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On the use of multivariate regression methods for longest path calculations from earned value management observations ☆

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ABSTRACT

This paper explores the use of multivariate regression methods for project schedule control within a statistical project control framework. These multivariate regression methods monitor the activity level performance of an ongoing project from the earned value management/earned schedule (EVM/ES) observations that are made at a high level of the work breakdown structure (WBS). These estimates can be used to calculate the longest path in the project and to produce warning signals for project schedule control. The effort that is spent by the project manager is thereby reduced, since a drill-down of the WBS is no longer required for every review period. An extensive computational experiment was set up to test and compare four distinct multivariate regression methods on a database of project networks. The kernel principal component regression method, when used with a radial base function kernel, was found to outperform the other presented regression methods.

1. Introduction

Completing a project on time and within budget is not an easy task for a project manager. Project control systems should consist of processes that are performed to observe project progress in such a way that potential problems can be identified in a timely manner. When these problems might bring the project objectives in danger, corrective actions are necessary and should be taken in order to bring these projects in danger back on track. Therefore, project control systems should be set up such that they provide periodic project performance metrics that measure the general state of the project and that easily allow the identification of deviations of the current project progress from the expected project baseline schedule. Therefore, monitoring the progress and performance of projects in progress requires a set of tools and techniques that should ideally be integrated into a single decision support system, allowing the project manager to easily identify unexpected behaviour and need for corrective actions, without calculating all time and cost details on the individual activities of the project network.

In this paper, the focus is restricted to controlling the timing of project progress, and the schedule control methodology used is known as the Earned Value Management/Earned Schedule (EVM/ES) methodology [1,2] which provides schedule performance measures to assist a project manager in his/her decision making [3,4]. In this methodology, the baseline schedule that defines the expected start and finish times for each activity is used as a starting point to calculate the EVM/ES performance metrics, and the future project progress is compared against this expected baseline schedule to trigger the need for corrective actions in case these deviations exceed a certain threshold. Consequently, a project control system such as EVM/ES allows the project manager to quickly compare the current state of the project progress with the baseline schedule, without the necessity to review every little detail of the activity level of this schedule. More precisely, it enables the manager to only control the top levels of the so-called work breakdown structure (WBS) and a detailed investigation of the bottom levels of this WBS is only necessary when the EVM/ES metrics exceed the pre-defined thresholds that acts as a warning signal for possible project problems. This project control process is known as top-down project control [5] and lies in the heart of the study of this paper.

More precisely, in this paper, the top-down project control methodology will be refined by using both EVM/ES metrics and four multivariate regression models at the top level of the WBS in order to estimate detailed information at the bottom level of this WBS, hereby improving the accuracy of project control without

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the need for the project manager to constantly calculated detailed activity information. It will make use of the longest path (LP) method [6] that has been proposed to connect the EVM/ES metrics available at the top WBS levels with the individual activity details from the bottom level of the WBS. In doing so, this paper presents a contribution to the theory on project schedule control that is threefold. First, it present a theoretical basis to the problem of estimating the detailed activity level performance in a project in progress from EVM/ES observations obtained at a high level of the WBS. Second, it implements four distinct multivariate regression models, which are tested in an extensive computational experiment and for which the parameters are optimised. Finally, this study also presents a practical and new way of estimating the activity durations of a project in progress from high WBS observations, by combining the EVM/ES methodology with the longest path method of [6]. This connection will be able to produce warning signals for project schedule control without constantly updating the activity information of the project in progress.

The outline of this paper is summarized as follows. In Section 2, the literature on top-down schedule control using EVM/ES is reviewed, and it will be shown that this process is characterised by an implicit inference of the activity level performance at low levels of the WBS. We will then proceed with a more explicit characterisation of this inference process, which allows the use of the multivariate regression methods to estimate the activity level schedule performance of a project from EVM/ES schedule performance measures that are observed at a high level of the WBS. Consequently, the longest path through the project at each review period can then be calculated, without using detailed activity information deep down in the WBS. In Section 3, the four distinct multivariate regression models, known as principal component regression (PCR), partial least squares regression (PLSR), kernel PCR (kPCR) and kernel PLSR (kPLSR), are presented. Section 4 describes the simulation experiments that were conducted to test and to compare the proposed multivariate regression models. The results for these experiments, which are presented in Section 5, show how the project control processes that use an estimated activity level schedule performance can approximate the performance of a process that requires the drilling down of the WBS by the project manager. We will draw overall conclusions in Section 6. In addition, an appendix was added at the end of this paper. Appendix A presents the theory on kernel transformations and provides the mathematical formulations of the multivariate regression methods, as they were implemented in this research paper.

