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An investigation of time buffer into the fundamentals of critical chain project
management: A behavioral perspective

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Abstract: The TOC technique for project management is often referred to as the “critical chain” technique. It’s pivotal to determine the buffer which is suggested to providing sufficient protection against delays in project completion time. Owing to the “Student syndrome”, many buffer sizing techniques have been investigated to increase project performance. However, the decision maker is human, “bounded” in its ability to acquire and process information. Further research is needed to be able to make reliable predictions of individual behavior in more complex real-world decision situations. We attempt to explore the application of prospect theory to investigate such phenomenon. Furthermore, a value function defined over variations of wealth and a probability weighting function reflects the subjective probability distortion shown by most individuals will be used .Given such findings, it becomes critical to observe the decision maker’s perception when the buffer allocations are resolved.

Keywords: Critical Chain Project Management; Behavioral Science;

Relative rationality; Prospect Theory

1. Introduction

Business is becoming increasingly projectized, and project managers need to develop a schedule for directing and controlling resources of workers, machines, and materials in a coordinated and timely fashion in order to deliver a project within the limited funding and time available. We have developed extensive empirically-based disciplines in project management in recent years. But common experience is that many projects fail or overrun. What makes projects behave in a different way from our expectations? How should managers manage projects in a new efficient way? This paper uses the system info of prospect theory to investigate such phenomenon, especially in critical chain project management.

This paper is structured as follows. First, however, we will get the reader familiar with the critical chain procedure. Section 2 offers a short overview of the current practice in critical chain project management and its strengths of the approach. That section is followed by a description of several typical methods for determining buffer sizes in critical chain project scheduling. Then, in section 3, a description of prospect theory is introduced in brief. We, thus, put forward a simplified model in time buffer scheduling according to prospect theory. Recognizing such problems, alternative methodologies based on the Expect Utility Theory and the Prospect Theory have been developed in section 4. Conclusions and the research agenda are discussed in the last section.

2. Critical Chain Management in Practice

Goldratt's Theory of Constraints (TOC) and its direct application to project management, known as Critical Chain Scheduling and Buffer Management, has recently emerged as one of the most popular approaches to project management. The development of such a technique for project scheduling is the main theme of Goldratt's novel^[1]. The application of the philosophy to develop a technique has recently been summarized by Rand^[2]. Such authors all describe the application of the TOC philosophy to project time management reduces project durations, There is often a little incentive to finish an activity ahead of schedule while not meeting a deadline normally reflects negatively on the individual . Rational people responsible for project activities therefore attempt to make commitment that they could meet with a high level to certainty. They are aware of the risks and even of the skewed probability distribution of activity duration assumed in stochastic PERT.

The TOC thinking tools applies the principle of aggregation to project schedule risks:Contingency reserves for individual activities are reduced so that activity durations are realistic but challenging. As a result of the effect of aggregation this time storage is smaller than the sum of the individual reserves that have been removed from low-level activities. Thus project duration is reduced. The higher the number of activities on the critical path of a project, the more project duration can be reduced. There is often a little incentive to finish an activity ahead of schedule while not meeting a deadline normally reflects negatively on the individual. Rational people responsible for project activities therefore attempt to make commitment that they could meet with a high level to certainty. Buffers in project scheduling are calculated

to reflect the uncertainty in the estimates of duration of tasks. There are three types of buffers: feeding, project and resource. Feeding buffers are added whenever a non-critical chain activity joins the critical chain, both to protect the critical chain from disruptions on the activities feeding it, and to allow critical chain activities to start early in case things go well. A project buffer is added to the end of the critical chain to protect the project delivery date. Resource buffers are characterized as warning systems or reminders that make sure the resources are ready when it is time to work on a critical task. Resource buffers do not change the planned time of the project^[1]. Obviously the size of a buffer has a significant impact on the project schedule. It might create new resource contentions, and it might even change the longest path. Furthermore, determining the size of a buffer in a high uncertainty environment is more crucial than determining it in an environment where there is less uncertainty. The most familiar and simple buffer sizing approaches suggested in the literature are as follows: the cut and paste method (C&PM) and the root square error method (RSEM). But Herroelen and Leus (2001) report that the C&PM seriously overestimates the buffer sizes, while RSEM performs better especially for larger projects^[4]. According to Oya I.T. and Walter O. R., they offer an in-depth analysis of the relationship between buffer sizing techniques and project performance and suggest two new methods for determining buffer sizes which take into account project complexity and resource tightness^[5].

