A Framework for Forecasting Project Estimate at Completion Using Historical and Current Performance Data

by

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Abstract

Earned value management (EVM) is an integrated project control method that incorporates project scope, budget, and schedule. EVM uses various metrics to report project cost or schedule performance, such as the cost performance index (CPI) and schedule performance index (SPI). In addition to reporting, EVM can also be used to forecast project estimate at completion (EAC) cost. Accurate estimation of the final cost of a project can initiate corrective actions designed to mitigate potential cost overruns. Because of widespread acceptance of EVM by practitioners, academic scholars have explored and recommended methods to improve EVM in practice. In spite of these advancements, the role of EVM in practice remains limited as a reporting tool.

Here, a survey was designed and disseminated to practitioners to further understand why EVM has not been adopted as a forecasting method in practice. Findings of this survey indicate that issues such as forecast inaccuracy may lessen practitioners' commitment to EVM application.

A factor contributing to inaccurate forecasts is the assumption, in current practice, to consider all activity groups (e.g., concrete, earthwork) as having the same performance, which is not always valid. Indeed, using an ANOVA-based methodology, the present study observed significant differences between performances of various construction disciplines in a historical dataset. To address the challenge of forecast inaccuracy from this perspective, a discipline-level approach for generating project forecasts, which aggregates discipline-level costs to obtain a project-level forecast, was developed. A Monte Carlo simulation modeling approach was implemented to demonstrate the added benefits of this more granular approach. Since Monte Carlo simulation has limitations in project continuity, Markov modeling was used. In addition, Bayesian statistics were used to incorporate current performance data into calculations. The proposed Markov-

Bayesian modeling technique was implemented in a real case study, where it was shown to outperform EVM forecasts.

To validate the proposed method, a framework based on randomly generated projects was developed and applied. Two sets of randomly sampled project performance data were generated to train the model and to be used for forecasting. The forecast accuracy of the proposed Markov method was compared against the traditional EVM method in various scenarios. The suggested approach was found to be significantly more accurate in the early stages of a project. Notably, this difference decreased as project performance reached stable conditions (i.e., as variation in cost performance decreased). Early detection of deviations from original plans is critical for initiating corrective actions that are effective. The application of randomly-generated performance data as a validation approach can also be used by other scholars to validate their findings in the area of earned value management.

Preface

This thesis is an original work by Amin Amini Khafri.

Ethics approval for work included in this study was granted by the University of Alberta's Human Research Ethics Board, Project Name "Investigation of earned value management practices in construction," Protocol No. Pro00075254, on October 21, 2017.

Historical data were provided by an industrial research partner. To maintain the partner's privacy, results based on partner-provided data were derived by multiplying results by a confidential factor.

To my dear parents

and my beloved sister,

without whom none of my success would be possible.

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List of Abbreviations

AACE – American Association of Cost Engineering

AC – Actual Cost

ANSI – American National Standards Institute

BAC – Budget at Completion

CPI – Cost Performance Index

DOD – Department of Defence

DOE – Department of Energy

EAC – Estimate at completion

EV – Earned Value

EVM – Earned Value Management

EVMS – Earned Value Management System

FAA – Federal Aviation Administration

MAD – Mean Absolute Deviation

MAPE – Mean Absolute Percent Error

NASA – National Aeronautics and Space Administration

RMSD – Root Mean Square Deviation

SPI – Schedule Performance Index

PMI – Project Management Institute

PV – Planned Value

VAC – Variance at Completion

WBS – Work Breakdown Structure

Chapter 1: Introduction

1.1 Background

Construction projects are notorious for being challenging to manage; every project is unique in terms of design and construction environment (Ahuja et al. 1994). Various indicators have been developed to measure the performance of many aspects of projects, including schedule, cost, safety, and customer satisfaction (Chan and Chan 2004).

Earned value management (EVM), formally introduced in 1962 by the United States (US) Navy (Canbari and Griffiths 2006), is an integrated project management technique that incorporates scope, budget, and schedule to quantify project cost and schedule performance (Anbari 2003). EVM metrics, which include cost performance index (CPI) and schedule performance index (SPI), are based on three variables: budgeted cost of work performed [i.e., earned value (EV)], budgeted cost of work scheduled [i.e., planned value (PV)], and actual cost of work performed [i.e., actual cost (AC)]. Since its introduction, EVM has emerged as a useful project management tool, having been adapted and used in projects from aerospace (NASA 2002) to software development (Warburton 2011).

For EVM to be useful in practice, data used for EVM calculations must be accurate and representative of current and future project conditions. Establishing EVM data collection standards is essential for maintaining reliability and timeliness of EVM metrics (Brodkorb 2011). For instance, EVM requires the identification of measurement methods to reliably convert executed work to earned value in the project baseline schedule (Fleming and Koppelman 2010); calculating the earned value of performed work prior to collecting or considering predefined measurement methods can result in inaccurate and subjective values for the EVM analysis.

Another important practice is to track and process changes to project a baseline, known as a change management system (ANSI/EIA 748), in a timely and structured manner. Failure to assess project performance without considering changes to scope, and consequently schedule and budget, can also result in unrealistic measures.

Accurately predicting final performance of a project throughout execution can act as an early warning that a project may be deviating from original plans. Accurate cost forecasts are essential for optimal project management, acting as an early warning of poor project performance (Fleming and Koppelman 2016), guiding decisions regarding the initiation of corrective actions (Batselier and Vanhoucke 2015), and, in certain cases (e.g., military construction), signaling early project termination (Christensen and Heise 1992). As mentioned earlier, EVM provides various indices to demonstrate project cost and schedule performance, including the cost performance index (CPI), which, in addition to indicating the cost-effectiveness of performed work, can also be used to forecast a project's estimated cost at completion (EAC).

1.2 Problem statements

Although EVM is widely practiced in the construction industry, studies investigating implementation level and obstacles for improved implementation are limited. Indeed, a shortcoming that hinders EVM from a full implementation in industry is inaccurate EAC forecasting. Variations in cost performance and aggregation of performance at the project level are two primary drawbacks of traditional EVM implementation (Czarnigowska et al. 2011).

1.2.1 EVM shortcomings

While earned value metrics are widely used throughout the construction industry, potential obstacles limiting EVM implementation in practice are poorly understood, making it difficult for academics and practitioners to improve EVM implementation in the construction sector.

1.2.2 Poor forecast accuracy

Unreliable input data, along with variations in project performance, increases the difficulty of EAC forecasting. In addition, differences in the performance of various activities and variable project conditions can further degrade EAC forecast accuracy. Empirical studies have demonstrated that low EAC forecast accuracy in construction is primarily associated with CPI variability (AminiKhafri et al. 2018). Construction project performance and CPI can vary considerably as a project evolves (Lipke et al. 2009): a project may be characterized by good cost performance in the early stages of project execution yet exhibit poor performance upon completion.

1.2.3 Data are being collected but not used

EVM accumulates all of the incurred costs and compares it against planned and earned budget to report project performance at the project level. In addition to reporting and monitoring project cost and schedule performance, using CPI (cost performance index) and SPI (schedule performance index), respectively, EVM can be used to forecast final project cost and duration from current-to-date performance. Regardless of the forecasting method, EVM-based forecast techniques assume that there are no differences between performances of various activity groups or disciplines.

However, projects are comprised of several work packages that can be categorized into various disciplines (e.g., concrete works, earthworks). To calculate project cost performance, to-date cost data for all performed activities are accumulated at the project level. Aggregation of project performance data at the project level, however, renders the analysis less accurate. Forecasting project cost performance based on project-level performance will yield the same forecast for all projects with the same budget and schedule, which may not be correct. Accumulation of various disciplines' cost performances at the project level cannot consider potential difference between each discipline's performance, which may differ depending on a company's area of expertise. Moreover, since every project has a unique budget and cost spread, performance differences of each discipline adds more uncertainty to calculations.

Application of computerized performance tracking systems have facilitated the collection of lower-level performance data (e.g., discipline level). Many companies use a systematic approach to categorize cost items during estimation and execution, with MasterFormat, as recommended by the Construction Specifications Institute (CSI) and Construction Specifications Canada (CSC), amongst the most popular coding systems in industry. MasterFormat uses hierarchical coding to categorize activities into different disciplines, thereby allowing the historical performance of each discipline to be mined from historical project databases. Accordingly, historical performances can then be used as inputs for various analytical techniques [e.g., Markov chain (Du et al. 2016)] to improve completion cost estimates.

1.3 Research objectives

The primary objective of this research is to identify and enhance shortcomings of EVM practice in construction. A survey was designed and distributed to construction practitioners to identify shortcomings of EVM. Inaccuracy of EVM forecasts was reported as a major challenge facing industry, and methods for improving EAC forecast accuracy were explored as the secondary objective of this research. This included the analysis of historical data at a more granular level (e.g., discipline level) to investigate any potential differences in the performance of various disciplines. Through the exploration of these historical data, significant differences were observed between various disciplines. Consequently, a methodology capable of integrating historical data and on-going project performance data was proposed. The proposed method was implemented in a construction company, and an improvement in EAC forecast accuracy was observed. Finally, a framework for validating and analyzing the sensitivity of the proposed method was proposed and applied.

1.4 Research methodology

Various methodologies were used to achieve the aforementioned objectives, as demonstrated in Figure 1.1. EVM shortcomings were identified using a survey-based research method. Based on previous publications and consultations with subject matter experts, a questionnaire was designed and distributed to practitioners in industry. Respondents were asked to rate EVMS implementation and the severity of the shortlisted shortcomings of EVM. Shortcomings that require management initiatives in industry (e.g., lack of training and understanding about EVM) along with inaccuracy in EAC values were reported to be challenging for the surveyed practitioners. Therefore, EAC forecast accuracy was selected as the primary focus of this research. To address this, a two-fold methodology was proposed and implemented. The first phase of the methodology analyzed historical data from various construction projects to identify performance differences between various activity groups (i.e., disciplines). Mined knowledge from these historical data was used to develop a Monte Carlo-based EAC forecasting tool.

Application of historical data was found to improve forecasting accuracy compared to the traditional EVM forecast, which is based solely on current performance data.

Monte Carlo simulation is limited with regards to simulating project continuity and for considering current project performance. In the next phase, Markov modeling and Bayesian statistics were used as means of modeling project performance as a related process and incorporating current project progress, respectively. Markov modeling mimics project performance as a chain, where the performance of each month depends on the previous month's performance. Bayesian statistics is a powerful tool for updating and incorporating new data to a model. A framework capable of randomly generating projects was designed and implemented to validate the proposed method as well as to investigate the sensitivity of the model. Two sets of randomly generated projects were generated for various types of budget breakdowns. The first set was treated as historical data and was used to train the Markov model; the second set of data was used to compare EAC accuracy of both the proposed and traditional EVM method. Detailed implementation of each methodology is described in Chapters 3 to 6.

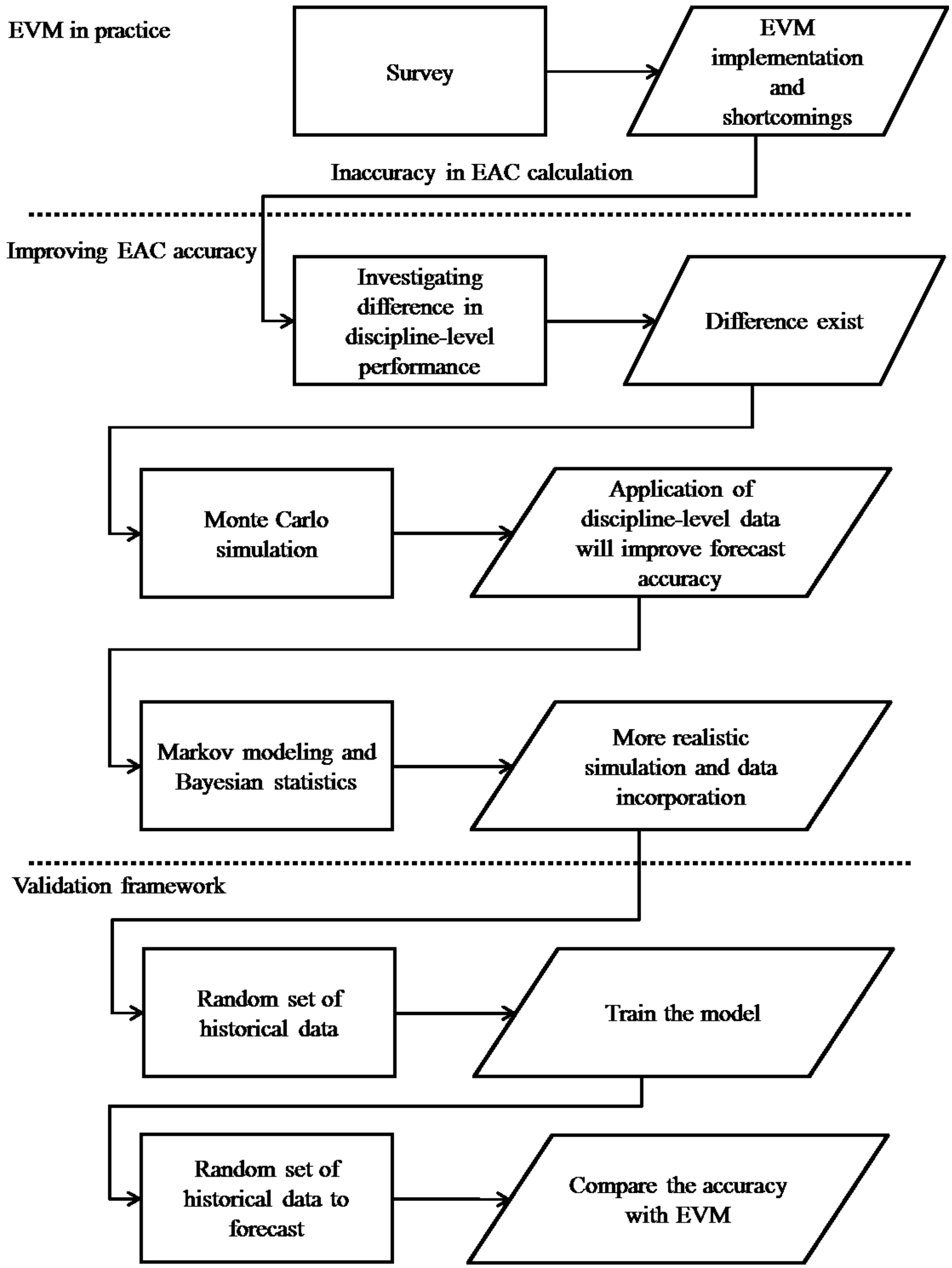


Figure 1.1 Overview of the implemented methodology

1.5 Scope of research

Once limitations of EVM practice were identified by practitioners using the survey, this research began to focus on improving EAC forecast accuracy. Although EAC accuracy was not identified as the most severe shortcoming, it was chosen as the focus of the remainder of this research as it had the most potential for improvement following academic exploration. Other, more severe shortcomings, in contrast, could be addressed by increasing training and top-level management initiatives in companies.

Although EVM provides metrics that represent schedule (e.g., SPI), the main focus of this study was on forecasting of project cost. This choice stemmed from recommendations that methods that capture activity dependency [e.g., critical path method (CPM)] should be used to forecast schedule instead of SPI (Fleming and Koppelman 2010). Moreover, while project schedule must be continuously updated during project execution for accurate forecasting, access to monthly revised schedules is limited in practice. Indeed, many companies do not update schedules monthly or simply override the baseline schedule. Nonetheless, the proposed methodology for CPI can be extended to forecast project duration if reliable schedule performance data are available.

1.6 Implementation environment

The survey was designed following a thorough literature review and based on recommendations from PMI. The survey was distributed electronically through SurveyMonkey (www.surveymonkey.com). The survey was available for approximately two months, and potential respondents were approached using intermediaries. Study procedures were approved by the Human Ethics Board at the University of Alberta.

The second component of the methodology was implemented in the following environments:

Microsoft Access: Microsoft Access was used to filter, aggregate, and format historical data, as MS Access facilitated the implementation of the proposed framework in the case company. Access queries and tables developed can be easily integrated with various databases, enhancing the practicality of the proposed system.

Microsoft Excel: Microsoft Excel was chosen for data quantification as well as statistical tests, such as analysis of variance (ANOVA). MS Excel also was used for output analysis and to generate graphs and figures.

Simphony.NET: Simphony.NET was used as the analytical engine for the proposed methodologies, namely Monte Carlo and Markov modeling. Simphony.NET model reads input data from MS Access database(s) and generates results that can be exported in MS Excel format.

1.7 Dissertation organization

The remainder of the dissertation is organized as follows: Chapter 2 reviews the literature relevant to each area that this research intends to improve. Survey methodology and findings are reported in Chapter 3. As reported by the survey respondents, inaccuracy in EAC, which is the second objective of this research, remains a challenge for practitioners. Potential differences between the performances of various disciplines and application of the mined discipline-level performance data to calculate EAC are discussed in Chapter 4. The method in proposed Chapter 4 was improved using Markov-Bayesian modeling and applied to real case studies, as detailed in Chapter 5. A framework based on randomly-generated projects to validate and analyze the sensitivity of the proposed method is presented in Chapter 6. Research findings, contributions, limitations, and future work are summarized in Chapter 7.

Chapter 2: Literature Review

2.1 Introduction

EVM is a simple concept that can be modified to fit into other applications, such as environmental performance of projects (Abdi et al. 2018). Extensions and new metrics, such as earned schedule (Lipke 2003) and customer earned value (Kim et al. 2015), can also be defined to provide additional insight for project managers. In this chapter, literature relevant to EVM and its potential challenges are summarized in the first section. As it was reported through the survey, EAC forecast accuracy was selected as the primary shortcoming to be addressed by this research. The remainder of this chapter summarizes previous studies that have explored EAC forecast accuracy. The last two subsections of the chapter discuss the analytical methods used in this research and their applications.

2.2 Practical challenges of EVM implementation

Scholars have investigated the practical challenges associated with EVM implementation using survey or interview methods. Extra implementation costs associated with the introduction of a new management system was found to be a commonly-reported drawback of EVM adherence [Krazert and Houser (2011), Kersbergen (2011), Kim et al. (2003), Wilson et al. 2013, Lukas (2008)]. Indeed, data collected from 1978 to 1992 indicate that companies spend up to 5% of contract costs implementing EVM (Christensen 1998). A survey of PMI members, conducted by Kim et al. in 2003, identified benefits and drawbacks of EVM across both construction and non-construction sectors. This study revealed that, while more than 80% of project managers who have experience working with EVM accept the methodology, drawbacks related to user or industry culture still remain. Studies examining the factors limiting EMV implementation specifically in construction, however, are limited.

2.3 EAC forecasting methods

Calculating EAC values during project execution can act as a leading indicator for the initiation of mitigation plans. EAC reporting has, therefore, become a routine part of monthly reports. In addition to conventional methods for project cost forecasting [e.g., unit area cost (UAC) and unit price analysis (UPA) (Bayram and Al-Jibouri 2016)], various EAC forecasting techniques have been proposed by academics. Although EVM is a commonly applied method for project control, EAC can also be calculated using project-related factors. Bayram and Al-Jibouri (2016) compared forecast accuracy of regression analysis with four, different, non-traditional methods (e.g., multilayer perception, radial basis function, grid partitioning algorithm, and reference class forecasting) in an empirical study. These authors concluded that different methods could outperform others for certain applications, and there is no single best method for forecasting cost.

Cheng et al. (2010) used an evolutionary vector machine inference model to consider climate, project performance, and market pricing effects in the final project cost of high-rise building projects. Khodakarami and Abdi (2014) used Bayesian networks to forecast project cost considering multiple factors of the project (e.g., safety, quality, stakeholders); accounting for these factors in EAC calculations yields a more accurate forecast (Khodakarami and Abdi 2014). In an effort to incorporate more factors into EAC calculations, Babar et al. (2017) defined and used risk performance index in EAC calculations. Leon et al. (2017) utilized system dynamics to account for other factors that can affect project cost (e.g., schedule, safety, quality). Abu Hammad et al. (2010) analyzed more than one hundred historical project performance data points and used linear regression to forecast final project cost for early planning. The regression model considers project scope, area, budget, and duration to calculate EAC. These approaches, however, require data that may not be readily available and collected (e.g., market pricing, stakeholders satisfaction) in practice. Moreover, some of the collected factors, such as quality, were subjective, and their measurements varied between practitioners. Considering all factors affecting cost is a challenging task in practice, as conditions may vary from one project to another based on contract requirements and company practices. Accordingly, application of the abovementioned approaches is limited to specific cases where such data is collected and available. Such methods, therefore, are often not suitable for application in other companies.

2.4 EVM-based methods

The majority of the aforementioned methods for enhancing EAC accuracy are complex and require input data are often not readily available in practice. Practitioners, nonetheless, are often inclined to use methods that are more straightforward to make use of available data. Due to their adaptability with ongoing project management performance and their ease-of-use, EVM-based methods for EAC cost forecasting are among the most commonly used methods in industry. Scholars have also focused on improving EAC accuracy using available EVM metrics [e.g., earned value (EV), actual cost (AC)]. As mentioned in the previous section, cost performance index (CPI), calculated using Equation 2.1, is a standard index that measures project cost performance and forecasts EAC, as demonstrated in Equation 2.2.

$$CPI = \frac{EV}{AC} \qquad \text{Equation [2.1]}$$

$$EAC = \frac{BAC}{CPI} \qquad \text{Equation [2.2]}$$

Where *BAC* is the budget at completion and *CPI* is the cumulative cost performance index in the month of the forecast.

Several other EVM-based cost forecasting calculations exist (summarized in Table 2.1). Each formula has its own assumption and is applied to calculate EAC cost forecasts based on project manager discretion and project conditions. For instance, for a cost overrun scenario, the optimistic formula assumes that the cost overrun occurred only once and will not be repeated. The pessimistic formula, on the other hand, assumes that the project will have the same inefficiency throughout execution. The rest of the formulas consider the effect of schedule delays in EAC using different weights for *CPI* and *SPI* (i.e., α and β). Multiple equations could be used at the same time to provide an interval, rather than a crisp number, and to better assist decision makers (Fleming and Koppelman 2016). Despite the ease of use of the formulas, forecasting logic is somewhat simplistic and only depends on past performance.

Table 2.1: EVM-based *EAC* cost forecasting formulae

	Formulae*
Optimistic Estimate^	$CV = AC - EV$
	$EAC = BAC + CV$
Pessimistic Estimate^	$EAC = \frac{BAC}{CPI}$
Formulae Considering Schedule Delays	$EAC = AC + \frac{BAC - EV}{(CPI*SPI)}$
	$EAC = AC + \frac{BAC - EV}{(\alpha * CPI + \beta * SPI)}$
	$\alpha + \beta = 1$

*Where CV = cost variance; EV = earned value; AC = actual cost; BAC = budget at completion

^Based on the assumption that project is running over budget

2.5 Efforts to improve EVM-based EAC accuracy

Since EVM metrics are widely collected in practice and are familiar to a majority of construction practitioners, scholars have focused on alternative forecasting methods that make use of EVM metrics. As can be inferred from Equation 2.2, EVM assumes that CPI is constant throughout the project, which does not necessarily occur in practice (Wauters and Vanhoucke 2015). Schedule pressure may affect the project CPI, and Narbaev and De Marco (2014) combined growth model and duration, calculated from the earned schedule method, to determine EAC for projects.

Batselier and Vanhoucke (2017) used an exponential smoothing-based method to improve project cost and duration forecasts. Their method incorporated trends and changes resulting from the learning curve effect or managerial decisions into EVM calculations. Inherent to the previous two methods, an up-to-date schedule, which is crucial for schedule analysis, may not be readily available in construction projects. Mortaji et al. (2014) used change point analysis to improve EAC forecast accuracy by capturing variations in CPI. Project cost performance is a stochastic process that varies over time. Du et al. (2016) combined Markov chain and Monte Carlo simulation to forecast CPI using historical cost performance data, and historical project data were analyzed to determine trends in project CPI. Since it considers 400 possibilities for project performance, the suggested approach requires a large historical database of similar projects (i.e., more than 50 projects with an average duration of 14 months).

2.6 CPI variation

CPI of a project, defined by Equation 2.1, is a factor in a majority of EVM-based EAC formulae (Table 2.1). Accordingly, variations in CPI will result in EAC variability. A project may be evaluated as having poor cost performance in the early stages of project execution (e.g., $CPI = 0.7$) and improved performance near completion (e.g., $CPI = 1.1$). Project specifications (Cheng et al. 2010), the learning curve effect (Batselier and Vanhoucke 2017), and differences in performance of diverse activities (de Souza et al. 2015) can contribute to CPI variability. AminiKhafri et al. (2018) conducted an empirical study and concluded that high CPI variability (i.e., late CPI stability) was correlated with poor EVM-based EAC forecast accuracy.

2.7 EVM as a stochastic process

As mentioned before, project cost performance is a stochastic process; He et al. (2017) used singular-value decomposition feature-extraction method to improve the accuracy and expedite computation of mined stochastic distributions. Alternatively, mined stochastic performance data can be used as input for advanced analyses, such as Monte Carlo simulation (Barraza et al. 2005), to generate stochastic S-curves, which represent the cumulative cost of the project during execution. Narbaev and De Marco (2014) combined growth models to calculate EAC considering project duration variation. Acebes et al. (2015) used Monte Carlo simulation to model expected project performance variability and detect anomalies in cost performance. Aliverdi et al. (2013) suggested statistical control charts as an alternative method to identify anomalies in project performance. Batselier and Vanhoucke (2017) applied an exponential smoothing method, which considers weights of previous observations, to forecast future performance. Chen et al. (2015) applied time series analysis to forecast actual project cost and earned value using planned value amounts. Wood (2017) integrated deterministic, fuzzy, and stochastic analysis to model project cost performance variability. Variation in the project performance, and consequently CPI values, necessitates stochastic analysis of projects.

2.8 Application of historical cost performance

To enhance EAC accuracy while considering additional project-related factors in EAC forecasting, scholars have proposed frameworks based on historical data from similar projects (e.g., industrial, commercial) within one company (Kaka 1999). Colin and Vanhoucke (2014) demonstrated the potential application of historical data in the area of project control using a set of fictitious projects. Du et al. (2016) combined Markov chain and Monte Carlo simulation to represent the evolving nature of a project based on historical performance data of power plant projects. Nassar (2005) derived dynamic Markov chains for construction projects based on the historical performance of similar projects. Dynamic Markov chains were then used to calculate the value of CPI throughout project execution. Chen et al. (2016) used historical data, time series, and regression analysis to calculate actual cost and earned value of a project based on the planned value. Caron et al. (2016) used Bayesian modeling to incorporate past project performance data for cost forecasting. He et al. (2017) used singular-value decomposition feature extraction to estimate trends in historical data to predict cost performance of construction projects. Previous studies (i.e., methods mentioned in Sections 2.5 to 2.9), however, have analyzed historical performance at the project level for similar projects and did not consider variations in performance of various disciplines.

2.9 Application of more granular historical cost performance

Although endeavors have improved the forecasting capability of EVM, aggregation of the performance of various activities to the project level decreases the effectiveness of the EVM method (Czarnigowska et al. 2011). This may average out cost performance variations across different disciplines, which may have different performances based on the company's area of specialty or the climate requirements of the region. To investigate project cost performance stability at a lower level (e.g., a work package level), Kim (2015) used Monte Carlo simulation to assess project stability time. It has been suggested that CPI stability at the project level depends on the work package level, and variation in the work package level will affect CPI stability (Kim 2015).

Various disciplines may have diversified performance, as de Souza et al. (2015) demonstrated in software development projects. In the software development industry, incorporation of historical cost performance data of four common activities (i.e., elaboration, implementation, testing, and error correction), separately, to forecast the final project cost enhanced EAC accuracy. De Souza et al. (2015) analyzed historical cost performance data in software development projects and proposed a new approach to calculate the final project cost. This study, however, is only limited to software development projects that are short in duration (i.e., half a month to one month) and composed of the same four activities. Whereas, construction projects are comprised of more than 100 different activities; considering the cost performance for each unique activity would be a tedious task. Alternatively, cost performance data could be grouped and aggregated for each discipline. Analyzing projects using detailed performance data is expected to provide more representative and accurate forecast results. Stochastic variation of project performance may be related to the nature of the activity (Kim 2015).

2.10 Efforts to improve modeling validity and incorporation of the project current performance

Relying only on past performance may result in misleading outcomes (Kaka 1999). Classic EVM-based formulae, such as Equation 2.2, consider to-date performance while ignoring the historical performance of previous projects. Bayes theorem is a well-known method for updating and incorporating new observations into previously observed instances, as shown in Equation 2.3 (Bishop 2006).

$$P(A|B) = \frac{P(B|A)P(A)}{P(B)} \qquad \text{Equation [2.3]}$$

Where, $P(B|A)$ is the conditional probability of B given A, denoted as the prior probability (i.e., obtained from historical data); $P(A|B)$ is the posterior probability (i.e., resultant distribution considering updated data); and $P(A)$ and $P(B)$ are probabilities of A and B, respectively (Bishop 2006).

Bayes theorem has been widely used in civil engineering and construction management to predict the duration of non-performed activities (Chung et al. 2006 and Zhang et al. 2013). Kim and Reinschmidt (2009) applied Bayesian inference to update Beta S-curves using current progress data from projects. Inferred project data improved accuracy of the model during the early stages of execution. Caron et al. (2013) applied a Bayesian approach to integrate expert knowledge with project performance data. The proposed approach has shown improvement in forecasting accuracy in early stages of projects. Caron et al. (2016) extended the proposed methodology by including historical data in the prior distribution for the Bayesian model. Kim (2015) used the second-moment Bayesian model to combine cost performance and project risks. The output of the suggested system was an interval of possible project cost with a defined confidence level.

2.11 Application of Markov modeling to improve the forecast accuracy

Markov model is a powerful tool for modeling sequential data, such as project performance. Markov models are capable of considering the previous status of a system to predict a subsequent state. The simplest type of Markov models are first-order Markov chains, which only consider the status of the previous observation (Bishop 2006) for forecasting current states. Markov model can be defined as a sequence of observations, where each observation takes values from finite set variables called the state space $\{x_1, \dots, x_n\}$. Consequently, the initial distribution within the possibility state can be presented in the form of vector $\lambda = (\lambda_1, \dots, \lambda_n)$, where λ_i is the initial probability for being in state x_i (Brooks et al. 2011). Subsequently, the state of the system transitions to another state in discrete time steps using a transition probability of matrix P, which has elements of $p_{i,j}$ as defined in Equation 2.4 (Brooks et al. 2011). Equation 2.5 demonstrates a sample calculation of a Markov model using matrix multiplication.

$$\Pr\left(X_{n+1} = x_j \middle| X_n = x_i\right) = p_{i,j} \quad i, j = 1, \dots, n. \qquad \text{Equation [2.4]}$$

$$\Pr(x_1, \dots, x_n) = (\lambda_1, \dots, \lambda_n) * \begin{bmatrix} p_{1,1} & \cdots & p_{1,n} \\ \vdots & \ddots & \vdots \\ p_{n,1} & \cdots & p_{n,n} \end{bmatrix} \qquad \text{Equation [2.5]}$$

Where $\Pr(x_i)$ denotes the probability of state x_i occurrence.

Markov models have been applied in different cases, such as wastewater system deterioration (Baik et al. 2006), bridge serviceability model (Morcous 2006), and invoice management (Younes et al. 2014). The Markov chain modeling technique, which simulates evolution of a system (e.g., project or operation) at discrete time points using a transition probability matrix, has been utilized in the project performance forecasting area to capture and model project evolution. For instance, if a project cost performance is outstanding (e.g., *CPI*=1.6) it is more likely to maintain good performance (e.g., greater than 1.0) and less likely to have low cost performance (e.g., 0.4).

Using historical cost performance of projects, Du et al. (2016) developed a probability transition matrix that incorporates evolution of project behavior to forecast cost performance at project completion. Performance factors were divided into twenty states, and Markov modeling was used to transfer from one state to another using historical data. Nevertheless, generalizing a single transition matrix for all activities may weaken the forecast accuracy for a new project comprised of various disciplines and specifications. Markov chains can be further elaborated by using flexible transition matrices, such as a dynamic transition matrix developed by Nassar

(2005). The function of dynamic transition matrices varies from one period to another based on the planned value curve of the project. In other words, the transition matrix from month two to three will differ from the matrix for month three to four. Notably, the developed transition matrices are limited to the assumption that the planned value graph (or S-curve) fits into a third-degree polynomial function, which is not necessarily valid for every project. In this research, Markov chains are used to model CPI behavior of projects.

Chapter 3: Investigation of the earned shortcomings in the construction industry

3.1 Introduction

While academia has investigated various aspects of EVM, issues associated with EVM in practice remain relatively unexplored. Without an understanding of EVM shortcomings, it may be difficult for academic researchers to develop improvements to EVM methods that are applicable and easily implementable in practice. Based on a thorough review of guidelines relevant to EVM, a survey, included as Appendix A, was designed and distributed to construction practitioners to assess the implementation level and to identify shortcoming common to current EVM practice. Consistent with previous reports, unachievable budget and schedule, along with lack of training and understanding about EVM, were perceived as the two most significant shortcomings of current EVM practice. Of the shortcomings identified, inaccuracy in EVM forecasts was determined to be the most amenable to improvement from an academic perspective. Results of the current study provide insight into the challenges associated with EVM in practice, which can be used to guide future research endeavors in this area. Results regarding implementation levels are presented in Appendix B.

3.2 Methodology

This study intends to assess the implementation level of EVM requirements in the construction sector and to identify shortcomings of EVM implementation in construction practice. A survey method, which has been successfully applied to study the implementation of other practices such as the critical path method (Galloway 2006), last planner system (Fernandez-Solis et al. 2012), and building information modeling (Ozorhon and Karahan 2016), was chosen to provide a more comprehensive overview of industrial practice. The survey was designed to assess the implementation level of the PMI's earned value document recommended practices, which is a simplified version of the ANSI/EIA 748 (Anabri 2003). Responses were collected voluntarily and anonymously using a protocol approved by the Human Research Ethics Board at the University of Alberta.

To ensure that survey participants were associated with the construction industry, only participants who indicated they had construction-related work experience were permitted to continue taking the survey. The survey was comprised of three sections. The first section of the survey focused on the implementation level; results are presented in Appendix B. The second section of the survey focused on the shortcomings of EVM from the practitioner's perspective. A literature review was conducted, and relevant studies were reviewed to identify a list of potential problem areas. Twenty-five problem areas were identified [Krazert and Houser (2011), Kersbergen (2011), Kim et al. (2003), Wilson et al. 2013, Lukas (2008), Thamhain (1998)]. Some of the identified factors were then combined to reach 13 problem areas, as summarized in Table 3.1. The last section of the survey focused on obtaining demographics of the respondent (e.g., experience, position, project type, and dollar value) and the respondent's company (e.g., company size and type). While an organization's size can be measured using various indicators such as number of employees, number of projects, annual profit, and annual revenue (Turner et al. 2009, Galloway 2006), a company's revenue was selected as the primary marker of organization size in the present study. Number of projects, number of employees, and annual profit were considered poor indicators: project budgets and specifications vary considerably, employees often differ in terms of experience and education, and reporting annual profit may be a sensitive issue for some respondents. Accordingly, companies were grouped based on their average annual revenue over the last three years into three categories: small (average revenue less than \$10 million), medium (average revenue between \$10 – 150 million), and large (average revenue greater than \$150 million).

Table 3.1 List of identified potential shortcomings of EVM

Code	Shortcoming
S1	Lack of structured management systems and support to implement earned value management.
S2	Difference between management system and accounting system's WBS.
S3	High cost of implementation.
S4	Time-consuming data collection.
S5	Absence of an integrated project baseline (e.g., WBS, schedule, and budget).
S6	Inability to identify sources of inefficiency.
S7	Subjectivity and inaccuracy in measuring the earned value of executed work.
S8	Lack of confidence in the earned value indices [e.g., schedule performance index (SPI) and cost performance index (*CPI*)].
S9	Absence of resource loaded schedules.
S10	Deviations from project baselines are not effectively incorporated into earned value calculations.
S11	Unrealistic (i.e., unachievable) schedule and budget.
S12	Inaccuracy in the earned value performance forecast.

S13	Lack of training and understanding about earned value.

A draft of the survey was first distributed to a focus group of practitioners and academics for review and was revised based on the feedback received. The survey went through a number of iterations to ensure that each statement was explicit and concise to save time for the respondents and to promote survey completion (Nutly 2008). The sampling aim of this study was to achieve a 10% margin of error with a 95% confidence level, which required the collection of 96 responses. The survey was internet-based and distributed through research partners of the Hole School of Engineering at the University of Alberta. Professionals across Canada were asked to circulate the survey link. Five-scale Likert responses were selected to measure the implementation level and severity (i.e., potential impact) of each practice or shortcoming, respectively, in the first two sections using the responses listed in Table 3.2. Responses were then quantified using weights defined in Table 3.2. "No answer" was valued the same as "Not a problem," as it was assumed that practitioners who were not familiar with the shortcoming (i.e., choosing "no answer") did not have issues with these shortcomings.

Average values were used to summarize implementation and severity of the practices or shortcomings, respectively. To investigate the effect of company size on implementation/severity, responses were grouped according to company revenue for further analysis. Differences between groups were assessed using Welch's t-test, which is a modified version of a Student's t-test that is used for unequal variance and sample sizes (Welch 1947), where $P<0.05$ is considered significant.

Table 3.2 Ranking and weighting system used in the survey

Weight	Level of practice	Severity (potential impact)
8	Fully implemented	Major problem
6	Often implemented	Problem
4	Somewhat implemented	Somewhat of a problem
2	Rarely implemented	Minor problem
0	Not implemented	Not a problem
0	No answer	No answer

3.3 Results and discussion

Ninety-five full responses were collected from various sectors of the construction industry. Since most respondents were approached by an intermediary to participate, it was not possible to calculate a response rate (i.e., how many professionals were asked for responses). As depicted in Figure 3.1, over half the participants were involved with industrial construction, while participants from infrastructure and building (either residential or commercial) accounted for 27% and 16% of responses, respectively. Nearly all (90%) of the respondents had six or more years of construction-related experience; notably, respondent level of experience was evenly distributed between experience groups. Responses were received from a variety of positions, yet a majority of the respondents (> 90%) were project managers or positions involved with project manager duties (e.g., project coordinator, senior manager). Distribution of various company sizes, based on companies' annual revenue, are summarized in Figure 3.2.

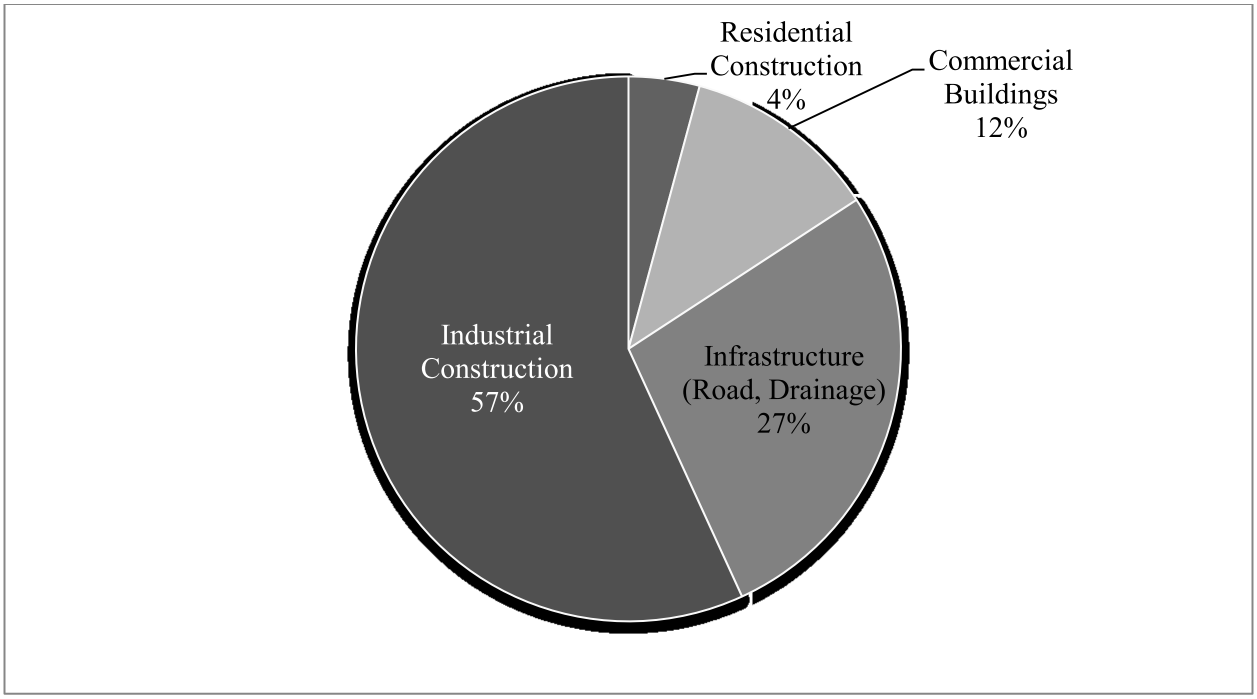


Figure 3.1 respondents' distribution by Industry

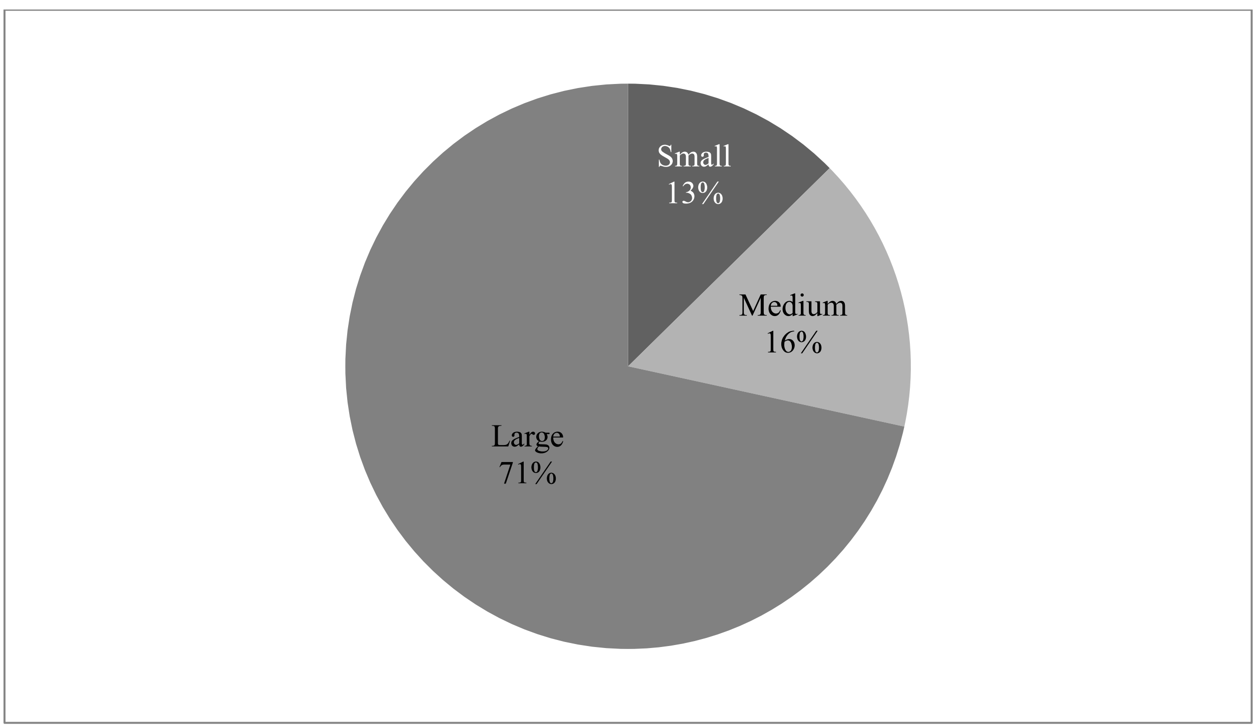


Figure 3.2 Distribution of company size classified by company revenue

3.3.1 Survey results

As implementation level results are not relevant to the scope of this research, the results are provided in Appendix B. The severity of the shortcomings are itemized in Table 3.3, in descending order. As can be inferred from Table 3.2, larger scores indicate a greater impact of the shortcomings on EMV implementation.

