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A Simulation Study on the Impact of Activity Crashing on the Project Duration and Cost under Different Budget Release Scenarios

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Abstract—**The main goal of project control is to identify project opportunities or problems during project execution, such that corrective actions can be taken to bring the project in danger back on track when necessary. In this study, we define different scenarios to allocate the limited budget used for the cost of activity execution, delays, and corrective actions, according to the timing and amount of the budget release. A large computational experiment is conducted on real-life project data to evaluate the performance of each scenario. The results show that both the timing and amount of the budget release have an effect on project performance.**

I. INTRODUCTION

PROJECT control is a key part of project management (PM), together with baseline scheduling and schedule risk analysis. Where baseline scheduling focuses on the construction of a timetable for the activities considering the technological and resource constraints in the project, risk analysis identifies high risk activities in the project. Both aspects belong to the static PM phase, i.e. prior to project execution, and are supported by state-of-the-art optimisation and simulation techniques to create optimal and robust project schedules. In contrast, project control is the process of monitoring the project during execution to detect potential problems and taking corrective actions when necessary, and belongs to the dynamic PM phase [1]. Since project success can only be achieved when the static PM phase is combined with an effective project control process, advanced modelling and simulation techniques are needed to support the project control process.

Earned Value Management (EVM) is a project control method to measure the project performance in terms of time and cost [2]. Using EVM, the project progress can be periodically measured and compared to a control limit [3]. When the progress is below this limit, the project is expected to exceed its deadline and a warning signal is generated to initiate corrective action. Since generating efficient and reliable warning signals is important to take effective corrective actions, this research topic has been investigated intensively in recent years [4], [5], [6]. Other recent research studies focused on the corrective action taking process [7], [8], [9]. Since many of these research efforts do not consider the fact that the project budget is limited in most real-life projects, [10] have investigated the performance of four different approaches to allocate a limited budget dedicated to corrective actions over different project phases. The authors developed an extensive simulation experiment to evaluate the four approaches using a large set of artificial projects and showed that the best allocation model considers the planned progression of work in the project and provides a control budget that increases in later project stages.

In this study, we simulate the impact of time-cost trade-offs given a limited project budget on the time and cost performance of a set of real-life projects. The timing and quantity of the release of the budget throughout the project life cycle is modelled using different scenarios: immediate or time-phased budget releases, proportional to the time or cost profile of the project and dynamically increasing or decreasing as the project progresses. We only consider activity crashing as a potential corrective action, which implies investing more budget in an activity to reduce the activity duration (i.e. time-cost trade-offs). This problem is related to the Project Scheduling Game (PSG, [11]), a project control game in which the project execution of a relatively complex project is simulated. The objective is to minimise the final project cost by controlling the project at six decision moments using activity crashing. While an unlimited budget is available in the PSG, we evaluate different strategies for using a limited budget during project execution to complete a project within this budget. Further, we extend the existing research by [10] in three ways. First, we do not consider a control budget that can only be used for activity crashing, but we determine a total project budget that should cover the cost of activity execution, delays and activity crashing. This is a more realistic situation since the cost of activity delays and penalty costs for project delays are explicitly considered. Second, our focus is on cost minimisation rather than timely project completion. Therefore, we consider projects that exceed the predefined project budget to be failed projects and we evaluate the performance of the different scenarios based on the actual project duration and cost and the portion of failed projects. Finally, we test the proposed approaches on real-life project data in order to incorporate realistic cost profiles.

II. METHODOLOGY

The methodology of this study consists of four phases. In the *data collection phase*, planning and risk data from real-life projects are collected. In the *scenario analysis phase*, different scenarios to allocate the project budget over the project life cycle are defined. During the *simulation phase*, progress data for each of the real-life projects is simulated to review the impact of activity crashing on the cost profile of the projects. The *evaluation phase* consists of an analysis of the duration and cost performance of the projects. Table I summarises the relevant terminology and parameters used in this study.

A. Data collection

In the data collection phase, real-life planning, progress and risk data from projects in various industries has been collected and documented. After a first meeting, the project owner or manager decides whether they are willing to collaborate. If this is the case, a project that is planned to start in the near future is selected for real-time periodical follow-up. This ensures that the documented data is correct and complete. At each period, it is reviewed whether the information is available at the activity level. If activity level data is available, the activity risk profiles are discussed with the project owner or manager. Otherwise, the follow-up process is terminated. When all collected data is clear, it is registered in a structured manner. This process is repeated periodically until the project is finished.

Table II gives an overview of the collected data and lists the industry, planned duration (PD), Budget at Completion (BAC) and number of activities (nract) of each project. These projects are included in the database of [12] and are online available at https://www.projectmanagement.ugent.be/research/data/realdata.