In most of these studies, however, the potential impact of various methods of sizing feeding buffers on project performance have been overlooked. Normally, only

the project manager makes a commitment on the project delivery date. The team-members at all levels below him or her just make estimates and communicate expectations. If they believed that they would be blamed for overdue delivery of outputs, they could be expected to build more time buffer as contingency reserves. Chapman and Ward^[3] realize that one should distinguish among targets, expectations and commitments but do not apply this notions explicitly to shorten project duration by eliminating commitments at levels below project level. The size of the estimated buffer allocation depends on the project planner's perception of risk with respect to a particular type of activity or subtask. To encourage everybody working on projects to quote realistic durations, we should uncover this dummy activity in a new perspective, especially with the increasing project complexity. In this study, our goal is to highlight the importance of subjective value of project decision makers and investigate the impact of it on time buffer scheduling behaviors.

3. A View on Prospect Theory

The TOC methodology of using feeding, resource and project buffers and the underlying buffer management mechanism provide a simple tool for project monitoring and realistic due date setting. Relying on a fixed, right-skewed probability distribution for the duration of project activities may prove to be inappropriate. For example, if a person responsible for the execution of an activity knows that the next job allocated to him has to be done somewhere in the distant future, and the successors of his activity can only start much later, he will be tempted to take his time

(Parkinson's Law). The study of the time buffer decision has typically assumed that the "firm" makes the decision using an economic utility model to best serve the long-term goals of the company. However, the employees that make the decisions are human, and human decision-making is "bounded" in its ability to acquire and process information. Humans tend to use simplifying heuristics to deal with complex problems^[6]. These heuristics are generally effective in decision-making. They help to filter and assimilate the data. Heuristics are especially likely to drive the decision outcome when the decision process enters a "gray" area where there is no clearly dominant best alternative. The danger, however, lies in the oversimplification.

Kahneman and Tversky's research on Prospect Theory has had an even greater impact, at least in economics, than their work on judgment. Reacting to the hegemonic position of expected-utility as a theory of decision under conditions of risk, they demonstrated experimentally that people systematically deviate from the predictions of Expected Utility Theory and some of the axioms upon which it is based. The Prospect Theory integrates these behavioral anomalies in rational decision theory into an alternative theory of risk choice. When the expected results of an alternative are "good"—that is to say, they are higher than the target level, the decision maker shows a risk-averse attitude. When the expected results are "bad", which is lower than the target level, the decision maker will be risk seeking. High expected results lead to a risk-averse attitude, while low expected results lead to a risk-seeking attitude.

Kahneman and Tversky distinguish two phases in the choice process. In the editing phase the actor identifies the reference point, the available options, the

possible outcomes, and the value and probability of each of these outcomes. In the evaluation phase, the decision maker combines the values of possible outcomes (as reflected in an S-shaped value function, which is characterized by concavity above the reference point, convexity below it, and a steeper slope on the loss side) with their weighted probabilities (as reflected in the probability weighting function) and then maximizes over the product. Attitudes toward risk are determined by the combination of the S-shaped value function and the probability weighting function and not by the value function alone. Although this combination usually generates risk aversion for gains and risk acceptance for losses, it can also produce (depending on the precise shape of the two functions) risk acceptance for gains and risk aversion for losses when probabilities are small^{[7][8]}.

4. Formulation of the Time Estimation Behavior Model

A project could eventually be decomposed into various activities; this section formulates a time estimation behavior model for single-activity project as an example, based on the Prospect Theory.