Table 3.3 Summary of survey results

Rank	Description	Severity
1	Unrealistic (i.e., unachievable) schedule and budget	5.31
2	Lack of training and understanding about earned value	5.14
3	Deviations from project baselines are not effectively incorporated into earned value calculations.	4.95
4	Subjectivity and inaccuracy in measuring the earned value of executed work	4.69
5	Lack of structured management systems and support to implement earned value management	4.55
6	Inaccuracy in the earned value performance forecast	4.55
7	Lack of confidence in the earned value indices [e.g., schedule performance index (SPI) and cost performance index (CPI)]	4.51
8	Time-consuming data collection	4.42
9	Difference between management system and accounting system's WBS	4.40
10	Absence of resource loaded schedules	4.32
11	Absence of an integrated project baseline (e.g., WBS, schedule, and budget)	4.11
12	Inability to identify sources of inefficiency	3.87
13	High cost of implementation	3.49

Identified shortcomings of EVM reflect issues originating from changes in construction (S10). Changes make it challenging to meet budgets and schedules, as they affect project cost and duration. Indeed, unrealistic schedule and budget was found to be the shortcoming associated with the greatest perceived severity (S11). A lack of training and understanding about EVM (S13) was also perceived as relatively severe, indicating that industry should invest in education of the project team at all levels (i.e., from the foreman to top management). The absence of a structured management system for EVM implementation (S1) was another setback ranked as relatively high in severity by practitioners. Becoming more knowledgeable about the benefits and necessity of EVM can urge management to comply with recommended practices.

In contrast to previous findings (Christensen 1998), high cost of implementation (S3) was perceived as the least severe of the listed shortcomings. EVMS, nonetheless, was still perceived as a relatively time-consuming (S4). In spite of the many efforts to improve EVM accuracy in academic literature, inaccuracy of EVM in for project performance forecasting (e.g., cost and schedule) was ranked as only moderately severe (S12) and as similar in severity to the lack of confidence in EVM indicators (S8). Practicality of the EVM was also found to be limited by problems resulting from changes in construction (S11 and S10).

3.3.2 Survey results: industrial vs. non-industrial construction

Industrial construction is a labor-intensive sector of the industry that is primarily involved with the construction of oil, gas, petrochemical, and processing facilities (AbouRizk et al. 2001). Industrial projects are often more complex, involve multiple suppliers (i.e., local and international), and are challenging to manage (Bubshait 2003). Using the demographic data, a comparison between industrial and non-industrial sector was conducted, as depicted in Figure 3.3.

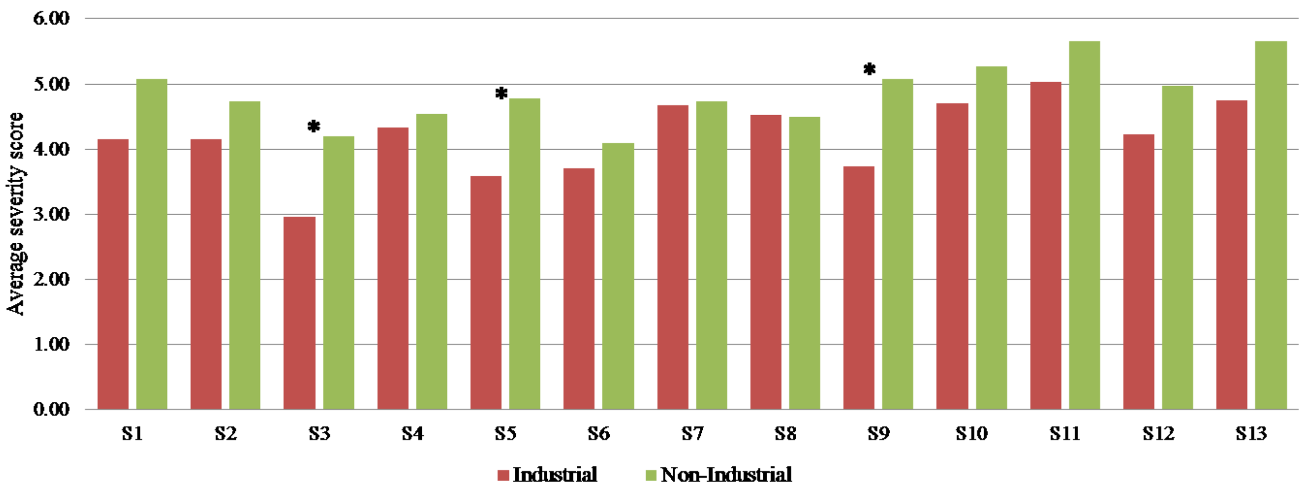


Figure 3.3 Comparison between industrial and non-industrial shortcomings. *P<0.05 versus industrial construction of corresponding shortcoming

The average perceived severity of EVM shortcomings for industrial and non-industrial construction are 4.2 and 4.9, respectively (P <0.05). Perceived severity of most shortcomings (10 out of 13) was similar between industrial and non-industrial construction (Figure 3.3). However, extra cost of EVM (S3), absence of an integrated project baseline (e.g., WBS, schedule, and budget) (S5), and use of resource-loaded schedules (S9) were perceived as more severe in non-industrial versus industrial construction (P<0.05; Figure 3.3). A trend of increased perceived severity (P=0.06) was also observed for two practices, namely lack of training (S13) and lack of structured management (S1) to support EVM implementation. This observation was expected, as a majority of companies that are involved in industrial construction have more established management systems. Consequently, practitioners reported to be less challenged in those areas.

3.3.3 Survey results: company size

A company's area of specialty is not the only factor affecting EVM in practice. Company size can affect the severity of EVM shortcomings, as industrial companies are often larger than non-industrial companies, as shown in Table 3.4. Indeed, effects of company size on project management practices have been well studied in other areas; for example, Guo et al. (2018) concluded that larger companies have more of a management commitment to safety compared to smaller firms. Company size could affect a company's practice, as smaller companies tend to adopt less formal management techniques than larger firms (Ghobadian and Gallear 1997).

Table 3.1 Distribution of company sizes by industry

Average revenue in the last three years	Industrial	Non-industrial
Small	7.4%	19.5%
Medium	11.1%	22.0%
Large	81.5%	58.5%

Perceived severity of all surveyed EVM shortcomings was similar between small, medium, and large companies (Figure 3.4), as no significant differences between groups were observed. Although not significantly different, a trend for larger companies perceiving differences between accounting systems and project management systems (S2) as more severe was observed. Indeed, larger firms have more established and rigorous accounting and management systems, which can be challenging to modify and interact with. A trend for smaller companies perceiving the inability of EVM to identify sources of inefficiency (S6) was also observed. Detailed results of the conducted survey can be found in Appendix B.

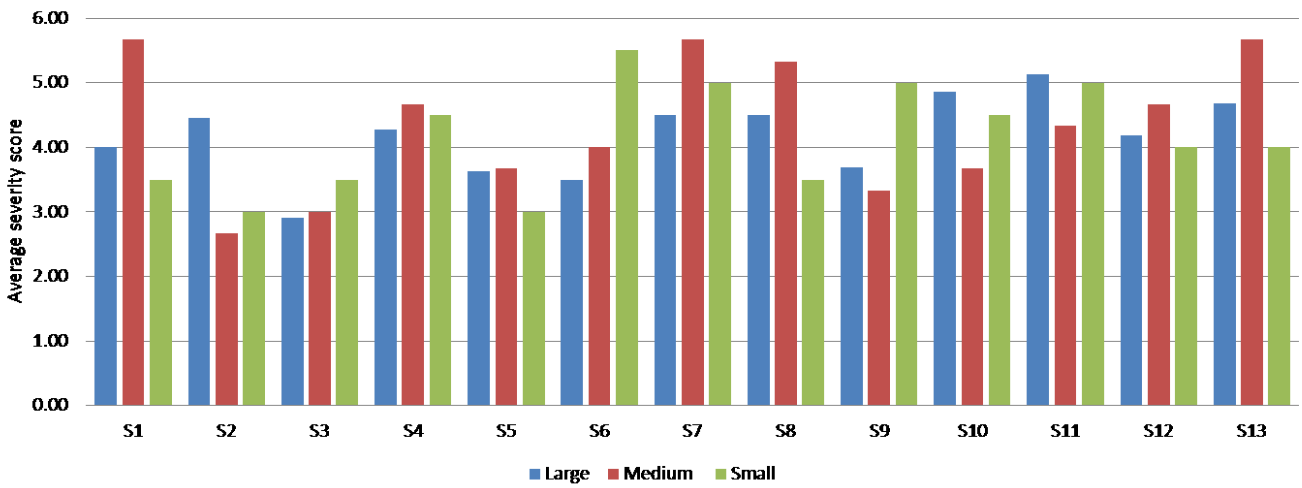


Figure 3.4 EVM shortcoming severity in industrial construction, categorized by company size

3.4 Discussion of the results

Management initiatives to support EVM implementation, including required training, were perceived as some of the most severe shortcomings of EVM practice. These practices are vital to the success of EVM (Song 2010, Vargas 2003, and Kim et al. 2003), and promoting the benefits of EVM implementation along with training programs for the project team can improve the project output (Hunter et al. 2014). Change orders can result in unachievable project outcomes (e.g., duration, budget), which have been identified to be challenging for practitioners. Changes are inevitable in construction projects and having too many changes can make the original estimate and schedule unachievable. A structured change management system capable of integrating changes into EVM analysis in real-time will enhance the validity of EVM metrics. Finally, setting up rules for EV measurement prior to execution together with the use of a resource-loaded schedule will reduce subjectivity in EVM metrics. Shortcomings were, in general, perceived as more severe for non-industrial experts compared to industrial colleagues, suggesting that the industrial construction sector is more comfortable and inclined to implementing EVM practice.

3.5 Limitations

Although the number of survey participants (n=95) nearly satisfies the statistical requirements for the study (n=96), and most of the observations confirm previous research and publications, additional responses would provide more comprehensive and generalizable results. As is inherent to any survey study, the results are biased and reflect practitioners' beliefs—in this case, a subjective opinion about the implementation level. In other words, the validity of the current study outputs is based on the assumption that participants are not biased towards their own practice. Observations by an unbiased third party could provide more objective data, particularly concerning implementation level.

3.6 Concluding remarks

As it can be interpreted from the survey, lack of training and unrealistic project schedule and cost were reported to be the most concerning areas from the practical point of view. In addition, poor change management (i.e., delays in updating project baseline), subjectivity, and lack of structured management systems were stated to be relatively severe. Identification of the aforementioned shortcomings provides invaluable insight into the industry's practice, highlighting the necessity of management initiatives to implement EVM. Moreover, this survey study indicated that, while academia proposed a variety of extensions and analytical methods, the surveyed industrial group believe that EVM's forecasts are still not accurate. The remainder of this research focused on the sixth most serious challenge identified by subject matter experts: inaccuracy of performance forecasts. Improving EVM forecast accuracy can promote the role of

EVM as an early warning system, which, in turn, may increase confidence in EVM metrics—the seventh most severe shortcoming.

Chapter 4: Investigation of the difference in cost performance of different activities and its application for forecasting

4.1 Introduction

The ability to reliably estimate final project costs or at completion (EAC) can initiate corrective actions, potentially enhancing project outputs (Winch 2010). Current project control practices, which are primarily based on the earned value method (EVM), aggregate performance of various disciplines at a project-level, which can result in inaccurate EAC. Currently, data are being collected at lower levels and combined at the project-level to calculate EAC. This chapter proposes a framework to investigate potential differences between performances of various disciplines and for using the mined performance data in EAC calculations. The proposed methodology was implemented in the industrial sector of a general contractor. It was observed that use of discipline level performance data can enhance the accuracy of EAC forecasts. In addition, the proposed methodology generates different forecasts based on project specifications and variations in discipline budgets.

4.2 Problem statement

Classic earned value-based EAC calculations assume constant cost performance throughout project execution. Although scholars have used project-level historical performance to simulate CPI variation during execution, previous studies were limited to project-level performance. More rigorous and detailed data collection practices have provided the opportunity to collect and track project performance at lower levels (e.g., discipline level). Forecasting projects without considering disciplines that were involved in the project may undermine forecast credibility. Forecasting projects using project-level performance produces the same forecast for projects with the same budget. Whereas, in practice, two projects with the same budget can involve different disciplines with different budgets. For instance, project A may be primarily concrete work, while project B, with almost the same budget, may have a considerable amount of earthwork. Using historical cost performance at the project level yields the same forecast for both projects, which is not necessarily accurate. To address this shortcoming, a methodology is proposed in the methodology section, which is followed by an example case study to demonstrate differences of the proposed approach.

4.3 Methodology

This research proposes a multifunctional framework. Functions of the proposed framework are twofold: (1) determination of whether or not there are statistically significant differences between cost performances of various disciplines during project execution and (2) a forecasting model. As depicted in Figure 4.1, historical data are first analyzed to calculate the CPI of each discipline throughout project execution. Mined information from historical performance data is then used as input for a Monte Carlo simulation model.

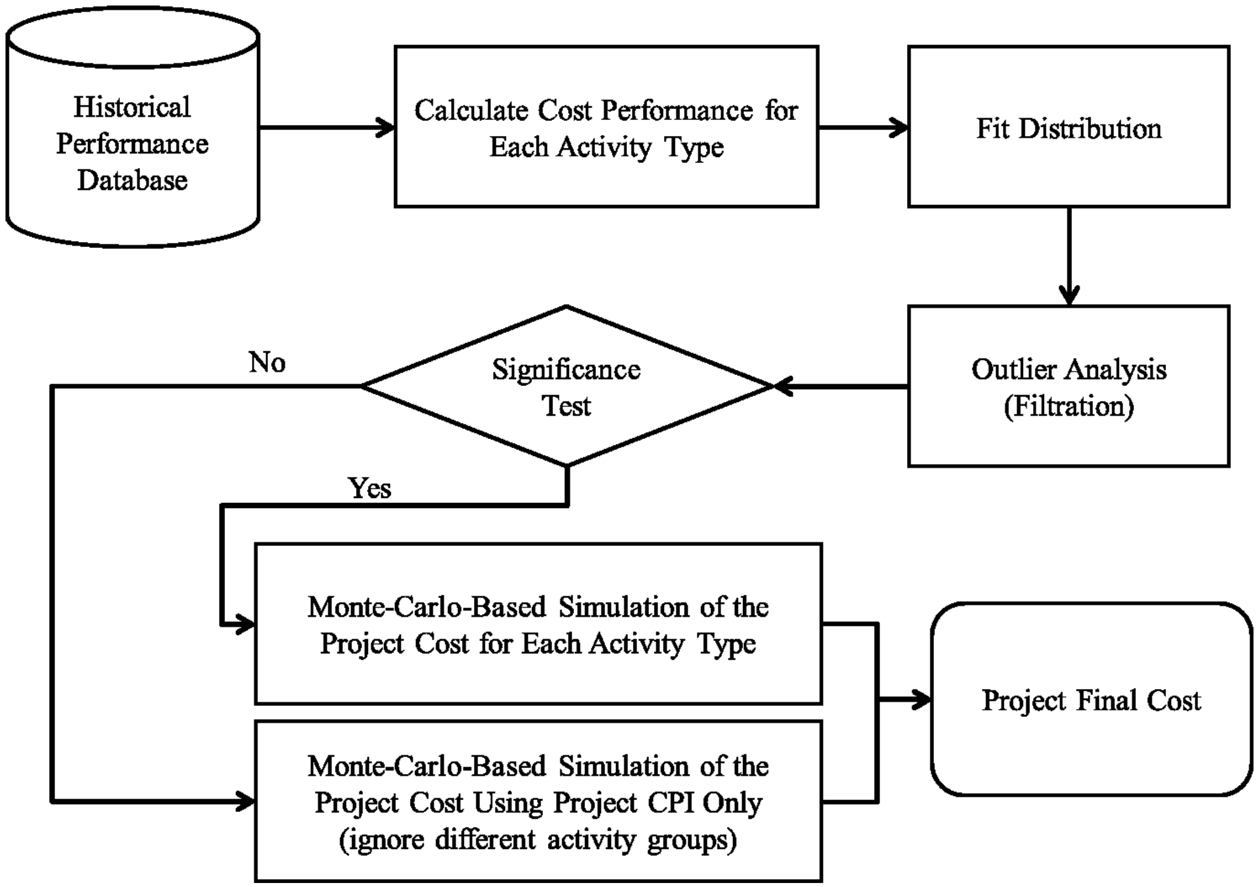


Figure 4.1 Proposed methodology framework

4.3.1 Input data

Detailed performance data for each discipline are required as input for the proposed framework. Depending on company practices, various cost tracking methods can be used to categorize cost performance into different disciplines. Many construction companies use a structured coding system to distinguish between disciplines. MasterFormat, as recommended by the Construction Specifications Institute (CSI) and Construction Specifications Canada (CSC), is one of the common coding systems in civil works (Kang and Paulson 1997). Actual cost (AC) and earned value (EV) amounts for each discipline are collected and aggregated during the project. Depending on the frequency, accuracy, and timeliness of progress reporting, discipline-level data can be further broken-down to the activity level (e.g., concrete formwork, concrete pouring). Because of the high diversity of the MasterFormat codes (greater than one thousand), conducting statistical analysis at the lowest level would be a challenging task. Alternatively, progress data can be aggregated at higher levels (discipline level; e.g., concrete work, earthwork).

4.3.2 Data adaptor

Calculated CPI should be filtered and refined to identify and remove outliers that may be generated because of data mishandling. Statistical distributions are fitted to each discipline (Lipke 2002). Based on the fitted distribution, secondary outlier analyses may be required. The third step is critical, as it investigates if there is a statistical difference between the average values of the fitted distributions of different disciplines. It also examines the difference between the distributions during execution of one discipline. Provided that CPI distributions are normally distributed, a two-way ANOVA test is used to identify significant statistical differences between disciplines. The ANOVA test determines the probability of differences between distributions occurring as a result of random variation (Rutherford 2001). If the P-value from the ANOVA test is less than a pre-defined threshold (i.e., P=0.05 in this case), the difference between two distributions is considered significant.

4.3.3 Simulation engine

Using historical cost performance results in a statistical distribution, as project cost performance is a stochastic process and CPI varies over time (Du et al. 2016). Monte Carlo simulation is a technique that is used to sample random variables from known distributions (Mooney 1997). Monte Carlo simulation has also been used in the earned value management research area. For example, Barraza et al. (2004) utilized Monte Carlo simulation to generate stochastic S curves for a project using variable inputs for cost and duration. Vanhoucke and Vandevoorde (2007) used Monte Carlo simulation to introduce uncertainty to randomly generated project networks and investigate the effect of project networks on project prediction accuracy. Acebes et al. (2015) used Monte Carlo simulation to generate all possible scenarios for projects. Consequently, the generated project cost and schedule data were then used to detect anomalies in performance using classification techniques. Kim (2016) used Monte Carlo simulation to evaluate cost performance stability. Monte Carlo technique has demonstrated a high degree of compatibility with other techniques and has been utilized in this research for random sampling. Monte Carlo simulation is used in this research to create random project scenarios.

A Monte Carlo simulation model is the predictor of the proposed methodology and will randomly sample from the fitted distributions to generate possible CPIs and to forecast the project's actual cost. Based on the significance test results, Monte Carlo simulation may be performed at the discipline level (Scenario 1), using Equation 4.1, or at project level (Scenario 2), using Equation 4.2.

$$AC_{P,t} = \sum_{1}^{i}\left(PV_{i,t}\right) * \left(CPI_{i,t}\right) \text{ For every discipline } i \quad \text{Equation [4.1]}$$

Where $AC_{P,t}$ represents actual cost of the project at time t (e.g., 20% completed). $PV_{i,t}$ represents the planned value of discipline type *i* (e.g., concrete, earth work) at time *t*. $CPI_{i,t}$ is the randomly sampled *CPI* from the fitted distribution for discipline *i* at time *t*.

$$AC_{P,t} = \left(PV_{P,t}\right) * \left(CPI_{P,t}\right) \qquad \text{Equation [4.2]}$$

Where $PV_{P,t}$ and $CPI_{P,t}$ are planned value and randomly sampled project cost performance index at time *t*, respectively. Scenario 1 occurs when fitted distributions for each discipline are deemed to be significantly different from other disciplines. In this case, planned value for each discipline would be multiplied by the sampled CPI from the fitted distribution for that discipline. Total project cost is the summation of all disciplines' costs. Contrary to Scenario 1, Scenario 2 occurs when no significant differences between distributions of various disciplines are observed (i.e., differences between fitted distributions likely result from natural variation in data). In this case, it is recommended to use project-level performance to estimate the final project cost, as it is easier to model project-level cost requiring only one distribution per. This is in contrast to a discipline-level analysis, which can require as many as 10 distributions.

4.4 Results

The functionality and accuracy of the proposed framework was tested through a case study. Historical project data for all industrial projects conducted in the last four years at the case company's regional office were collected. Out of 76 available projects, 35 had a complete set of required data for analysis (e.g., earned value, actual cost, and planned budget). Durations of projects varied between 4 and 14 months, with an average of 7.13 months. Selected projects were industrial projects that were implemented in Northern Alberta. Dollar values of projects ranged from 0.25 million to 24 million dollars, with an average of 6.7 million.

The studied company uses a MasterFormat-based breakdown structure, which was used in this research to benchmark performance for each discipline. MasterFormat uses hierarchical codes to classify various types of work (e.g., 03XXXX codes are used for concrete work, and 031XXX is used for various types of concrete formwork). Each work package was broken down to the MasterFormat code level, and costs of each discipline were spread accordingly. The studied company estimates, collects, and reports costs on a monthly basis for each MasterFormat code.

Figure 4.2 demonstrates a sample MasterFormat breakdown for concrete work. Each discipline is associated with a code that reflects a concrete work hierarchy. Using standard coding for each work package and tracking actual costs and earned value provides the possibility to study each group and adjust estimates for future work. It also provides the opportunity to conduct earned value analysis for each discipline (e.g., concrete, earthwork).

4.4.1 Data analysis

The proposed methodology was implemented at the studied company. Cost aggregation was implemented at two levels using the first two or three digits of the MasterFormat codes. For instance, for concrete work case, the first two digits represent all concrete-related work activities, with the third digit providing detailed information about the discipline (e.g., code 031 is for concrete formwork). Data analysis for both high and low levels demonstrated that, although a low-level analysis provided more detailed information, a high-level analysis yielded more accurate results in the studied case. This was attributed, in part, to shortcomings in cost reporting systems, earned value measurement rules, and activity dependencies. For instance, the performance of the concrete pouring activity may be affected by concrete formwork performance. Moreover, some activities may take less than a month to accomplish, while progress reports are created monthly.

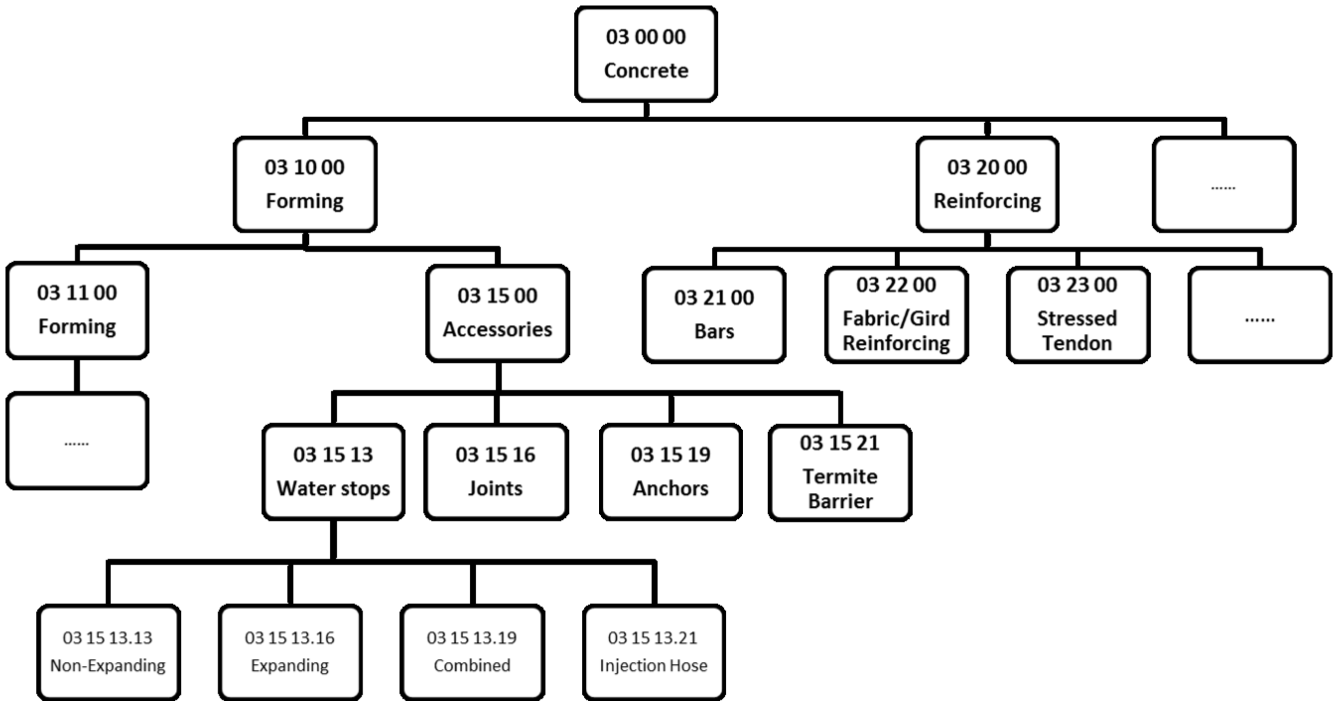


Figure 4.2 Sample MasterFormat breakdown for concrete work

Project duration varies, making the comparison between projects even more challenging. For example, in a project that lasts for three months with monthly progress reports, CPI values are reported at the 33%, 67%, and 100% completion points, whereas in a four-month project, CPIs are calculated at 25%, 50%, 75%, and 100% of the total duration. To have a valid benchmark for all projects, linear interpolation was used to calculate CPI at 20%, 40%, 60%, 80%, and 100% completion points. Selecting five points was limited to average project duration (i.e., 7.13), but more points can be chosen if projects are longer in duration. The studied company's data were grouped and analyzed in 12 different disciplines, as itemized in Table 5.2. Figure 4.3 presents CPI averages for concrete and earthwork based on historical performance of the studied company. As it can be inferred from the graph, concrete work's cost performance, on average, was considerably lower in the earlier phases of project, which may be because concrete work requires more preparation and material ordering early in the project, resulting in added costs without earning. Similar to concrete work, CPI for earthwork was relatively lower in the early stages of the project. Earthwork CPI value, in contrast, was always greater than one, which demonstrates the company's good cost performance in that discipline. It is important to note that historical performance data were multiplied by a confidential value to maintain company privacy.

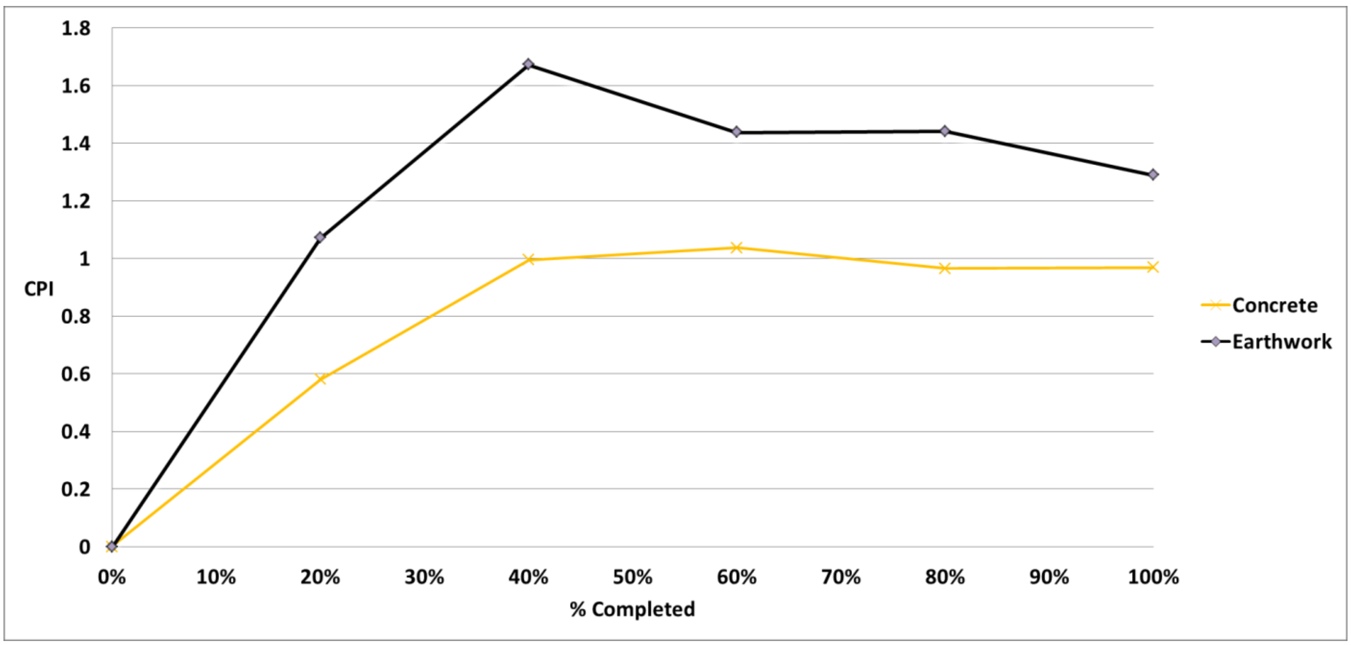


Figure 4.3 CPI variations over project execution for concrete and earthwork

Since the expected value for CPI is one and its variation was limited, one standard deviation from the average was selected as a threshold for outlier identification. Values outside of this defined boundary were treated as outliers and were not used in the analysis.

To investigate if there are significant statistical differences between disciplines, a two-way ANOVA test was performed. Two-way ANOVA test was performed for two factors: percent complete and discipline type. The results of the ANOVA test are summarized in Table 4.1. A significant difference was observed between percent complete values within one discipline. Moreover, within the same percent complete, different disciplines were found to vary significantly. In contrast, combinations of different disciplines during project execution did not show statistical differences amongst each other.

Table 4.1. Two-way ANOVA test results

Source of Variation	% of Total Variation	P value	Significant?
% Complete	7.137	<0.0001	Yes
Discipline	8.54	<0.0001	Yes

Because of the significant differences observed, a Monte Carlo simulation was employed to generate, stochastically, the actual cost of projects using Equation 4.1. Beta distributions were fitted to data, and Kolmogorov-Smirnov, Anderson-Darling, and Chi-Squared tests were performed to assess goodness of fit. A Beta distribution was used to prevent the generation of negative CPI values in the random sampling process. Running Monte Carlo sampling for multiple instances resulted in a new distribution for the final cost of the project.

4.4.2 Example case study

This section provides an example case study to illustrate the benefits of the proposed approach. Two hypothetical projects were forecasted using the proposed method. Hypothetical projects were used because two projects that had the same duration, budgets, and planned value throughout implementation were not available in the studied database. Duration, budget, and planned value were the same for Project 1 and Project 2, as presented in Table 4.2. Out of a 7.5 million dollar budget, the projects were assigned 3.3 million dollars (i.e., 44% of the budget) in the same category of work. Both projects had the same budget and schedule for "general requirements," and both projects included concrete work.

Table 4.2 Hypothetical project inputs for the simulation model

		% Complete				
	Discipline	20%	40%	60%	80%	100%
Planned Value Project 1 (M$)	General Requirements	0.5	0.95	1.7	2.15	2.55
	Subsurface Investigation	0.4	0.7	1.2	1.35	1.35
	Concrete	0.1	0.7	1.7	2.3	2.7
	Electrical	0	0.15	0.4	0.7	0.9
	Total	1	2.5	5	6.5	7.5
Planned Value Project 2 (M$)	General Requirements	0.5	0.95	1.7	2.15	2.55
	Concrete	0.2	0.35	0.6	0.75	0.75
	Earthwork	0.3	0.9	2.15	2.45	2.65
	Piping	0	0.3	0.55	1.15	1.55
	Total	1	2.5	5	6.5	7.5

Project cost forecasts for the hypothetical projects were calculated using the proposed method. Results for 10000 simulation runs are summarized in Table 4.3.Although both projects had the same budget and planned value, actual cost forecast varied between projects. Variation resulted as a consequence of the different disciplines comprising each project. Where Project 1 was primarily focused on concrete work and subsurface investigation, Project 2 included earthwork and piping-related work packages. Figure 4.4 depicts CPI variation of the hypothetical projects during project execution. Both projects have low CPI (i.e., lower than 1) in early stages of execution, which reversed approximately halfway through execution. Ultimately, both projects achieved relatively good cost performance. Detailed information about model inputs and outputs are provided in Appendix C.

Table 4.3 Forecast results for hypothetical projects

	% Complete	20%	40%	60%	80%	100%
	EV	$ 1,000,000	$ 2,500,000	$ 5,000,000	$ 6,500,000	$ 7,500,000
Project 1	Average Cost	$ 1,214,005	$ 2,835,643	$ 4,664,339	$ 5,966,305	$ 7,179,655
	CPI	0.82	0.88	1.07	1.09	1.04
Project 2	Average Cost	$ 1,469,151	$ 2,539,118	$ 4,280,991	$ 5,612,557	$ 6,783,141
	CPI	0.68	0.98	1.17	1.16	1.11

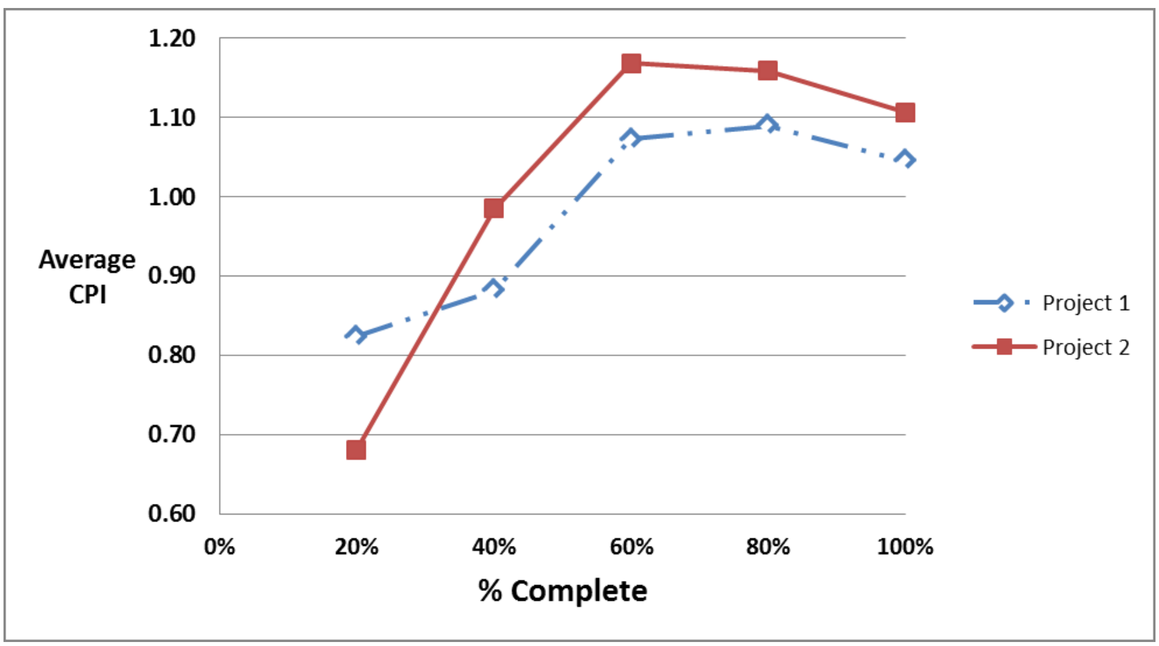


Figure 4.4 Comparison between average CPIs of two hypothetical projects

Using discipline-level performance data, unlike most available forecasting methods, generated two different forecasts for EAC. Graphs, such as Figure 4.4, can assist project managers to more precisely plan for the project. As per the graph, lower CPI can be expected early in project execution. This fictitious scenario analysis highlights the fact that two projects with the same budget and planned value can have different cost forecasts. The proposed method also provides stochastic forecasts that more accurately estimate project cost.

4.4.3 Practical case study

To measure the accuracy of the cost forecast using the proposed method, an industrial construction project undertaken by the studied company was selected. The studied project's budget was approximately 17.5 million dollars. Planned value for each discipline throughout the project is summarized in Table 4.4. Note that historical performance data were multiplied by a confidential value to maintain company privacy. As it can be inferred from the table, more than 88% of the total project budget was distributed between three different work categories: general requirements, earthwork, and industrial piping. If subsurface investigation and concrete work had been added, 96% of the total budget could have been forecasted using only five disciplines.

Table 4.4 Cost breakdown of the studied project (CAD $)

% Complete	20%	40%	60%	80%	100%	% of the Total Budget
General Requirements	2,531,878	4,005,255	8,027,989	9,141,586	11,250,253	63.97%
Subsurface Investigation	338,518	353,367	487,001	492,919	605,248	3.44%
Concrete	-	66,868	172,644	388,937	710 ,656	4.04%
Metals	-	-	-	322	5,392	0.03%

Special Construction	5,084	5,084	5,084	62,570	126,084	0.72%
Conveying Equipment	6,872	21,074	29,063	35,276	42,378	0.24%
Earthwork	1,440,275	1,765,723	1,978,991	2,029,882	2,156,108	12.26%
Piped Utilities	-	2,693	2,693	2,693	2,693	0.02%
Transportation Systems	-	18,316	41,142	41,447	199,727	1.14%
Industrial Piping	188,877	352,071	1,504,007	1,772,343	2,194,960	12.48%
Install Underground Piping	-	27,995	47,996	87,977	115,176	0.65%
Industrial Equipment	9,411	9,411	47,051	47,051	75,282	0.43%
Electrical	16,137	16,137	61,816	90,834	103,902	0.59%
Total Planned Value	**4,537,052**	**6,643,992**	**12,405,477**	**14,193,837**	**17,587,857**	100.00%

4.4.3.1 Results of the practical case study

A Monte Carlo simulation model for the studied project was built, and results of the analysis were compared with earned value and forecasting at the project level (i.e., using the last line of Table 4.4). Results of the analysis were compared to actual project cost, as presented in Table 4.5. Forecasts from 40% onward were compared.

