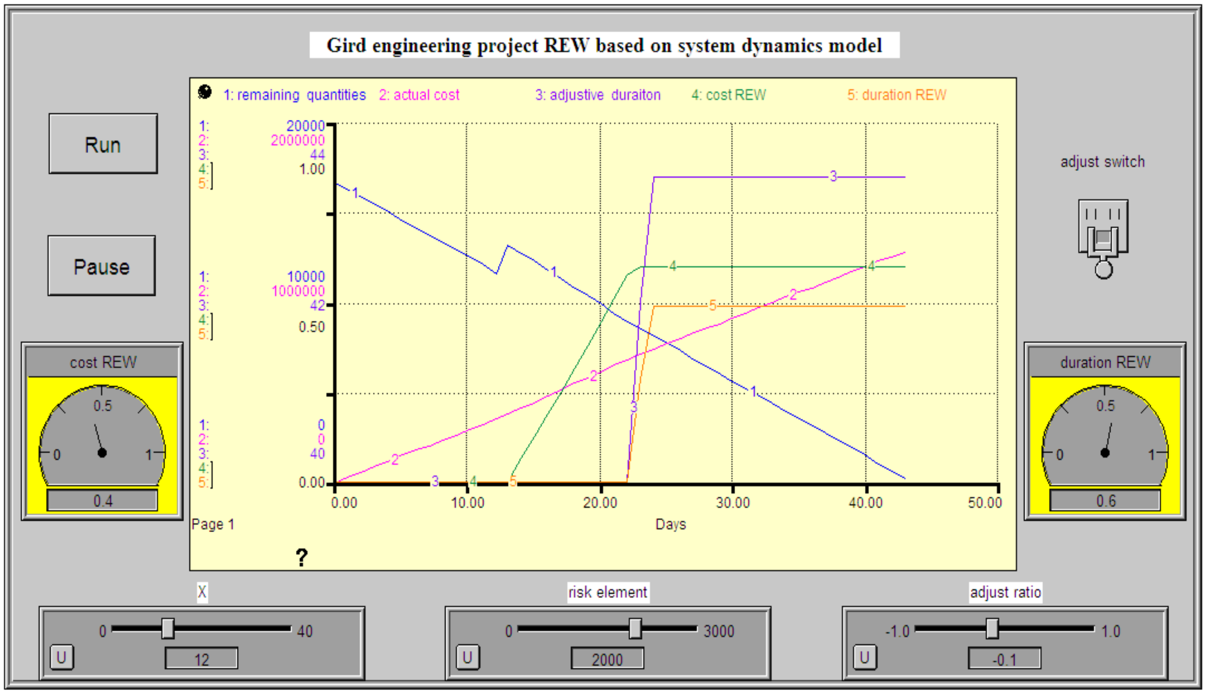

Fig. 3: The analogue-control and result-display interface of *REW*

to planned CP is, the longer the labor's overtime work will be. In this way, construction efficiency affected by fatigue will be more serious, so labor cost will eventually be increased. For another, material fees and machinery cost will be more because of the added project quantities. Eq. (3) shows above discussion:

$$\begin{aligned} \textit{cost rate} &= \textit{actual CP} * (\textit{other cost per quantity} \\ &+ \text{labor } \textit{cost per quantity} * \textit{CP effect on } \text{labor}) \end{aligned} \quad (3)$$

Then, the cost REW, similar with the duration REW, can be presented as:

$$\textit{cost REW} = \frac{(\textit{actual cost} - \textit{budget})}{\textit{elastic cost}} \quad (4)$$

When duration or cost risk warning signal is given, managers need to decide whether to adjust the progress or not, which is denoted as a change-over switch named adjust switch in the model. As for the button of adjust switch in Fig. 3, it has a value of 1 when it is switched on and the value of 0 when it is switched off. Moreover, the magnitude of the progress adjustment is expressed as variable called adjust ratio, so variable actual CP is signified as in Eq. (5):

$$\begin{aligned} \textit{actual CP} &= \max(\textit{planed CP}, \textit{anticipated CP} \\ &+ \textit{adjust switch} * \textit{anticipated CP} * \textit{adjust ratio}) \end{aligned} \quad (5)$$

With no doubt that the acceleration of schedule would exert some influence on engineering quality which is expressed as CP effect on quality, so as to bring about the increase of rework quantities. It should be noted that the function relationship of variables *CP* effect on labor and CP effect on quality are both signified by graphics function, the specific parameters vary depending on the specific project.

MODEL SIMULATION AND APPLICATIONS

A transmission line stringing and accessories installation engineering project of an 110KV double circuit in western China in 2011 will be taken as an example here. Engineering parameters and the initial values of corresponding variables in the model can be seen in Table 1.