B. Scenario analysis

Before the project start, the *total project budget* is defined as the BAC (section II-A) increased with a management reserve to take corrective actions and to deal with activity delays during execution. In the computational experiment, the size of the management reserve is varied and different scenarios considering the timing and quantity of the budget release are considered for the release of the project budget during execution.

a) Size of management reserve: In this study, the size of the management reserve (MR) is defined as the difference between the average actual project cost (APC) without activity crashing and the BAC, multiplied with a factor m_B (equation (1)). The APC without activity crashing is calculated by adding uncertainty profiles to the activity durations and using Monte Carlo simulations to imitate the actual project progress (section II-C).

$$\mathrm{MR} = (\mathrm{APC} - \mathrm{BAC}) \times m_B \tag{1}$$

b) Timing of budget release: Two different approaches are considered regarding the timing of the budget release. First, the *immediate approach* assumes that the entire project budget is made available from the start of the project. Second, the *time phased approach* assumes that the project is divided in different phases, and a portion of the total project budget is released at the start of each phase.

c) Quantity of budget release: The quantity of the budget release depends on the applied timing approach. For the immediate timing approach, the entire budget (BAC + management reserve) is released at the start of the project. For the time phased approach, the planned budget at the end of each phase is increased with a portion of the management reserve and released at the start of each phase. To determine the portion of the management reserve to be released at each phase, two viewpoints are used. First, using the *time focus* viewpoint (equation (2)), the management reserve is allocated to each phase proportional with the relative duration of each phase ($\frac{\mathrm{PD}_{\mathrm{phase}}}{\mathrm{PD}_{\mathrm{project}}}$). Second, using the *cost focus* viewpoint (equation (3)), the management is allocated to each phase proportional with the relative budgeted cost of each phase ($\frac{\mathrm{BAC}_{\mathrm{phase}}}{\mathrm{BAC}_{\mathrm{project}}}$).

$$\text{Assigned budget}_{\text{phase, time}} = \mathrm{BAC}_{\mathrm{phase}} + \frac{\mathrm{PD}_{\mathrm{phase}}}{\mathrm{PD}_{\mathrm{project}}} \times \mathrm{MR} \tag{2}$$

$$\text{Assigned budget}_{\text{phase, cost}} = \mathrm{BAC}_{\mathrm{phase}} + \frac{\mathrm{BAC}_{\mathrm{phase}}}{\mathrm{BAC}_{\mathrm{project}}} \times \mathrm{MR} \tag{3}$$

While equations (2) and (3) allocate the management reserve over the different phases proportionally with the time or cost (i.e. the *standard version*), the management reserve can be allocated in a dynamically increasing or decreasing way as well [10]. The *increasing version* ensures that the allocated management reserve is relatively low at the start of the project and systematically increases along the project progress by allocating the management reserve based on the square of the relative duration or cost of each phase (Equation (4)). The *decreasing version* uses the square root to start with a relatively high amount of the budget which increases degressively along the project progress (Equation 5). In table III, an overview of the scenarios reviewed in the simulation experiment is given.

$$\text{Assigned budget}_{\text{phase, time, increasing}} = \mathrm{BAC}_{\mathrm{phase}} + \left(\frac{\mathrm{PD}_{\mathrm{phase}}}{\mathrm{PD}_{\mathrm{project}}}\right)^2 \times \mathrm{MR} \tag{4}$$

$$\text{Assigned budget}_{\text{phase, time, decreasing}} = \mathrm{BAC}_{\mathrm{phase}} + \sqrt{\frac{\mathrm{PD}_{\mathrm{phase}}}{\mathrm{PD}_{\mathrm{project}}}} \times \mathrm{MR} \tag{5}$$

C. Simulation

In the simulation phase, 1,000 simulated project executions are generated for each project collected in the data collection phase. Before the start of each project, the tolerance limits for the project progress are set as introduced by [4]. During each simulated execution, the project progress is measured and compared to these limits periodically. When the incurred

TABLE I
OVERVIEW OF TERMINOLOGY

Concepts		**Parameters**		**Performance measures**	
Project		*Project*			
nract	number of activities	m_B	multiplier total budget	AFP	Actual Failed Projects
BAC	Budget at Completion	m_D	multiplier delay cost	APD	Actual Project Duration
PD	Planned Duration	C_D	Cost of unit delay	APC	Actual Project Cost
AD	Actual Duration		$= \frac{\text{BAC}}{\text{PD}} \times m_D$		
Activities		*Activities*			
AD_i	Actual duration act i	$C_{C,i}$	Crash cost of act i		
$C_{F,i}$	Fixed cost of act i		$= 2 \times C_{F,i}$		
$C_{V,i}$	Variable cost of act i				
UC_i	Crashed units of act i				