Table 4.5 Results of the EAC forecast for the studied case (CAD $)

% Complete		40%	60%	80%	100%	Mean absolute percent error (MAPE)	Mean absolute deviation (MAD)	MAD / Total project cost
Project actual cost		6,577,359	10,764,216	13,387,232	15,703,225			
Discipline-based forecast	Average AC	6,337,666	10,569,259	12,355,945	15,825,408	3.48%	397,030	2.53%
	% Error	3.64%	1.81%	7.70%	0.78%			
Project level forecast	Average AC	4,759,545	10,060,751	12,128,500	16,011,977	11.39%	1,022,191	6.51%
	% Error	27.64%	6.54%	9.40%	1.97%			
Earned Value	AC using *CPI* =1.0	6,643,992	12,405,477	14,193,837	17,587,857	8.57%	1,099,783	7.00%
	% Error	1.01%	15.25%	6.03%	12.00%			
Earned Value at 40% complete	AC using *CPI* (40%) = 1.01	-	12,281,060	14,051,485	17,411,466	9.98%	1,296,445	8.26%
	% Error	-	14.09%	4.96%	10.88%			

Four different project cost forecasting methods were used to forecast the final cost of the project. A forecast based on the discipline types (Equation 4.1) and a forecast using project-level distributions (Equation 4.2) are shown in Table 4.5. Two earned value-based forecasts, using Equation 2.1, are also examined to assess the accuracy of current practices. The first earned value-based forecast using CPI equals 1.0, as it represents the EAC forecast at the beginning of the project. The second earned value-based analysis uses CPI at 40% completion.

4.4.3.2 Accuracy comparison of the practical case study

To examine the assumption that forecasting using discipline-level performance data results in more accurate forecasts compared to project-level forecasts, two metrics were calculated: mean absolute percent error (MAPE), which was used to calculate the average percent error of forecasted amounts and actual costs, and mean absolute deviations (MAD), which were used to determine the average deviation of forecasts from the actual cost (Equation 4.3). MAD accounts for the average magnitude of error in the cost forecast and highlights the effect of error towards the end of the project.

$$MAD = \frac{\sum |AC_t - Forecasted\ Cost_t|}{n} \qquad [4.3]$$

As it can be concluded from Table 4.5, using discipline-level historical data outperformed other methods and forecasted the final project cost more accurate compared to other available methods. Using discipline-level performance data resulted in lower MAPE and MAD. Figure 4.5 compares forecasted EAC using the proposed methodology with the actual project cost (solid line) and forecast using EVM from the beginning of the project (dotted line). As it can be seen from the graph, the results of the proposed approach are stochastic, and relative variation decreases as the project progresses.

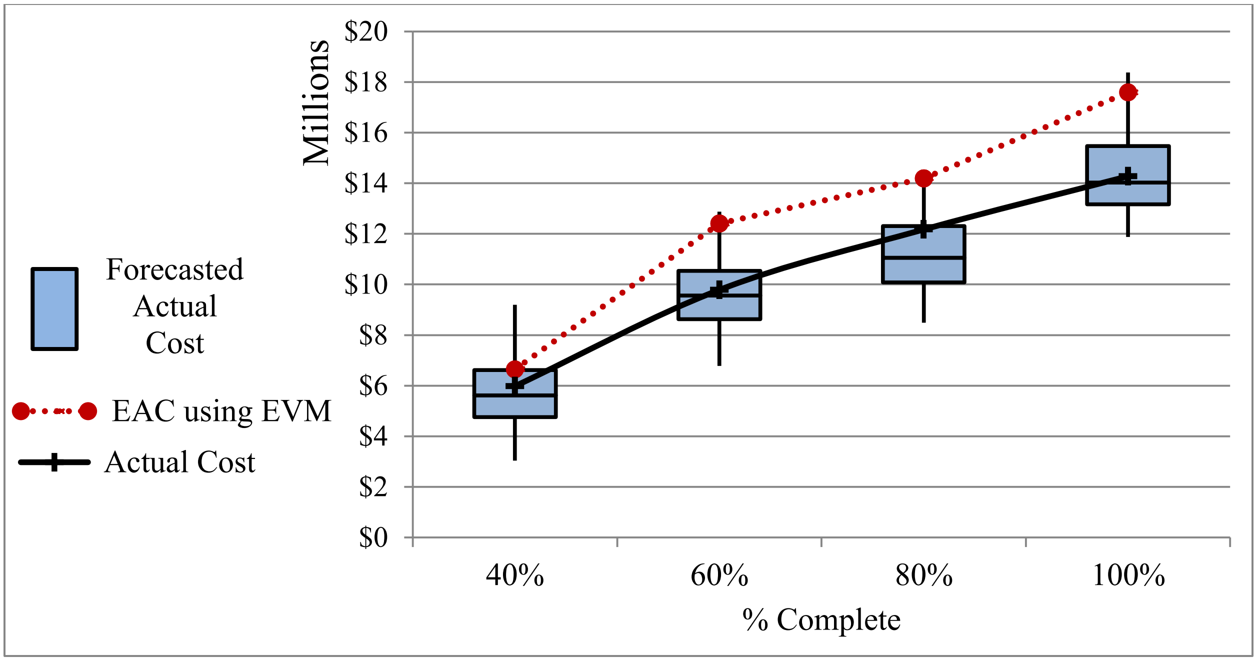


Figure 4.5 Comparison of forecasted EAC using the proposed methodology and EVM method

4.5 Limitations

Although results of the suggested methodology demonstrated improvement in EAC accuracy, implementation was limited to one company. Regarding significant differences between various disciplines, although the studied case demonstrated significant differences, other companies may not observe such differences. With regards to the Monte Carlo model, it does not consider project continuity, as it samples a different CPI for each stage of the project, regardless of the performance in the previous stage. In practice, however, CPI is a combination of the current month's performance and the performance of all previous months. In other words, following Monte Carlo logic, a project can transition from a CPI of 0.8 to 1.2 in one month and again to 0.7 in the following month. In addition, the suggested Monte Carlo simulation algorithm is incapable of recalibrating itself based on current project performance. To improve model fidelity, a combined Markov modeling technique and Bayesian inference may be used.

4.6 Concluding remarks

The proposed framework exhibited the application of historical performance data for performance forecasting. Due to the advancement of data collection techniques and the application of computer-based tracking systems, granular performance data are becoming increasingly accessible. The proposed methodology proposes a methodological way to mine and use historical performance data for EAC calculations. Using discipline-level historical performance data was found to improve EAC forecast accuracy and could provide forecasts that were based on disciplines involved in the project.

Chapter 5: Application of current project performance data for forecasting project estimate at completion

5.1 Introduction

Differences in the performance of various disciplines can be used to improve forecast accuracy, and a Monte Carlo simulation method was proposed to forecast EAC during execution. The proposed approach, nonetheless, can be improved by incorporating current project performance into calculations. In addition, modeling project performance as isolated months that have no dependency previous performance may not be representative of an actual project. To address this shortcoming, a Markov modeling approach was proposed. Using Markov modeling, monthly project performance can be modeled as a series of interconnected performances. This chapter first describes the proposed Markov-based methodology in detail. To validate the proposed method, data from the industrial division of a general contractor were analyzed, and a real project from the studied company was forecasted using the proposed approach. Overall, the proposed method improved EAC forecast accuracy in the early months of project execution. With regards to the final months of the project, both EVM and the proposed method yielded the same accuracy.

5.2 Methodology

The proposed framework is depicted in Figure 5.1. The framework has three functions, namely historical data analysis, simulation modeling, and the integration of historical and current project performance.

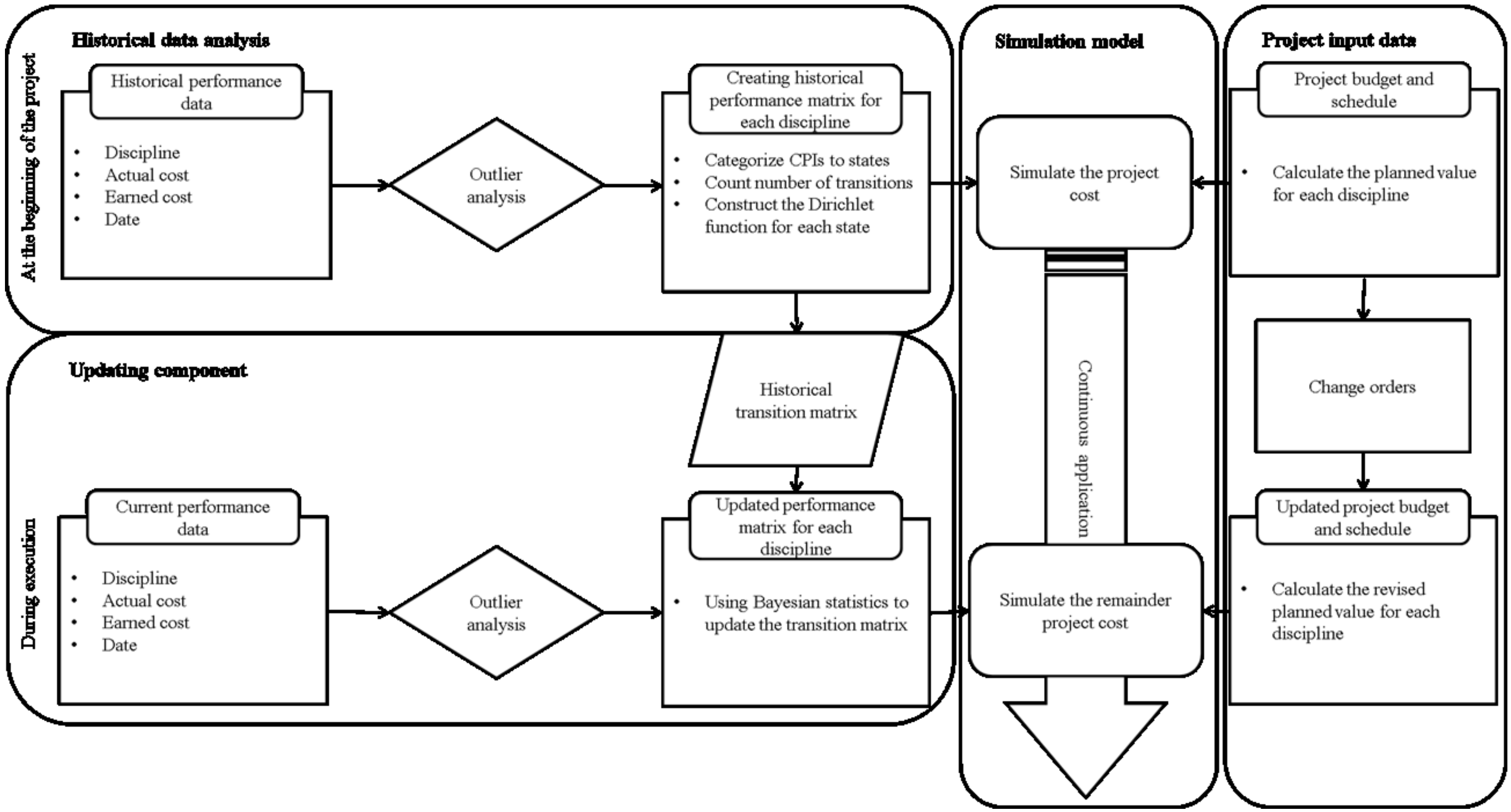


Figure 5.1 Markov-Bayesian framework

5.2.1 Historical data analysis

Historical project cost performance can be used as a resource to aid practitioners with EAC forecasting. The historical data analysis component of the framework analyzes, filters, and generates transition matrices for Markov modeling using previous cost performance values. Based on company practices, cost performance can be stored and analyzed at various levels (e.g., project or discipline). Regardless of the granularity level of the input data, filtration and cleaning of the data is required. Delays in tracking and recording performed activity costs, as well as unapproved changes orders, are some potential sources of faulty data. Outliers must also be removed from the dataset prior to further analysis. Mean and standard deviation is a common method that is widely used by academics (Leys et al. 2013). According to this method, any value outside the interval of the mean ± three standard deviations is considered an outlier (Howell 1998).

Net CPI (CPI_i) or CPI for month i (Equation 5.1) values are analyzed in this component, as the forecasting algorithm forecasts the performance of each month separately. To simulate the project using Markov modeling, filtered CPI data are categorized into states (e.g., Table 5.1). The number of states and range of each stage depends on the size and the standard deviation of the dataset. Defining n different states requires having an $n * n$ matrix for Markov modeling or n^2 elements, where the number of the transition matrix elements increase exponentially with an increasing number of defined states.

$$CPI_i = \frac{EV_i - EV_{i-1}}{AC_i - AC_{i-1}} \qquad \text{Equation [5.1]}$$

Markov chains simulate a system using the transition matrix presented in Equation 2.6, where $p_{i,j}$ represents the probability of transitioning from state i to j. As each CPI transition element is based on a sample observation, the Dirichlet distributions were used to represent each transition matrix. The Dirichlet distribution is a stochastic distribution for modeling categorical phenomena, as shown in Equation 5.2 (Bishop 2006). It is a generalized form of the Beta distribution and, instead of considering binary variables, can be used to sample probabilities in the defined state space. Since each row of the transition matrix indicates the probability of remaining at state i or transitioning to another state, one Dirichlet distribution is defined for each row of the transition matrix.

$$P(\theta|\alpha) = \frac{\Gamma(\sum_{k=1}^{m} \alpha_k)}{\prod_{k=1}^{m} \Gamma(\alpha_k)} \prod_{k=1}^{m} \theta_k^{\alpha_k - 1} \qquad \text{Equation [5.2]}$$

Where α_ks are the function parameters (i.e., in this case, number of instances in each category), Γ represents the Gamma function, and θ_k is the probability of occurrence for the k th state. As can be inferred from the equation, the Dirichlet distribution is essentially a generalized form of the Beta distribution (i.e., for $k = 2$). Each row of the transition matrix is presented by one Dirichlet distribution using vector notation $(Y_1, Y_2, \dots, Y_k)$, where Y_k represents the occurrence probability of the kth state. To construct the stochastic transition matrix for each discipline, net CPI values are first categorized into states based on the defined intervals. In turn, the number of instances that performance is transferred from one state to another state is counted. A same frequency, consequently, is sampled from the Dirichlet distribution.

5.2.2 Simulation component

The simulation component of the framework forecasts the final project cost using Markov modeling. The proposed Monte Carlo simulation model in Chapter 4 forecasts monthly project cost individually (i.e., as isolated months). However, the performance of each month is somewhat dependant on the performance of the previous month. Markov modeling is a powerful tool for modeling progressive data such as project performance. Although time series, derived from CPI data analysis (e.g., Figure 4.3), may be used as an alternative to Markov modeling, this method is limited by its requirement for percentage completion as an input, potentially increasing calculation errors. First, implementation of a time series approach would require that CPI at various completion points be calculated using linear interpolation, which may generate inaccurate values. Second, time series has difficulty adjusting to variability in project duration, which can impact percent completion and overall time series results.

Defined stochastic transition matrices in the previous section are used to transfer project performance from one state to another. The Gamma distribution can be used to generate random numbers from the Dirichlet distribution (Narayanan 1990). According to this method, first, a random variable Z_k is generated from the Gamma distribution using α_k, as per Equation 5.3. Consequently, randomly generated Z_k values are inserted into Equation 5.4 to generate a random vector $(Y_1, Y_2, \dots, Y_k)$, which is a row of the transition matrix. To forecast the future state of the system, the entire transition matrix is sampled using this procedure.

$$Z_k = Gamma\ (\alpha_k, 1) \quad \text{Equation [5.3]}$$

$$Y_k = \frac{Z_k}{\sum_{j=1}^{k} Z_j} \quad \text{Equation [5.4]}$$

The forecasted state of each discipline must be quantified for EAC calculations. To convert the state to a CPI value, each state is assumed to have a uniform distribution within the defined interval (e.g., Table 5.1). Eventually, $PV_{i,d}$ values are multiplied by randomly-sampled $CPI_{i,d}$, which are planned values (i.e., budgeted), and CPI for month i and discipline d, respectively.

Equation 5.5 denotes the project EAC calculation, which is the summation of all monthly forecasts during the project execution period (T) for all disciplines (d).

$$EAC = \sum_1^d \sum_{i=1}^T PV_{i,d}/CPI_{i,d} \quad \text{Equation [5.5]}$$

5.2.3 Bayesian updating

This component of the framework updates the fitted historical Dirichlet distributions to incorporate current project performance. The ongoing project may have consistently high performance for the previous months, which necessitates modification in the transition matrix. Bayesian statistics are a powerful method for modifying previously observed samples (i.e., prior distributions) using newer samples (Bishop 2006). The Dirichlet distribution can be used as the prior distribution and be updated, based on the *N* number of new observations, using Bayesian statistics to generate a posterior distribution (Bishop 2006). The Dirichlet distribution is a conjugate, where the posterior distribution is of the same family of distributions as the prior distribution (Bishop 2006), as shown in Equation 5.6. Note that m_k represents the number of new observations for each instance.

$$P(\theta|\alpha + N) = \frac{\Gamma(\sum_{k=1}^{m} \alpha_k + N)}{\prod_{k=1}^{m} \Gamma(\alpha_k + m_k)} \prod_{k=1}^{m} \theta_k^{\alpha_k + m_k - 1} \quad \text{Equation [5.6]}$$

Updates to the Dirichlet functions are incorporated into the simulation model to simulate the remainder of the project with up-to-date probability transition matrices. Cost performance is not the only variable; often, schedule and budget change during execution. Accordingly, PV amounts may require updating, depending on both budget and schedule. Eventually, at the end of each month, updated planned value amounts, as well as updated Dirichlet distributions, will be used as input for the simulation component of the framework.

5.3 Implementation

The proposed methodology was implemented in the industrial sector of a general contracting company. Data from the company's Northern Alberta branch were used to construct Markov model inputs using historical cost performance. The majority of projects that are managed by the branch are exposed to similar geographical and market pricing and were managed through the same management team. Although dissimilarities in performance exist between each project and project manager, that projects were performed in the same division and the same region is believe to create some degree of similarity.

5.3.1 Historical data analysis

Cost performance data for the last three years of the industrial sector were analyzed to generate the transition matrix of the Markov model. Actual cost (AC), earned value (EV), and the activity discipline were analyzed for each month during project execution. The data was cleaned using the mean and standard deviation method. Because the studied data showed relatively high variance, two standard deviations from the average were considered as the outlier interval instead of the classic three standard deviation rule. Following the traditional three standard deviations would have resulted in negative values or values close to zero for CPI. The choice of two standard deviations represents 95% percent of the data while omitting outliers. This resulted in a range of 0.3 and 1.7, which was broken down into six states, as itemized in Table 5.1.

Table 5.1 Defined states and ranges for the cost performance index

State	Distribution
A	Uniform (1.4, 1.7)
B	Uniform (1.2, 1.4)
C	Uniform (1.0, 1.2)
D	Uniform (0.8, 1.0)
E	Uniform (0.6, 0.8)
F	Uniform (0.3, 0.6)

Historical data analysis was performed in Microsoft Access and Excel. Data aggregation and filtration were executed using crosstab queries in Access. Aggregated data in Access, notably cumulative *AC* and *EV* values, were transformed into Excel format and converted to net or monthly values and, consequently, nominal performance, as per Table 5.1. In turn, Markov transition matrices were extracted from the categorized nominal performance data. As mentioned in the methodology section, each row of the transition matrix was represented using one Dirichlet distribution defined by α_k. α_ks were derived by counting the number instances project net performance transitioned from one state to another. For instance, α_2 for the first Dirichlet distribution represents the number of instances the project performance transitioned from state A to B. The number of state conversions for each month was counted to extract α_ks for each discipline. Expectedly, not all disciplines had enough data or the same importance with regards to the total budget (i.e., having less than one percent of the total project budget) to support this type of analysis. These disciplines were aggregated into a discipline referred to as miscellaneous and contributed less than two percent of total project costs. As the effect of the miscellaneous group on the total project cost is limited, it was assumed to have a CPI value of one.

5.3.2 Simulation model implementation

The extracted α_ks for transition matrices for each discipline were stored in Microsoft Access tables for use by the simulation model for random sampling from the Dirichlet distribution. The simulation model was implemented using Simphony.NET (Hajjar and AbouRizk 1999). Figure 5.2 is a screenshot of the simulation model, which comprised of three components as follows:

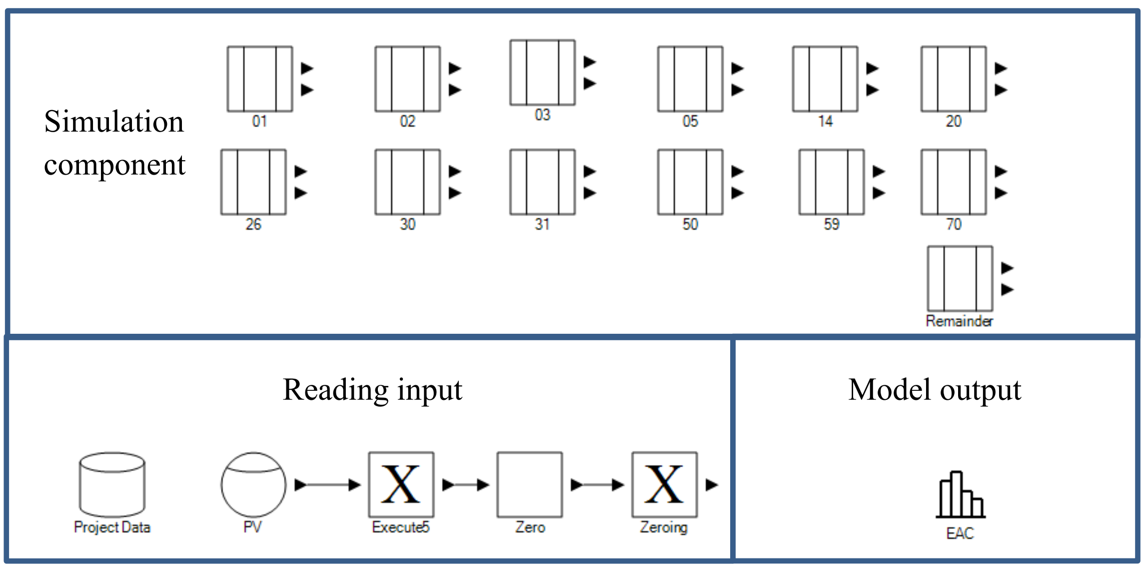
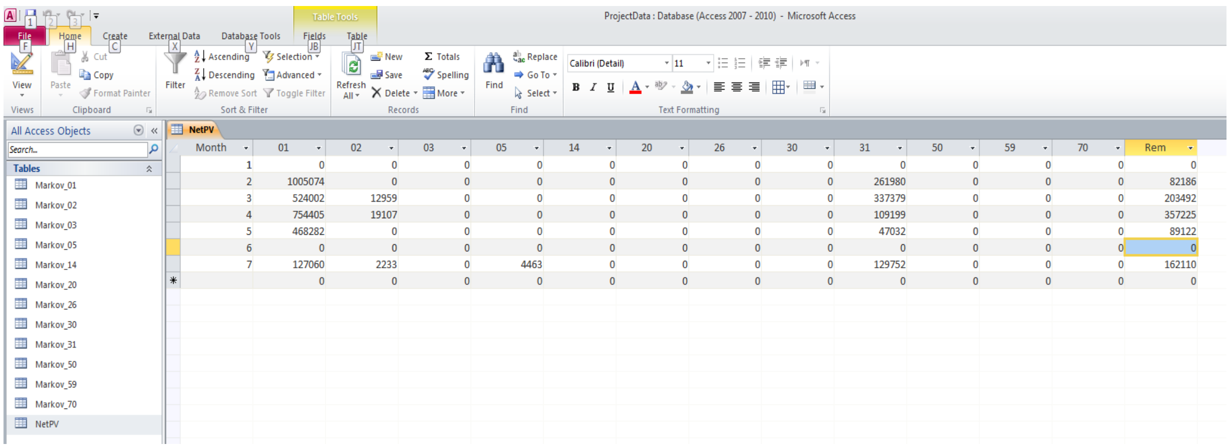


Figure 5.2 Screenshot of the Simphony.NET simulation model

5.3.2.1 Reading project input data

The developed simulation model reads two types of input data for each discipline: project planned value data and transition matrices (α_ks). Project managers or end-users calculate *PV* values for each discipline using project budget and schedule. Figure 5.3 shows a sample *PV* table for the case study, where each column represents a certain discipline (i.e., first two digits of

MasterFormat code) and each row represents a month. The majority of disciplines were assigned a value of zero, indicating there was no work planned in these areas. Markov transition matrices were also populated in Access and imported into the simulation model.



Month	01	02	03	05	14	20	26	30	31	50	59	70	Rem
1	0	0	0	0	0	0	0	0	0	0	0	0	0
2	1005074	0	0	0	0	0	0	0	261980	0	0	0	82186
3	524002	12959	0	0	0	0	0	0	337379	0	0	0	203492
4	754405	19107	0	0	0	0	0	0	109199	0	0	0	357225
5	468282	0	0	0	0	0	0	0	47032	0	0	0	89122
6	0	0	0	0	0	0	0	0	0	0	0	0	0
7	127060	2233	0	4463	0	0	0	0	129752	0	0	0	162110
*	0	0	0	0	0	0	0	0	0	0	0	0	0

Figure 5.3 Screenshot of the net PV table in Microsoft Access

5.3.2.2 Simulation component

Analyzing the studied company’s database resulted in 12 different disciplines, as itemized in Table 5.2. Each discipline is represented by the first two digits of the MasterFormat code, as can be seen in Figure 5.2. A transition matrix was not extracted for the miscellaneous category (e.g., masonry work in the studied company). Notably, the simulation model reads and stores monthly PV amounts (i.e., net planned value) for each discipline separately.

Table 5.2 List of various disciplines in the studied company

Discipline code	Description
01	General requirements
02	Subsurface investigation
03	Concrete
05	Metals
14	Conveying equipment
20	Mechanical
26	Electrical
30	Special job
31	Earthwork
50	Industrial piping
59	Shop fabrication
70	Electrical- Industrial
Remainder	Miscellaneous

As depicted in Figure 5.2, each discipline is modeled as a subcomponent (i.e., composite element) with its own elements. Figure 5.4 illustrates a screenshot of one discipline. The first component of the discipline's model reads and stores α_k values for the transition matrix. A transition matrix with six states (Table 5.1) is defined, as demonstrated in Figure 5.5. Each state is represented by oval-shaped elements (A, B, etc.), and arrows between each state symbolize the probability of transitioning from one state to another. In other words, each arrow represents an element in the transition matrix. For instance, as per Figure 5.5, the probabilities of altering from state A to B and vice versa are 8.6% and 29.9%, respectively. An initial probability for each state was defined considering the number of times that projects were in each state (i.e., the frequency of each state). In this case, the likelihood of having performance A in the very first month is 9%, as shown in Figure 5.5. Notably, the transition probabilities indicated in Figure 5.5 are for demonstration purposes.

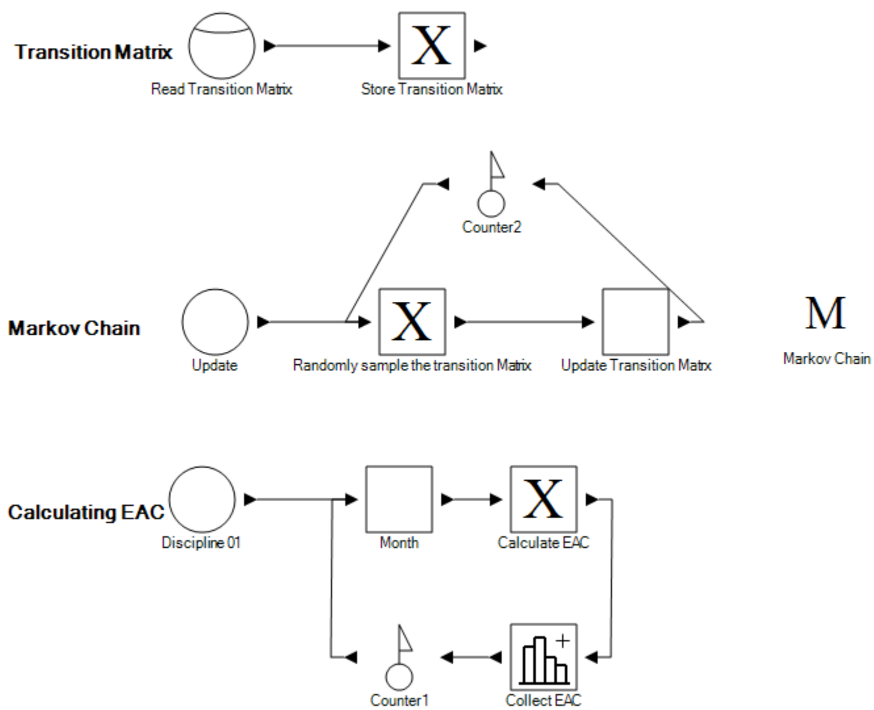


Figure 5.4 Simulation model for discipline 01 (general requirements)

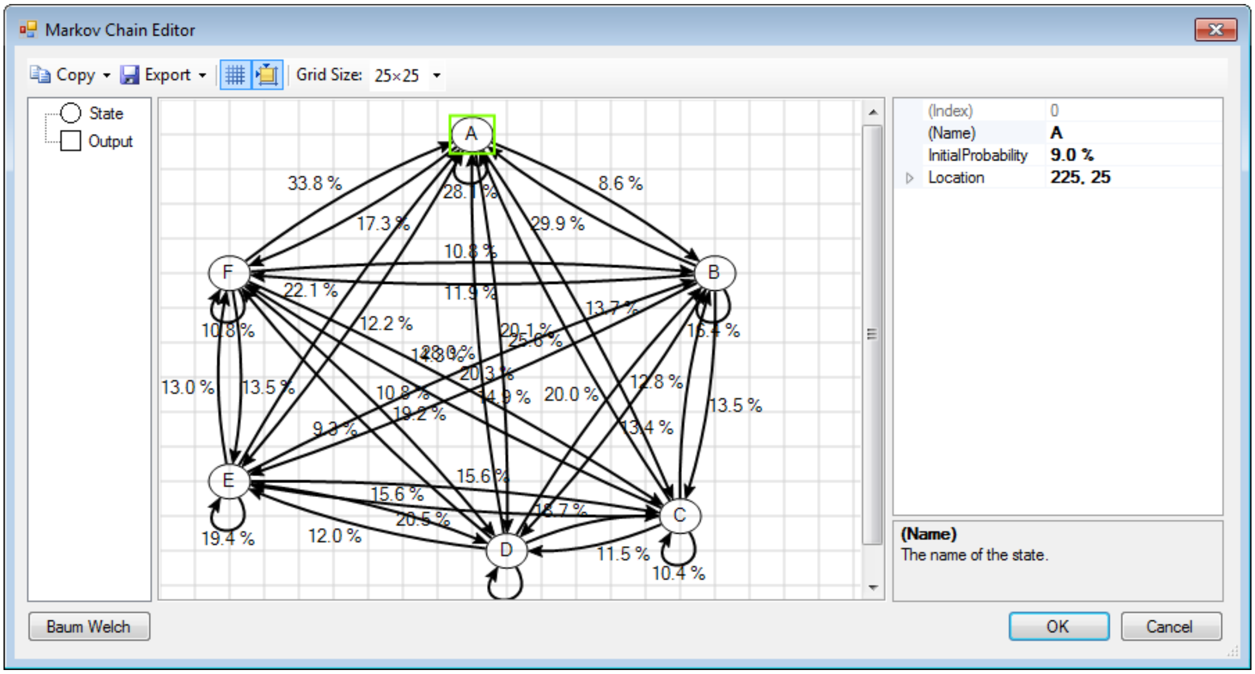


Figure 5.5 Markov model of discipline 01's performance

To update transition likelihood values, random samples from the Dirichlet distribution are generated using α_k values as well as Equations 5.3 and 5.4. In turn, the transition matrix elements are updated to simulate project performance for each month. Project performances for each discipline are forecasted monthly, as one transition per month.

Once the nominal cost performance of each state is forecasted, it is quantified for *EAC* calculations. Consequently, each nominal state is randomly sampled using uniform distributions of the intervals defined in Table 5.1. For instance, if the cost performance of a discipline is in state A, a random CPI between 1.7 and 1.4 is sampled. The sampled CPI is inserted into Equation 5.5 to compute EAC for the specific discipline. Simphony.NET codes for all simulation elements are provided in Appendix D.

5.3.2.3 Output component

Simulated EAC values are collected and stored in Simphony.NET. The chart element of the simulation software is used to collect and time-stamp the EAC of each discipline, separately. Figure 5.6 plotted a sample EAC forecast, where the *X*-axis represents time (i.e., month in this case) and the *Y*-axis, the forecasted values. Each line indicates EAC forecasted values for a discipline.

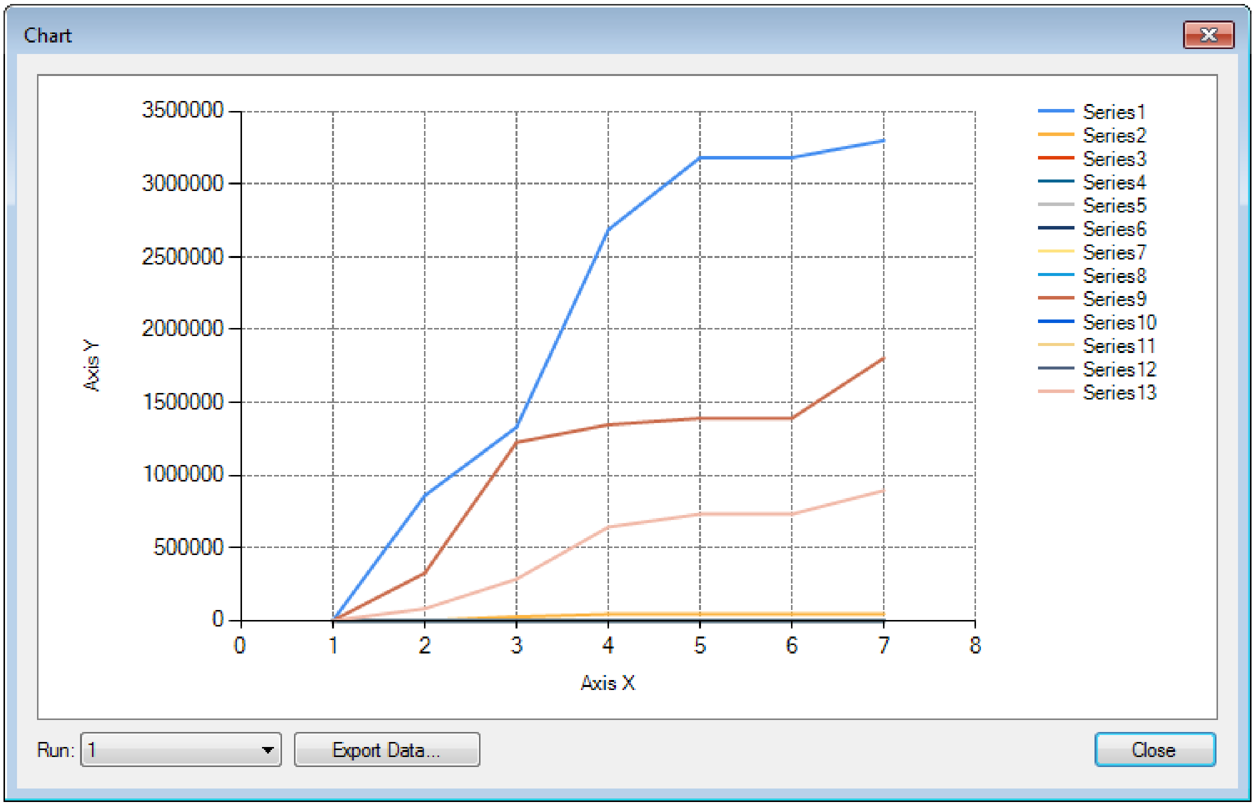


Figure 5.6 Sample output for EAC forecast for separated by discipline

5.3.3 Output analysis metrics

EAC is forecasted on a monthly basis, where the EAC forecast of a specific month is referred to as the "forecasting month" in this study. EAC was calculated, twice, using the Bayesian-Markov-based model and traditional EVM forecast (Equation 2.1). Here, accuracy represented the proximity of the forecasted value to the actual cost, where "accuracy measures the ability of a forecasting method to predict actual data" (Makridakis 1993). Accuracy can be quantified using error notation, which calculates the differences between actual cost and forecasted cost. Accordingly, lower error values are considered more accurate. Errors associated with each forecasting month (i.e., difference between the forecasted EAC amount and the project AC in following months) are measured using the following metrics:

- Mean absolute percentage error (MAPE) was used to calculate the average percent error of forecasted amounts and actual costs throughout project execution for all forecasting months.

- Mean absolute deviation (MAD) was calculated, as per Equation 5.7, to determine the average deviation of the forecast from the actual cost for each method. The MAD_i accounts for the average error value in cost forecast differences in forecasting month *i* and measures the magnitude of the error.

$$MAD_i = \frac{\sum|AC_t - Forecasted\ Cost_t|}{n} \qquad [5.7]$$

- Root-mean-square deviation (RMSD) was also measured as an alternative indicator to *MAD* for the average error values in forecasting month *i* (Equation 5.8).

$$RMSD_i = \sqrt{\frac{\sum(AC_t - Forecasted\ Cost_t)^2}{n}} \qquad [5.8]$$

Where AC_t stands for the actual cost of the project in month *t*, and $Forecasted\ Cost_t$ is for the forecasted cost in the same month.

5.3.4 Results

To examine the accuracy of the forecast, the proposed methodology was implemented to forecast EAC of an industrial project. A new project, which was under construction at the time that this research was being carried out and, therefore, was not included in the historical database, was used for forecasting purposes. The studied project duration was six months and had a budget breakdown as itemized in Table 5.3. Figure 5.7 illustrates the cumulative project *PV* graph (i.e., S-curve) for the case study project. The majority of the project budget was planned for the first four months. The studied project performance had high variation in CPI, as observed in Figure 5.8, which can impair forecast accuracy (AminiKhafri et al. 2018). Please note that historical performance data were multiplied by a confidential value to maintain company privacy.

Table 5.3 Monthly planned value amounts for each discipline in dollars

Month	General requirements	Subsurface investigation	Metals work	Earthwork	Miscellaneous	Total
1	1,005,074	0	0	261,980	82,186	1,349,239
2	524,002	12,959	0	337,379	203,492	1,077,833
3	754,405	19,107	0	109,199	357,225	1,239,936
4	468,282	0	0	47,032	89,122	604,436
5	0	0	0	0	0	0
6	127,060	2,233	4,463	129,752	162,110	425,618

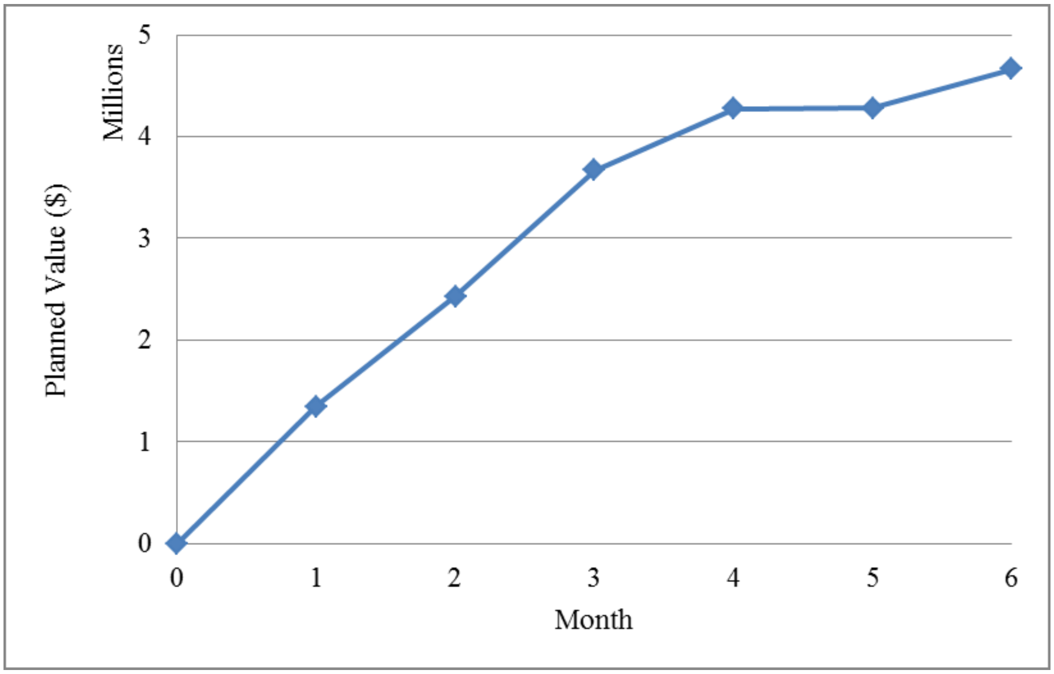


Figure 5.7 *PV* curve of the case study project

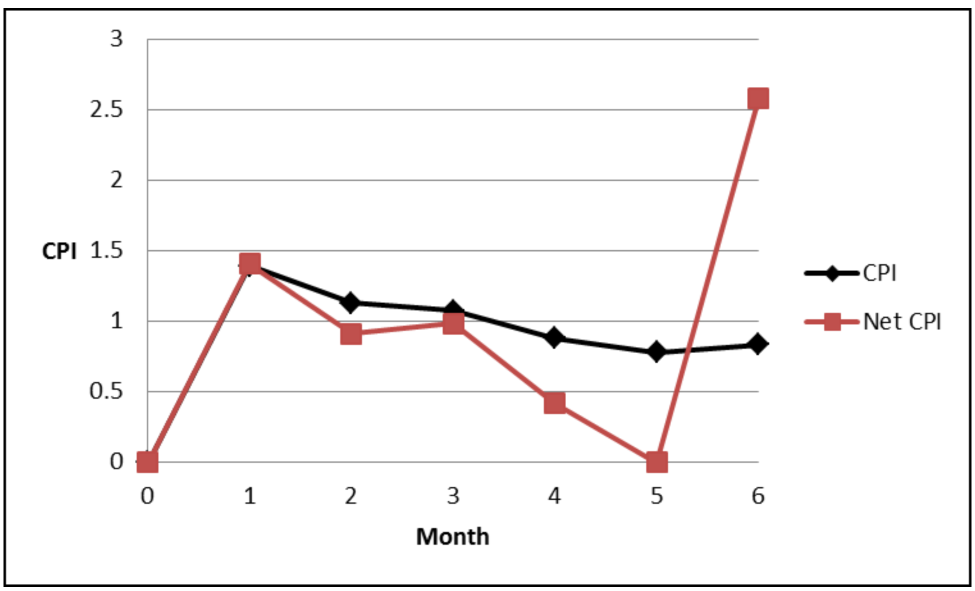


Figure 5.8 Actual *CPI* and net *CPI* (monthly *CPI*) for the studied project

The project was forecasted using the proposed method and using the traditional EVM Equation 2.2. Figures 5.9 to 5.13 illustrate box plot graphs for forecasting months 0 (i.e., at project start) through 6 (i.e., one month prior to completion). The first and fourth quartiles of the forecasted costs are represented by the whiskers of the whisker box plot, and the second and third quartiles are represented by the black and grey boxes, respectively. Because the forecasted cost spread was not symmetrical (Figures 5.9- 5.15), the average value for each forecasting month was used instead of the median. The average value, on the other hand, considers the wider spread in the higher cost end, resulting in more realistic measures.