Managers divide the REW signals into three levels. When the values of duration REW and cost REW belong to (0,0.3), the button of duration REW and cost REW in Fig. 3 show green, which means that the occurrence of cost and schedule risk is unlikely and so adjustment is generally in no need; when they belong to (0.3,0.7), the button will show yellow, which indicates that there is a moderate likelihood of risk occurrence and managers can both adjust or not adjust the project; when belong to (0.7,1) , the button will show red, which tells that the risk is very likely to occur and so the

Table 1: Model variables of the engineering project

Variable name	Value	Unit
X	0-40	day
Remaining quantities	16600	m
Planned duration = Intial adjusted duration	40	day
Labour per quanity	12.4	yuan/m
Other cost per quantity	56.4	yuan/m
Elastic duration	7	day
Elastic cost	90000	yuan
Adjust ratio	-1-1	unitless
Adjust switch	0 or 1	unitless
Planed PC	415	m/day
Budget rate	28552	yuan/day

project must be adjusted. As for the situations that variables duration REW and cost REW are less than 0 and greater than 1, they indicate that no risk at all and risk already occurred, thus there is no need to send out any risk warning signals.

Then the model can be simulated. Firstly, the situation that anticipated CP is not allowed to be adjusted, namely the adjust switch is in closed state.

Provided that risk element happens at the day 12 (X = 12), then the model is simulated with different risk element values respectively. Outcomes indicate that when risk element = 1090 m, the final result of cost REW is 1 and duration REW is 0, namely the whole project can be finished successfully at day 40. So, under the circumstance of no adjustment on anticipated CP, the critical risk quantities of cost risk occurrence is 1090 m and cost risk will occur once it is over 1090m. Of course this is just the situation at day 12, other situations can be simulate in the same way.

Secondly, the situation that anticipated CP is allowed to be adjusted is simulated. Similarly, assuming X = 12 and setting the value of risk element above 1090 at 2000 to display the function of risk warning on the project. After running the model, if the adjust switch has been in closed state, then the final result of cost REW will be 2.3 which means that cost risk occurs. To prevent it, cost risk warning signal should be sent out to adjust the project progress. The model can simulate the above mentioned process.

As shown in Fig. 3, firstly set the adjust switch at the closed state and then click the "Run" button to activate the model. When the model carries on to the 19th day, a cost risk warning signal will be sent out as button of cost REW turns from green to yellow and its value reaches 0.3. At this moment, it depends on the managers to choose whether stopping the model to adjust project progress or going on. Suppose the manager decide to go on, when the value of cost REW reaches up to 0.5, click the "Pause" button to stop the model and then click the "adjust switch" button to make the button up, next set the value of variable adjust ratio at -0.1 to slow down project CP, then go on running the model. At this moment, the value of cost REW will stop rising when it reaches 0.6, meanwhile the duration REW would turn from green to yellow and its value would keep rising. To prevent the duration risk from occurring, when the value of duration REW reaches 0.5 at day 24, stop the model again and shut down adjust switch. Finally, this whole project will be accomplished at day 44 and the cost will be 1293 thousand Yuan, while the value of cost REW and duration REW will be 0.4 and 0.6, respectively. Judging from the outcomes, it can be deduced that risk occurrence can be effectively prevented if timely adjustment to project CP can be done after receiving the risk warning signals.

Above simulation process only considers one specific situation of a grid engineering project. Actually, when risk occurrence time, risk project quantities and manager's decision on adjustment of project CP are different, the simulation results will change. Hence, on the foundation of establishing grid engineering project risk warning model, corresponding analogue-control and result-display interface is built as illustrated in Fig. 3. When it comes to the model applications, the initial value of model variables in Table 1 should be set at first and then various controls in Fig. 3 can be used to control the model.

CONCLUSION

Considering the characteristics of grid engineering project that it must require quality and safety goals while duration and cost goals enjoy a certain elasticity, system dynamics method was applied to build a REW model about cost and duration as well as corresponding analogue-control and result-display interface of the model. By simulating a grid engineering project, on the one hand we calculated the critical risk quantities that this project can endure when no adjustment on engineering CP. On the other hand we proved that risk occurrence can be effectively prevented if timely adjustment on anticipated CP was acted after receiving risk warning signal. Apart from this, through the analogue-control interface of the model, we can simulate the conducting process of different grid engineering projects under different circumstances and have a real-time display of the REW value or sending out risk warning signals in time, therefore to provide useful information and guidance for decision making.

ACKNOWLEDMENT

This study is supported by National Natural Science Funds of China (No. 71071054 and 71271084) and "211 Project" of North China Electric Power University.

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