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An empirical validation of the performance of project control tolerance limits

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ABSTRACT

The goal of project control is monitoring the project progress during project execution to detect potential problems and taking corrective actions when necessary. Tolerance limits are a tool to assess whether the project progress is acceptable or not, and generate warnings signals that act as triggers for corrective action to the project manager. In this paper, three distinct types of tolerance limits that have been proposed in literature are validated on a large and diverse set of real-life projects mainly situated in the construction sector. Moreover, a novel approach to construct tolerance limits that integrate the project risk information into the monitoring process is introduced. The results of the empirical experiment have shown that integrating project-specific information into the construction of the tolerance limits results in a higher efficiency of the monitoring process. More specifically, while including cost information increases the efficiency only marginally, incorporating the available resource information substantially improves the efficiency of the monitoring process. Furthermore, when projects are not restricted by scarce resources, the efficiency can be enhanced by integrating the available project risk information.

1. Introduction

An important factor of project success is the timely completion of projects. In this paper, three control methodologies proposed in recent literature to control the schedule progress of projects are empirically compared and validated on the large and diverse real-life project database of Batselier and Vanhoucke [1]. From this database, 93 projects have been selected, of which 71 are situated in the broad construction sector. More specifically, the tolerance limits have been evaluated for commercial, residential and institutional building projects and for civil and industrial construction projects. Moreover, a novel control methodology that integrates the activity risk information into the project control phase is introduced.

Project control is, together with baseline scheduling and risk analysis, one of the three major components of Integrated Project Management and Control [2]. While the scheduling and risk analysis phases are performed before the project execution is started, the project control phase is conducted during project execution. The goal of this phase is to identify potential problems or opportunities during project execution, and to take corrective actions to get the project back on track if necessary. During project execution, the actual project progress is monitored and evaluated by comparing it to the baseline schedule. A well-known methodology to monitor the project progress is Earned Value Management (EVM), which originated in the 1960s at the US Department of Defense [3]. While EVM provides simple metrics to measure the current performance of a project, they should be used in conjunction with tolerance limits to assess this performance. These tolerance limits for project control have been established as a tool to support the project manager in deciding whether corrective actions should be taken to get the project back on track. Hence, the goal of these tolerance limits is generating warning signals when the monitored project progress is below a certain threshold, indicating that it is likely that the project will exceed its deadline. These warning signals thus act as a trigger for corrective action for the project manager. The control methodologies validated in this paper are analytical tolerance limits for schedule control using EVM metrics. This type of tolerance limits sets threshold values for the schedule progress at each project phase based on project-specific characteristics. Moreover, each of the tolerance limits evaluated in this paper are constructed for projects with a project buffer. Hence, these tolerance limits generate warning signals when it is expected that the project buffer will be consumed entirely before the project is completed, resulting in a project exceeding its deadline.

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The contribution of this paper is twofold. First, the analytical tolerance limits proposed in [4,5] and [6] are empirically validated using the real-life project database of Batselier and Vanhoucke [1]. A distinctive characteristic of these tolerance limits is their ease of implementation, since they are constructed using only project-specific information and do not require any historical or simulated data. However, since the performance of these limits has been validated using large simulation studies only, the ease of implementation in a real-life context has not been verified yet. Therefore, in this paper, both the ease of implementation of the tolerance limits for real-life data and their performance will be reviewed, using empirical data rather than artificial simulations. These empirical data comprise of 71 real-life construction projects and 22 real-life projects in the education, event management, engineering and IT management sector. Second, a new approach is proposed, which integrates the available activity risk information into the construction of the tolerance limits. Based on the results of the empirical study, guidelines are proposed for when to use which type of tolerance limit.

The outline of this paper is as follows. In Section 2, the literature on Integrated Project Management and Control and on project monitoring is briefly introduced. Subsequently, the empirical experiment is described in Section 3. Further, the results of this experiment are reviewed in Section 4. Finally, Section 5 discusses the conclusion of this paper.

2. Literature review

Since project control is one of the three major components of Integrated Project Management and Control, these components are briefly discussed in Section 2.1. Subsequently, in Sections 2.2 and 2.3, we elaborate on the project monitoring process and the construction of tolerance limits for project control.

2.1. Integrated Project Management and Control

In this section, the three components of Integrated Project Management and Control, namely baseline scheduling, risk analysis and project control, are introduced. Further, research efforts in recent literature are highlighted for each component.