For each forecasting month, the project cost was forecasted for the remaining months, which resulted in variation in forecast accuracy for each month. As can be seen in Figure 5.9, a consistent trend regarding accuracy between the proposed method and EVM was not observed. While the proposed method and EVM had similar forecasts in forecasting month 0, the proposed method generated more accurate forecasts in the second half of the project. MAPE, RMSD, and MAD were used to indicate the difference between the forecasted cost for each month and the AC of the project at that given month. The accuracy of the proposed method was compared against EVM due to the limitations of the studied historical data, both with regards to requiring schedule data and limitation of the number of data points. The majority of previous studies require either schedule data [Narbaev and De Marco (2014), Batselier and Vanhoucke (2017), Chen et al. (2015)] or large data sets [Du et al. (2016)].

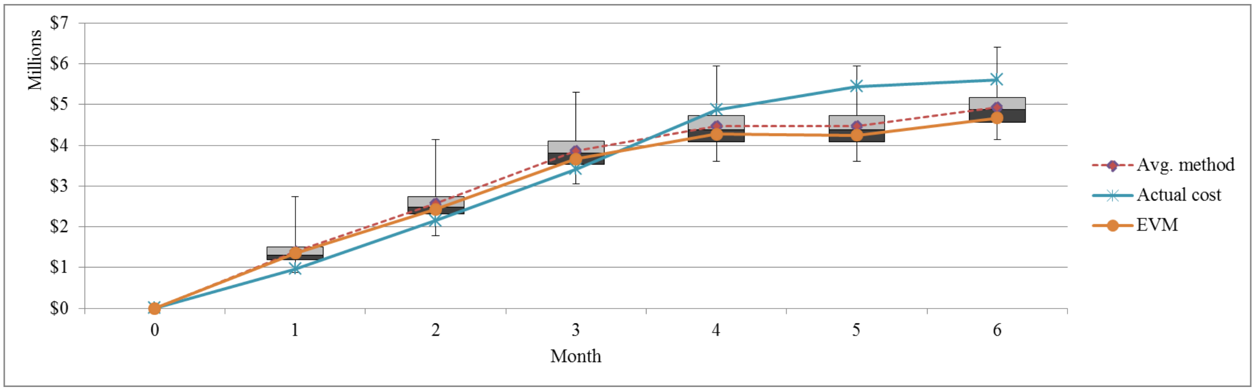


Figure 5.9 Box plot figure of the forecasted project value compared to EVM for forecasting month 0

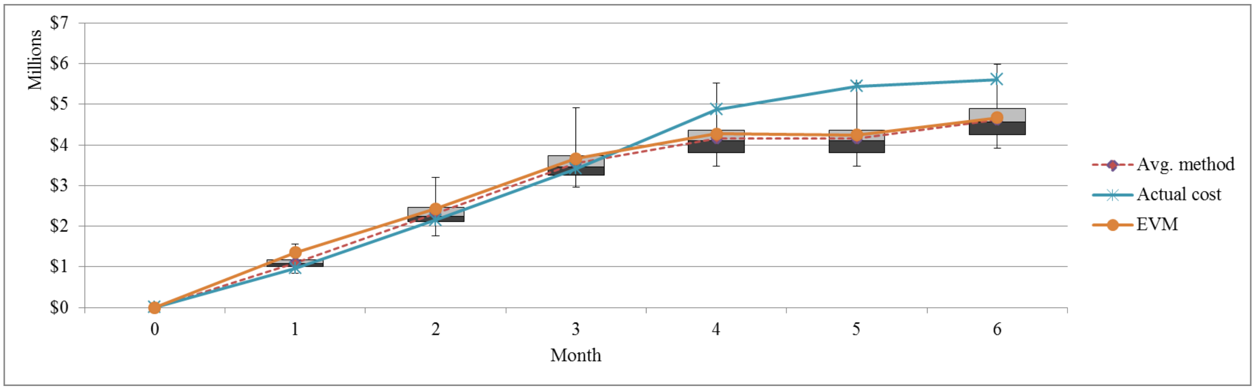


Figure 5.10 Box plot figure of the forecasted project value compared to EVM for forecasting month 1

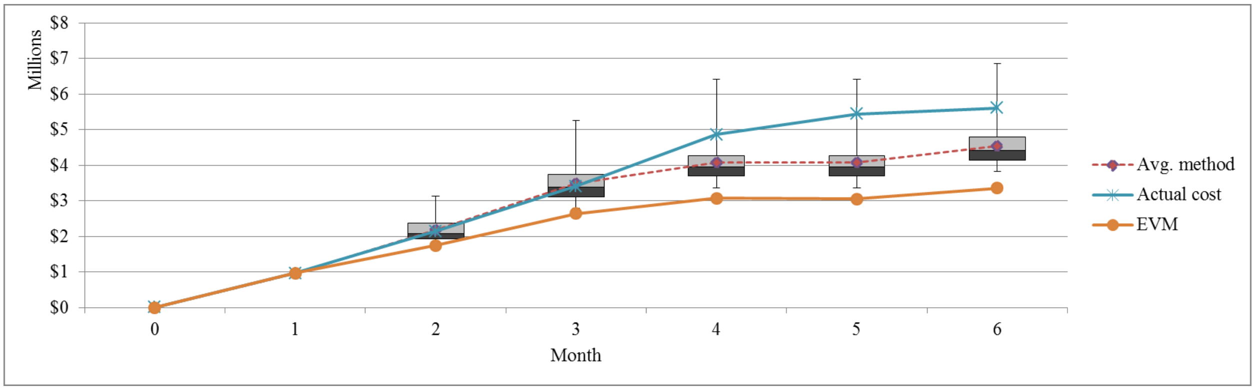


Figure 5.11 Box plot figure of the forecasted project value compared to EVM for forecasting month 2

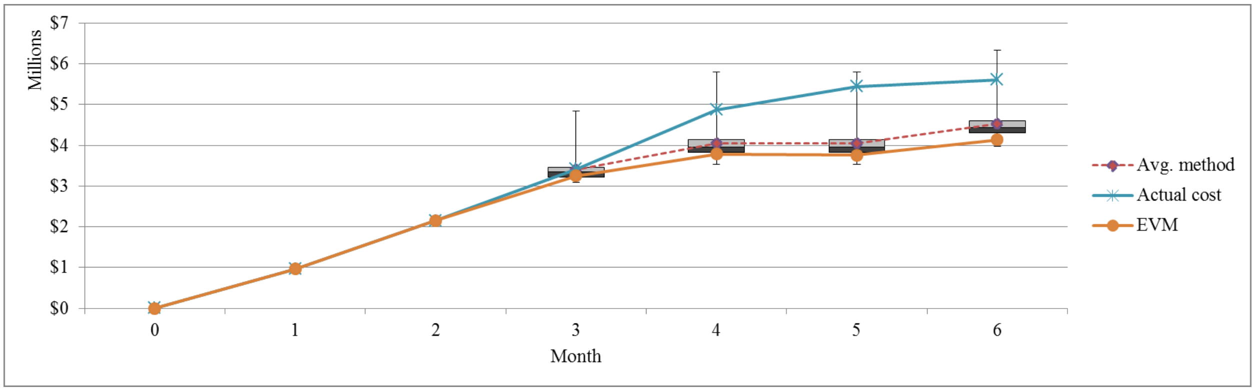


Figure 5.12 Box plot figure of the forecasted project value compared to EVM for forecasting month 3

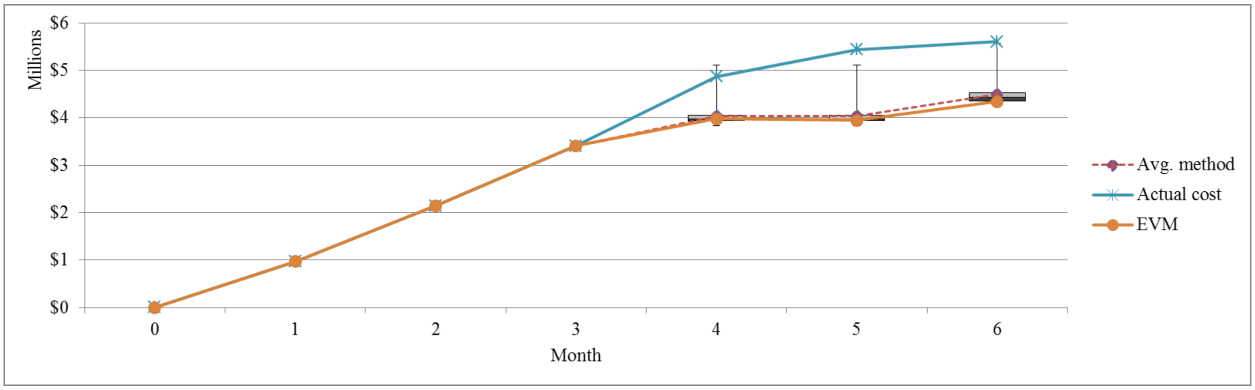


Figure 5.13 Box plot figure of the forecasted project value compared to EVM for forecasting month 4

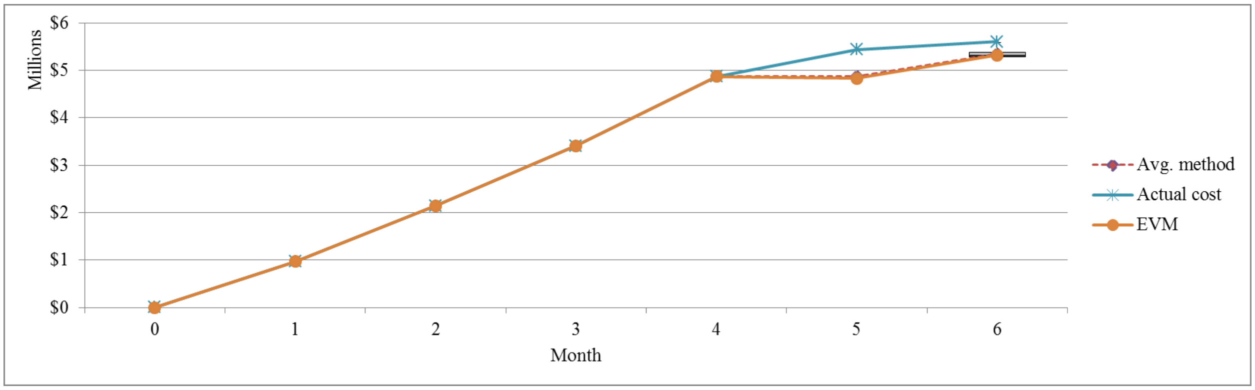


Figure 5.14 Box plot figure of the forecasted project value compared to EVM for forecasting month 5

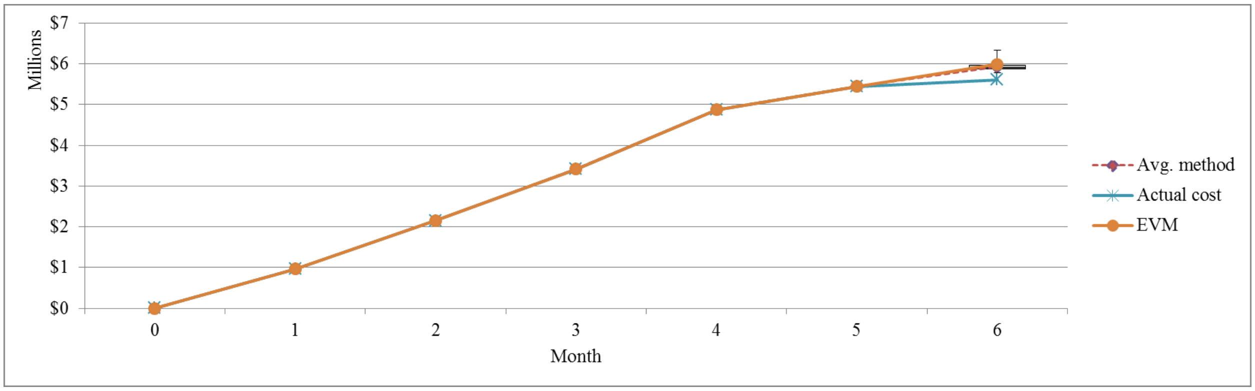


Figure 5.15 Box plot figure of the forecasted project value compared to EVM for forecasting month 6

MAPE, MAD, and RMSD results for each forecasting month are presented in Figures 5.16, 5.17, and 5.18, respectively. As it can be observed in Figure 5.16, the proposed method generated more accurate results (i.e., lower MAPE), compare to the EVM method, early in the project. This difference decreases as the project approaches the final months. Percent error in forecast may not be the most appropriate indicator of forecast accuracy, as the PV, and consequently the magnitude of the error, for each month differs. MAD was calculated as a secondary metric to evaluate forecast accuracy (Figure 5.17). The proposed approach resulted in lower MAD values compared to the EVM method. The difference is greater early in the project and decreases as the project finalizes. RMSD also was calculated as a secondary measure for the magnitude of the error (Figure 5.18). RMSD has the same pattern as MAD, yet slightly different values because of differences in formula (i.e., Equation 5.7 vs. 5.8).

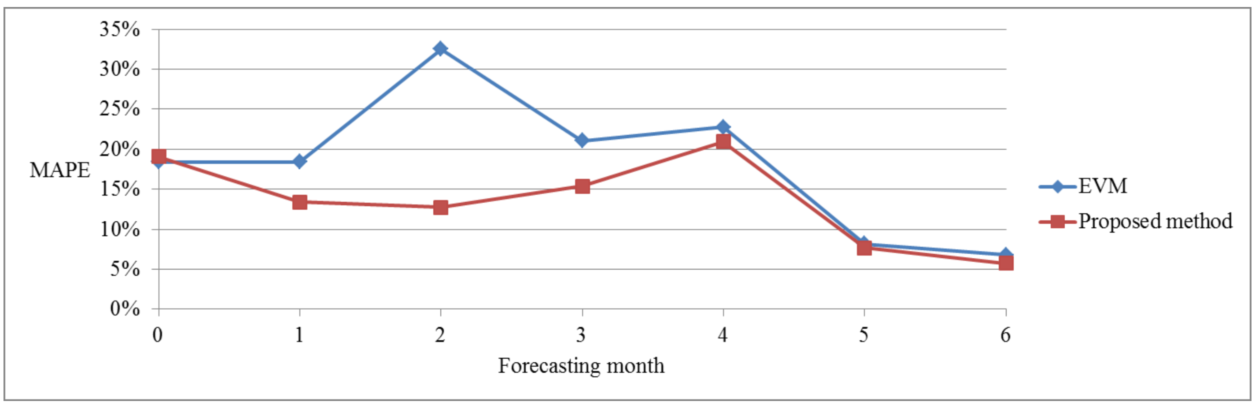


Figure 5.16 MAPE comparison between EVM and the proposed method for the case study project

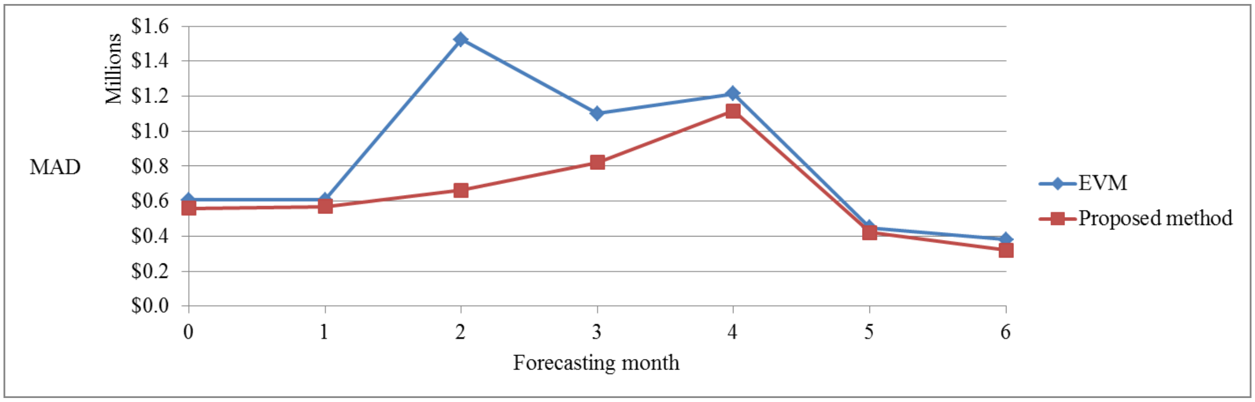


Figure 5.17 MAD comparison between EVM and the proposed method for the case study project

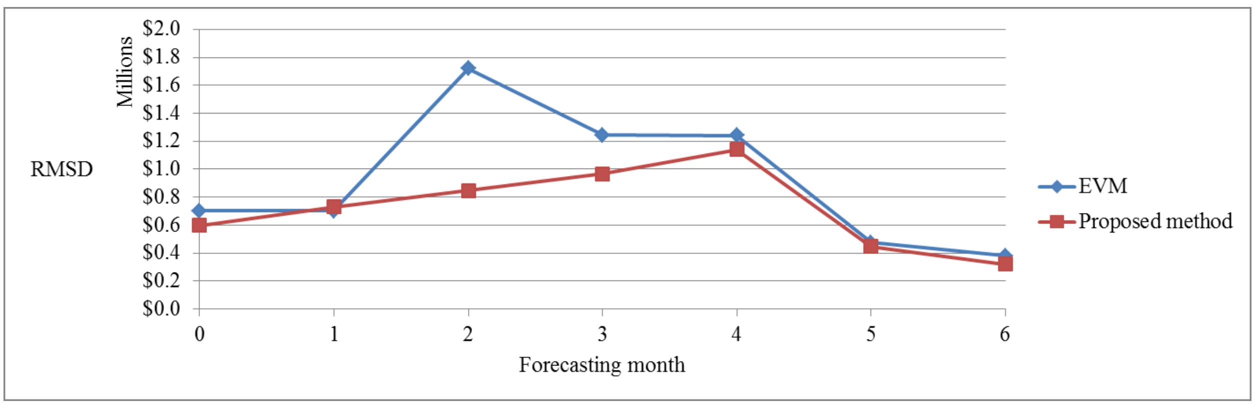


Figure 5.18 RMSD comparison between EVM and the proposed method for the case study project

5.4 Limitations

Although early findings presented an improvement in forecasting accuracy by the proposed method, the proposed method was only tested using one project. A more comprehensive analysis is required to validate the model. In addition, implementation of the proposed framework was limited to one company and should be explored in other organizations.

5.5 Concluding remarks

In this chapter, a forecasting framework was proposed and implemented to enhance EAC accuracy. The method was used to forecast EAC in a real case study to examine accuracy of the method. It was found that application of the proposed method can enhance forecasting accuracy, particularly in the early stages of project execution. Earlier detection of deviations from the budget can initiate corrective actions to mitigate the impact of poor performance. Notably, the proposed method provides more accurate results in the early stages of a project. In addition, the proposed method forecasts as accurately as EVM during the later stages. It is important note that all of the mentioned remarks are based on the analysis of one project, and additional projects are required to validate the framework.

Chapter 6: Application of randomly-generated projects for validation and sensitivity analysis of the developed method

6.1 Introduction

Utilization of historical cost performance data has been shown to improve EAC forecast accuracy (Chapter 5). EVM, as a conventional EAC forecasting method, was compared to the proposed method to test the hypothesis that application of historical performance data will improve forecast accuracy. In this chapter, the proposed method was applied to a set of randomly-generated project performance data. Randomly-generated datasets can provide a means of examining the performance of the proposed methods across a variety of scenarios. Vanhoucke (2012) used a hypothetical dataset to test the project schedule control performance in various scenarios. To validate the proposed Bayesian-Markov-based methodology, a set of randomly-generated projects were generated. The randomly-generated projects were comprised of four disciplines with various budgets and schedules. The proposed methodology, first, was applied to the randomly generated dataset to derive transition matrices required for Markov modeling. Then, an additional four sets of 30 random projects were generated to test the accuracy of the proposed methodology and to compare it against the EVM method.

6.2 Validation framework

A flow chart for the validation procedure is depicted in Figure 6.1. The validation framework is composed of two modules, training and forecasting. Each module is detailed in the following subsections.

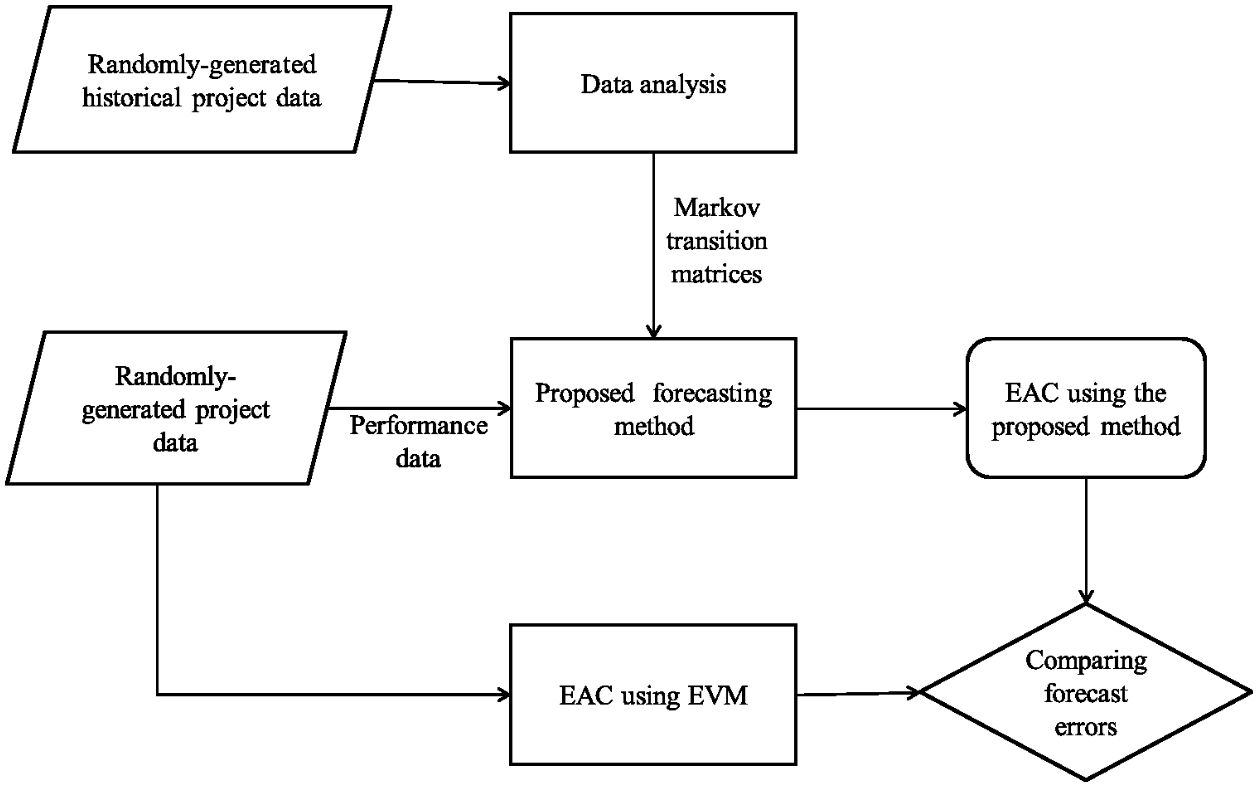


Figure 6.1 Flowchart of the validation methodology

6.2.1 Randomly-generated projects to train the model

As illustrated in Figure 6.1, performance data for a set of 100 fictitious projects were generated to train the model. The randomly-generated projects were comprised of four disciplines, namely 01, 02, 03, and 04. Planned value (PV), earned value (EV), and actual cost (AC) for each discipline was randomly generated for each month.

A project's cumulative budget (PV) usually forms an S-shaped graph called an S-curve. Planned cost usually begins with milder slopes, as there are a limited number of activities to perform. The expenditure rate (i.e., slope of the PV curve) increases as the project progresses and more activities are executed simultaneously. Finally, the rate decreases in closing stages of the project resulting in an S-shaped curve. Depending on project schedule, budget, and construction method, projects have diversified S-curves (Kaka and Price 1993). For instance, projects with shorter duration tend to have higher costs at the beginning, compared to longer projects (Kaka and Price 1993), known as a front-loaded S-curve. Higher costs can also be planned for the final implementation stages, referred as a back-loaded S-curve. Various types of S-curves are illustrated in Figure 6.2. Certain projects may have a uniform amount of budget to spend, resulting in a linear PV curve. S-curves can be used as inputs to forecast project duration and cost (Chen et al. 2016).

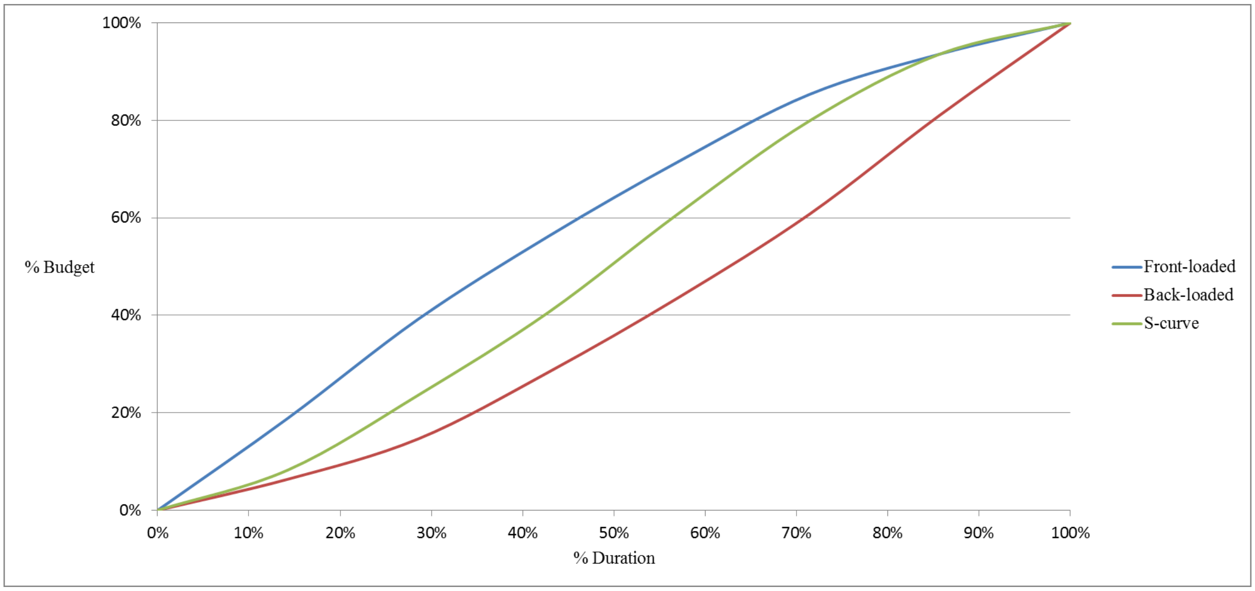


Figure 6.2 Sample different types of S-curve

The shape of the S-curve may affect the accuracy of the forecast, according to Kim and Kim (2014). Various researchers have tried to find mathematical formula for S-curves, such as logit transformation (Kaka and Price 1993), Beta distributions (Bhaumik 2016), and sigmoid functions (Cioffi 2005). Nonetheless, to the best of the author's knowledge, an established measurement does not exist to distinguish front-loaded and back-loaded S-curves. Miskawi (1989) defined an envelope for front-loaded and back-loaded S-curves using empirical data from petrochemical projects. The defined envelope generates S-curves, as plotted in Figure 6.3. As it can be inferred from the graph, back-loaded and front-loaded graphs progress about 40% and 65%, respectively, at the 50% completion point.

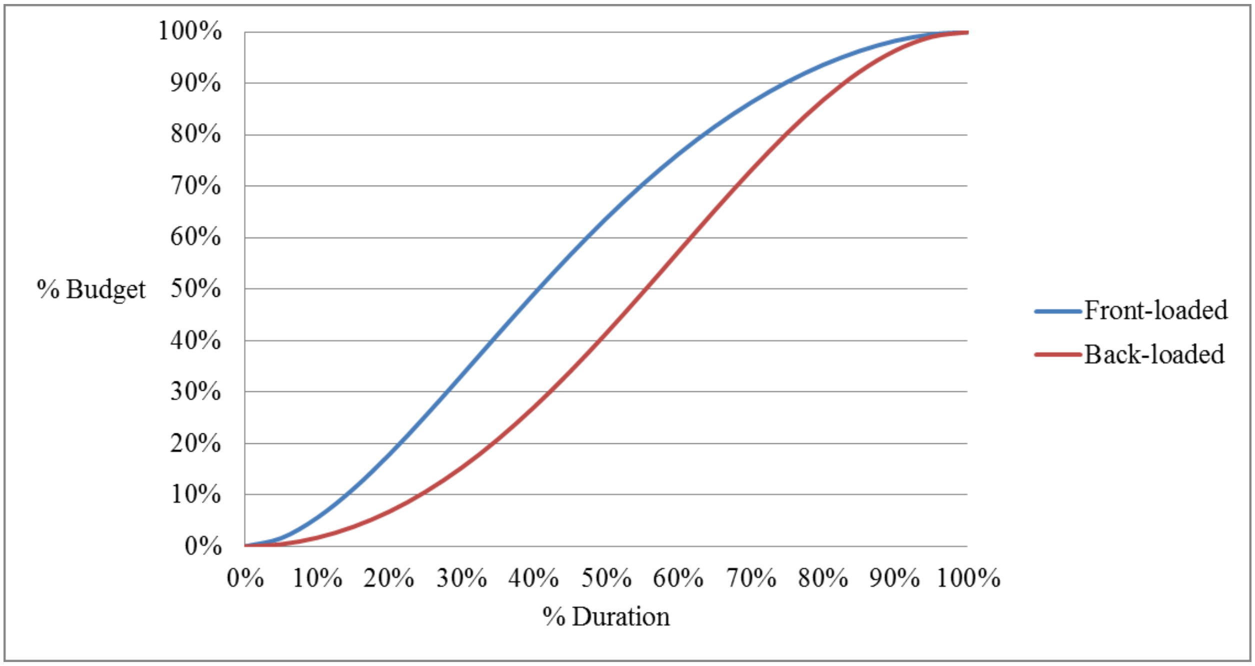


Figure 6.3 Front-loaded and back-loaded S-curve envelopes (Miskawi 1989)

To generate a diversified group of projects, 25 hypothetical projects were generated for each planned value type, namely linear, S-curve, front-loaded, and back-loaded. Each hypothetical project was assumed to have duration of 24 months with budget spread across four disciplines. EV amounts were generated based on the assumption that projects were delivered on time (i.e., SPI=1). Hence, EV equals PV. This assumption does not interfere with the proposed methodology, as it is trained using CPI values, which are only dependent on EV and AC. In other words, PV amounts were generated to create more sensible project data, and forecasting EV based on PV is not in the scope of this research. AC values were calculated by dividing EV by a random CPI sampled from a uniform distribution, with different intervals for each discipline, as presented in Table 6.1. As demonstrated in Chapter 4, various disciplines may have different monthly CPI (i.e., net CPI) values throughout the project. The intervals were intentionally defined to be relatively wide to generate diverse performances for each discipline. The ranges were defined based on observations of the studied company's cost performance data. For instance, discipline 01 often has low performance, whereas discipline 03 has high-cost performance. While a uniform distribution was chosen to demonstrate differences in project performance of various disciplines, it can be replaced by another distribution (e.g., normal, Beta). The uniform distribution represents an equal spread of performance in the defined interval, which represents the most challenging case, compared to normal or Beta distribution. In other words, for discipline 03, the normal distribution with a mean of 1.3 and standard deviation of 0.15 provides more information about the probability compared to any number between 0.9 and 1.5. Randomly-generated project data are provided in Appendix E.

Table 6.1 Defined cost performance intervals for each discipline

Discipline code	Minimum	Maximum
01	0.5	1.1
02	0.5	1.7
03	0.9	1.5
04	0.8	1.7

To train the model, hypothetical project performance data were categorized and processed to create a transition matrix for each discipline. A schematic flow of the training component is illustrated in Figure 6.4.

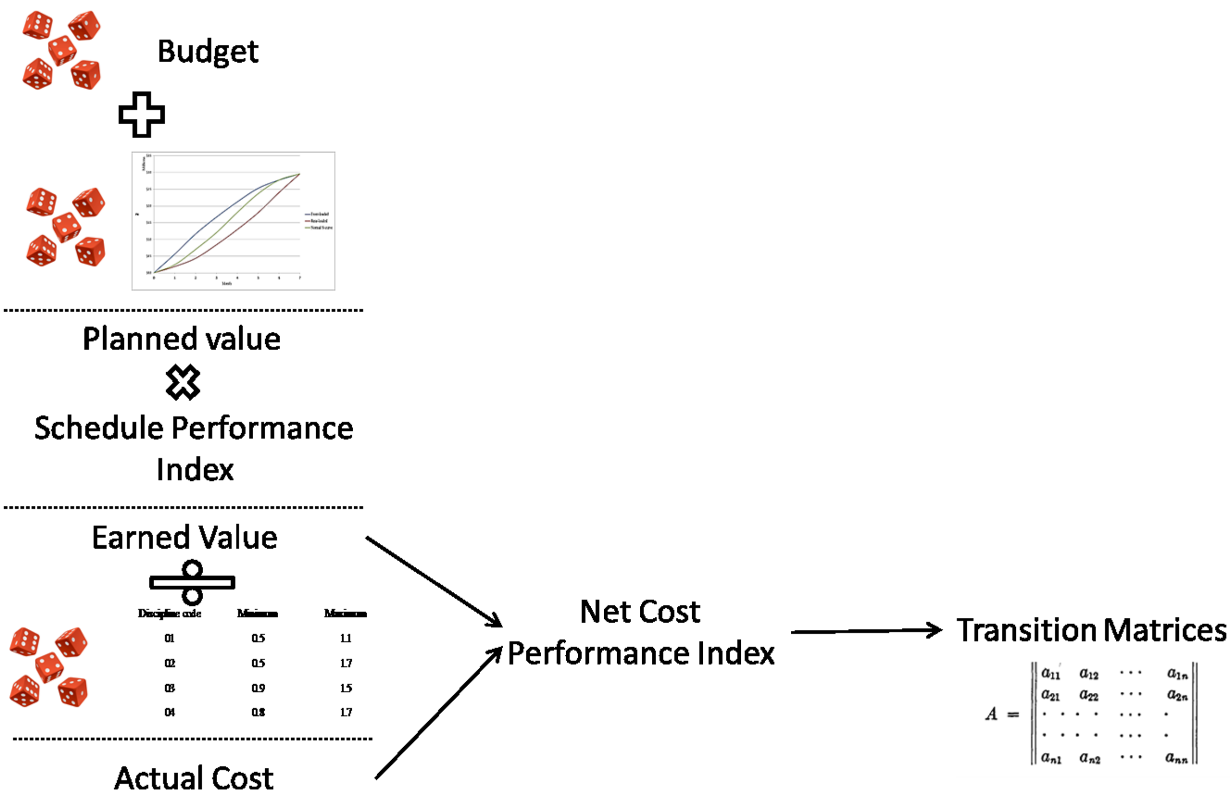


Figure 6.4 Schematic sketch of the training component of the validation framework

6.2.2 Randomly-generated projects to examine model accuracy

After the model was trained (i.e., transition matrices were derived), another set of fictitious projects were generated for forecasting purposes. Four sets of 30 projects representing linear, front-loaded, back-loaded, and S-curve projects were sampled. The projects were generated using the same distributions that were used to generate the historical data to satisfy the assumption of consistency in performance of specific disciplines. It should be noted that, although the same distributions were used for each discipline, the interval for each discipline's performance was deliberately made wide to increase project diversity.

Each randomly-generated project was forecasted throughout project implementation, from month 0 (i.e., at the beginning of the project) to one month prior to project completion. EAC forecast for each month is referred to as "forecasting month" in this study. EAC was calculated using both the Bayesian-Markov-based model and the traditional EVM forecast. Errors associated with each forecasting month (i.e., the difference between the forecasted AC amount and the randomly generated project AC in following months) were measured using the metrics described in Section 5.3.3. Figure 6.5 portrays a graphical representation of the validation component of the framework.

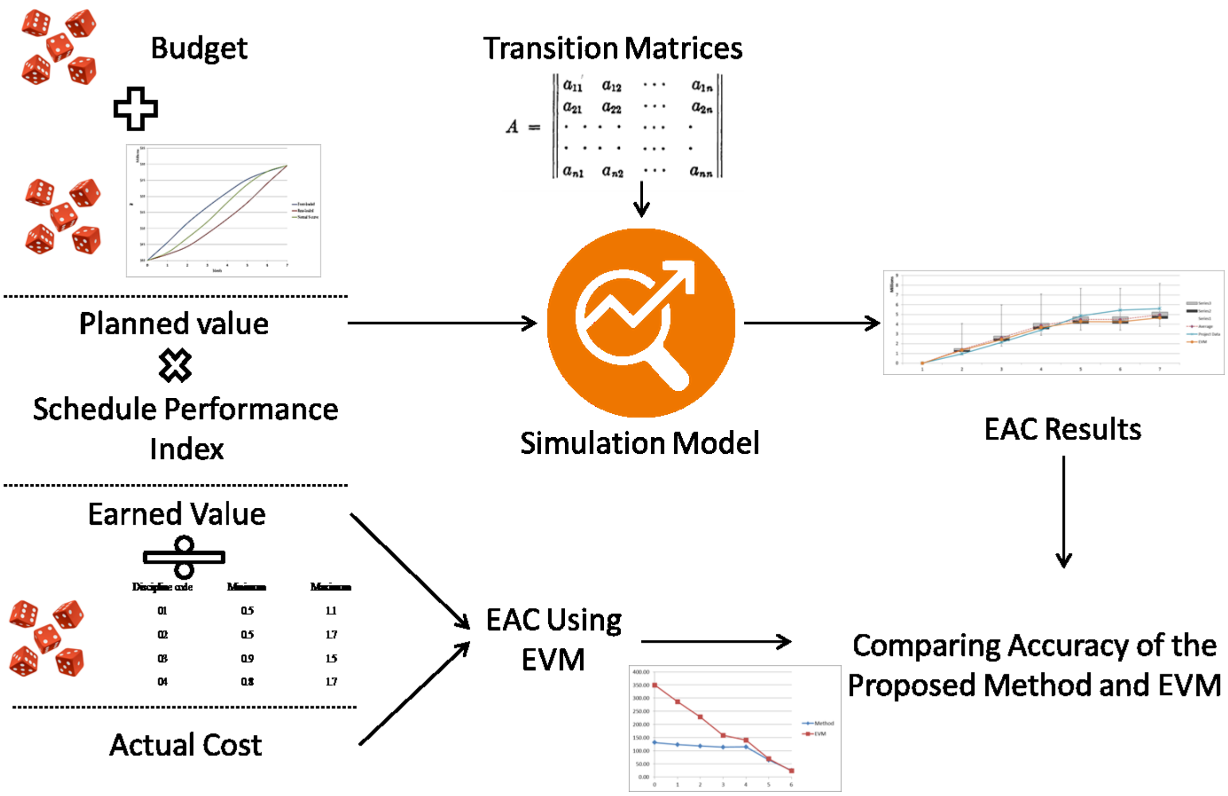


Figure 6.5 Schematic sketch of the validation module of the framework

6.3 Results

Each project was forecasted using both the proposed method and EVM from forecasting month zero (i.e., at the beginning of the project) to one month prior to project completion. MAPE, MAD, and RMSD for each forecasting month and each project were calculated. Accordingly, the average values and standard deviations for each forecasting month were calculated. RMSD and MAD indicators presented the same trends with slightly different values (i.e., because of the difference in formula); therefore, only RMSD graphs are presented in this section. Different S-curve types were compared to investigate the sensitivity of EVM and the proposed method to the shape of S-curve (i.e., budget breakdown or schedule). Results are summarized in the following subsections.

