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Project buffer sizing of a critical chain based on comprehensive resource tightness

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ABSTRACT

A buffer sizing method based on comprehensive resource tightness is proposed in order to better reflect the relationships between activities and improve the accuracy of project buffer determination. Physical resource tightness is initially determined by setting a critical value of resource availability according to the law of diminishing marginal returns. The design structure matrix (DSM) is then adopted to analyze the information flow between activities and calculate the rework time resulting from the information interaction and the information resource tightness. Finally, the project buffer size is adjusted and determined by means of comprehensive resource tightness which consists of physical resource tightness and information resource tightness. The experimental results indicate that the proposed method considers the effect of comprehensive resource tightness on a project buffer, thus overcoming the deficiencies of traditional methods which consider only physical resource tightness and ignore information resource tightness. The size of the project buffer determined by the proposed method is more reasonable, thus signifying that it can doubly optimize project duration and cost.

1. Introduction

The development of methods that can be used to successfully initiate, plan, execute, and close projects is a major concern of project management practice and research. The competition in project management is continuously increasing and project teams are constantly required to deliver their projects on time, within the budget, and with high quality. Project managers need project planning and control techniques to handle both these issues and those of uncertainties and resource constraints.

Resource-constrained project scheduling is one of the most complicated subjects in the field of project management (Rabbani, Fatemi Ghomi, Jolai, & Lahiji, 2007). The typical method applied to resource-constrained project scheduling in stochastic networks simplify solution procedures, usually resulting in managers underestimating the project duration and providing an erroneous resource profile (Golenko-Ginzburg & Gonik, 1997).

Goldratt (1997) introduced the direct implementation of the theory of constraints in project management, denominated as the critical chain. TOC evolved from the basic assertion that the output of a system is limited by a single constraint. Based on this, this author proposes that: (1) 50% of the activity duration is estimated as the likely duration and that the safe time is extracted from the buffer zone; thus the realistic estimates is 50% level not 90%. Specifically, a “no blame” culture is essential for the smooth implementation of CCPM theory; (2) all non-critical tasks are scheduled as late as possible in order to reduce the work-in-process and all tasks should be started as soon as their predecessors have finished. However, inspection of subcontractor deliveries and work scheduled should be scheduled as early as possible. This author states that managers will add a large amount of safety time to the project plan. However, this safety time will be consumed during the implementation of the project owing to various factors, such as the student syndrome, which contribute to the project being delayed and increase project costs. Goldratt accordingly adopts the concept of a buffer to absorb the uncertainties in the project rather than using the safety time term. According to Steyn (2001), three types of buffer are available in the project: (1) the project buffer (PB), which is added at the end of the critical chain to protect the whole project from delay; (2) the feeding buffer (FB), which is added to the noncritical activities feeding into the critical chain to prevent noncritical activities from delaying critical ones; and

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(3) the resource buffer (RB), which is a flag to alert, which resources have been planned in the critical chain and which different resources have been used in the previous critical chain activities.

The buffers in a critical chain contain the project buffer and the feeding buffer, and their size-setting method may directly determine the planned project duration and project completion risk. The classic buffer sizing methods are the Cut and Paste Method (C&PM) proposed by Goldratt (1997) and the Root Square Error Method (RSEM) proposed by Newbold (1998), which is based on the Central Limit Theorem and the idea that the durations of activities are supposed to be mutually independent. Many research works have pointed out that the C&PM seriously overestimates buffer sizes, while the RSEM performs better, especially when used in larger projects (Herroelen & Leus, 2001, 2002; Yang & Fu, 2009). The RSEM can avoid the overprotection implied by the C&PM when the number of project activities is large. However, the activities in one network have correlations and might therefore be affected by the same factors, such as resource constraints or network complexity, which make the buffer size calculated by the RSEM smaller than necessary. In this respect, Tukel, Rom, and Eksioglu (2006) suggest improving the RSEM through the use of resource constraints and network complexity. These three methods have therefore become the theoretical basis of buffer research. Subsequent studies report serious problems related to the buffer theory:

