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The integration of constrained resources into top-down project control

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ABSTRACT

The timely completion of a project is one of its main factors for success. During the scheduling phase, a project buffer can be installed to protect the project deadline. During the execution phase, tolerance limits that generate warning signals when the project deadline is endangered should be constructed to monitor the buffer consumption. These tolerance limits will be constructed for the dynamic progress data provided by the Earned Value Management/Earned schedule methodology (EVM/ES).

In this paper, we incorporate information on the availability of scarce resources into the construction of analytical tolerance limits for EVM/ES, in order to improve the efficiency and reliability of these tolerance limits. In order to review the performance of the limits, a computational experiment has been carried out in which they are compared to analytical tolerance limits that disregard the availability of resources. Results have shown that the performance of analytical tolerance limits can be significantly enhanced by incorporating the available resource information.

1. Introduction

The goal of project control is detecting potential problems or opportunities during project execution, by measuring the deviations from the baseline schedule. Top-down project control involves measuring and monitoring the progress of a project at the aggregated project level. Hence, a single metric which includes the aggregated project progress information can be used by the project manager in order to review the project progress. When this aggregated metric indicates a problem at the highest Work Breakdown Structure (WBS) level, the project manager should drill down the WBS in order to investigate which activities require corrective actions to resolve the problem. A well-known top-down project monitoring technique is Earned Value Management (EVM), which originated at the US Department of Defense in the 1960s. This methodology integrates the scope of the project with the time and cost dimension. In this paper, focus lies on the timely completion of projects. An extensive introduction to EVM is given in Fleming and Koppelman (2010). For a recent comprehensive overview of the literature on EVM and its extensions and applications, we refer the reader to Willems and Vanhoucke (2015). While many studies have discussed and applied EVM or proposed extensions to the methodology, they all disregard the resources required by projects. Nevertheless, the (limited) availability of renewable resources is an important limitation for real-life projects that affects the outcome of the project execution, and thus the monitoring process.

The aim of this paper is twofold. First, since monitoring the project progress at the aggregated level implies that specific activity level information might be overlooked, we discuss the implications of disregarding the presence of limited resources on the top-down project control process. Subsequently, we incorporate this activity level information into the EVM monitoring process. More precisely, we propose tolerance limits for EVM performance metrics, which generate warning signals when the project is expected to be late, given a project deadline and a limited resource availability. The performance of these tolerance limits is evaluated by means of a computational experiment.

The outline of this paper is as follows. In Section 2, we discuss the concept of Integrated Project Management and Control and the implications of including resource constraints on the monitoring process. Subsequently, in Section 3, we introduce tolerance limits for EVM which explicitly consider the availability of limited resources. Section 4 discusses the methodology used in this paper. In Section 5, the results of the computational experiment are discussed. In this experiment, the performance of the tolerance limits

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is evaluated for a diverse set of project networks, for which a large number of project executions are simulated. Finally, the conclusions of this experiment are reviewed in Section 6.

2. Integrated Project Management and Control

Integrated Project Management and Control specifies that the project life cycle consists of three major phases that should be integrated, i.e. the scheduling phase, the risk analysis phase and the project control phase (Vanhoucke, 2014). In the scheduling phase, a baseline schedule is constructed which serves as a point of reference during the risk analysis and project control phase. Subsequently, the sensitive parts of the constructed baseline schedule are analysed during the risk analysis phase. Finally, during the project control phase, the deviations between the project execution and the baseline schedule are measured in order to detect potential problems or opportunities. The remainder of this section is structured as follows. First, the baseline scheduling phase is briefly discussed in Section 2.1. Subsequently, we focus on the monitoring process of the project control phase in Section 2.2.

2.1. The scheduling phase

The goal of the scheduling phase is constructing a feasible baseline schedule, by setting start and finish times for all project activities. In the 1950s, two well-known scheduling standards which address the project scheduling problem in absence of resource restrictions have been established, i.e. the critical path method (CPM, Kelley & Walker, 1959) and the program evaluation and research technique (PERT, Fazar, 1959). Ever since, project scheduling problems and their extensions have been widely studied. For an integrated overview of the deterministic project scheduling literature, we refer the reader to Kolisch and Padman (2001). One of the well-known standard scheduling problems discussed by Kolisch and Padman (2001), the resource-constrained project scheduling problem (RCPSP), aims at minimising the project makespan when limited renewable resources are available. Many variants and extensions of this problem have been explored in literature, such as the discrete time/resource trade-off problem (DTRTP, De Reyck, Demeulemeester, & Herroelen (1998)). In the DTRTP, the workload with regard to a single renewable resource is given for each activity, and each activity can be performed in each discrete combination of a resource requirement and activity duration that allows to reach the workload. In Hartmann and Briskorn (2010), the DTRTP and other variants and extensions of the RCPSP are reviewed.