An ANOVA test was performed to examine if differences between forecasting methods were observed during project execution. As data are required to be normally distributed to perform an ANOVA test, normality of the computed MAPE and RMSD values were tested using Kolmogorov-Smirnov, Anderson-Darling, and Chi-Squared test. Table 6.2 summarized the goodness of fit results for MAPE in the first forecasting month using EVM and the proposed method. To pass the normality test, the calculated statistic for each test must be lower than the predefined statistic for the predefined significance level of *alpha* = 0.05. ANOVA *P* value was calculated during project execution and presented for each S-curve type accordingly. Hellinger distance was also calculated, as a secondary measurement, to indicate the distance between the fitted normal distributions. Hellinger distance is useful in trials with independent observations (Cam and Yang 2000), such as randomly-generated and forecasted projects. The Hellinger distance varies between zero and one, where zero indicates identical distributions and one is the maximum difference (Pollard 2002). The squared Hellinger distance for two normal distributions is calculated using Equation 6.1 (Pollard 2002).

$$H^2(P,Q) = 1 - \sqrt{\frac{2\sigma_1\sigma_2}{{\sigma_1}^2+{\sigma_2}^2}}\, e^{\frac{-1(\mu_1-\mu_2)^2}{4({\sigma_1}^2+{\sigma_2}^2)}} \qquad [6.1]$$

Where σ_1,σ_2 is the standard deviation of, and μ_1 , μ_2 the average value for, the first and second distributions, respectively.

Table 6.2 Normality test results for calculated *EAC* in forecasting month 0

Test	Test statistic for alpha= 0.05	Test statistic	
		EVM	Proposed method
Chi Squared	7.81	1.2	2.27
Kolmogorov-Smirnov	0.242	0.123	0.121
Anderson-Darling	2.49	0.37	0.681

6.3.1 S-curve

30 projects with a 7-month duration were randomly generated with S-curves similar to the S-curve in Figure 6.2. As mentioned before, since a standard definition for S-curves does not exist, curves with milder slopes, both in the beginning and at the end, and sharp slopes in the middle were considered as normal. In addition, percentage of the total budget and duration were used as a secondary measure. For instance, 50% of the project budget is spent at the 50% completion point. MAPE and RMSD comparisons are graphed in Figures 6.6 to 6.9 and Figures 6.10 to 6.13, respectively. As can be inferred from the figures, the proposed method outperformed EVM forecasts in the early stages of the project, as evidenced by both the percentage error (i.e.,

MAPE) and the error magnitude (i.e., RMSD),. As the project budget and cumulative performance reached a relatively stable condition, both EVM and the proposed method yielded the same accuracy. ANOVA test (Figures 6.8 and 6.12) and Hellinger distance (Figures 6.9 and 6.13) were used to quantify differences during project execution. A detailed comparison between each forecasting method's accuracy is summarized in the discussion section.

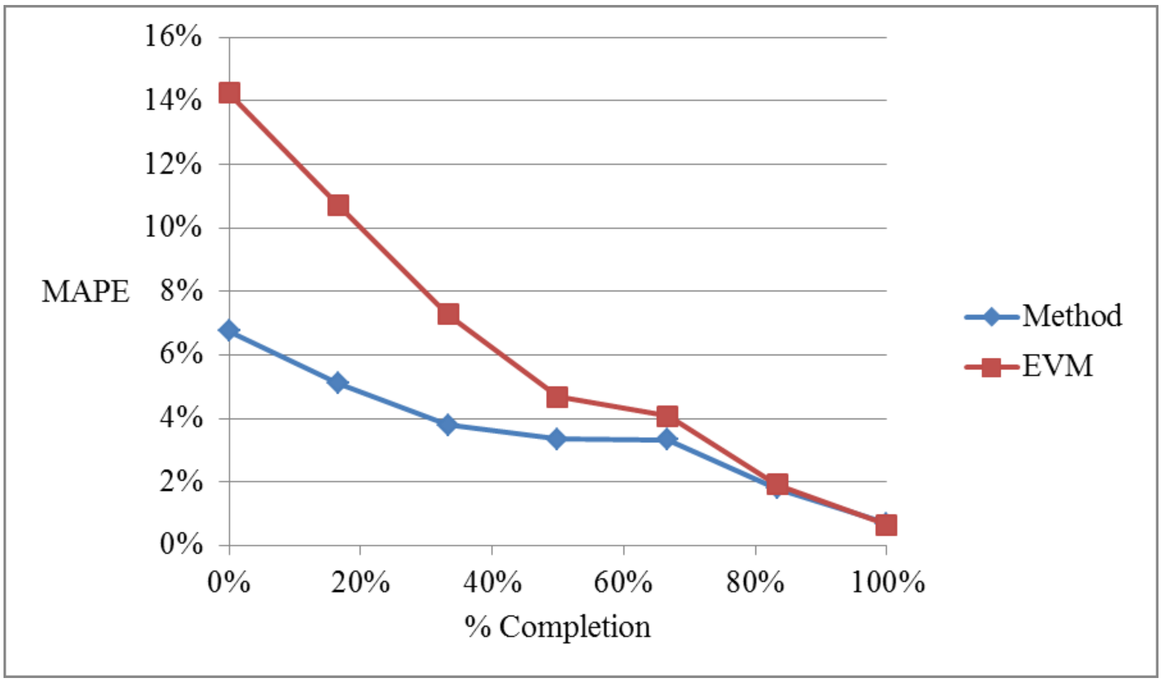


Figure 6.6 MAPE average errors for each forecasting month using the proposed method and EVM for S-curves

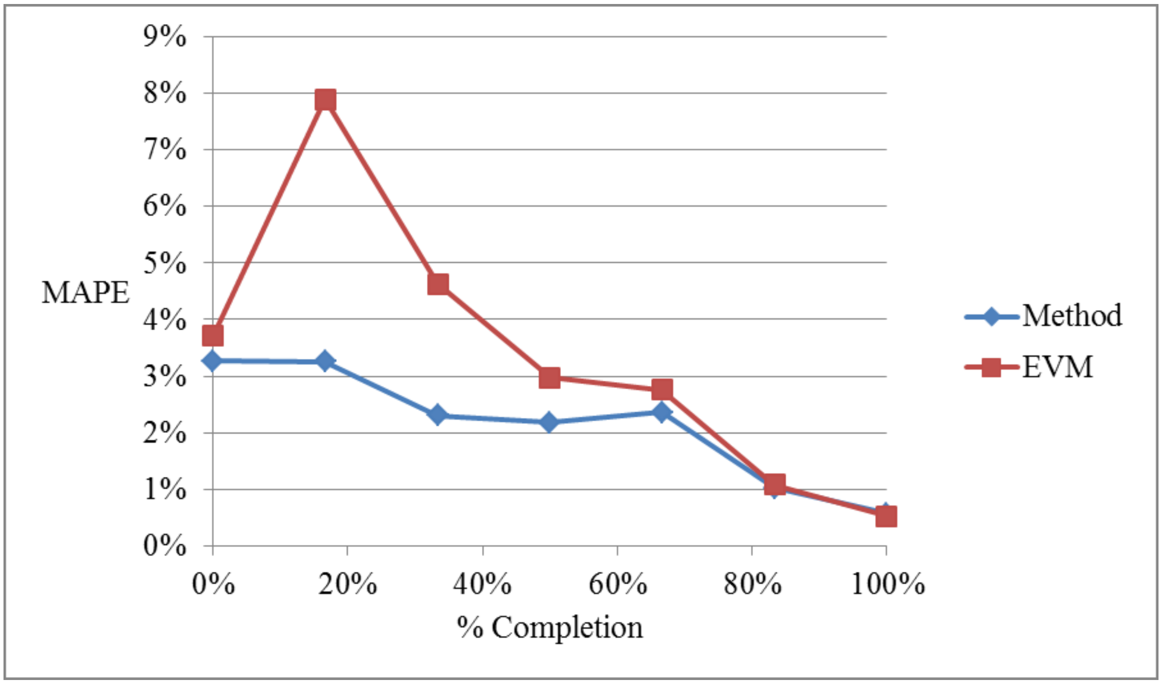


Figure 6.7 MAPE standard deviations for each forecasting month using the proposed method and EVM for S-curves

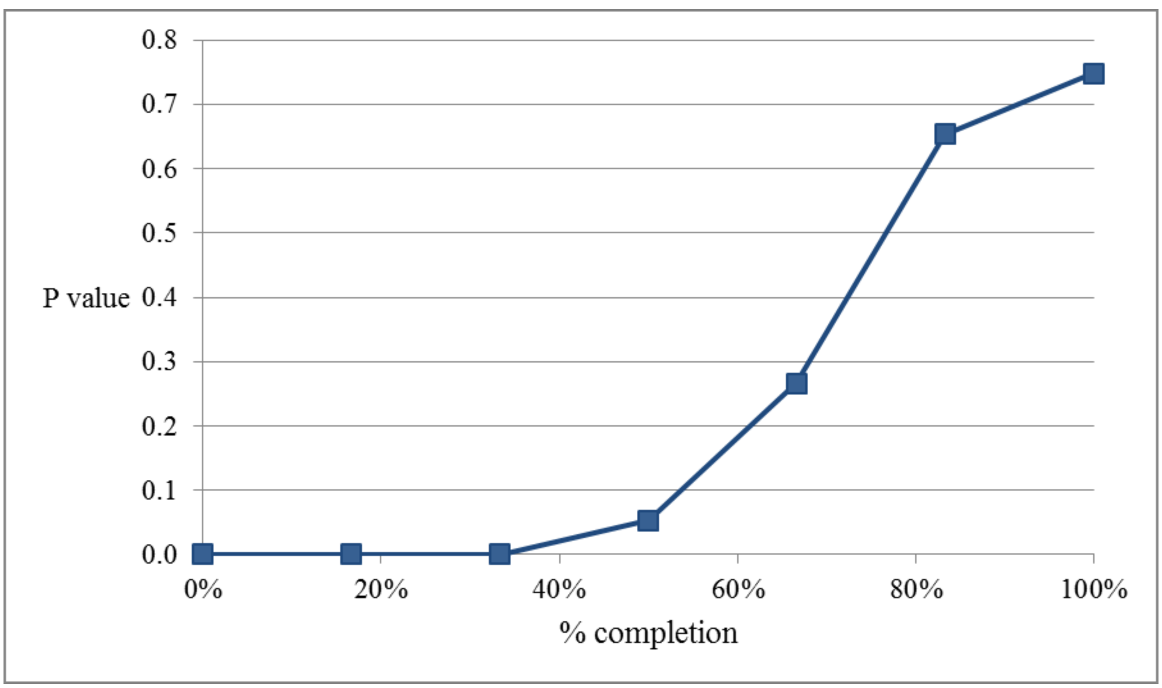


Figure 6.8 ANOVA P-values for MAPE comparing the proposed method and EVM for S-curves

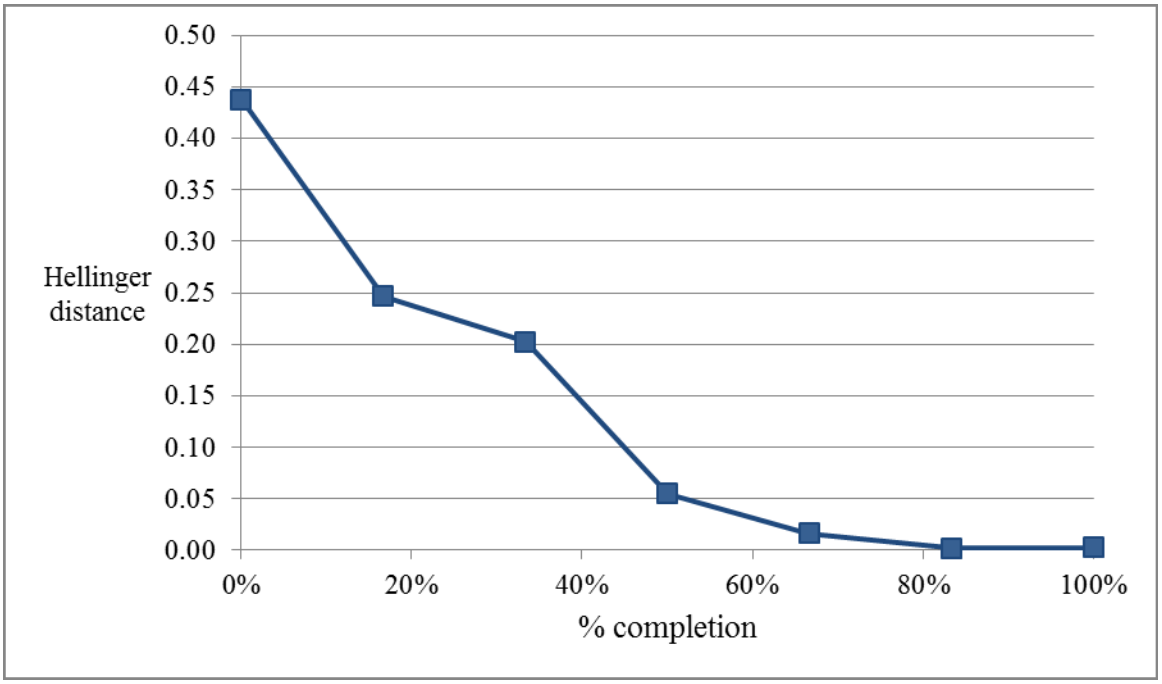


Figure 6.9 Hellinger distance between MAPE of the proposed method and EVM for S-curves

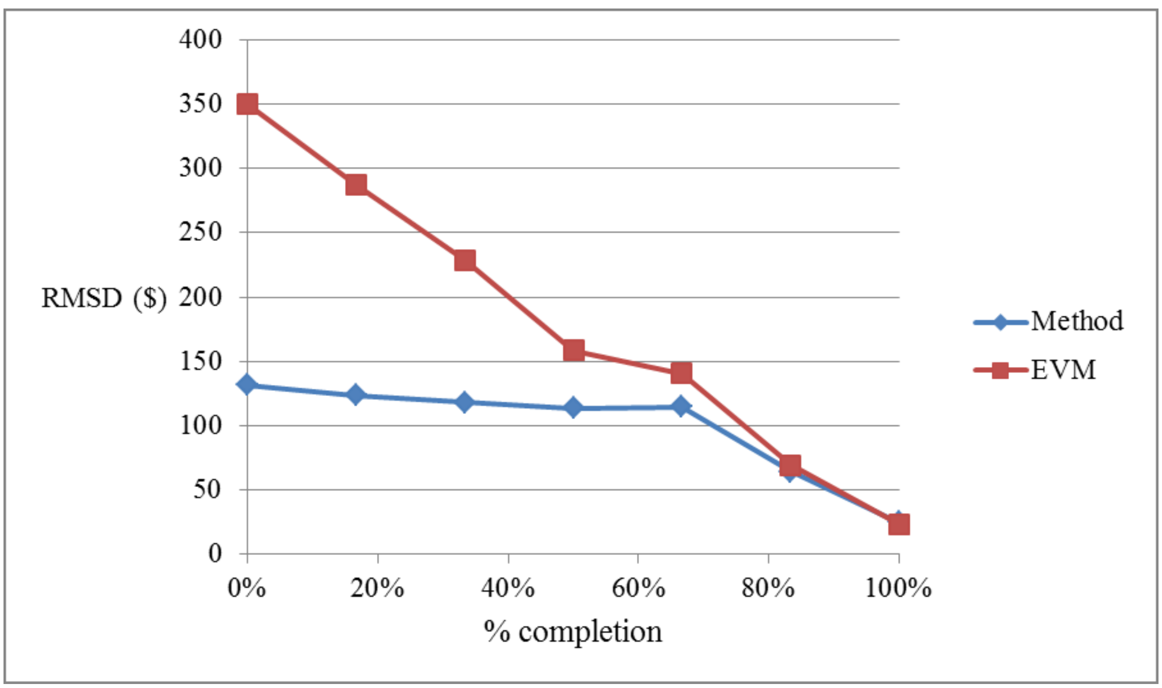


Figure 6.10 RMSD average errors for each forecasting month using the proposed method and EVM for S-curves

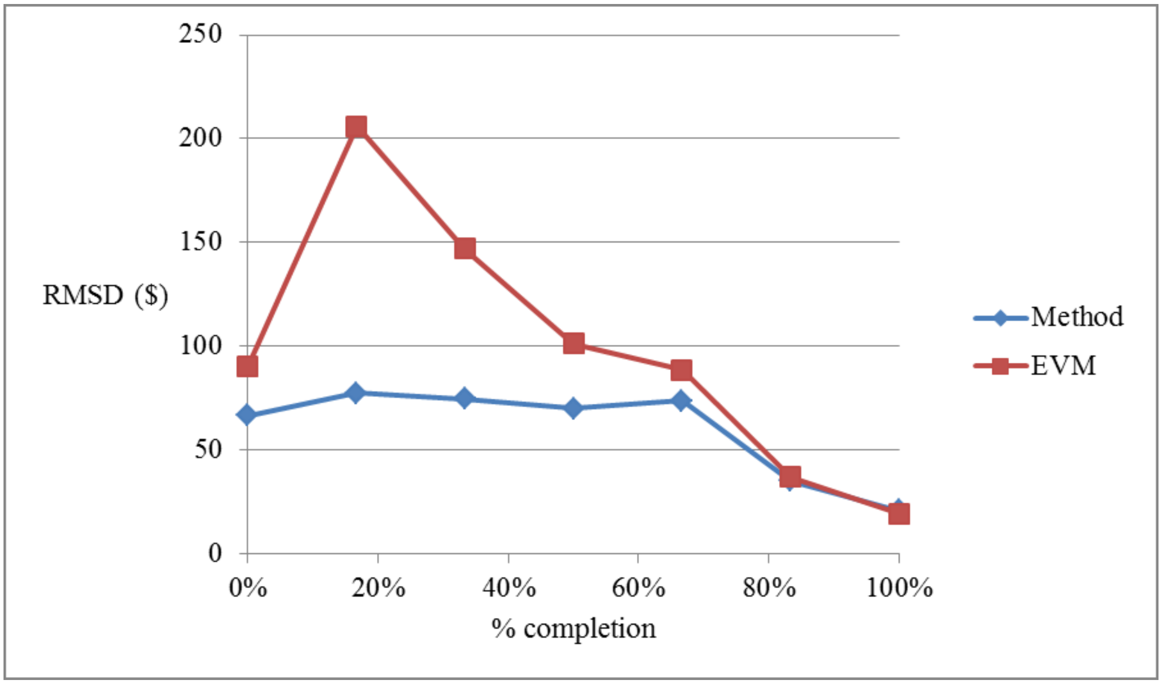


Figure 6.11 RMSD standard deviations for each forecasting month using the proposed method and EVM for S-curves

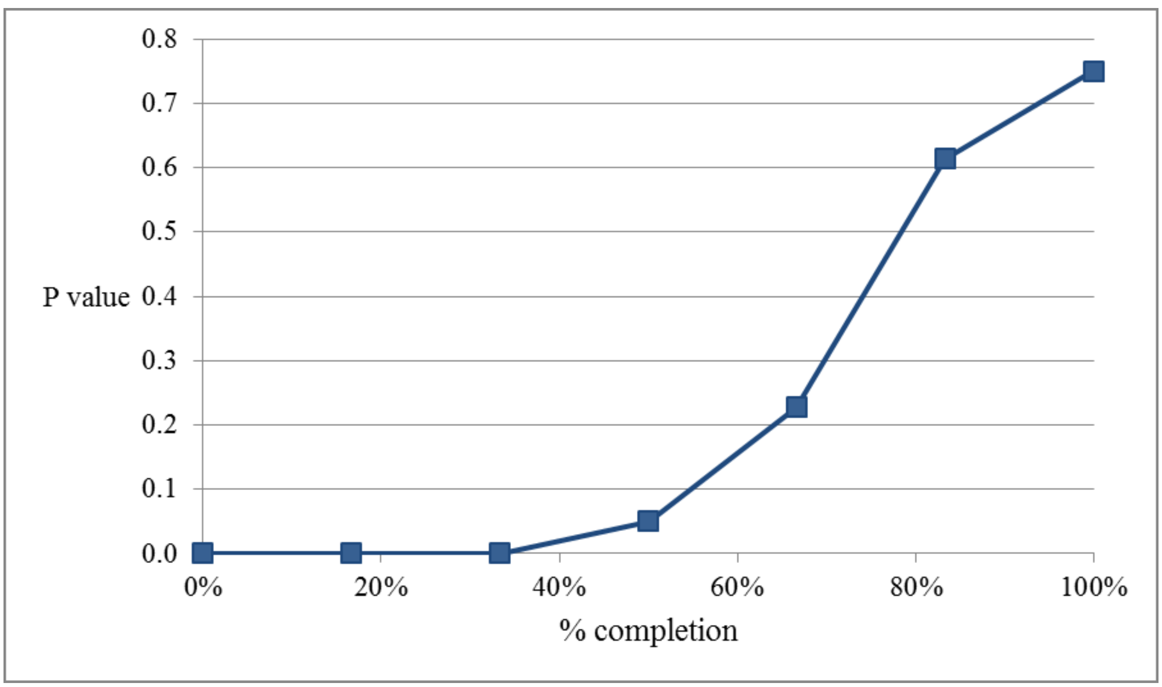


Figure 6.12 ANOVA P-values for RMSD comparing the proposed method and EVM for S-curves

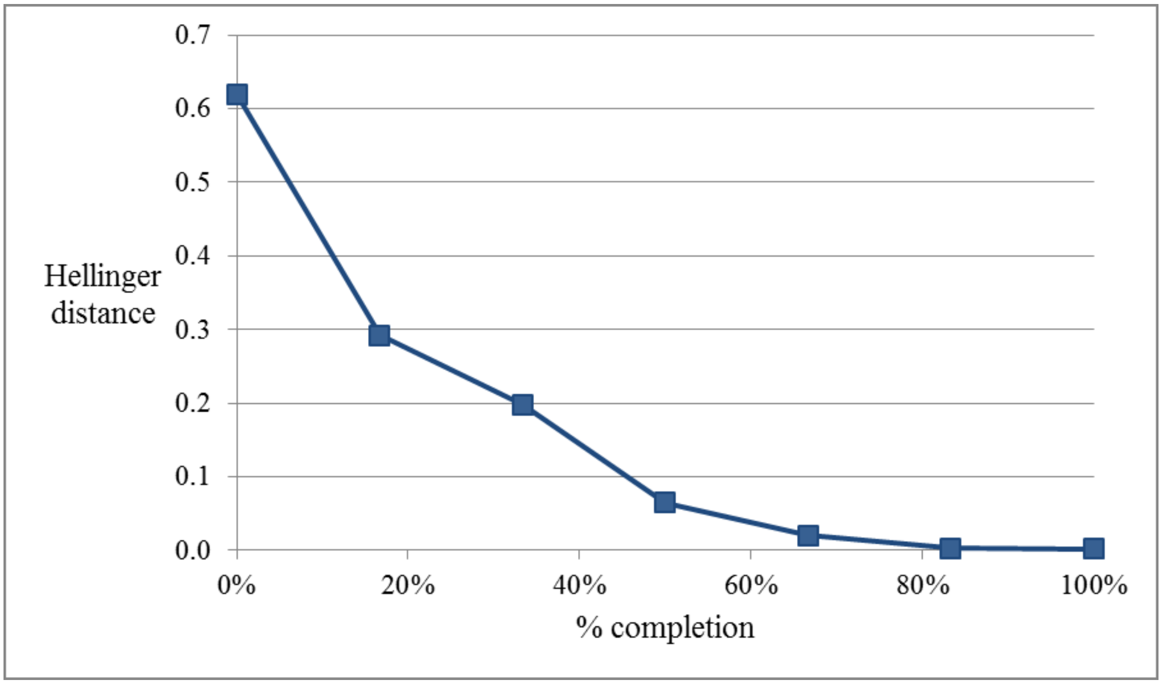


Figure 6.13 Hellinger distance between RMSD of the proposed method and EVM for S-curves

6.3.2 Front-loaded

Similar to the previous section, an additional 30 projects were randomly generated to represent front-loaded S-curves. Analogous to normal S-curves, the proposed method forecasted final project cost of front-loaded projects more accurately than the traditional EVM method.

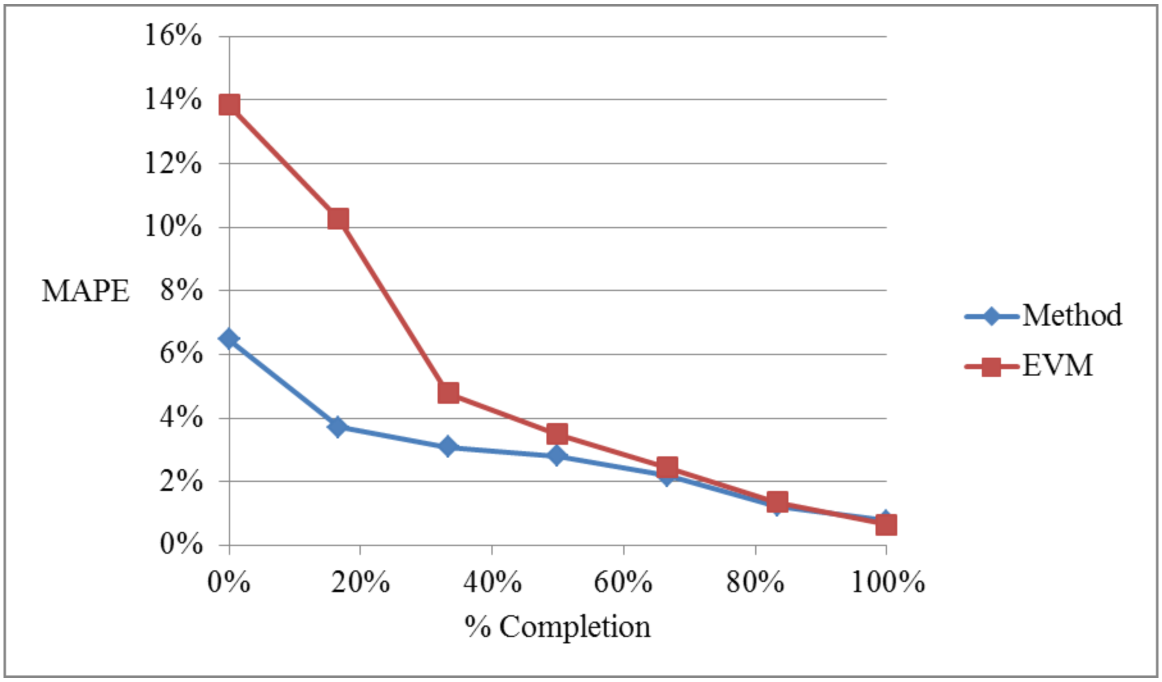


Figure 6.14 MAPE average errors for each forecasting month using the proposed method and EVM for front-loaded curves

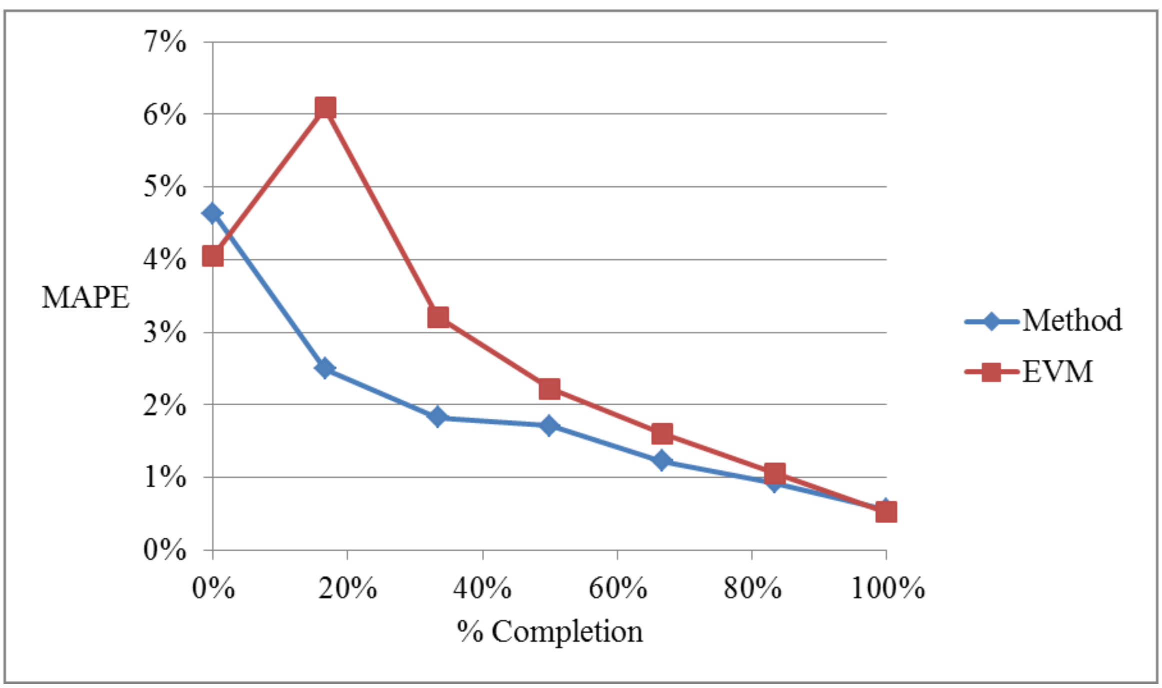


Figure 6.15 MAPE standard deviations for each forecasting month using the proposed method and EVM for front-loaded curves

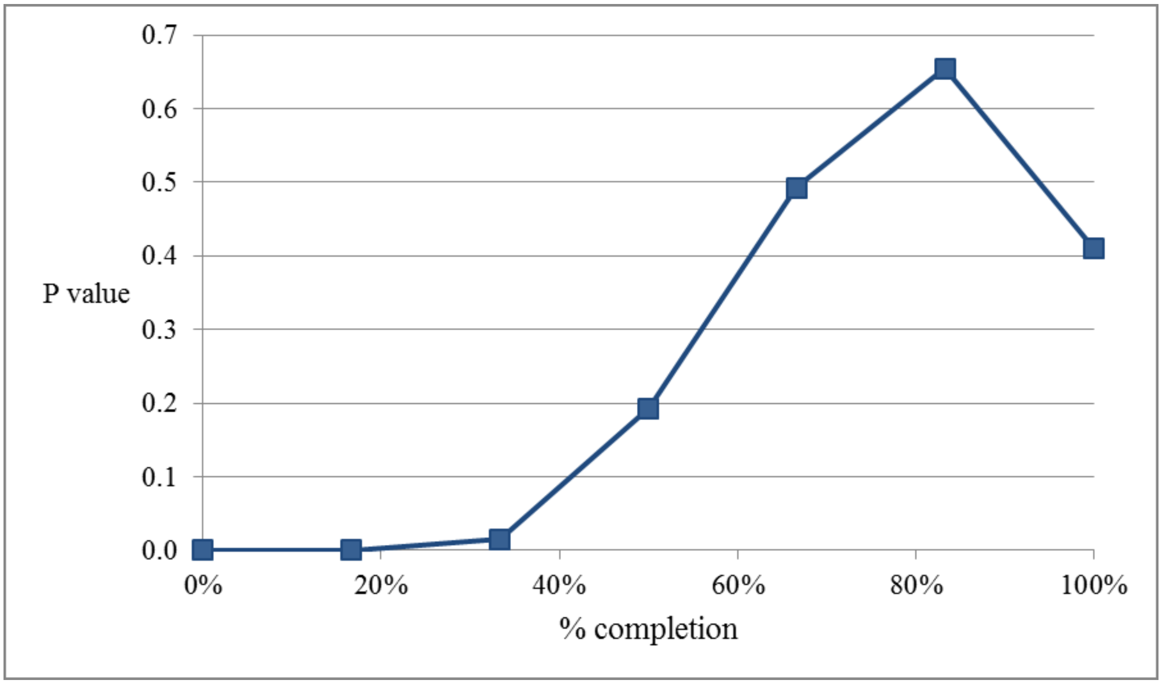


Figure 6.16 ANOVA P-values for MAPE comparing the proposed method and EVM for front-loaded curves

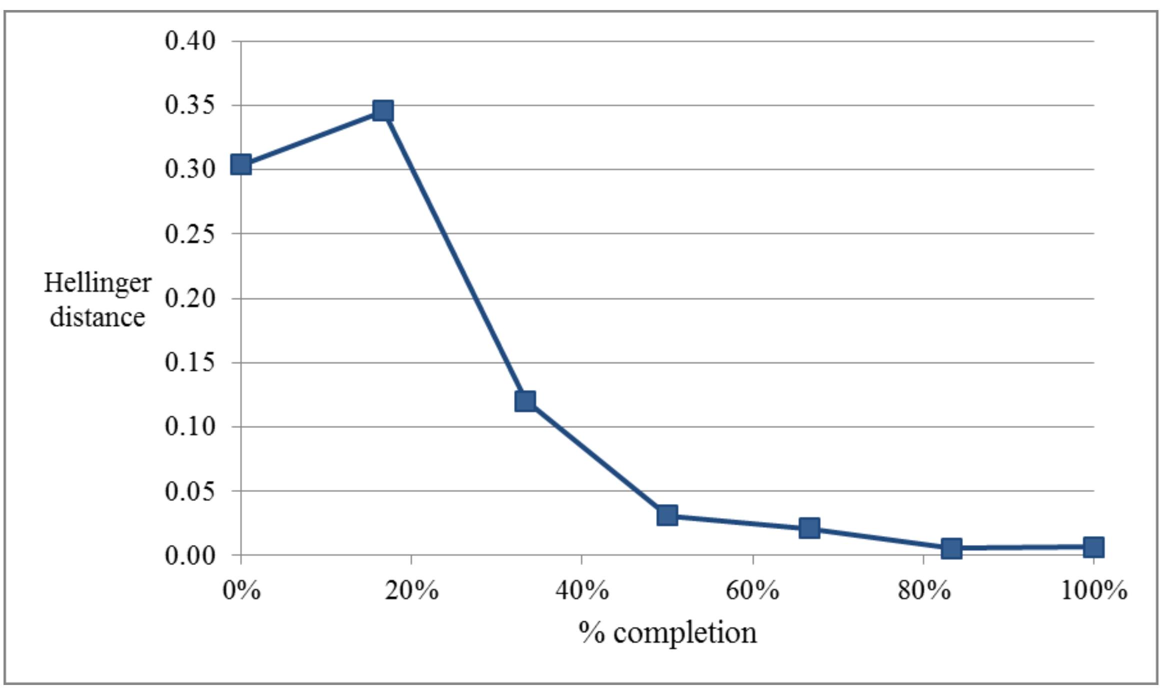


Figure 6.17 Hellinger distance between MAPE of the proposed method and EVM for front-loaded curves

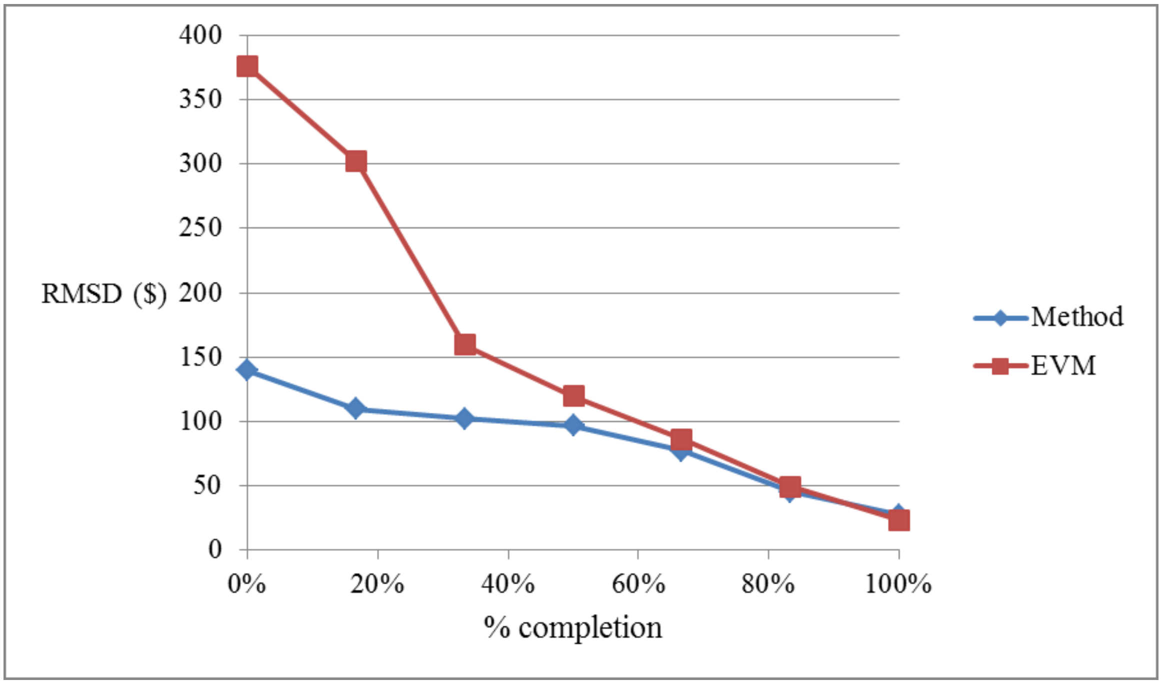


Figure 6.18 RMSD average errors for each forecasting month using the proposed method and EVM for front-loaded curves

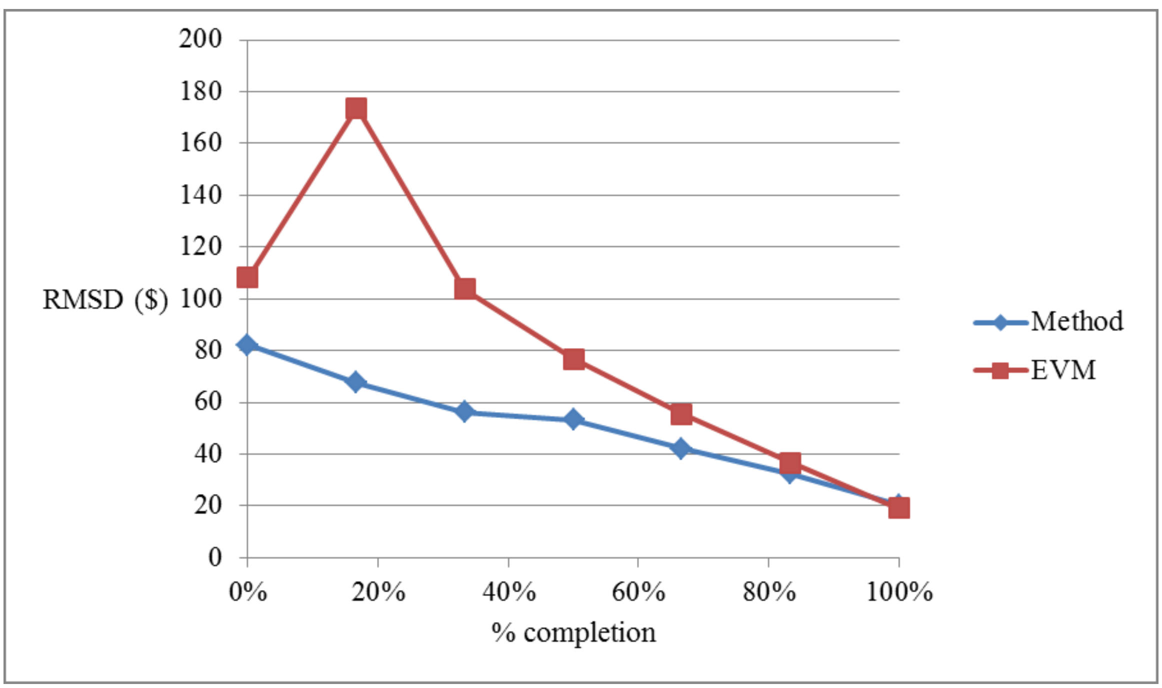


Figure 6.19 RMSD standard deviations for each forecasting month using the proposed method and EVM for front-loaded curves

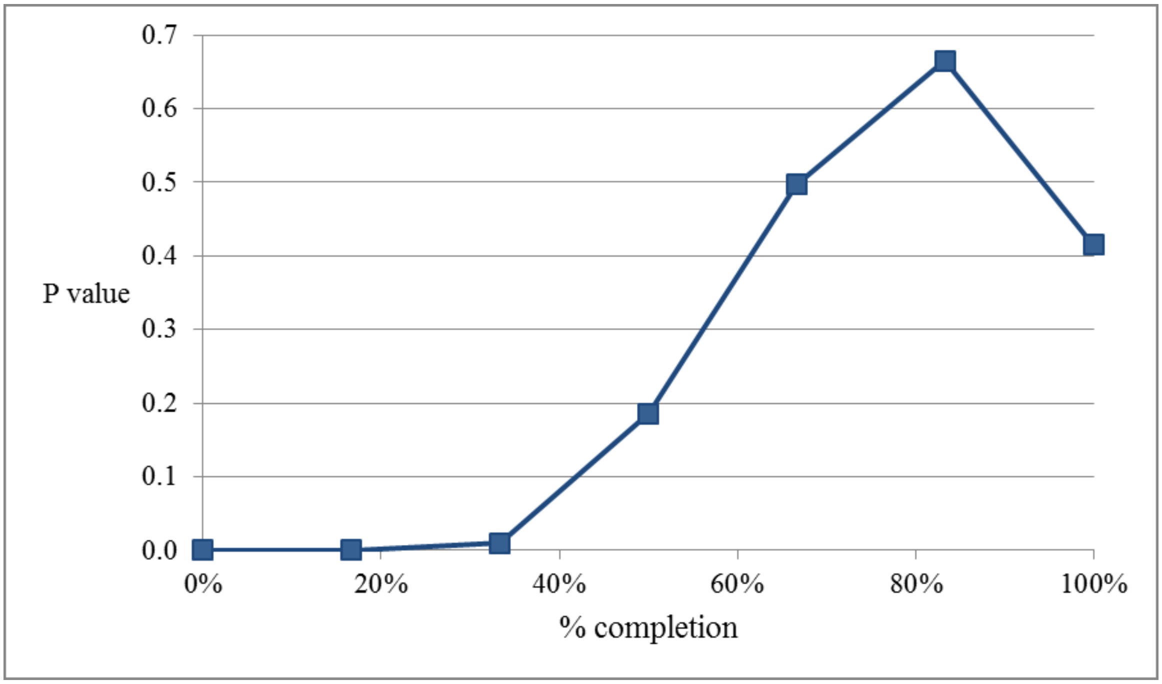


Figure 6.20 ANOVA P-values for RMSD comparing the proposed method and EVM for front-loaded curves

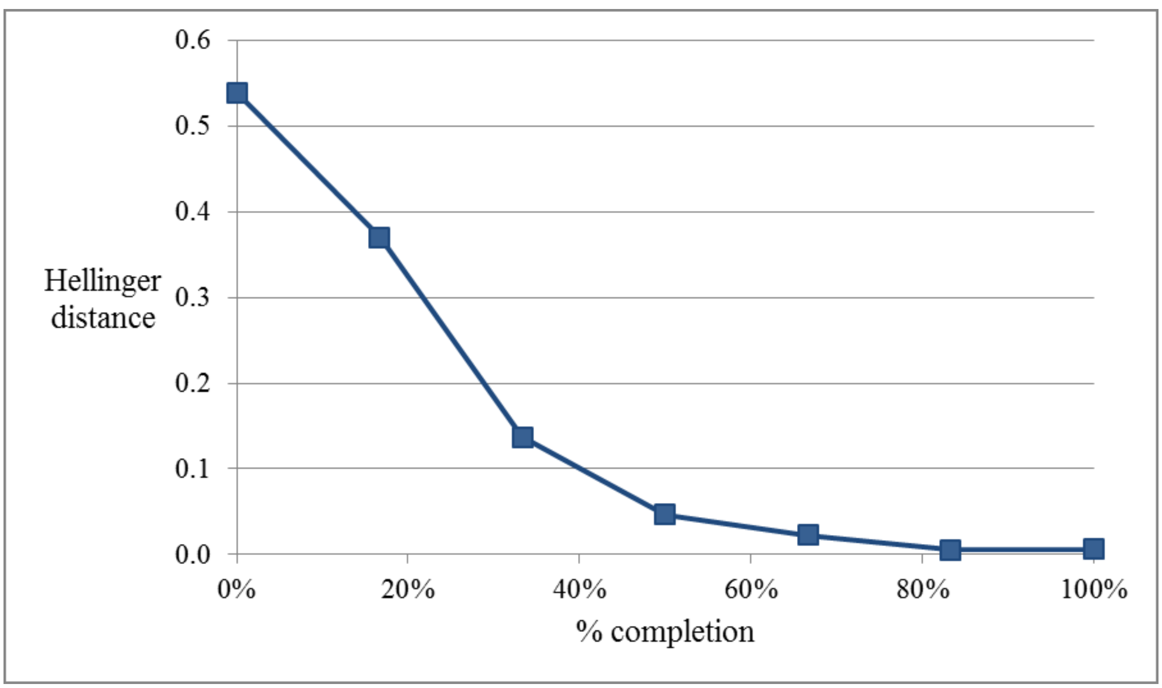


Figure 6.21 Hellinger distance between RMSD of the proposed method and EVM for front-loaded curves

6.3.3 Back-loaded

Similar to the previous section, an additional 30 projects were randomly generated to represent back-loaded S-curves. Analogous to normal S-curves, the proposed method forecasted final project cost of back-loaded projects more accurately than the traditional EVM method.