Baseline scheduling

During the baseline scheduling phase, a feasible baseline schedule is constructed that acts as a point of reference during the risk analysis and project control phase. While the project scheduling problem has initially been addressed in absence of resource restrictions by the critical path method (CPM, [7]) and the program evaluation and research technique (PERT, [8]), the resource-constrained project scheduling problem (RCPSP) has been defined to explicitly incorporate resource restrictions. The aim of the RCPSP is minimising the project makespan when limited resources are available. For an overview of the variants and extensions of this problem that are explored in literature, the reader is referred to [9–11]. Moreover, extensions and novel approaches to solve this problem are still being developed, e.g. by [12–14].

Schedule risk analysis

In this phase, a Schedule Risk Analysis (SRA) is performed to connect the activity risk information to the baseline schedule such that the sensitivity and cruciality of the project activities can be measured. The resulting SRA measures indicate the impact of the activities on the final project duration and can be used by the project manager to decide which activities require managerial effort during project execution [15,16]. Further, the merits and pitfalls of these SRA measures are reviewed by Elmaghraby [17].

Project control

During the project control phase, deviations from the baseline schedule are measured during project execution such that corrective actions can be taken by the project manager when problems are detected. A wide variety of project control problems has been studied in literature, e.g. determining the timing of control points [18–20], forecasting the final project duration [21,22], optimal buffer sizing [23–25] and corrective action taking [16,26]. In this paper, we focus on constructing tolerance limits for the schedule progress of projects. The aim of these tolerance limits for project control is to support the project manager in deciding whether corrective actions should be taken by comparing the monitored progress to a certain threshold. Therefore, in Section 2.2, the monitoring process is briefly discussed. Subsequently, the literature on tolerance limits for project control is reviewed in Section 2.3.

2.2. Progress monitoring: Earned Value Management

A well-known technique to monitor project progress is Earned Value Management (EVM, [3]). This methodology measures the project schedule and cost progress in terms of Earned Value (EV) and Actual Cost (AC). The cost progress is evaluated by comparing the AC with the EV using two EVM cost performance metrics, the Cost Performance Index $\left(CPI = \frac{EV}{AC}\right)$ and the Cost Variance ($CV = EV - AC$). Further, the schedule progress is examined by comparing the EV to the Planned Value (PV), which is the value that is planned to be earned according to the baseline schedule. Based on these key metrics, two EVM schedule performance metrics are constructed, namely the Schedule Performance Index $\left(SPI = \frac{EV}{PV}\right)$ and the Schedule Variance ($SV = EV - PV$). However, it is known that, since the PV and EV are both cost-based rather than time-based metrics, the SPI behaves unreliably towards the end of the project. In order to overcome this drawback of EVM, the Earned Schedule (ES) concept has been introduced by Lipke [27] as an extension of EVM. The ES is a time-based metric for the schedule progress, and is determined as follows:

$$ES = t + \frac{EV - PV_t}{PV_{t+1} - PV_t} \tag{1}$$

with t such that $EV \geq PV_t$ and $EV < PV_{t+1}$. Consequently, the schedule performance of projects can be measured using the SPI(t) $\left(=\frac{ES}{AT}\right)$, which is a more reliable metric than the SPI. Therefore, the SPI(t) will be used in this experiment to measure the schedule progress of the projects. In the remainder of this section, the integrated earned value/earned schedule method will be referred to as EVM/ES. For an extensive introduction to EVM/ES, the reader is referred to [28] and [27]. Further, a recent comprehensive overview of the applications and extensions of EVM/ES is given in [29].

2.3. Tolerance limits for project control

In order to evaluate the monitored project progress, tolerance limits for project control are constructed. For each phase of the project, a threshold value for the progress is determined. When the actual progress is below this threshold at a certain time during execution, a warning signal is generated. This signal indicates that, given the current progress, the project is likely to exceed its deadline and corrective actions should be taken in order to get the project back on track.

In recent literature, tolerance limits have been proposed that can be classified in three groups; static tolerance limits, statistical tolerance limits and analytical tolerance limits. *Static tolerance limits* are constant throughout the entire project life cycle and are determined using rules of thumb. Since these limits do not consider any project-specific information or information from historical data, they are not always very accurate or fail to dynamically take project progress features into account. This type of tolerance limits has been introduced by Goldratt [30] and Leach [31]. Further, *statistical tolerance limits* have been proposed. This type of limits applies concepts of Statistical Process Control (SPC, [32]) and requires historical data or Monte Carlo