Developing a framework for statistical process control approaches in project management

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Abstract

Different statistical process control (SPC) approaches were proposed over the years for project management using earned value management/ earned schedule. A detailed examination of these approaches has led us to express a need for a unified framework in which to test and compare them. The main drivers for this need were the lack of a formal definition for a state of control, the unavailability of a benchmark dataset, the absence of measures to quantify the SPC performance and the lack of consensus on how to overcome and test the normality assumption. In this paper, we present such a framework that combines a classification from empirical data, a known project dataset, a sound simulation model and two quantitative measures for project control efficiency. Four SPC approaches from prior literature have been implemented and an exhaustive experiment was set up to compare and to discuss their value for the project management practice.
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1. Introduction

Research on the construction of the project baseline schedule has been an integral part of the project management literature, ever since the first occurrence of project planning approaches such as the critical path method (CPM, Kelley, 1961), the programme evaluation and review technique (PERT, Malcolm et al. (1959)) and more advanced algorithms to construct a schedule under the limited availability of resources (Hartmann and Briskorn, 2010). During the execution of a project, the baseline schedule is reduced to a single point of reference for the actual progress that has been made. According to Rozenes et al. (2006), a project control system is required to produce a reliable indication of the direction of change when actual performance is compared with preliminary planning variables. Consequently, an efficient project control system should generate a warning signal when the gap between planning and performance becomes unacceptably large, in order to allow the project manager to take corrective actions.

Earned value management/earned schedule (EVM/ES) is such a system that generates performance metrics from which, after interpretation, signals can be acquired and corrective actions can be planned. This interpretation however, is impeded by the unintuitive dynamics that some of these performance metrics suffer from. Therefore, the use of EVM/ES is often characterized in practice by decision making from practical experience, rules-of-thumb and anecdotal evidence (Colin and Vanhoucke, 2014). In order to overcome this problem and to assist project managers in controlling a project, statistical process control/statistical quality control (SPC/SQC, ReVelle (2004)) techniques have been implemented to determine action limits on the EVM/ES performance metrics. In this paper, we will discuss the approaches published by Bauch and Chung

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(2001), Wang et al. (2006), Leu and Lin (2008) and Aliverdi et al. (2013). We will discuss the approaches of these aforementioned authors in greater detail in Section 2. These authors propose distinct solutions for the problems associated with the implementation of SPC/SQC charts and often apply them to different performance metrics from the EVM/ES system. Moreover, all of these project control systems have been validated on different datasets from different case studies of project executions. In order to compare their performance, we present a unified framework in which we will conduct an exhaustive simulation experiment.

The outline of this paper is described along the following lines. Section 2 reviews the SPC/SQC methods that were proposed for schedule control using EVM/ES. Section 3 presents the project simulation framework that is used to quantify the performance of the SPC/SQC methods in extensive simulation experiments. We will show the results of the experiments in Section 4 and the conclusions of this work are presented in Section 5.

2. Literature overview

2.1. Earned value management/earned schedule

Since its development in the 1960s as a unified methodology for cost and schedule control for US. Department of Defence projects, EVM has received a lot of attention in the academic literature (Anbari, 2003; Cioffi, 2006; Fleming and Koppelman, 2010; Hunter et al., 2014; Khamooshi and Golafshani, 2014; Narbaev and De Marco, 2014). A noteworthy extension to the EVM methodology, to improve its schedule control capabilities, was proposed by Lipke et al. (2009) in the form of earned schedule (ES). Their combined use, abbreviated as EVM/ES, has been integrated with risk management in the large simulation experiment by Vanhoucke (2011).

In EVM/ES, a project performance baseline is calculated from initial estimates for the activity costs and durations. The monetary value of the work that is supposed to be done at a given time is the planned value (PV). During project progress, the budgeted cost of the work that is actually performed (earned value, EV) is compared with the PV. From this comparison the schedule variance and the schedule performance index can be calculated:

$$SV = EV - PV \quad \text{Schedule variance}$$
$$SPI = EV/PV \quad \text{Schedule performance index.}$$

The schedule performance metrics are based on the monetary values EV and PV. Consequently, SV is expressed in monetary units. To overcome this, Lipke et al. (2009) defined the ES, which is expressed in time units (days, weeks, months,…) and can therefore be directly compared to the time that has passed since the beginning of the project (actual time, AT). This leads to two additional performance metrics, the schedule variance using ES (SV(t)) and the schedule performance index using ES (SPI(t)):

$$SV(t) = ES - AT \quad \text{Schedule variance using ES}$$
$$SPI(t) = ES/AT \quad \text{Schedule perfomance index using ES.}$$

The reader is referred to the original work by Lipke et al. (2009) and the detailed discussion by Vanhoucke (2011) for a background on the calculations of the EVM/ES system.

2.2. Statistical process control/statistical quality control

The field of SPC encapsulates all methods which are applied to monitor and to control processes in services and manufacturing. SQC focusses on the outputs of the process rather than the process itself (ReVelle, 2004). Despite this distinction, the two terms have been used interchangeably in the context of statistical control for project management. The schedule control metrics from EVM/ES can be used both to monitor the instantaneous health of the project as to forecast final project duration and therefore, both SPC and SQC are applicable. For the remainder of this paper, we refrain from the use of the term SQC and proceed with SPC.

SPC was pioneered by W. Shewhart at Bell laboratories in the early 1920s. He developed control charts to identify significant variation in the process before it could lead to sub-standard process outputs. At any given time, a process is said to be potentially under the influence of two classes of variation (Shewhart, 1931). "Common cause" or "non-assignable" sources of variation act constantly on the process and produce a stable and repeatable distribution of outputs over time. "Special cause" or "assignable" sources affect only some of the process outputs and should be removed. In SPC, control charts always attempt to differentiate between the two classes of variation in order to eliminate the latter from the process.

A SPC system is required to use variables that allow "the process to speak for itself." Control limits are therefore derived from the recorded variables of the ongoing process when special cause sources of variation have been removed. Over the years, a large number of different control charts have been developed to cope with different characteristics and assumptions for the process variables (CUSUM (Page, 1954), EWMA (Jones, 2002),…). One major assumption for most of these is that the recorded samples need to be normally distributed variables. Although this assumption is not explicitly stated for all control charts, such as the individual moving range (I-mR) chart proposed by (Shewhart, 1931), their use on non-normally distributed data is strongly discouraged (Montgomery, 2012).

2.3. SPC for project schedule control

SPC charts have been applied to schedule control in four research studies by Bauch and Chung (2001), Wang et al. (2006), Leu and Lin (2008) and Aliverdi et al. (2013). These SPC control chart implementations provide distinct solutions to a common problem, which is how to set action limits for schedule control during project progress, based on a "state of statistical control" reference. Table 1, and the succeeding paragraphs, present the different approaches of the aforementioned authors with respect to the choice of control charts, how normality is tested, how is dealt with normality, what reference is used to define the state of statistical control and how the approach is validated.