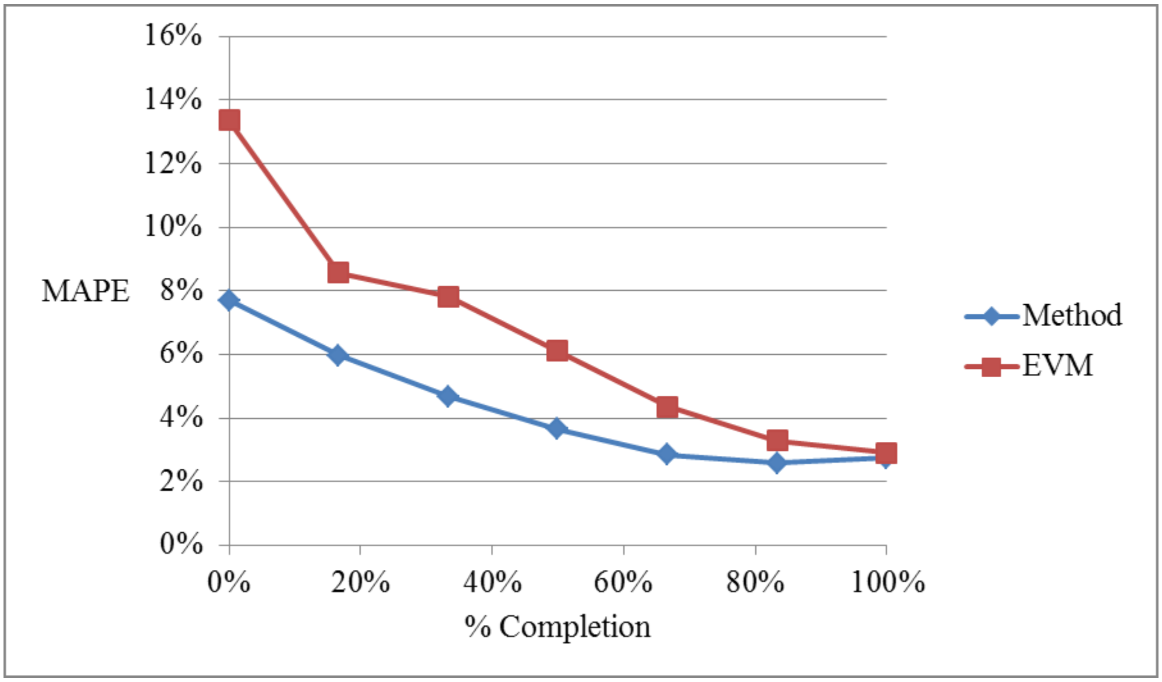


Figure 6.22 MAPE average errors for each forecasting month using the proposed method and EVM for back-loaded curves

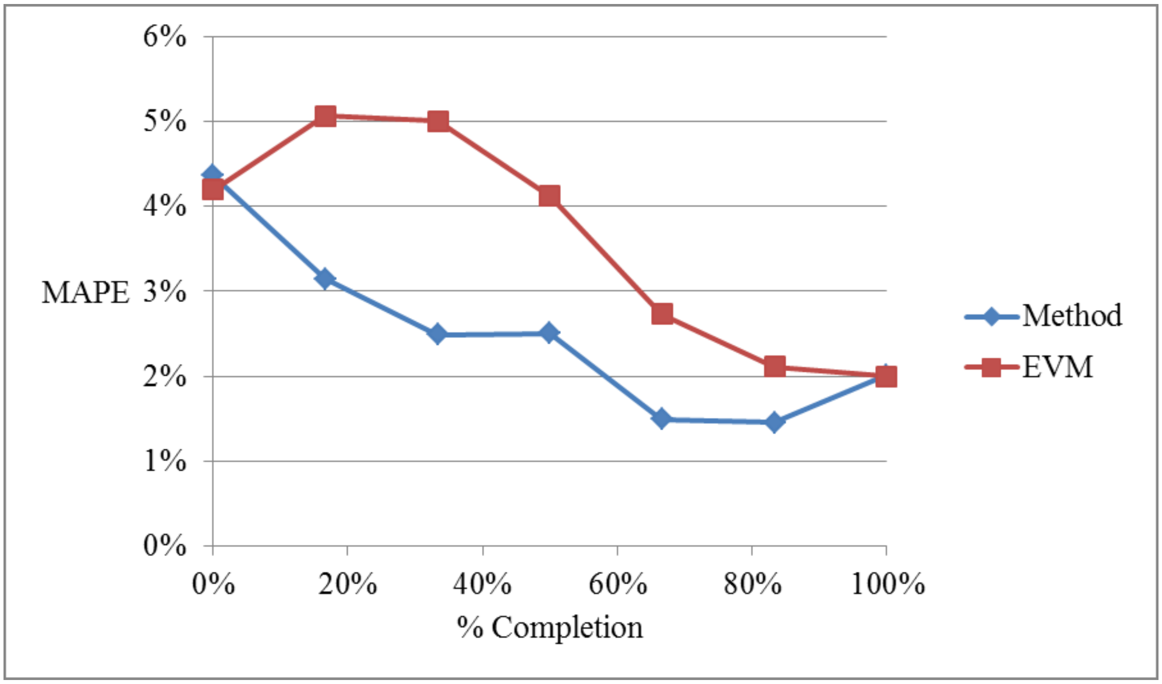


Figure 6.23 MAPE standard deviations for each forecasting month using the proposed method and EVM for back-loaded curves

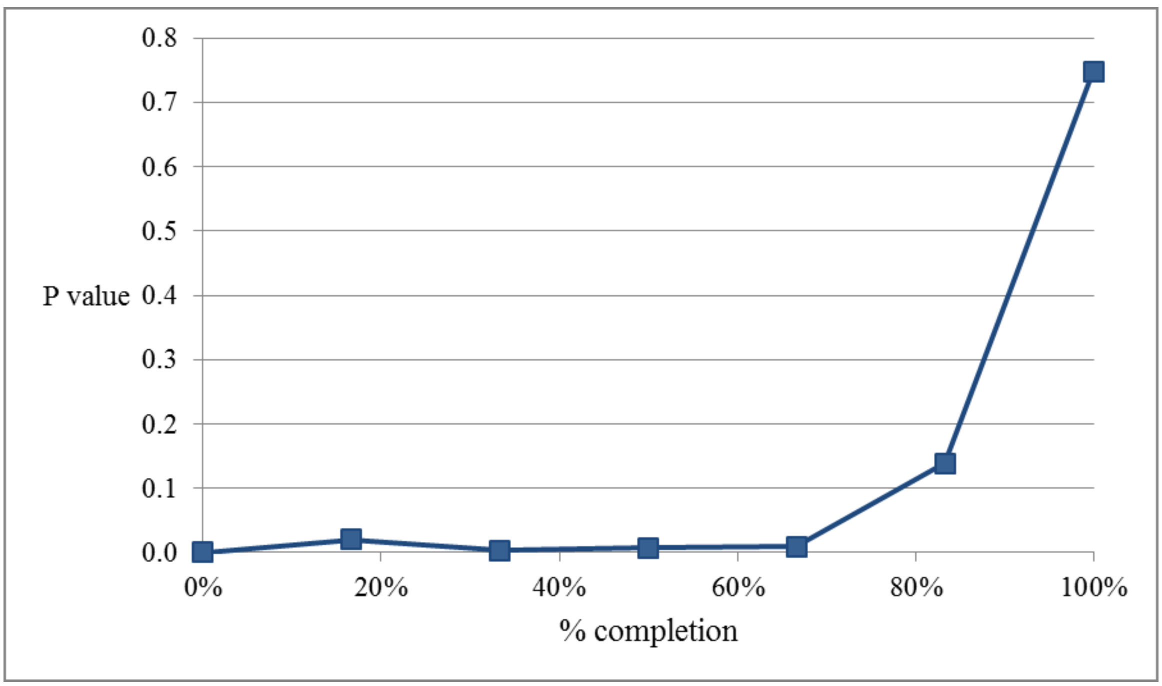


Figure 6.24 ANOVA P-values for MAPE comparing the proposed method and EVM for back-loaded curves

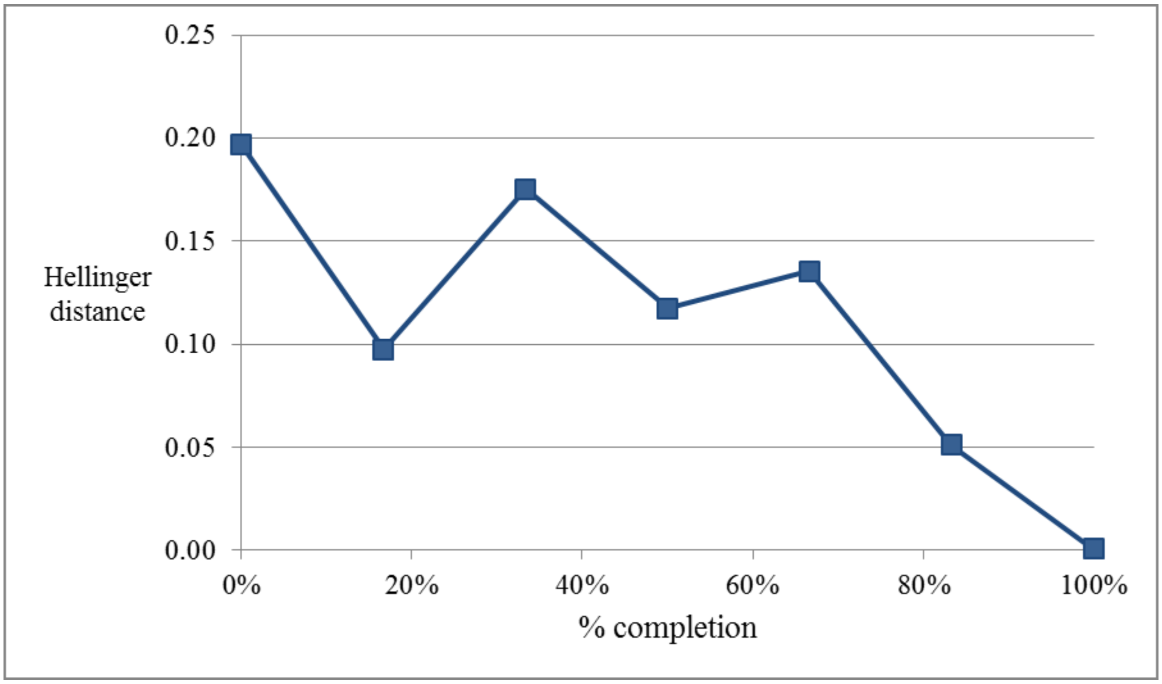


Figure 6.25 Hellinger distance between MAPE of the proposed method and EVM for back-loaded curves

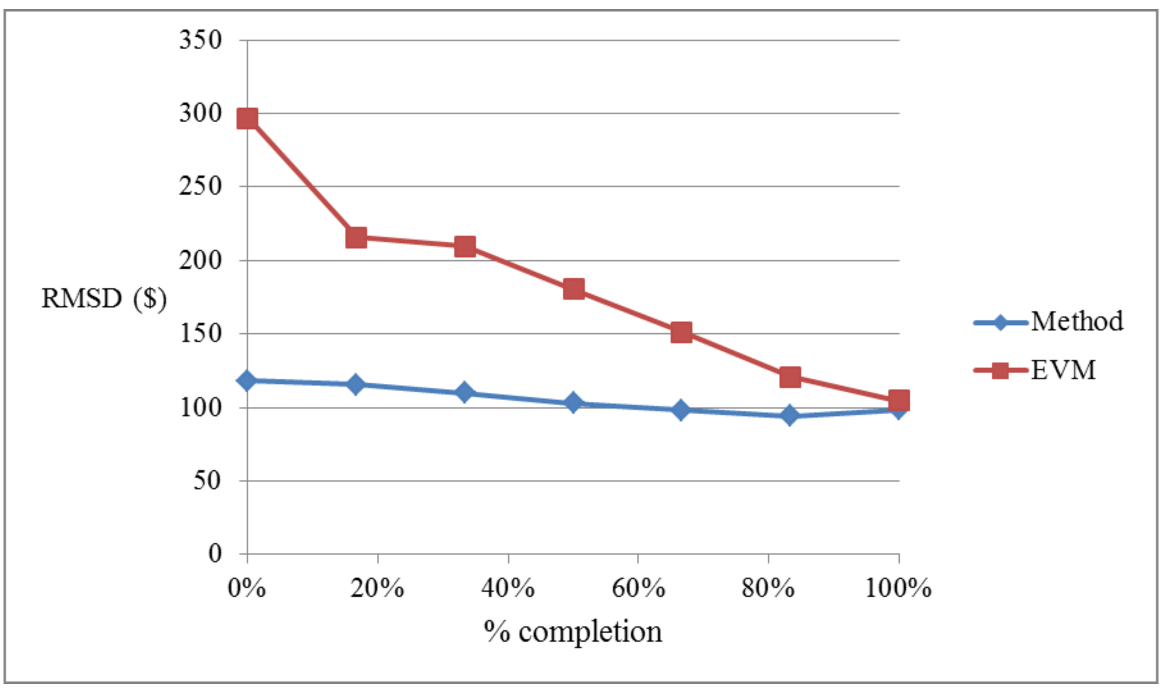


Figure 6.26 RMSD average errors for each forecasting month using the proposed method and EVM for back-loaded curves

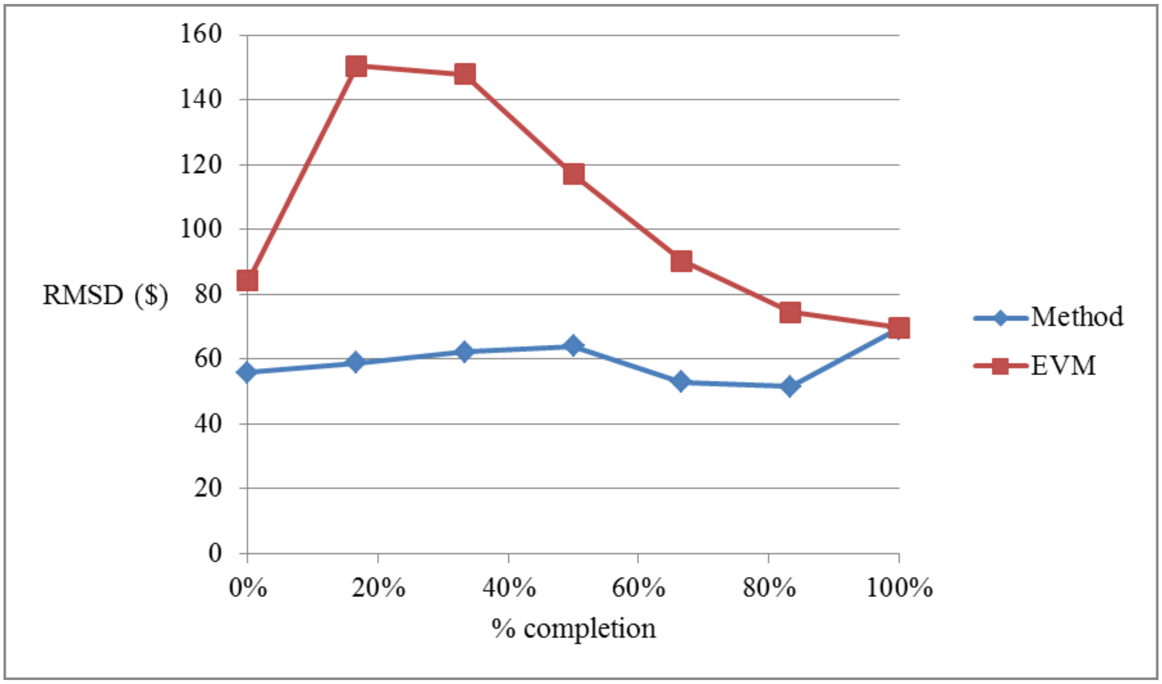


Figure 6.27 RMSD standard deviations for each forecasting month using the proposed method and EVM for back-loaded curves

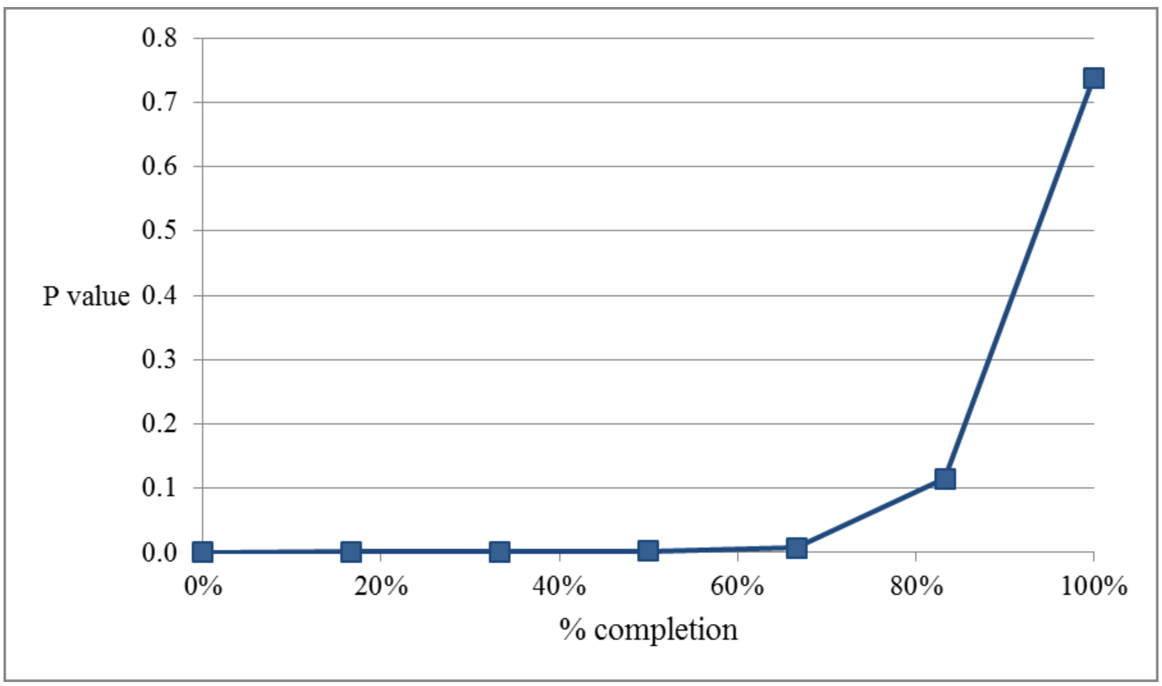


Figure 6.28 ANOVA P value for RMSD comparing the proposed method and EVM for back-loaded curves

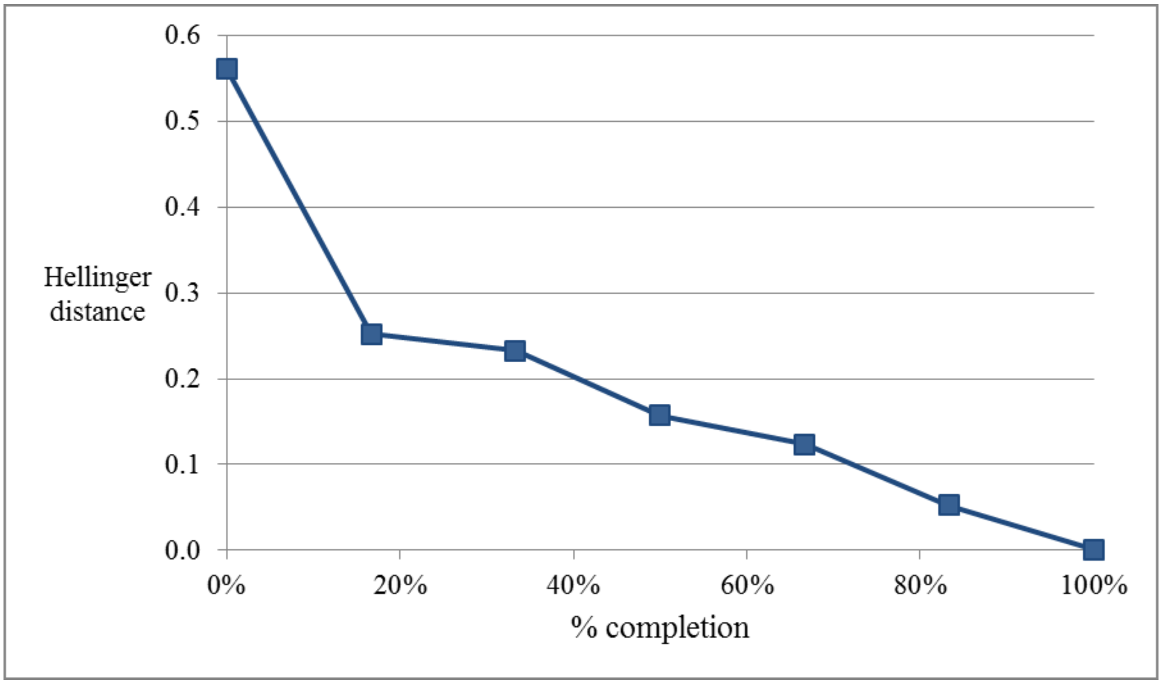


Figure 6.29 Hellinger distance between RMSD of the proposed method and EVM for back-loaded curves

6.3.4 Linear

Finally, the last set of randomly/ -generated projects, which represent the uniform distribution of the total budget, were sampled. Similarly, the proposed method forecasted the project EAC more accurately than EVM.

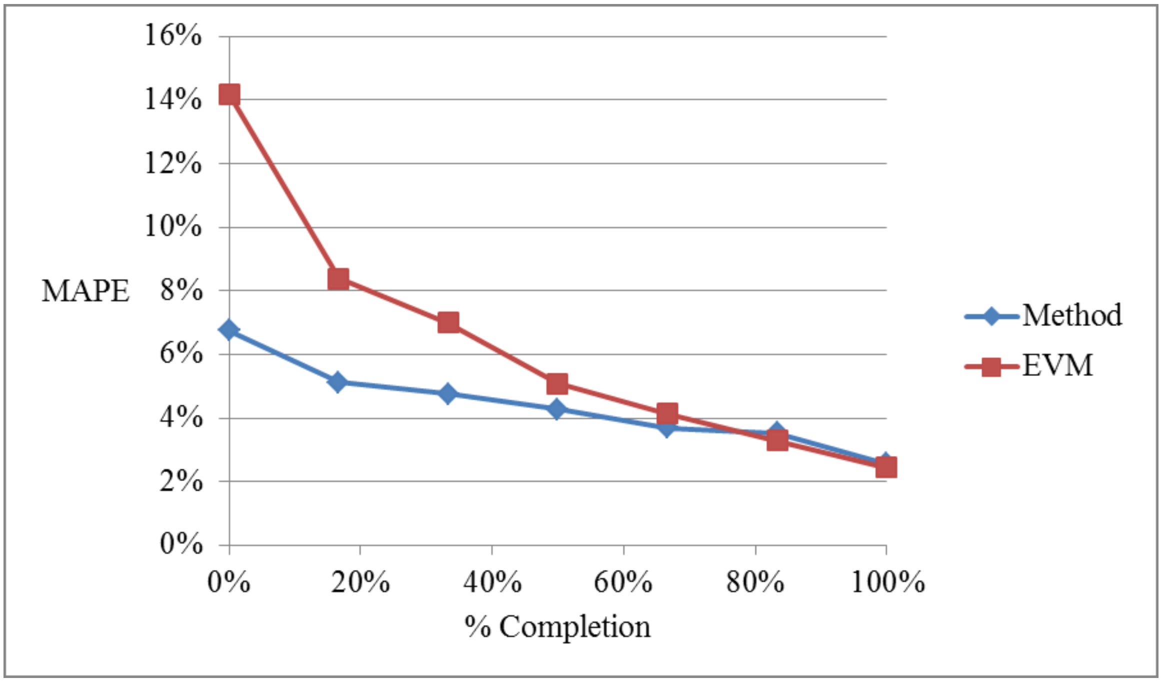


Figure 6.30 MAPE average errors for each forecasting month using the proposed method and EVM for linear PV

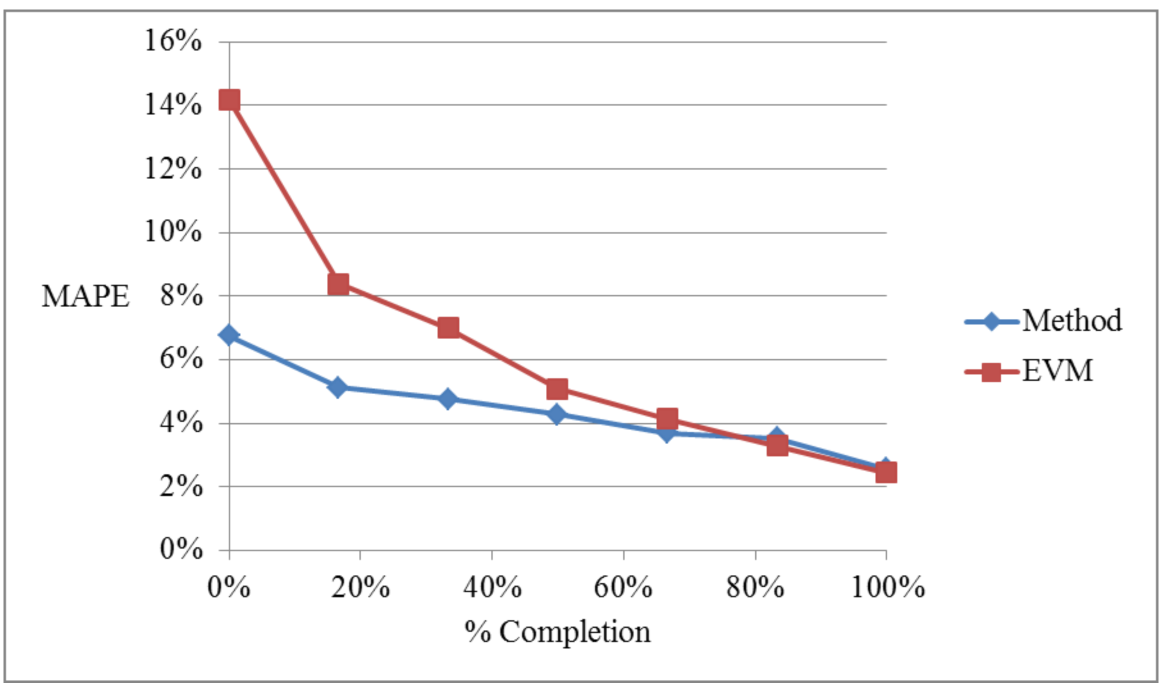


Figure 6.31 MAPE standard deviations for each forecasting month using the proposed method and EVM for linear PV

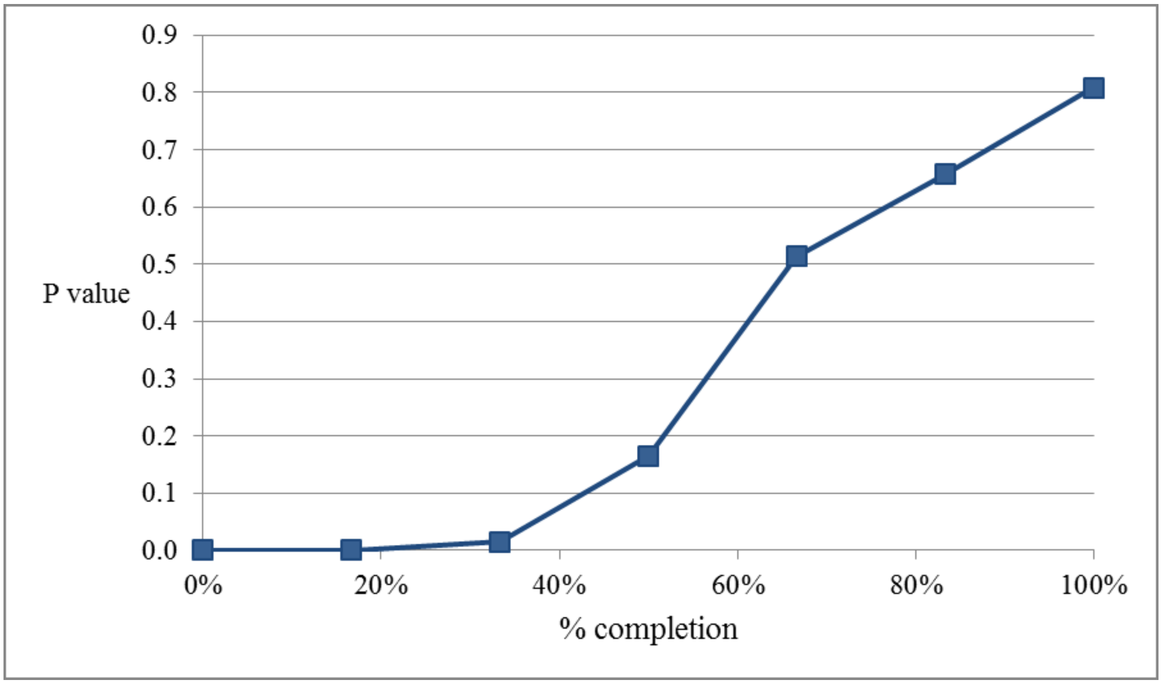


Figure 6.32 ANOVA P-values for MAPE comparing the proposed method and EVM for linear PV

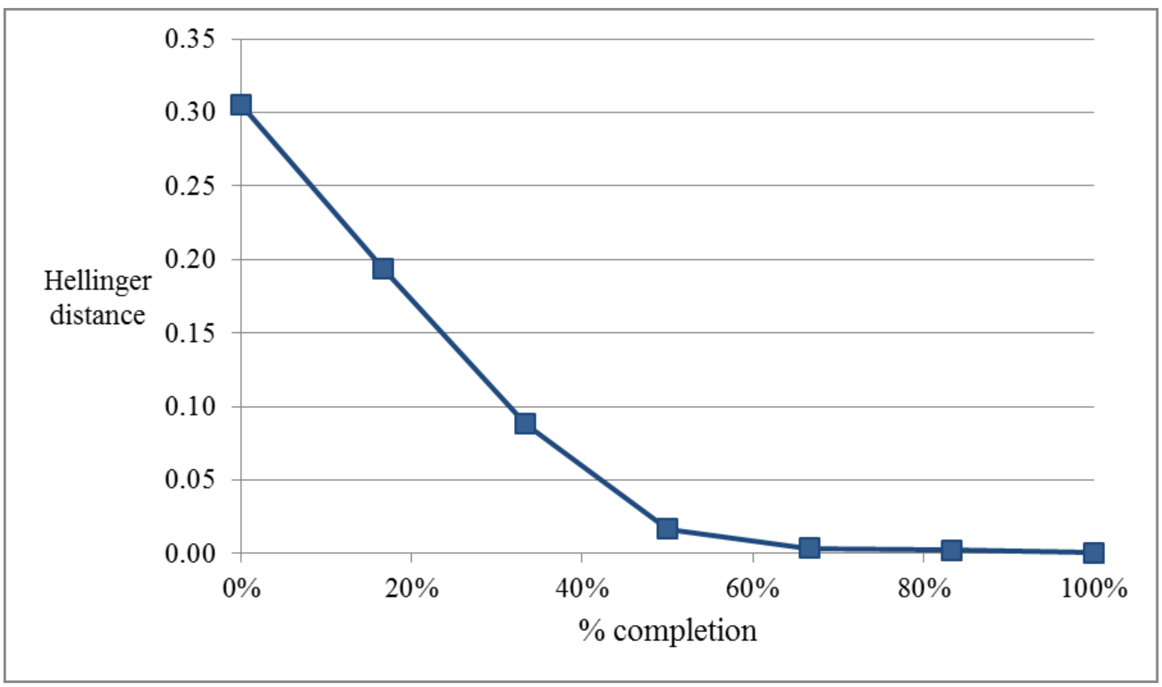


Figure 6.33 Hellinger distance between MAPE of the proposed method and EVM for linear PV

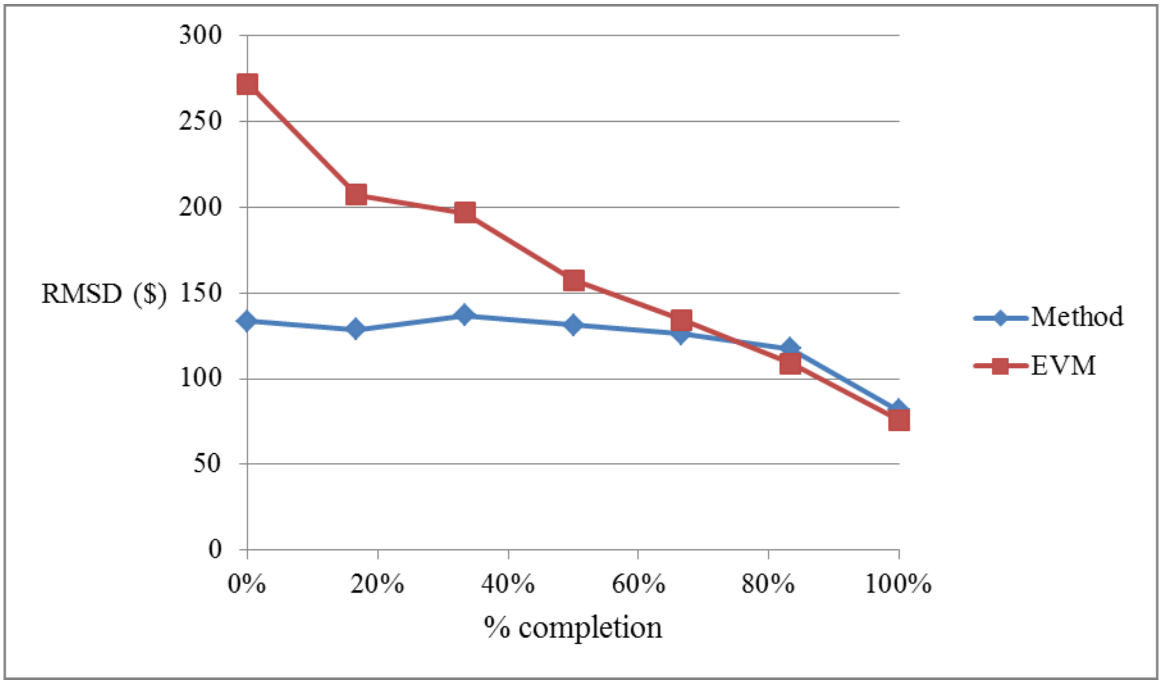


Figure 6.34 RMSD average errors for each forecasting month using the proposed method and EVM for linear PV

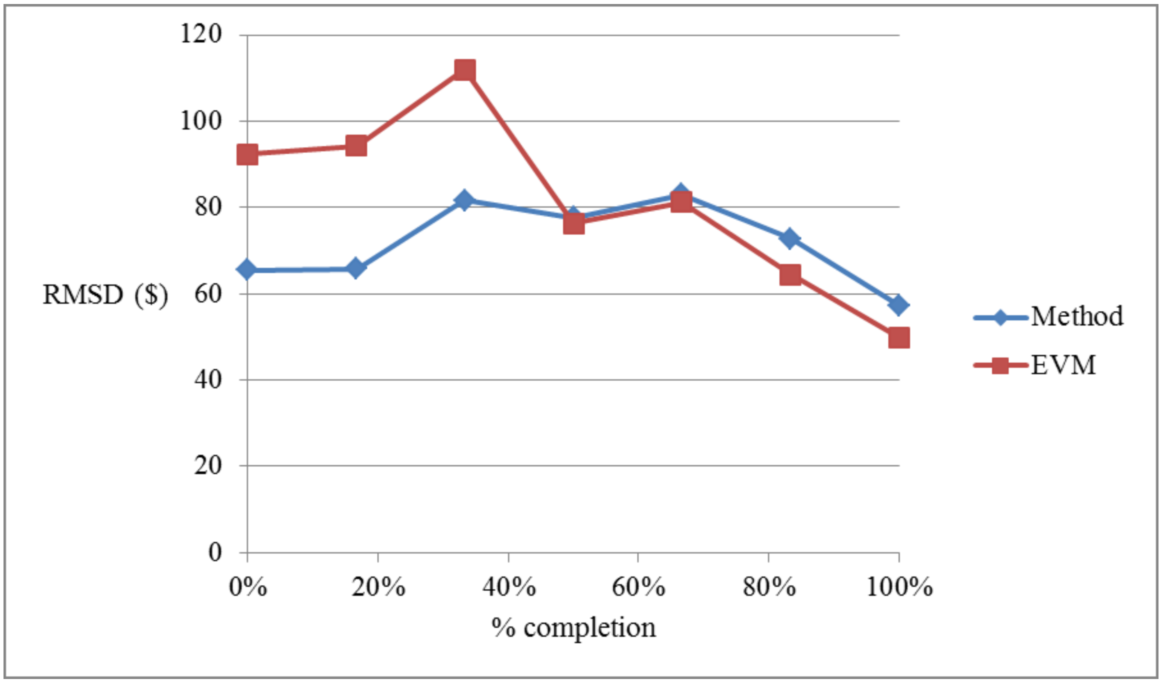


Figure 6.35 RMSD standard deviations for each forecasting month using the proposed method and EVM for linear PV

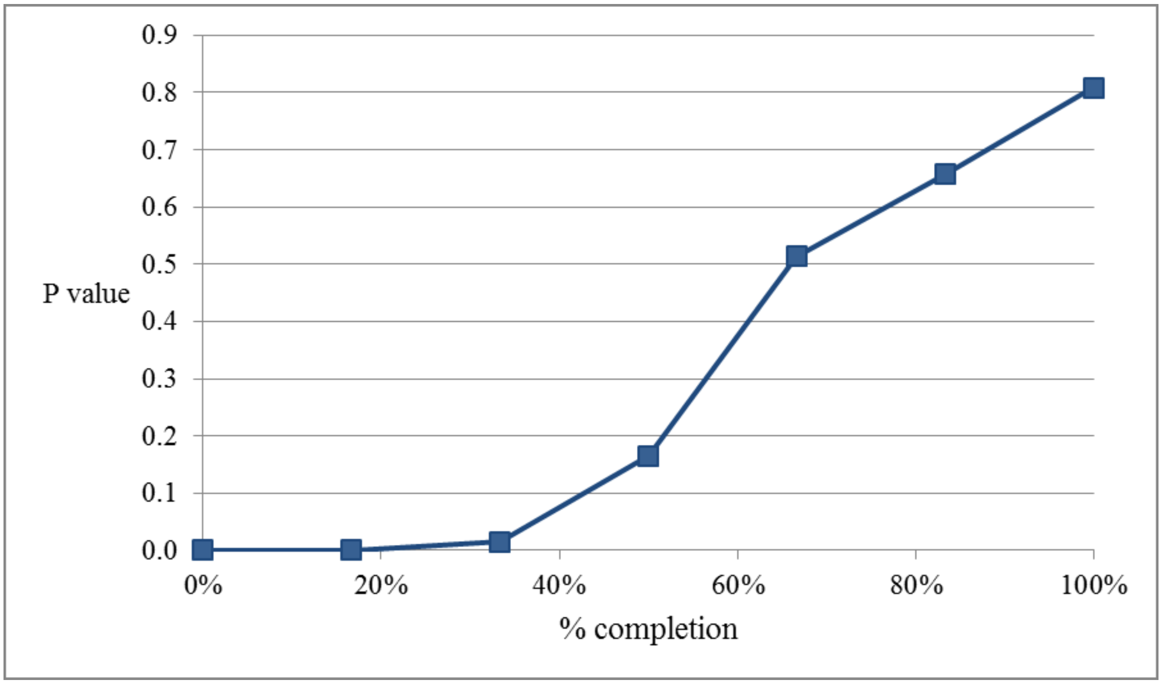


Figure 6.36 ANOVA P-values for RMSD comparing the proposed method and EVM for linear PV

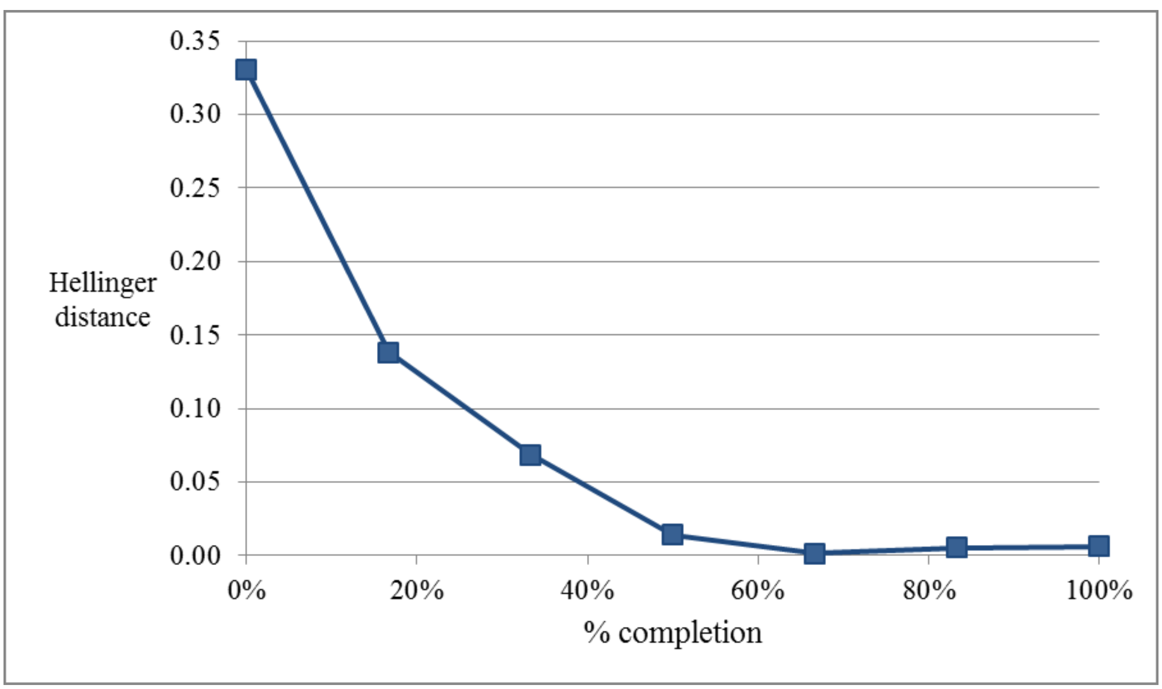


Figure 6.37 Hellinger distance between RMSD of the proposed method and EVM for linear PV

6.3.5 S-curve with different durations

All of the previous 30 projects had durations of seven months. To investigate the accuracy of the proposed method for projects with longer durations, two additional sets of 30 projects of 14- and 21-month duration were randomly sampled. All of the randomly-generated projects followed the default S-curve. The results for projects with durations of 14 and 21 months are presented in Figures 6.38 to 6.42 and 6.43 to 6.47, respectively.