1) Scholars consider that network complexity is the main cause of the independence of activity duration (Tukel et al., 2006). However, network complexity only affects the starting time of activities and has no effect on the independence of activity duration. For example, the duration of an activity is 5 days. The starting time of this activity may be delayed when the network is complex and may begin ahead of schedule when the network is simple. Neither the starting time delay nor beginning in advance is important since they will not affect the duration of this activity.
2) Previous research into methods with which to calculate resource tightness has considered only the physical resources, such as equipment, raw materials or fuel, and has never considered the resource of information, which is principally measured by means of the information flow. Traditional methods therefore consider part of the resource tightness, which is unable to reflect the real resource tightness completely. Steward (1981) states that information flow exists between almost all project activities and that information flow embodies the real and inner relationships between activities. The information flow transmitted by the immediate predecessor activity may lead to a change in scope of the successor activity, while the information feedback provided by the subsequent activity may lead to a rework of the predecessor activity. The information resource transmission is therefore the main reason why activity durations are not independent of each other. The information resource has a significant impact on a project schedule and the buffer as an intangible resource. In view of the limitations of traditional methods, this study adopts the design structure matrix (DSM) in order to measure the information resource and calculate information resource tightness. The project buffer is then determined by means of comprehensive resource tightness (the combination of information resource tightness and physical resource tightness).

Given this backdrop of fragmented insights, the study's contribution to existing literature is threefold. First, this research suggests the concept of information resource tightness and applies it to the determination of a project buffer. The information resource resulting from the information flow between project activities is the significant inner relationship between activities and reflects the true logical relationship between these activities. The proposed method therefore makes a breakthrough in the research area of buffer determination. Second, the method used to calculate physical resource tightness is improved by setting a critical value of physical resource availability beyond which the resource is not tight, thus signifying that it is not necessary to add an additional project buffer to deal with resource tightness. In addition, traditional methods use network complexity to adjust the project buffer. The proposed method suggests that network complexity merely measures the uncertainty of the project and does not affect the mutual independence of project activity duration, and is not therefore suitable for buffer determination. Third, previous research on information flow uses the DSM to sequence and optimize the activities based on the assumption that the order of the activities can be randomly changed and resources can be satisfied without considering how the sequence is changed. The proposed method considers mandatory logical relationships and resource constraints between activities, thus overcoming the deficiency of the DSM technique.

The remainder of this paper is structured as follows. The second part contains a review of previous studies dealing with buffer sizing methods based on project attributes and DSM research results. Section three proposes a buffer sizing model based on comprehensive resource tightness. Section four describes the model by means of an example from an industrial process using the optimization and simulation methods. Finally, the authors elaborate on the major findings, discuss the implications of the research, clarify the limitations of the study and suggest further research directions.

2. Literature review

Goldratt (1997) suggested that the critical chain is determined by both logical relationships and resource constraints. In this case, the critical chain is usually not the critical path and it solves resource conflicts with minimal disruption. This author introduces the C&PM to determine the size of the project buffer. This method takes half of the estimated time as the average time of the activities, half of the safety sum cut from the critical chain as a project buffer, and half of the safety sum cut from the non-critical chain as a feeding buffer. However, considering 50% of the critical chain length as a project buffer may cause the project buffer to be too long, which will lead to a waste of resources and the loss of business opportunities (Bie, Cui, & Zhang, 2012; Herroelen & Leus, 2001). What is more, based on the property that project activity time obeys logarithmic normal distribution, Ashtiani, Jalali, Aryanezhad, and Makui (2007) use a mathematical statistics method to study the buffer size, and reach the conclusion that Goldratt's 50% buffer size method leads to serious waste. Another alternative to Goldratt's approach is the RSEM, which is based on the central limit theorem and performs much better, particularly in the case of larger projects (Newbold, 1998). In this method, it is supposed that the activities are mutually independent for central limit theorem to work. In fact, the activities in one network have correlations and might therefore be affected by the same factors, such as the resource constraints or the network complexity, which make the buffer size calculated by RSEM smaller than necessary. Besides, the RSEM also cuts half of the estimated duration as the planned duration. Under this condition, when the risks are slight, the buffer is larger and the planned duration is smaller than the requirement, which will cause the project to fail; when the risks are serious, the reserved duration will be excessive and the excessive part will be wasted because of the student syndrome.

In order to overcome the limitations of RSEM, other studies have adjusted the project buffer, principally through the use of project attributes. Tukel et al. (2006) introduce two methods to determine the feeding buffer in critical chain project scheduling, namely the Adaptive Procedure with Resource Tightness (APRT) and the Adaptive Procedure with Density (APD). Various simulation results show that these methods are better than the RSEM and the C&PM. More specifically, the APRT method incorporates resource tightness while the APD method uses network complexity. Long and Ohsato (2008) simulate project uncertainty by using fuzzy numbers and calculate the size