4.1 The decision-making steps of project decision makers

According to the Prospect Theory, the decision-making process in project scheduling will keep to the following three steps:

- (1) Decision maker apperceives the costs incurred by different options subjectively;
- (2) Decision maker estimate the “gains” and “losses” in accordance with the “reference point” when various options are chose;

(3) Decision maker is assumed to select the prospect with the highest weighted value, in accordance with the value function and the probability weighting function.

4.2 The perceptive expense of project decision maker and correlative hypotheses

The description we presented perfectly matches the formation of the problem associated with the Prospect Theory. From this perspective, the buffer time is based on the perceptive expense of project decision maker subjectively. The perceptive expenses are described as follows:

(1) The directness expenses: such as the direct laborage and the outlays for raw materials, which can be reckoned in cost directly. The shorter the time limit, the more profits will be achieved.

(2) The overhead expenses: such as the management outlays, the penalty for time overrun, the bonus for ahead of schedule, the interest payable, which can not be reckoned in cost directly. In addition, it should be assumed that the decision maker is self-regard, pay close attention to two kinds of overhead expenses, the penalty for time overrun and the bonus for ahead of schedule.

(3) The search fee: such as the expenses for search information and opportunity evaluations which can sustain correct decisions. Due to the existence of experience, the decision maker will reduce the search fee. On the other hand, products or services are unique, we assume the search efficiency will bring less impact on expenses reduction.

Let's consider that the decision maker come into play at time T_k , the completion time is T_{finish} , the actual activity duration is t^k , then $T_k + t^k = T_{finish}$. The T_{EF} can be

described as early finish date and the T_{LF} can be described as late finish time. If $T_{finish} > T_{LF}$, the penalty for time overrun will come into being; whereas, the bonus for ahead of schedule will be occurred. Both of these expenses may reduce profit. The penalty for time overrun per unit time is designated as p ; the bonus for ahead of schedule per unit time is designated as b ; the actual cost per unit time is designated as c . In order to simplify the stochastic variables, project can be identified as a single activity one. Given these settings, the following items are defined:

- (1) The single activity is the critical activity, as a result, $T_{EF} = T_{LF}$;
- (2) The relationship among cost characteristics are as follows: $p > c > b$;
- (3) The search fee is ignored, $X=0$.

4.3 The prospect value of time buffer estimation

In this system, the subjective expense of project decision maker is:

$$U(t^k) = ct^k + \sigma b(T_{EF} - T_{finish}) + (1 - \sigma)p(T_{finish} - T_{EF}), \text{ where } \sigma \text{ is the 0-1 variable,}$$

$$\sigma = \begin{cases} 0, & T_{finish} > T_{EF} \\ 1, & T_{finish} \leq T_{EF} \end{cases}$$

Solving the above equality, we obtain the following expressions:

$$U(t^k) = [c - \sigma b + p(1 - \sigma)] t^k + [\sigma b - (1 - \sigma)p] (T_{EF} - T_k) \quad (1)$$

Selecting an appropriate reference point has a significant impact in Prospect Theory, and it is helpful to quantity the prospect value. According to Cumulative Prospect Theory, decision maker frames a problem around a reference point and

evaluate outcomes above or below the reference point^[8]. This has a critical influence on their choices. In this study, we consider the expected expense as the reference point.

We determine the desired completion moment is T_{desired} , T_k is the start moment, the scheduled completion time is t_{desired}^k , $t_{\text{desired}}^k = T_{\text{desired}} - T_k$. Using $U(t^k)$ from (1),

U_{desired}^k can be calculated as

$$U_{\text{desired}}^k = U(t_{\text{desired}}^k) = [c - \sigma b + p(1 - \sigma)] t_{\text{desired}}^k + [\sigma b - (1 - \sigma)p] (T_{\text{EF}} - T_k) \quad (2)$$

We also determine the subjective evaluation of completion moment is \widehat{T}_p , T_k is the start moment, the desired completion time is \widehat{t}_p^k , $\widehat{t}_p^k = \widehat{T}_p - T_k$. Using $U(t^k)$ from (1), \widehat{U}_p^k can be calculated as

$$\widehat{U}_p^k = U(\widehat{t}_p^k) = [c - \sigma b + p(1 - \sigma)] \widehat{t}_p^k + [\sigma b - (1 - \sigma)p] (T_{\text{EF}} - T_k) \quad (3)$$

If $\widehat{U}_p^k \leq U_{\text{desired}}^k$, the project planners consider to obtain gains; whereas, if $\widehat{U}_p^k > U_{\text{desired}}^k$, the project planners consider to obtain losses.