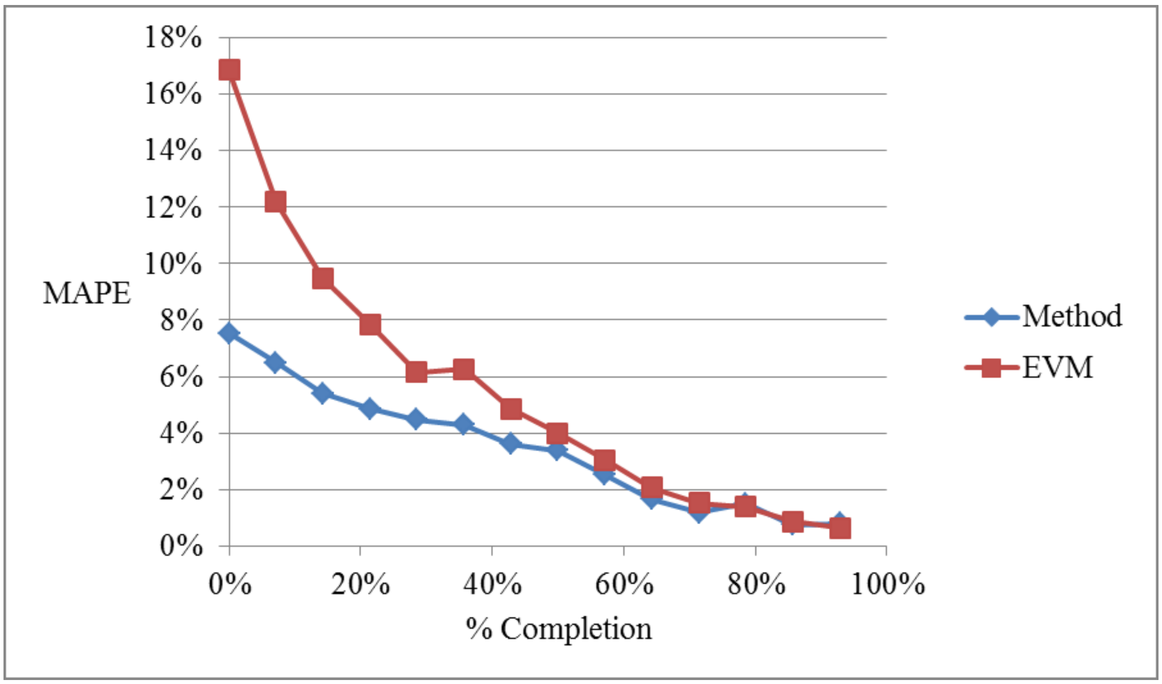


Figure 6.38 MAPE average errors for each forecasting month using the proposed method and EVM for 14-month projects

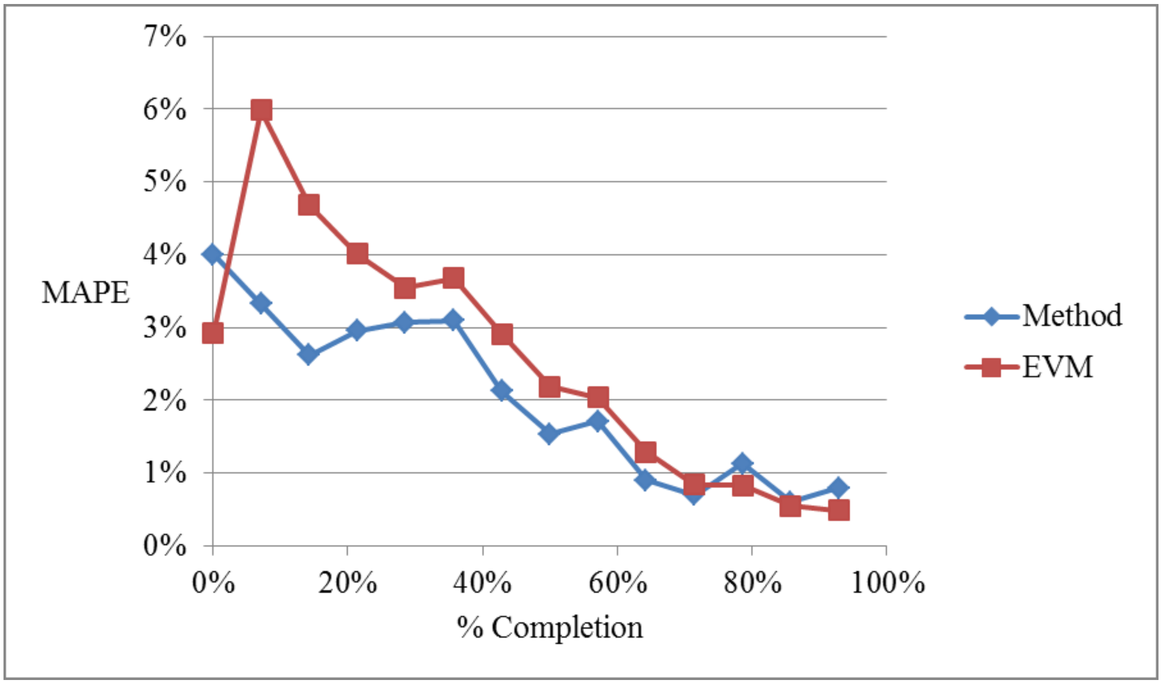


Figure 6.39 MAPE standard deviations for each forecasting month using the proposed method and EVM for 14-month projects

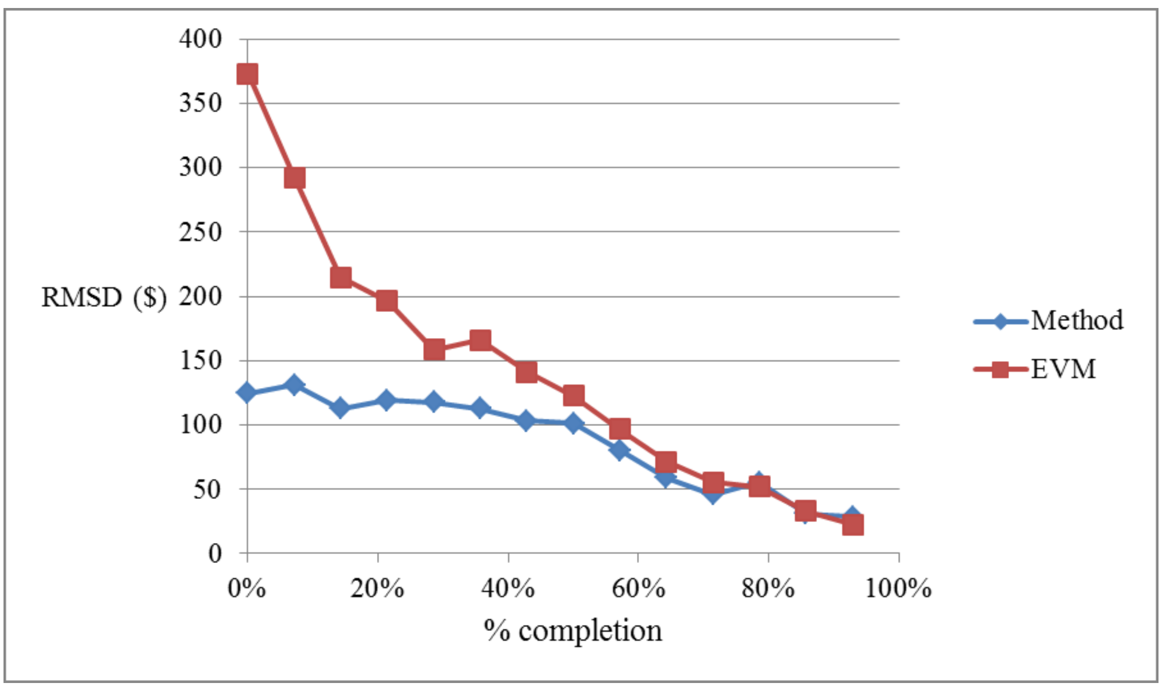


Figure 6.40 RMSD average errors for each forecasting month using the proposed method and EVM for 14-month projects

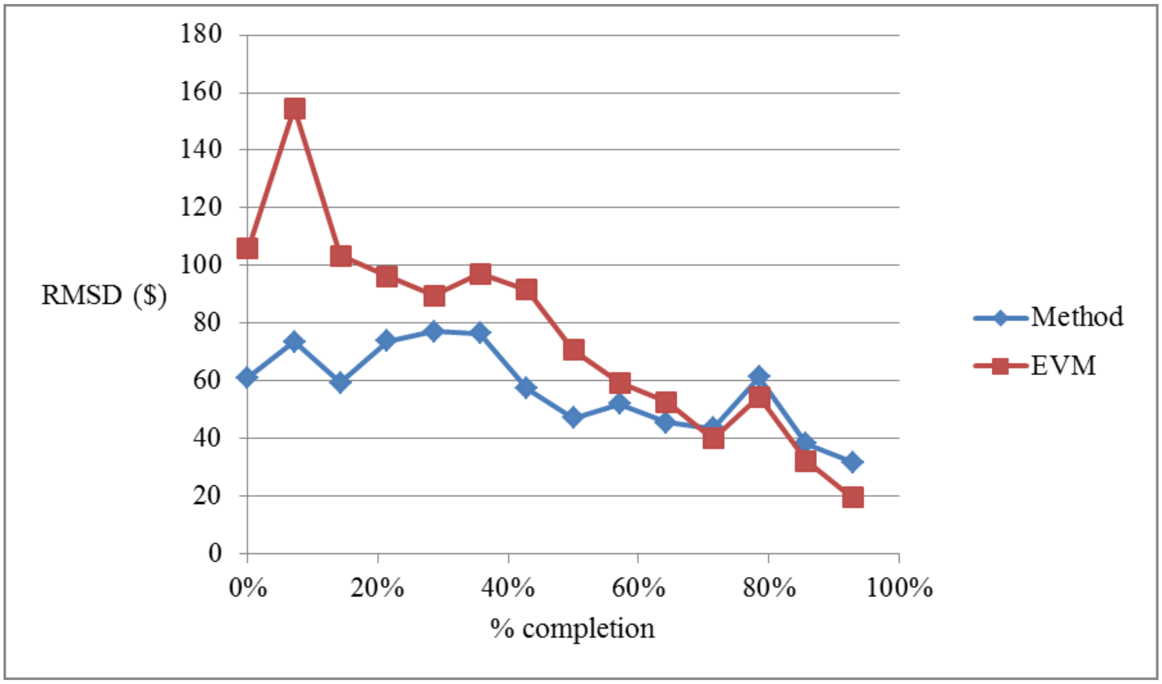


Figure 6.41 RMSD standard deviations for each forecasting month using the proposed method and EVM for 14-month projects

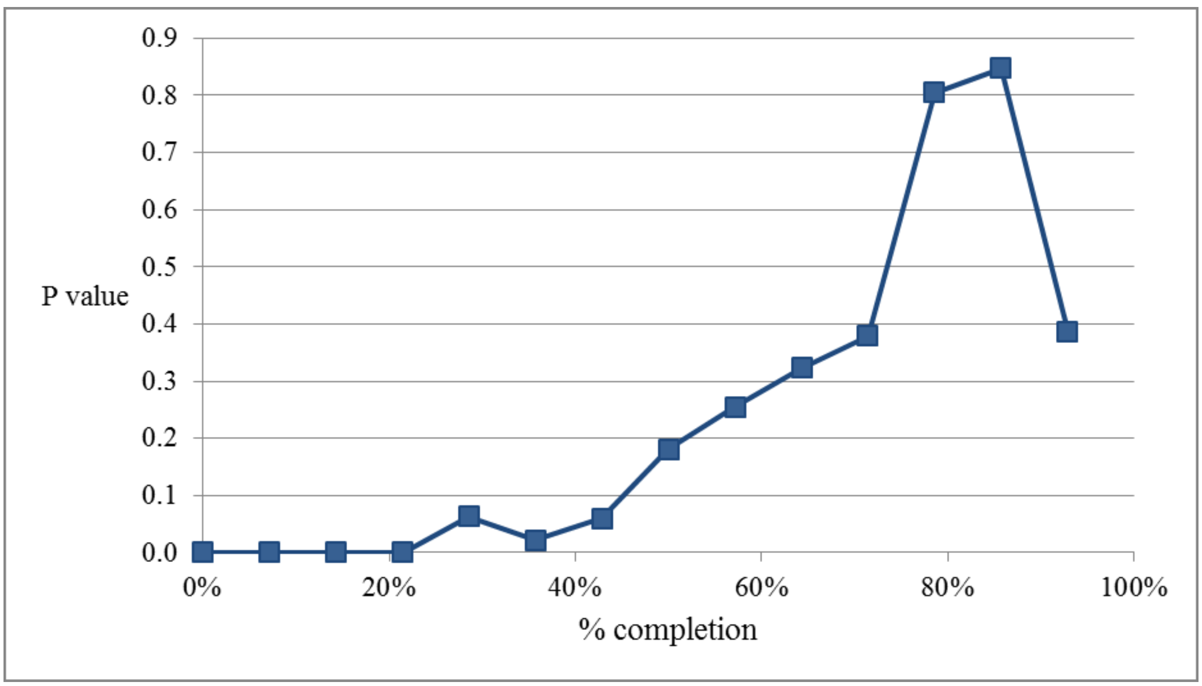


Figure 6.42 ANOVA P-values for RMSD comparing the proposed method and EVM for 14-month projects

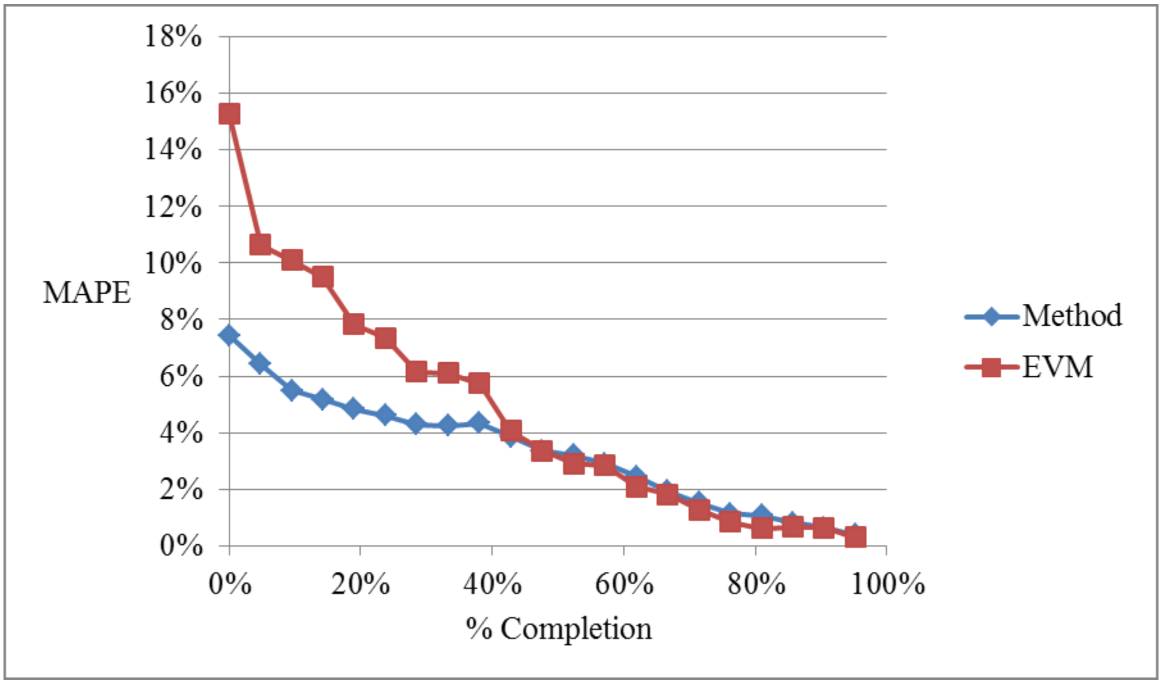


Figure 6.43 MAPE average errors for each forecasting month using the proposed method and EVM for 21-month projects

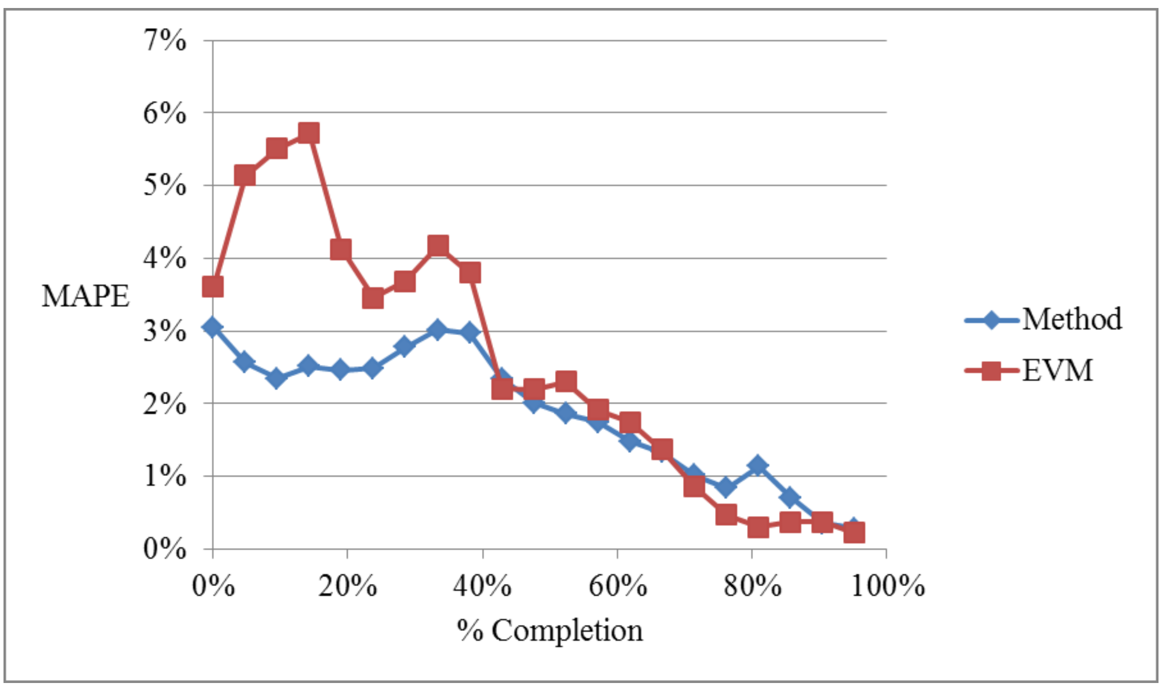


Figure 6.44 MAPE standard deviations for each forecasting month using the proposed method and EVM for 21-month projects

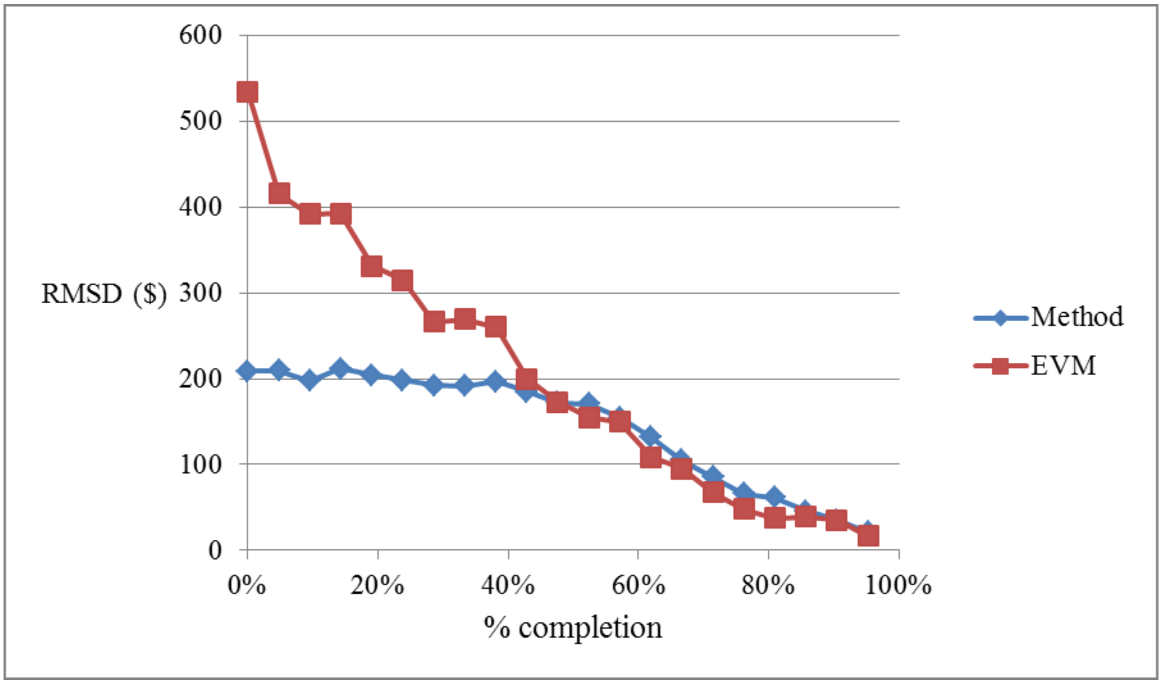


Figure 6.45 RMSD average errors for each forecasting month using the proposed method and EVM for 21-month projects

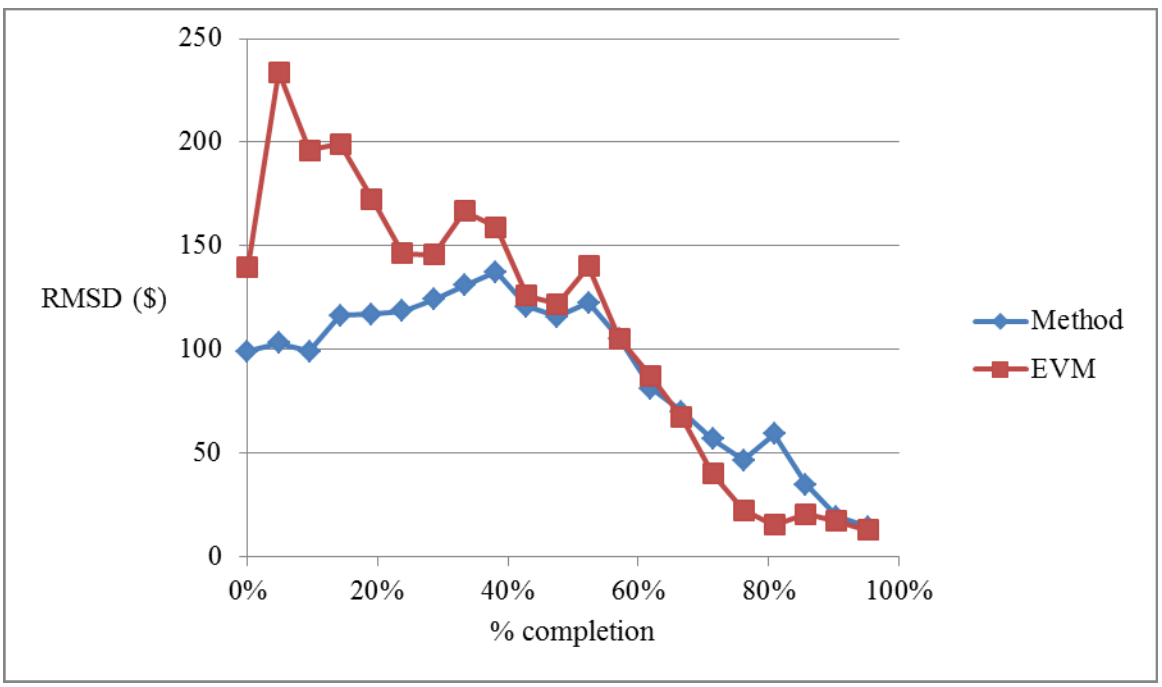


Figure 6.46 RMSD standard deviations for each forecasting month using the proposed method and EVM for 21-month projects

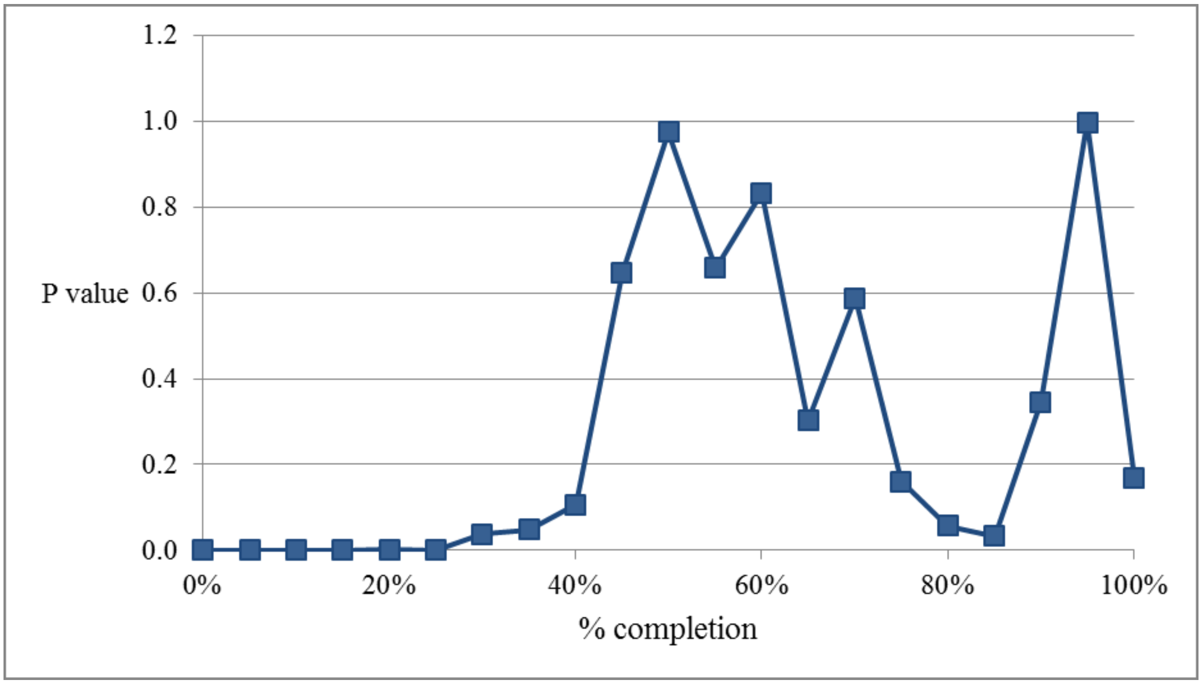


Figure 6.47 ANOVA P-values for RMSD comparing the proposed method and EVM for 21-month projects

6.4 Discussion

Investigating forecast accuracy using randomly-generated projects determined that the proposed method was found to be more accurate in the early stages of the project. As the project budget and cumulative performance variation decreased towards the end of the project, both EVM and the proposed method yielded the same accuracy. In addition to the lower average error, the proposed method had a considerably lower and more consistent standard deviation early in the project. Nonetheless, there are two exceptions with relatively close standard deviation values in the first forecasting month for both front-loaded and back-loaded S-curve MAPE (Figures 6.15 and 6.23), while RMSD for those cases remained considerably lower.

Figures 6.48 and 6.49 plotted average MAPE and RMSD values of 7-month projects for different types of S-curves. Overall, the proposed method provided more accurate estimates for front-loaded curves. With regards to the EVM method, although front-loaded S-curves were forecasted slightly more accurately in later stages of the project (Figures 6.50 and 6.51), variation in accuracy was too high to make a generalized conclusion. The recent observation also confirms Kim and Kim (2014)'s observation regarding the effect of S-curves on EVM duration forecasting.

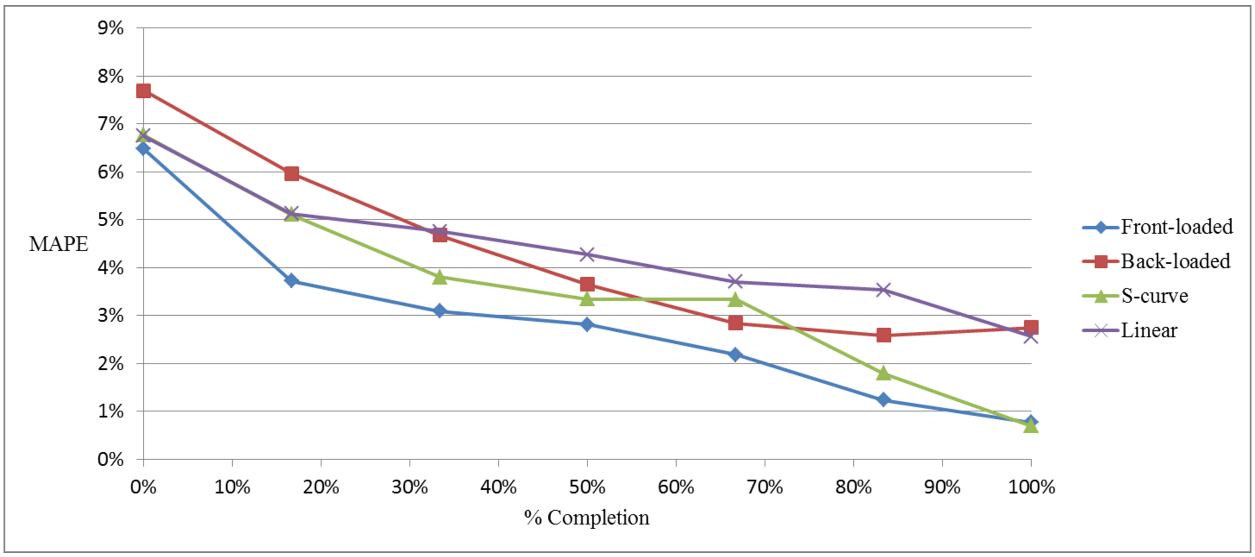


Figure 6.48 MAPE average values using the proposed method for various types of S-curves

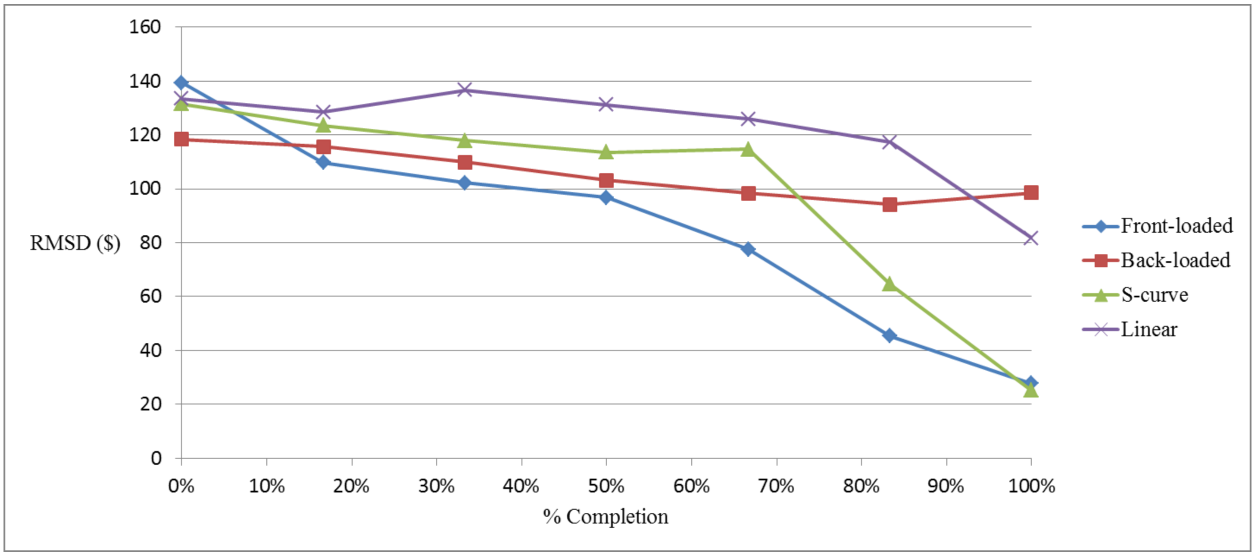


Figure 6.49 RMSD average values using the proposed method for various types of S-curves

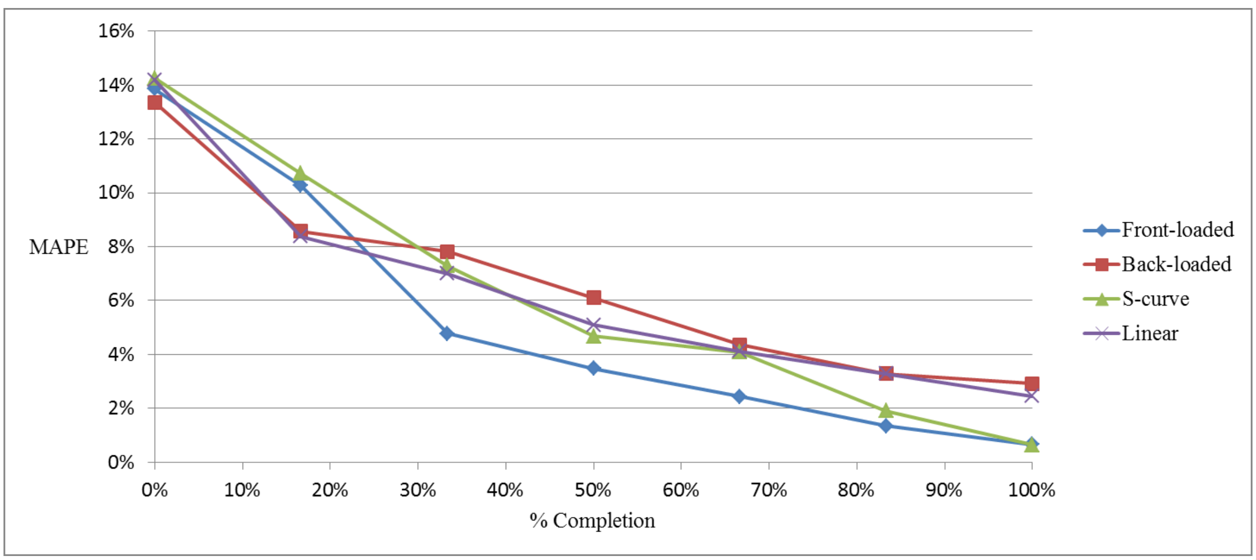


Figure 6.50 MAPE average values using EVM method for various types of S-curves

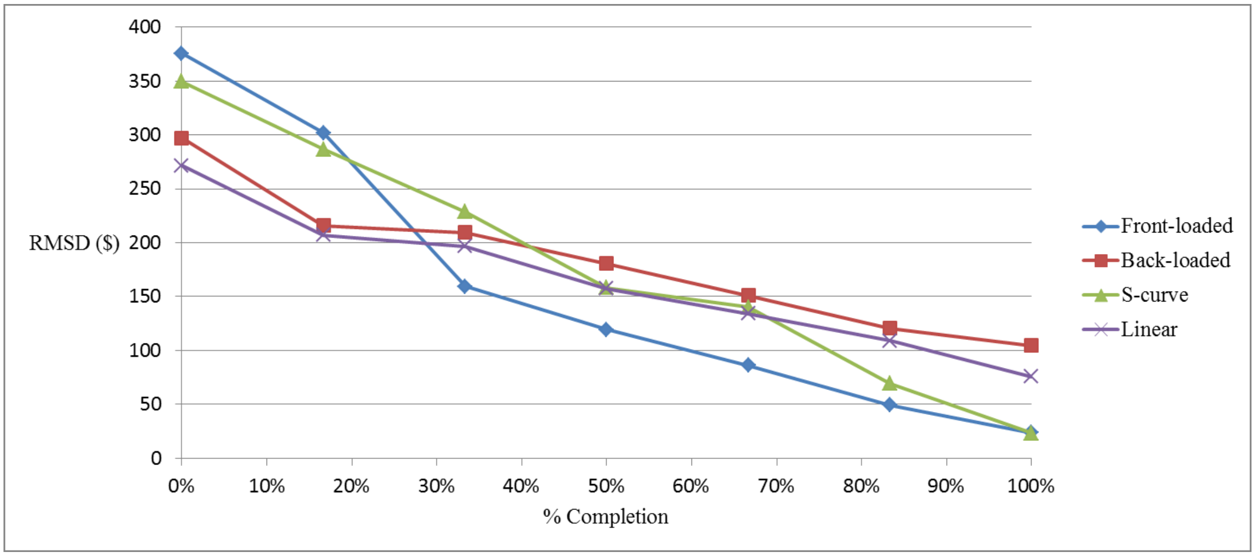


Figure 6.51 RMSD average values using EVM method for various types of S-curves

ANOVA *P*-values and the Hellinger distance were used to assess differences between the forecasting errors in a forecasting month. Both the *P*-value and Hellinger distance supported similar conclusions. In this analysis, P values less than 0.1 were considered as significant, with *P*-values lower than the threshold representing significant differences, whereas lower Hellinger distances denote closeness or similarity between distributions. Since the Hellinger distance does not define a specific threshold for significance, and given that both *P* values and the Hellinger distance follow the same logic, *P* values were used to determine if there were significant differences between each method.