2. Literature

This literature section will focus on the recent advances that have been proposed in the literature for top-down project schedule control using the EVM/ES methodology and reviews its use in relation to the Work Breakdown Structure as a system to drill down to the lowest levels for taking actions. The construction of a Work Breakdown Structure (WBS) involves the decomposition of major project deliverables into smaller, more manageable components until the deliverables are defined in sufficient detail to support the development of project activities [7]. The WBS is a tool that defines the project and groups the project's discrete work elements to help organise and define the total work scope of the project. It provides the necessary framework for detailed cost estimation and control along with providing guidance for schedule development and control. Each descending level of the WBS represents an increased level of detail of the project work. The WBS is displayed graphically as a hierarchical tree in Fig. 1 and has multiple levels of detail. The top node gives a short description of the project scope. Below this root node, various levels can be defined. The second level is the level of the work items in which the project scope is broken down into manageable pieces (items) to be able to cope with the project complexity. Each work item can be further subdivided into work packages. At this level, the collection of time and cost data is important for efficient project control. The lowest WBS level is used for the project activities. This level contains all the details on time, cost and resource estimates to define the project network and to construct the baseline schedule.

While the construction of the project baseline schedule is done prior to the project start using all the detailed activity data at the bottom level of the WBS, monitoring and controlling the project of the project in progress must be done periodically, and should therefore not require that much effort for the project manager. Therefore, the EVM/ES methodology is used at the top level of the WBS with a so-called top-down methodology. The term top-down schedule control was formally defined by Vanhoucke [5] to refer to a system that collects data at the highest levels of the WBS that give a general overview of the current state of the project. These EVM/ES metrics at the top level of this WBS allow the project manager to quickly review the current state and to decide whether actions are necessary without investigating all the little details of the activity schedule. This top-down control approach is presented in the left picture of Fig. 1 in which the downward arc represents a drill-down of the project manager when corrective actions are needed.

The primary reason for restricting the control focus to aggregate EVM/ES measures at top WBS levels rather than to a detailed activity performance is mainly pragmatic and for reasons of efficiency, and has also been recognized by other authors. Lipke et al. [2] argue that the schedule control process should not to be too time consuming and interruptive, but therefore it should be implemented at a high level of the work breakdown structure (WBS) of the project. This means that aggregated measures of schedule performance from the EVM/ES system should be monitored regularly during the project execution at a high level of the WBS, and drilling down to the activity level should only be done occasionally when the EVM/ES metrics report a performance that is no longer tolerated and indicates that the project is in danger.

While this approach is a very pragmatic one, leading to a control system that enables the project manager to quickly assess the overall health of the project, it is not without danger. Indeed, the decision making process that follows from these EVM/ES measures is often impeded, since activity level detail might be lost when the aggregated measures are calculated. Consequently, in some situations, the project will be in danger, but it will not be reported by the aggregate EVM/ES metrics, and hence the project manager will likely not react and refrain from drilling down in the WBS. This might lead to project problems left unnoticed, which will have a dramatic impact on the project objectives much later in the project progress, when little to no room for corrective actions is left. For this very reason, other extended approaches using this same top-down methodology have been proposed, trying to improve its overall accuracy for taking timely actions, which are briefly described hereunder.

Vanhoucke [5] was the first who experimentally showed that the performance of a top-down project control approach using EVM/ES works best for projects with a serial structure, and its performance decreases as the project structure becomes more and more parallel. In his paper, he also compared this approach with an alternative bottom-up method and showed that its performance is complementary, leading to a better performance for parallel projects, but unable to compete with the top-down approach for more serial networks.

Inspired by the observation that top-down control only performs well for serial structured networks, Elshaer [8] was the first to integrate the top-down method with the bottom-up method using Schedule Risk Analysis (SRA) [9] to improve the accuracy of forecasting the final project duration along the life of the project. Ever