Assuming $\Delta U = U_{\text{desired}}^k - \widehat{U}_p^k$, we can present ΔU as following:

$$\Delta U = [c - \sigma b + p(1 - \sigma)] (t_{\text{desired}}^k - \widehat{t}_p^k) \quad (4)$$

$$\text{When } t_{\text{desired}}^k > \widehat{t}_p^k, \Delta U \geq 0, \Delta U = (c - b) (t_{\text{desired}}^k - \widehat{t}_p^k) \quad (5)$$

$$\text{When } t_{\text{desired}}^k \leq \widehat{t}_p^k, \Delta U < 0, \Delta U = (c + p) (t_{\text{desired}}^k - \widehat{t}_p^k) \quad (6)$$

According to Cumulative Prospect Theory^{[7][8]}, decision maker is assumed to select the prospect with the highest weighted value. The weighted value of Prospect X that pays x_1 with probability p_1 and x_2 otherwise is:

$$V(X) = v(x_1)\pi(p_1) + v(x_2)\pi(p_2) \quad (7)$$

where $v(x_1)$ is the subjective value of outcome x_1 , and $\pi(p_1)$ is the subjective weight of outcome x_1 . The subjective values are given by a value function that can be described as follows:

$$v(\chi) = \begin{cases} \chi^\alpha, & \chi \geq 0 \\ -\lambda(-\chi)^\beta, & \chi < 0 \end{cases} \quad (8)$$

The parameters $0 < \alpha < 1$ and $0 < \beta < 1$ capture the assumption of diminishing sensitivity in the gain and the loss domain respectively. The parameter λ captures the basic idea of the loss aversion assertion; when $\lambda > 1$, losses loom larger than gains. In this model, let's consider $\alpha = \beta$ and $\chi = \Delta U$. According to the researcher's demarcate, when $\alpha = 0.88$, $\lambda = 2.25$, the results are consistent with experimental studies.

The subjective weights are assumed to depend on the outcomes' rank, sign, and on a cumulative weighting function. When the two outcomes are of different sign, the weight of outcome is:

$$\omega^-(p) = \frac{p^\delta}{[p^\delta + (1-p)^\delta]^{1/\delta}}$$

$$\omega^+(p) = \frac{p^\gamma}{[p^\gamma + (1-p)^\gamma]^{1/\gamma}} \quad (9)$$

The parameters $0 < \lambda < 1$ and $0 < \delta < 1$ capture the tendency to overweight low probability outcomes. When the outcomes are of the same sign, the weight of the most extreme outcome (largest absolute value) is computed with equation (9), and the weight of the less extreme outcome is the difference between that prospect values.

According to the researcher's demarcate^[4], when $\gamma=0.61, \delta=0.69$, the results are consistent with experimental studies.

In the editing phase the decision makers identifies the reference point, the available options, the possible outcomes, and the value and probability of each of these outcomes. In the evaluation phase, they combine the values of possible outcomes with their transformed probabilities by maximizing over the product of the value function (Equation 8) and the probability weighting function (Equation 9). Let us now turn to applications of these basic Prospect Theory concepts to a simple example.

4.4 A simple example of buffer decision based on the Prospect Theory

We presume there are two scenes:

I: The late completion date of the activity is 10 days, postpone will be confronted with punishment and ahead of schedule will be confronted with incentives.

II: The late completion date of the activity is 5 days, postpone will be confronted with punishment and ahead of schedule will be confronted with incentives.

Given two events A and B:

A: The probability of accomplishment in 6 days is 40%, the probability of accomplishment in 14 days is 60%;

B: The probability of accomplishment in 10 days is 100%.