TABLE II
OVERVIEW OF REAL-LIFE PROJECTS

Project ID	Industry	PD (days)	BAC (€)	nract
C2011_03	Event	97	31,675	24
C2011_04	Construction	125	59,831	20
C2011_05	Telecom	43	180,485	23
C2011_08	Construction	72	254,564	28
C2011_11	Event	299	37,760	26
C2012_01	Manufacturing	45	61,699	31
C2012_11	Manufacturing	13	1,535,854	24
C2013_17	Construction	161	244,205	25
C2014_07	Construction	353	1,102,537	27
C2014_08	Construction	233	1,992,222	41

costs at the period exceed the released budget until that time, the project is interrupted until an additional part of the project budget is released and the project can be resumed. Further, when the total project budget is exceeded, the project is terminated and classified as a failed project. When the project is not interrupted or terminated, the project progress is reviewed. If the progress is below the tolerance limit, the activities eligible for activity crashing are determined by comparing the activity crash cost of the ongoing critical activities (i.e. activities on the critical path) to the expected delay cost reduction. If there are eligible activities and the required budget for activity crashing is available at the period, the actions are taken and the project is continued.

D. Performance evaluation

After completion of the simulation phase, the performance of the simulated executions is reviewed. For each simulation experiment, the number of failed projects (AFP), i.e. the number of projects that exceeded their budget, is observed. Further, the time and cost performance is evaluated using the actual project duration (APD) and actual project cost (APC). The APD and APC are expressed relatively to the planned duration and the total project budget of the projects, respectively.

III. RESULTS AND DISCUSSION

In this section, the performance of the scenarios depicted in table III is evaluated using the project performance measures listed in table I (Experiment 1). In Experiment 2, the impact on the project performance of a change in the total project budget is examined by varying the value of m_B (equation (1)). Finally, Experiment 3 reviews the impact of changes in the cost per unit delay ($C_D = \frac{\text{BAC}}{\text{PD}} \times m_D$) by varying the value of m_D.

a) Experiment 1: Comparison of scenarios: The results of Experiment 1 are summarised in table IV. The results show that the immediate budget release approach (S1) outperforms the time phased budget release approaches in terms of AFP, APD and APC. All project runs are finished within the assigned project budget, with an average duration of 101.7% of the PD. Further, for the standard time phased assignment versions, the time focus (S2) performs better than the cost focus (S5) for all performance measures. This can be explained by the fact that the cost focus assigns higher portions of the management reserve to more costly project phases. Since the activities planned in these phases are typically more expensive to crash, less corrective actions can be taken with the same budget. Finally, the decreasing version of the time focus approach (S3) uses the available project budget most effectively, since it results in the lowest AFP, APD and APC of all time phased approaches.

b) Experiment 2: Impact of changes in total project budget size: Since experiment 1 showed that the time phased scenarios using a time focus outperform the scenarios using a cost focus, the remaining discussion focuses on scenarios S1-S4. In general, table V shows that reducing the size of the management reserve increases the APD, APC and especially the AFP. For an immediate budget release (S1), a reduction of 10% ($m_B = 0.9$) has a limited impact, while a reduction of 20% ($m_B = 0.8$) results in considerably more failed projects. For the time phased scenarios, the impact of reducing the budget is more substantial. For a reduction of 10%, S3 still outperforms S2 and S4. When the management reserve is reduced with 20%, however, the performance of these scenarios become comparable.

c) Experiment 3: Impact of changes in the cost of delays: Table VI shows that reducing the unit cost of delay (m_D) has a limited impact. Both the AFD, APD and APC increase slightly for lower unit costs of delay. The increase in APC can be explained by the fact that activities are only crashed when the expected reduction in delay costs is higher than the increased costs due to the crashing action.