However, while the literature on project scheduling under a limited availability of resources is rich and diverse, incorporating resource restrictions into EVM/ES project control has been largely ignored. Therefore, in this paper, we extend the well-known EVM/ES project control approach by incorporating the information on the limited availability of resources into the construction of EVM/ES tolerance limits for schedule control.

2.2. The project control phase

The project control phase consists of three parts. First, the progress of the project should be adequately measured. A well-known methodology to measure this progress is Earned Value Management/Earned Schedule (EVM/ES). Therefore, in this paper, we will adapt EVM/ES to be suitable to adequately measure project progress when scarce resources are explicitly considered. Subsequently, the progress should be assessed in order to determine whether corrective actions are required. In order to asses the progress, tolerance limits for the project's progress should be constructed. We propose tolerance limits for the adapted EVM/ES methodology, which explicitly consider the limited availability of renewable resources. Finally, if necessary, corrective actions should be taken to get the project back on track. For instance, when time-resource trade-offs are present, these actions could consist of altering the execution mode of scheduled activities, in order to reduce their planned duration by using more resources. Since we propose tolerance limits which consider the limited availability of resources, the remainder of this section will focus on the first two steps of the project control phase. The abbreviations used in this section are listed in Table 1.

2.2.1. Measuring the project's schedule progress

EVM measures the actual progress of projects in monetary units and constructs performance metrics for the schedule progress by comparing this value to the baseline planned value. More specifically, EVM measures the actual project progress in terms of Earned Value (EV), and compares this EV to the planned progress, in terms of Planned Value (PV). Based on these key metrics, the EVM schedule performance metrics SPI ($=\frac{EV}{PV}$) and SV ($=EV - PV$) can be determined. Due to the fact that the schedule progress is measured in monetary units, these performance indicators behave unreliably towards the end of the project. In order to overcome this issue, Lipke (2003) introduced the Earned Schedule (ES) concept, which translates the EV of a given status date into time units. The ES of a status date t, ES_t, can formally be defined as $ES_t = x + \frac{EV_t - PV_x}{PV_{x+1} - PV_x}$, with x such that $EV_t \geqslant PV_x$ and $EV_t < PV_{x+1}$. Similar to EVM, two ES-base schedule performance metrics can be defined, i.e. the SPI(t) ($=\frac{ES}{AT}$) and the SV(t) ($=ES - AT$), with AT the actual time. However, while these performance metrics measure the schedule progress in time units, they are still based on the EV, which is a cost-based metric. Therefore, Khamooshi and Golafshani (2014) proposed the Earned Duration Management (EDM) methodology and the ED(t) concept, which is a completely time-based metric. The EDM equivalent of the SPI and the SPI(t) of the EVM/ES methodology is the Duration Performance Index ($DPI = \frac{ED(t)}{AT}$).

However, none of these methodologies considers the impact of scarce resources during project execution explicitly. Consequently, they do not manage to adequately show the actual progress in case there are limited resources available. This is illustrated by the toy example in Fig. 1. In the left and mid pane of this figure, the project network and baseline schedule of the example project are depicted. Further, the right pane of Fig. 1 depicts two different executions of this example project. In the first execution, activity 1

Table 1
List of abbreviations.

Baseline Schedule information	
PD	Planned Duration of the project
BAC	Budget At Completion of the project
PB	Project buffer
Project monitoring information	
Project key parameters	
PV_t	Planned Value of the project at period t
EV_t	Earned Value of the project at period t
ES_t	Earned Schedule of the project at period t
$ED(t)$	Earned Duration of the project at period t
WC_t	Work Content of the project at period t
Project performance metrics	
SPI_t	Schedule Performance Index of the project at period t using EV
$SPI(t)_t$	Schedule Performance Index of the project at period t using ES
SPI_{WC}	Schedule Performance Index of the project at period t using WC
DPI_t	Duration Performance Index of the project at period t using ED
with:	
$t = 1, \ldots, T$	Current time period (otherwise denoted as AT)
T	Total duration of the project