Recognizing such problems, alternative methodologies based on the Expect Utility Theory and the Prospect Theory have been analyzed. The relative optimal decisions derived from the two theories are shown in Table 1.

The simulation results reveal two important insights. Firstly, people tend to overweight losses with respect to comparable gains, engage in risk-averse behavior with respect to gains (choose event B in scene I) and risk-seeking behavior with respect to losses (choose event A in scene II), and respond to probabilities in a non-linear manner. While the result is usually risk aversion for gains and risk acceptance for losses, the overweighting of small probabilities can sometimes lead to a reversal of risk propensities, depending on the precise shapes of the two functions^[8]^[9]. Secondly, we can make a primary conclusion that expectation levels, aspiration levels, social norms, market comparisons, project environment and recent losses can also influence the location of an actor's reference point and their decisions.

Table 1: Simulation result under different theories

Scene	Scheme	Attribute	Expect Utility	Prospect Value	Relative Optimal Decision	
					Expect Utility Theory	Prospect Theory
I	A	(40%, 6; 60%, 14)	1520	-470		
	B	(100%, 10)	1000	0	※	※
II	A	(40%, 6; 60%, 14)	2490	-1178		※
	B	(100%, 10)	1750	-1195	※	

5. Conclusions and suggestions for further research

In this paper we provide a prospect value analysis of different events which express different time buffer decisions. A simple simulation was performed using the Prospect Theory. The method is evaluated through two performance indicators: length

of the planned completion times and probability of meeting the planned completion times. It seems like the adaptive procedures are good choices for meeting this objective especially in a project environment where uncertainty is low. As a result, control effort will shift from input-oriented control to a combination of output and behavior control.

A manager is able to build the time buffer on the basis of a scientific estimate of prospect value rather than by trial-and-error. The extension of this study would be to include other performance indicators such as cost optimization. The earlier than necessary start times for tasks result in work in process cost, whereas delays in project completion times result in penalties. Whether we can make the optimal tradeoffs among penalty for time overrun, the bonus for ahead of schedule and the actual cost relatively has come to play an increasingly important role in time buffer decision-making. On the other hand, this calculation of the prospect value has been done with the assumption of a single-activity project system. The next step in such research will be to evaluate the prospect value for a multi-activities project system, while the evaluation may require a more complicated mathematical analysis.

This study is an effort to incorporate the critical chain project concept into the Prospect Theory literature which will be a starting point for further research.

Appendix A Prospect value calculation using the Prospect Theory

In event A, according to formula (4), when $\sigma = 1$, $\Delta U_1 = U_{\text{desired}} - U_{\text{early}} = 200 > 0$, which means the decision makers will tend to obtain; when $\sigma = 0$,

$\Delta U_2 = U_{\text{desired}} - U_{\text{late}} = -1000 < 0$, which means the decision makers will be faced with losses.

According to the ascending sequence, we can obtain a sequence :
 $f = (-1000, 60\%; 200, 40\%)$.

In equation (8) and (9), $v(\chi_1) = \chi_1^\alpha = 200^{0.88} = 105.9$;

$$\omega^+(p_1) = \frac{p_1^\gamma}{[p_1^\gamma + (1-p_1)^\gamma]^{1/\gamma}} = \frac{0.4^{0.61}}{[0.4^{0.61} + 0.6^{0.61}]^{1/0.61}} = 0.3702;$$

$$v(\chi_{-1}) = -\lambda(-\chi_{-1})^\beta = -982.16; \quad \omega^-(p_{-1}) = \frac{p_{-1}^\delta}{[p_{-1}^\delta + (1-p_{-1})^\delta]^{1/\delta}} = 0.5181.$$

Then in equation (7), $V(X_1) = \omega^-(p_{-1})v(\chi_{-1}) + \omega^+(p_1)v(\chi_1) = -469.65$

In event B, $\Delta U = 0$, $f = (0, 100\%)$, $V(X_2) = 0$.

$V(X_1) < V(X_2)$, event B may tend to happen.

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