To conclude, this simulation experiment indicates that a management reserve should be considered to control projects during execution. Experiment 1 shows that both the timing

TABLE III
OVERVIEW OF CONSIDERED SCENARIO SETTINGS

Scenario	**S1**	**S2**	**S3**	**S4**	**S5**	**S6**	**S7**
Timing	Immediate	Time phased	Time phased	Time phased	Time phased	Time phased	Time phased
Quantity	-	Time	Time	Time	Cost	Cost	Cost
Version	-	Standard	Decreasing	Increasing	Standard	Decreasing	Increasing

TABLE VI
IMPACT OF CHANGES IN COST OF DELAYS ($m_B = 1$)

Scenario	m_D	**AFP (%)**	**APD (%)**	**APC (%)**
S1	**1.00**	0	101.7	89.6
	0.75	0	101.7	91.1
	0.50	0	101.7	92.6
S2	**1.00**	16	105.4	90.8
	0.75	20	106.4	92.5
	0.50	22	107.1	92.6
S3	**1.00**	6	102.9	89.7
	0.75	8	103.3	91.2
	0.50	11	103.9	92.8
S4	**1.00**	28	108.5	92.7
	0.75	32	109.1	93.7
	0.50	38	109.7	94.6

TABLE IV
COMPARISON OF SCENARIOS ($m_B = 1, m_D = 1$)

Scenario	**AFP (%)**	**APD (%)**	**APC (%)**
S1	0.0	101.7	89.6
S2	15.8	105.4	90.8
S3	5.8	102.9	89.7
S4	27.7	108.5	92.7
S5	19.8	105.8	91.2
S6	6.1	103.1	89.7
S7	33.7	111.3	94.4

TABLE V
IMPACT OF CHANGES IN TOTAL PROJECT BUDGET SIZE ($m_D = 1$)

Scenario	m_B	**AFP (%)**	**APD (%)**	**APC (%)**
S1	**1.0**	0	101.7	89.6
	0.9	3	101.8	91.5
	0.8	19	102.7	94.0
S2	**1.0**	16	105.4	90.8
	0.9	41	108.7	94.6
	0.8	72	113.3	99.7
S3	**1.0**	6	102.9	89.7
	0.9	28	105.8	92.7
	0.8	70	111.8	98.6
S4	**1.0**	28	108.5	92.7
	0.9	50	110.7	95.9
	0.8	75	114.0	100.2

and amount of the budget release have an effect on the actual project duration and cost. Further, experiment 2 shows that the total size of the management reserve is of importance as well. If the management reserve is too low, the performance of different strategies for the amount of budget release perform equally low. Finally, when the cost of delays is decreased, this has a more substantial impact on the actual project cost than on the actual project duration.

REFERENCES

[1] M. Vanhoucke, *Project Management with Dynamic Scheduling: Baseline Scheduling, Risk Analysis and Project Control.* Springer, 2012, vol. XVIII.

[2] Q. Fleming and J. Koppelman, *Earned Value Project Management*, 3rd ed. Newton Square, Pennsylvania: Project Management Institute, 2010. [Online]. Available: http://books.google.be/books?id=ZMRVngEACAAJ

[3] J. Colin and M. Vanhoucke, "Setting tolerance limits for statistical project control using earned value management," *Omega The International Journal of Management Science*, vol. 49, pp. 107–122, 2014.

[4] A. Martens and M. Vanhoucke, "A buffer control method for top-down project control," *European Journal Of Operational Research*, vol. 262, pp. 274–286, 2017.

[5] J. Zhang, S. Jia, and E. Diaz, "Dynamic monitoring and control of a critical chain project based on phase buffer allocation," *Journal of the Operational Research Society*, vol. 69, pp. 1–12, 2018.

[6] H. Hadian and A. Rahimifard, "Multivariate statistical control chart and process capability indices for simultaneous monitoring of project duration and cost," *Computers & Industrial Engineering*, pp. 788–797, 2019.

[7] M. Madadi and H. Iranmanesh, "A management oriented approach to reduce a project duration and its risk (variability)," *European Journal of Operational Research*, vol. 219, no. 3, pp. 751–761, 2012.

[8] P. Ballesteros-Pérez, K. Elamrousy, and M. Gonz'ales-Cruz, "Non-linear time-cost trade-off models of activity crashing: Application to construction scheduling and project compression with fast-tracking," *Automation in Construction*, vol. 97, pp. 229–240, 2019.

[9] A. Martens and M. Vanhoucke, "The impact of applying effort to reduce activity uncertainty on the project time and cost performance," *European Journal of Operational Research*, vol. 277, no. 2, pp. 442–453, 2019.

[10] J. Song, A. Martens, and M. Vanhoucke, "The impact of a limited budget on the corrective action taking process," *European Journal Of Operational Research*, vol. 286, no. 3, pp. 1070–1086, 2020.

[11] M. Vanhoucke, A. Vereecke, and P. Gemmel, "The project scheduling game (PSG): Simulating time/cost trade-offs in projects," *Project Management Journal*, vol. 51, pp. 51–59, 2005.

[12] J. Batselier and M. Vanhoucke, "Construction and evaluation framework for a real-life project database," *International Journal of Project Management*, vol. 33, pp. 697–710, 2015.