For 7-month projects, the proposed method forecasted more accurately in the first four months (i.e., 57% completion). Back-loaded projects had smaller portions of the total budget (e.g., 30% of the total budget) in the early stages (e.g., 40% of the total duration) (Figure 6.2). In these types of curves, the cumulative CPI was more sensitive to performance alteration, as the monthly budget in consecutive months increased throughout the project. CPI variation reduces EVM forecast accuracy, as CPI is the only variable in the forecast formula (AminiKhafri et al. 2018).

Accordingly, the difference between the proposed method and EVM was significant until the late stages of the project (e.g., 71% project duration) (Figures 6.24 and 6.28).

Unlike projects with back-loaded curves, the difference was lower in front-loaded projects, as the first three months (i.e., 43%) were significantly different (Figures 6.16 and 6.20). Front-loaded projects spend the majority of their budget (e.g., 60% of the total budget) in the early stages (e.g., 40% of the total duration) (Figure 6.2). Consequently, the cumulative CPI varies less in later stages of the project compared to other types of S-curves. Less variability in CPI improves forecast accuracy of EVM (AminiKhafri et al. 2018), and therefore, the difference between the proposed method and EVM was less than that of S-curves and back-loaded curves. As it can be seen in Figures 6.16 and 6.20, the proposed method is significantly more accurate only for the first half of the project execution. Similar to front-loaded curves, the proposed method forecasted projects with uniform budget spread (i.e., linear *PV*) more accurately in the first three months (Figures 6.32 and 6.36). P-values for different S-curve types are plotted in Figure 6.52.

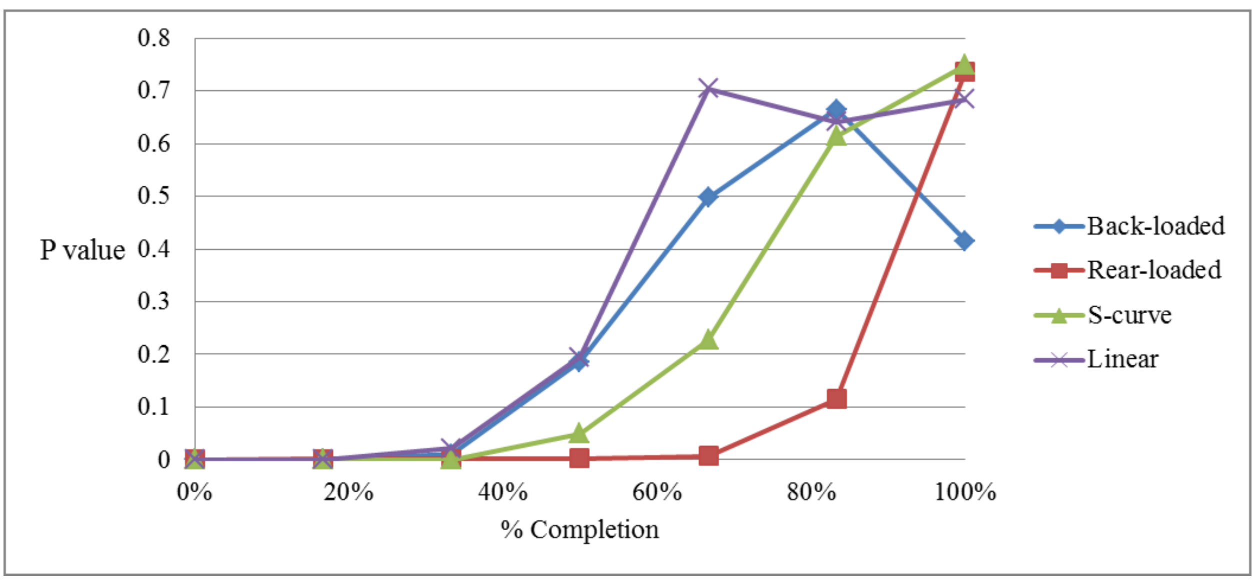


Figure 6.52 P-values for various types of S-curves

Finally, the sensitivity of the proposed method was investigated in projects with different durations (i.e., 14 and 21 months). Figure 6.53 plotted the P-values between the means of the EVM and the proposed method. As it can be inferred from the figure, as the project duration increased, significant differences between both methods were observed in earlier stages. For instance, for 14 -month projects, the proposed method was significantly more accurate for the first half (i.e., first seven month). Whereas, in the case of 21-month long projects, the method was significantly more accurate up to the 43% completion point (i.e., first nine months). Although projects with shorter durations showed more significant differences in the later stages, the difference between various project durations was trivial and was limited to a one-month difference. Moreover, it important to emphasize that the proposed method generates EACs as accurately as EVM forecasts for the remaining months.

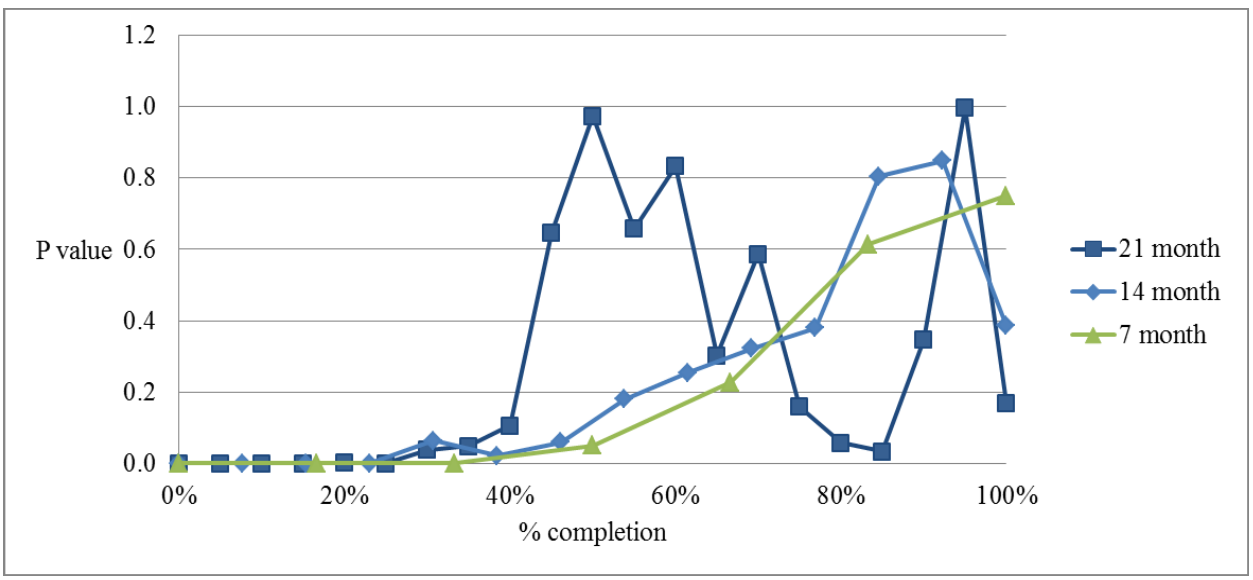


Figure 6.53 P-values for projects with various durations

6.5 Limitations

Although this experiment was designed to generate a diversified list of historical project data, CPIs are still sampled from a predefined interval. This is necessary, however, as the hidden supporting assumption for the proposed framework is that different disciplines have different performances. The basis of the experiment may appear not to favor EVM, as EVM does not consider any historical data. However, the primary objective of the proposed method was to use historical data to generate more accurate EAC. Hence, the validation framework serves the purpose of testing the hypothesis introduced in Section 6.1.

6.6 Concluding remarks

Through substantial modeling and testing, it was found that the proposed method generates more accurate EAC compared to EVM in the early stages of a project (i.e., first half). The forecasting accuracy of the proposed method and EVM were compared for a variety of S-curve types. It was concluded that the proposed method had better performance for back-loaded curves compared to S- and front-loaded curves. Applying the proposed method to projects with longer durations, it was determined that, while the method as consistently more accurate compared to EVM, the accuracy was significantly lower for the first half of the project. During this period, managerial actions to mitigate costs have the greatest impact. Hence, the proposed method can contribute to the potential improvement of project outcomes by signaling deviations from the expected performance.

Chapter 7: Conclusions and Recommendations

7.1 Research summary

EVM, as an integrated project management tool, has various functionalities including calculating EAC. Application of EVM in the construction industry, however, remains primarily limited as a reporting tool (West and McElroy 2001). The primary objective of this research was to identify and improve current shortcomings of EVM in practice. This research surveyed industry to assess EVMS implementation (Appendix B) in construction and to investigate shortcomings associated with the practical application of EVM. The majority of the reported shortcomings require management initiatives (e.g., lack of understanding). Although improving EAC accuracy was the focus of academic research, it was still reported to be a somewhat challenging issue that industry is currently facing.

Reviewing the relevant literature, it was found that, even though various analytical techniques were used in academic research, the majority of these research endeavors were performed at the project level. Currently, granular data are being collected at a more granular level (e.g., task or activity level) and aggregated at the project-level for EVM analysis. Thanks to computational advancement of computers, more granular data are collected with less processing time (Shahi et al. 2014). The second motive of the current research was to utilize available data to improve EVM calculations and, specifically, forecasts. In Chapter 4, historical data were analyzed, and an ANOVA test was used to investigate if significant differences exist between the performances of various disciplines. Significance differences were observed, suggesting that forecasting EAC based on discipline-level, rather than project-level, performance may result in improved forecast accuracy in the studied case. A simplistic Monte Carlo simulation model was developed, using the outputs of the historical data analysis, to determine any potential improvement in forecasting accuracy.

In spite of its enhancement of forecasting accuracy, the proposed Monte Carlo model remained limited by its inability to simulate project performance as an interrelated process. Chapter 5 improved Monte Carlo model fidelity and functionality by incorporating current project performance and Markov modeling into the proposed framework. Bayesian statistics were used to update the Markov model based on current project performance, and the proposed method was implemented in a construction company to forecast EAC. The proposed method was compared against EVM in a real case study to determine if the method was more accurate than EVM. Analyzing one project, it was found that the proposed method outperformed the EVM method in the early stages of the project. As project CPI variation decreased with ongoing project execution, both EVM and the proposed method forecasted with similar accuracy.

It is critical to investigate the accuracy and sensitivity of the proposed method in various conditions, and the proposed approach was applied across a variety of budget breakdown types (i.e., S-curves) in Chapter 6. Cost performance data for 100 random projects were generated to mimic historical project data, and an additional set of projects were sampled to compare the proposed method's accuracy with EVM. Results indicated that S-curve shape does not have a meaningful impact on the forecasting accuracy of both EVM and the proposed method. It was also observed that the proposed approach significantly improved EAC forecast accuracy early in the project and that the improvement in accuracy decreased as the project cost performance reached the final stages of implementation.

7.2 Research contributions

The primary contribution of this research is the improvement of EAC forecasting accuracy through the development of a Markov-Bayesian cost forecasting framework.

7.2.1 Academic contributions

1) Survey results provide insight into the practical shortcomings of EVM and can be used as an input for future research projects: Scholars in the EVM research area can steer their focus towards reported shortcomings to enhance the practicality of their findings. Focusing future research efforts on specific industrial needs will be crucial for enhancing EVM implementation in practice.
2) Development of a methodological approach for investigating differences in the cost performance of various disciplines. Significant differences in performance were observed between various disciplines in the studied company: Observed differences can be the point of departure for researchers in EVM domain and initiate more studies to investigate observed trends. Monte Carlo simulation was used to generate stochastic EAC forecasts, based on mined performance data, from historical data.
3) Development of a stochastic Markov modeling framework that uses Bayesian statistics to modify the Markov model based on ongoing project data: The developed framework can be extended to other areas that model categorical data (e.g., bridge condition, road serviceability) and can be applied to non-categorical cases, such as productivity forecasting and daily or weekly performance forecasting.
4) Development and application of a validation method for future research projects, which might have limited access to data for validation purposes. The validation framework can be used in other research projects in the area of project performance prediction. The

unique approach of the framework, which considers the forecasting accuracy of each subsequent month, can be extended to other areas.

5) And, finally, improvement of foresting accuracy using discipline-level historical data. The proposed approach enhances the reliability of EVM forecasting and promotes the role of EVM as a project control method.

7.2.2 Industrial contributions

1) The survey highlights the importance of the recommended EVMS guidelines for having valid EVM metrics. The questionnaire also can be used by companies or organizations for internal assessment purposes and to identify the implementation level of various EVMS practices (Appendix A). Companies can identify and improve areas that are lacking and, consequently, enhance the reliability of EVM metrics.
2) The proposed historical discipline-level data analysis methodology can guide practitioners on how to investigate differences between the cost performances of various disciplines. Each company, based on their area of expertise and strategic goals, may have different or equal cost performance for different disciplines. Mined information from historical discipline-level performance data can assist companies to revise their estimates. Consistently high or low CPI values can be a symptom of flaws in the estimation process.
3) Understanding trends in CPI variability can reduce unnecessary mitigatory actions during execution. For instance, as per Figure 4.4, a CPI value of 0.7 at 20% completion for Project 2 is indicative of good performance, whereas in the case of Project 1, a CPI value of 0.7 CPI should be treated as an indicator of poor performance. Companies can evaluate the performance of each project based on the disciplines that are involved in the project. For example, as per Figure 4.4, in the case that both Projects 1 and 2 have a final CPI of

1.05, Project 2 has achieved a lower than expected CPI value based on the discipline types. This information also provides a direction for companies to target projects that result in higher cost performance and, consequently, additional profit.

4) Historical data analysis can be performed for different divisions in a local branch as well as across the same division between different locations to assess performance at the portfolio level.

5) Improved EAC forecast accuracy can result in more effective and timely corrective actions, which can, in turn, improve project outputs. In addition, implementing the proposed framework will enhance an identified practical challenge, inaccuracy in EAC forecasting, and may also improve confidence in EVM, another shortcoming of EVM that has been reported by certain industrial practitioners.

7.3 Limitations

- With regards to the survey, survey results reflect the opinion of 95 respondents. In-depth studies are required before generic conclusion about the practical shortcomings of EVM can be ascertained.
- Although EVM has other metrics for forecasting project duration [e.g., SPI, earned schedule (Lipke 2003)], the primary emphasis of this research was on cost forecasting (EAC). This was due, in part, to the absence of reliable schedule data and EVM metrics such as PV. However, the developed method can be extended to forecast project duration.
- This research was limited to the last four years of performance data of the industrial division of a general contractor. Additional, in-depth historical data analysis should be conducted prior to generalization of these results. Since the primary input of the forecasting tool is historical data, the historical data to be used as input should be made

with care. Focus should be on projects with reasonably high similarity, either geographically, divisionally, or by project type. This will increase the probability of observing consistent performance trends, increasing the representativeness of the generated forecasts. In addition, historical data should be related to current practice; using performance data of out-dated projects (e.g., last ten years) may result in inaccurate results, as construction methods and market prices can change within a ten-year time span (Statistics Canada 2008).

- Although having six states for the Markov-Bayesian framework is a reasonable assumption (i.e., given the limitations of the historical data), additional studies are required to investigate the effect of the number defined states on model accuracy.
- Currently, the performance of various disciplines can go from one state to any other without limitation. Randomly-generated project performance data can be embellished by using more logical approaches that represent the project cost performance as a continuous process, preventing the consideration of project trends.

7.4 Recommendations for future research

Discipline-level performance, which was used in this research, can be further broken down to a more granular level, such as the equipment, labor, material, and subcontractor level, as each discipline, based on the company's area of expertise, construction market, and the nature of the activity, may be affected differently by the performance of each subcategory. For instance, earthwork may be more sensitive to equipment performance compared to material. Indeed, different risk factors (e.g., environmental factors) will affect each discipline differently, and inputs from project risk analysis or planning may also be incorporated to increase model fidelity. The data adaptor component of the model can be expanded to include the ability to change and adjust the number of defined states. The simulation component of the model, accordingly, could be modified to adjust the Markov modeling component based on the defined number of states.

In this study, a first degree Markov chain was used, which only considers the performance of the prior month. The Markov model can be extended to higher degrees (e.g., second degree) to mimic the projects in more detail. In addition, the proposed method is expected to have better performance in cases where more frequent updates to input data are available (e.g., weekly performance reports). The proposed framework can also be applied to other areas (e.g., productivity). As mentioned before, although the main focus of the current study was improving EAC forecasting, the methodology can be easily modified to forecast project duration given the availability of the required data (e.g., up-to-date resource loaded schedule).

Finally, the sensitivity of the proposed method can be examined in more diversified cases based on the availability of historical data. Data from different companies must be analyzed to investigate any potential trends in the performance of other disciplines.

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Appendix A: Sample of the conducted survey

Earned Value Analysis Questionnaire

1. Earned Value Analysis Questionnaire

I have read the "Consent to Participate in Research Study" information included in the email and consent to participating in this study.

◯ Yes

This questionnaire is examining the of earned value management in construction. Do you have construction-related working experience?

◯ Yes

◯ No

1

Earned Value Analysis Questionnaire

2. Earned Value Practice in Your Organization

What was the implementation level of the following practices on the last five projects that you were involved with?

	Fully Implemented	Often	Somewhat	Rarely	Not Implemented
Project scope definition (i.e., a definition of the work to be accomplished) prior to project planning.	○	○	○	○	○
Assignment of activity performers (e.g., project managers, major subcontractors) during project scope definition.	○	○	○	○	○
Planning and scheduling of the project based on the defined scope including all critical milestones.	○	○	○	○	○
Involvement of all parties (owner, consultant, senior management) in the planning phase.	○	○	○	○	○
Estimation of the project based on the planned execution method including identification of significant cost elements (e.g., labor, material, etc.).	○	○	○	○	○
Application of a project's resource-loaded schedule as the benchmark for earned value analysis.	○	○	○	○	○
Integration of technical scope, authorization, planning, scheduling, estimating, budgeting, and cost accumulation of the work with the functions performing the actual work through the work breakdown structure (WBS).	○	○	○	○	○
Identification of metrics (measurement methods) to convert executed work to earned value in the baseline project schedule.	○	○	○	○	○
Identification of management control points (i.e., points in the WBS that project cost and schedule is controlled) based on project baseline.	○	○	○	○	○
Measurement of project performance within each of the identified management control points as well as at the project level.	○	○	○	○	○
Recording all project direct costs in a manner that is consistent with the authorized baseline budgets.	○	○	○	○	○
Continuous monitoring of earned value performance indicators to determine cost and schedule expectations of baseline plan as well as potential deviations.	○	○	○	○	○
Continuous application of earned value to forecast final project cost.	○	○	○	○	○
Continuous application of earned value data in conjunction with critical path analysis to forecast final project duration.	○	○	○	○	○
Continuous application of only earned value to forecast final project duration.	○	○	○	○	○

	Fully Implemented	Often	Somewhat	Rarely	Not Implemented
Tracking sources of inefficiency using earned value analysis.	◯	◯	◯	◯	◯
Tracking and processing changes to project baseline using a structured workflow (e.g., change management system).	◯	◯	◯	◯	◯
Incorporation of approved changes to project baseline in a timely manner to increase accuracy of earned value analysis.	◯	◯	◯	◯	◯
Overall practice of earned value management regardless of contract requirements.	◯	◯	◯	◯	◯

Earned Value Analysis Questionnaire

3. Earned Value Management Shortcomings

Through a literature review and interviews with construction practitioners, a shortlist of potential shortcomings of applying the earned value management (EVM) system in construction has been identified. Please rate the severity (or potential impact) of each problem below.

	Not a Problem	Minor Problem	Somewhat of a Problem	Problem	Major Problem
Lack of structured management systems and support to implement earned value management.	◯	◯	◯	◯	◯
Difference between management system and accounting system's WBS.	◯	◯	◯	◯	◯
High cost of implementation.	◯	◯	◯	◯	◯
Time-consuming data collection.	◯	◯	◯	◯	◯
Absence of an integrated project baseline (e.g., WBS, schedule, and budget).	◯	◯	◯	◯	◯
Inability to identify sources of inefficiency.	◯	◯	◯	◯	◯
Subjectivity and inaccuracy in measuring the earned value of executed work.	◯	◯	◯	◯	◯
Lack of confidence in the earned value indices [e.g., schedule performance index (SPI) and cost performance index(CPI)].	◯	◯	◯	◯	◯
Absence of resource loaded schedules.	◯	◯	◯	◯	◯
Deviations from project baselines are not effectively incorporated into earned value calculations.	◯	◯	◯	◯	◯
Unrealistic (i.e., unachievable) schedule and budget.	◯	◯	◯	◯	◯
Inaccuracy in the earned value performance forecast.	◯	◯	◯	◯	◯
Lack of training and understanding about earned value.	◯	◯	◯	◯	◯

Earned Value Analysis Questionnaire

4. Tell more about yourself

Which option best describes your organization?

- ◯ General Contractor
- ◯ Fabrication Facility
- ◯ Client Organization
- ◯ Project Management Consultant
- ◯ Government Establishment
- ◯ Architectural Organization
- ◯ Engineering Consultant

Select the option that best describes your current position?

- ◯ President/CEO
- ◯ Vice President
- ◯ Director/Senior Manager
- ◯ Commercial Manager
- ◯ Project Manager
- ◯ Project Coordinator
- ◯ Superintendent
- ◯ Foreman

What was the average annual revenue of your firm in the last three years?

- ◯ < 5 Million $
- ◯ 5-10 Million $
- ◯ 10-50 Million $
- ◯ 50-150 Million $
- ◯ 150 – 600 Million $
- ◯ > 600 Million $

5

How many years of construction-related experience do you possess?

- ◯ 0-5
- ◯ 6-10
- ◯ 11-15
- ◯ 16-20
- ◯ 21-25
- ◯ >25

What is the average dollar value of the last five projects that you were involved with?

- ◯ <2 Million $
- ◯ 2-5 Million $
- ◯ 5-15 Million $
- ◯ 15- 50 Million $
- ◯ >50 Million $

What type of construction project are you<u>primarily</u> involved with?

- ◯ Residential Construction
- ◯ Commercial Buildings
- ◯ Infrastructure (Road, Drainage)
- ◯ Industrial Construction

Appendix B: Supplementary results and analysis of the survey

B.1 Respondents demographics results

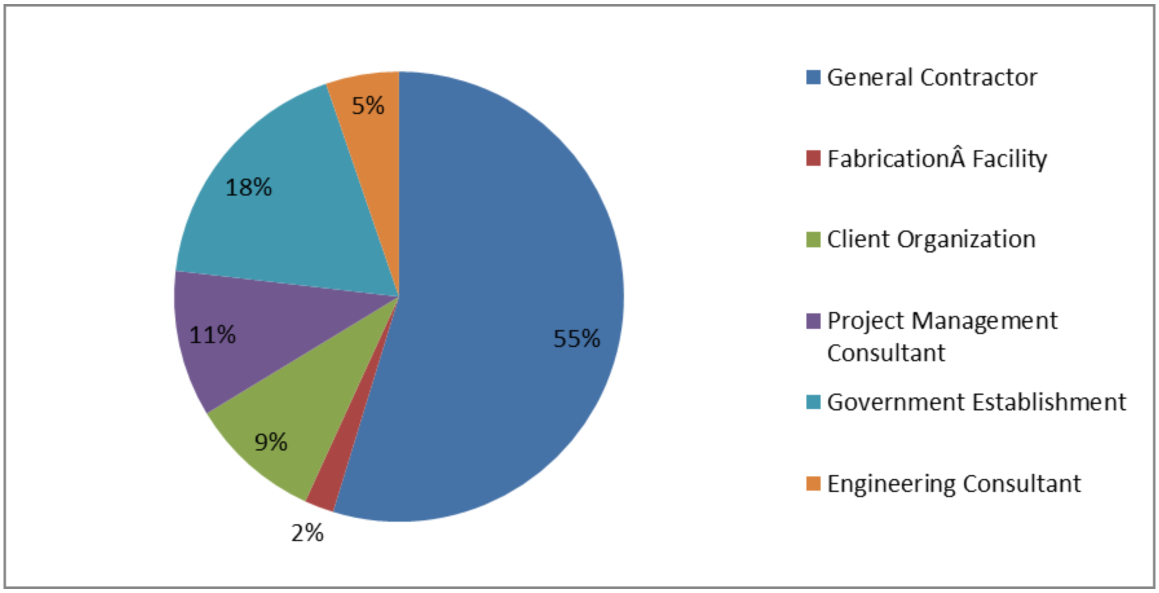

Figure B.1 respondents' distribution by organization type

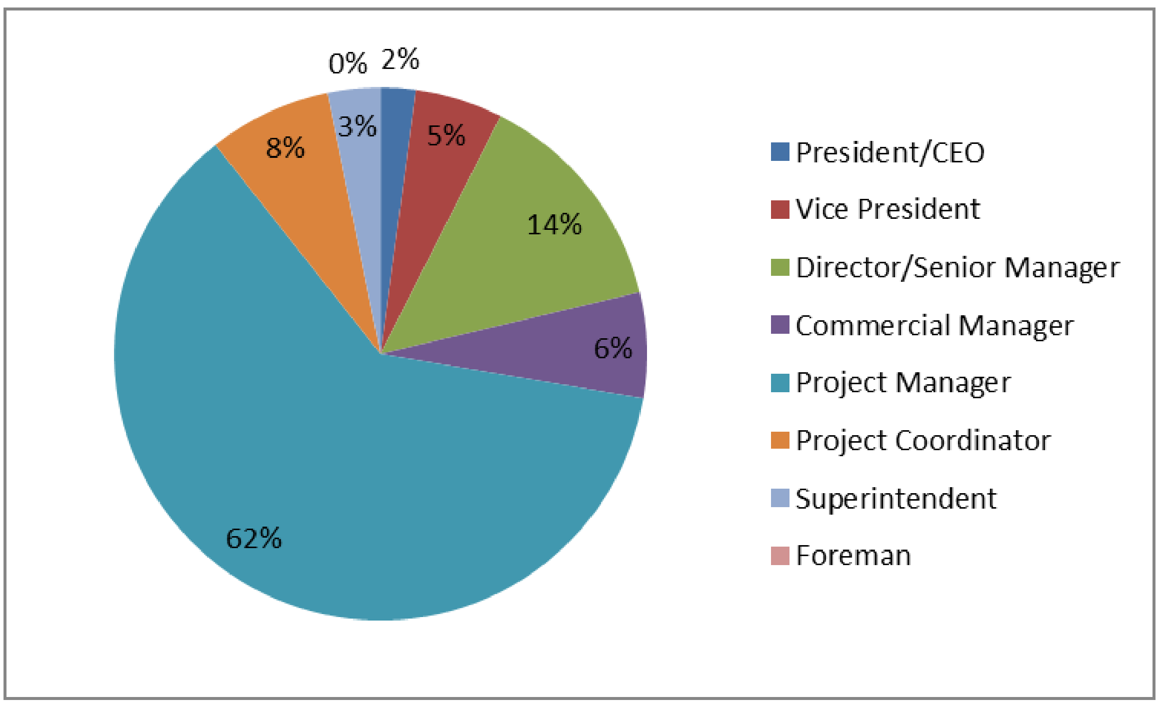

Figure B.2 respondents' position

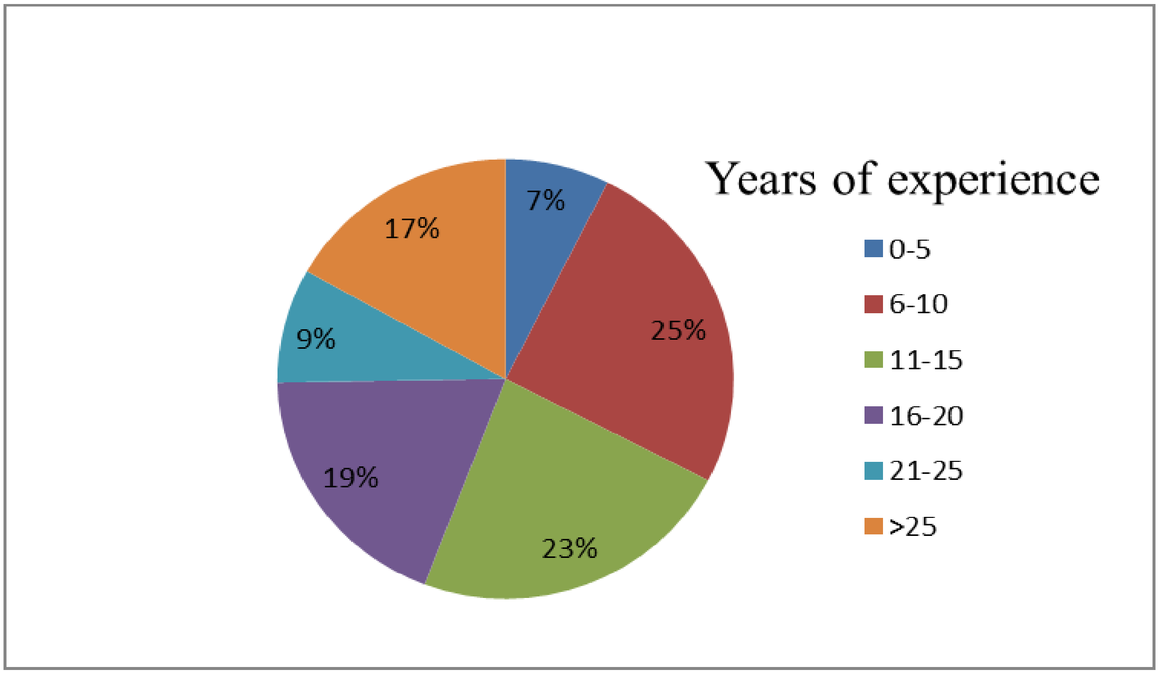

Figure B.3 respondents' breakdown based on the years of experience

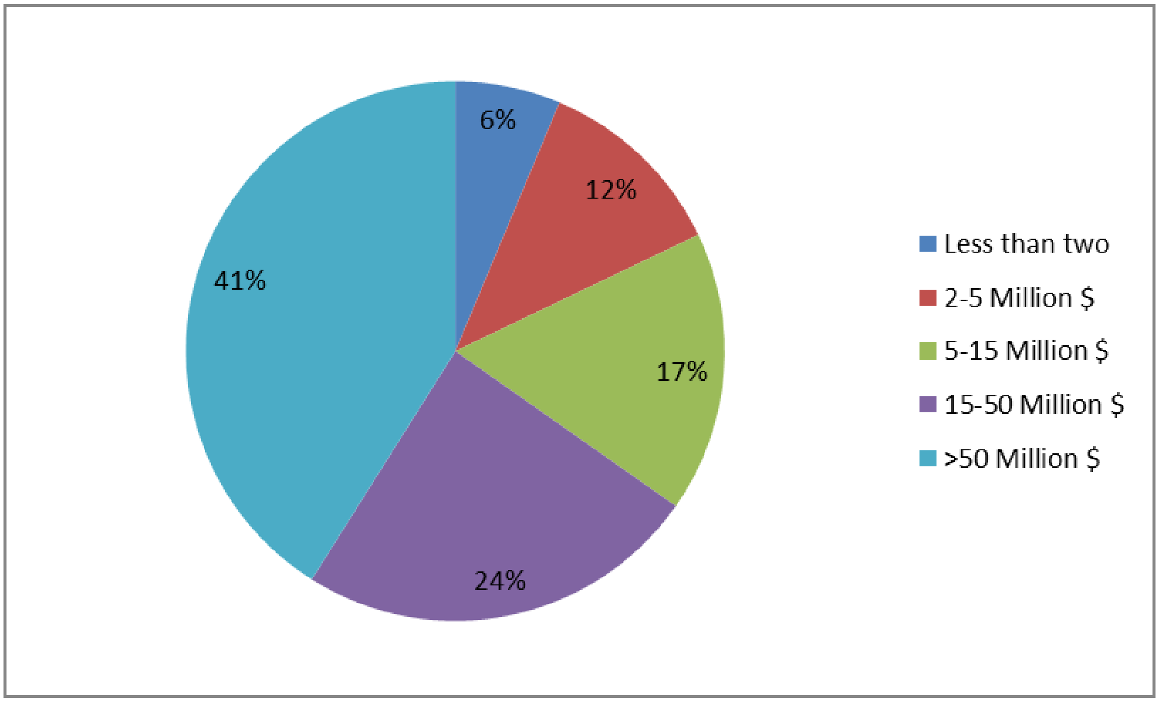

Figure B.4 Average dollar value of the last five projects that respondents were involved with

B.2 Implementation level Results

B.2.1 Background

As mentioned before, earned value management (EVM) is an integrated project control method that is used to manage project scope, duration, and cost. To ensure the reliability of EVM metrics, multiple organizations have recommended specific practices known as EVM systems (EVMS). While EVMS requirements are mandated in certain sectors, the implementation level in construction, where adherence to EVMS standards is not often required, is relatively unexplored. Without an understanding of the EVM shortcomings, it may be difficult for academic researchers to develop improvements to EVM methods that are applicable and easily implementable in practice. Accordingly, a survey was designed to examine the implementation level and drawbacks of EVMS in construction. Based on a thorough review of guidelines relevant to EVM and EVMS, a survey was designed and distributed to construction practitioners to assess the implementation level of EVMS and to identify drawbacks common to current EVM practice. Overall, practices were found to be moderately implemented, where implementation was reported to be higher for large construction organizations and in the industrial construction sector. Unexpectedly, unachievable budget and schedule along with lack of training and understanding about EVM were perceived as the two greatest drawbacks of current EVM practice. Amongst identified shortcomings that can be improved by academic research, inaccuracy in EVM forecasts identified to be the most concerning shortcoming by practitioners. Results of the current study provide insight into the challenges associated with EVM in practice, which can be used to guide future research endeavors in this area.

Various publicly funded organizations have defined and mandated EVMS regulations and guidelines for both internal and external projects (Kwak and Anbari 2012). Guidelines are primarily based on the American National Standards Institute (ANSI)/Electronic Industries Alliance (EIA) (ANSI/EIA 748) standards, which are a list of 32 criteria designed to ensure the reliability of EVM metrics. The 32 criteria are categorized into five sections, namely organization, planning and budgeting, accounting, analysis, and revisions and data maintenance (ANSI/EIA 748), and are expressed in generic terms to provide flexible implementation for industry.

Notably, however, the ANSI/EIA 748-based standards are not always applicable to all project scenarios and locations, and alternate EVMS guidelines have been proposed. For instance, requirements may not align with regulations of other nations, resulting in the establishment of new standards in other countries. Indeed, the Canadian General Standards Board (CGSB) (1993) introduced its own national EVM standards as the core method to measure project performance (Brandon 2005). The PMI has provided a 10-criteria summary based on the ANSI/EIA 748 (Fleming and Koppelman 2010) to enhance the practicality and feasibility of EVM, assisting companies with less established management system (e.g. smaller firms or projects that are not publicly funded) to implement EVMS practices at an intermediate level. In addition to regulations provided by governments and professional organizations, scholars have also developed EVMS for specific projects. Hanna (2012) developed an EVMS to control electrical projects as a labor-intensive type of work, Jung et al. (2011) created a customized EVMS for nuclear projects, Brandon and Daniel (1998) demonstrated a simplified yet effective version of EVM to be used by firms that are not required to follow laborious standards (e.g., ANSI/EIA 748), and Benjaoran (2009) demonstrated an EV-based cost control system for small and medium-sized companies using MS Access and using material quantities for progress reporting. Naeni et al. 2009 suggested the application of fuzzy logic to enhance quantification of EV metric.

As evidence of its ability to enhance project management practices, the US Department of Defense (DOD) (DOD 2015), NASA (NASA 2002), the US Federal Aviation Administration (FAA) (FAA 2011), and the US Department of Energy (DOE) (DOE 2015) all require ANSI/EIA 748 to be implemented as part of their acquisition requirements. For instance, the DOD earned value requirements have been mandated for military projects carried out between the US government and any national or international contractor. NASA has benefited tremendously from the implementation of EVMS in its significant acquisitions (Kwak and Anbari 2012, Hunter et al. 2014). Furthermore, NASA has also mandated EVMS requirements in its space flight program and project management requirements, NPD 7120.5-NASA (NASA

2008a), and institutional infrastructure program and project requirements, NPD 7120.7-NASA (NASA 2008b).

While benefits of EVM implementation are well documented in practice, a majority of the reported successes are within large companies or organizations that have committed to adhering to stringent EVMS requirements. In contrast, the majority of construction companies are not required to implement ANSI/EIA 748 or similar rigorous guidelines, as the majority of construction companies are not working with a client who requires EVMS. In spite of this, the use of EVM indicators, either for internal or client-reporting purposes, continues to be a common component of construction practice. While ANSI/EIA 748-compliant companies are being audited and certified by client or third-party organizations, other construction companies are not benchmarked and assessed with regards to EVMS practice. Their implementation of and adherance to EVMS requirements or guidelines, particularly in the Canadian construction industry, remains relatively unknown. Indeed, a survey of the United Kingdom (UK) construction industry revealed that only 7% of contractors use EVM as a project cost control tool and that EVM is not practiced as a project schedule control tool (Olawale and Sun 2010).

The first section focused on practices required to implement EVM in a company. Fleming and Koppelman (2010) recommend ten criteria to implement EV in an organization. Nineteen practices were extracted from these criteria and further validated with the ANSI/EIA 748 standard as summarized in Table B.1.

Table B.2 Summary list of practices suggested by Fleming and Koppelman (2010)

Code	Practice
P1	Project scope definition (i.e., a definition of the work to be completed) prior to project planning.
P2	Assignment of activity performers (e.g., project managers, major subcontractors) during project scope definition.
P3	Planning and scheduling of the project based on the defined scope including all critical milestones.
P4	Involvement of all parties (owner, consultant, senior management) in the planning phase.
P5	Estimation of the project based on the planned execution method including identification of significant cost elements (e.g., labor, material, etc.).
P6	Application of a project's resource-loaded schedule as the benchmark for earned value analysis.
P7	Integration of technical scope, authorization, planning, scheduling, estimating, budgeting, and cost accumulation of the work with the functions performing the actual work through the work breakdown structure (WBS).
P8	Identification of metrics (measurement methods) to convert executed work to earned value in the baseline project schedule.
P9	Identification of management control points (i.e., points in the WBS that project cost

and schedule is controlled) based on project baseline.

P10 Measurement of project performance within each of the identified management control points as well as at the project level.

P11 Recording all project direct costs in a manner that is consistent with the authorized baseline budgets.

P12 Continuous monitoring of earned value performance indicators to determine cost and schedule expectations of baseline plan as well as potential deviations.

P13 Continuous application of earned value to forecast final project cost.

P14 Continuous application of earned value data in conjunction with critical path analysis to forecast final project duration.

P15 Continuous application of only earned value to forecast final project duration.

P16 Tracking sources of inefficiency using earned value analysis.

P17 Tracking and processing changes to project baseline using a structured workflow (e.g., change management system).

P18 Incorporation of approved changes to project baseline in a timely manner to increase accuracy of earned value analysis.

P19 Overall practice of earned value management regardless of contract requirements.

B.2.2 Results

The level of implementation for each practice is summarized in Table B.2. As can be inferred from Table 3.3, larger scores indicate a more complete implementation of the practice.

TableB.2 Summary of survey results

Practice	Implementation
P3	6.21
P11	6.21
P1	6.19
P5	6.02
P17	5.77
P2	5.49
P7	5.47
P4	5.24
P8	5.18
P12	5.18
P9	5.09
P10	5.09
P19	4.78
P13	4.74
P18	4.57
P6	4.34
P14	4.29

P16	3.79
P15	3.60

Overall, application of EVM in the construction industry was found to be somewhat dependent on contract requirements (P19). Listed practices that ranked highest in implementation pertained to early scope definition (P1), application of the scope in estimation (P5), scheduling and planning (P3), and recording costs according to the baseline budget (P11). Higher implementation levels of these practices are expected in construction, as estimation based on the scope of work is a vital part of construction project management.

In contrast, practices associated with project duration forecast (P15 and P14) and the identification of inefficiency sources (P16) were associated with the lowest rates of implementation. The low implementation of these practices have been discussed in literature; Fleming and Koppelman (2010) have suggested using methods capable of incorporating activity dependencies to forecast project duration (e.g., CPM), since EVM does not consider activity dependency in its analysis. In spite of this, earned value application in cost forecasting was ranked relatively low in practice (P13).

Surprisingly, application of a resource-loaded schedule (i.e., a schedule with assigned resources (e.g., cost) to perform each activity) to perform EVM analysis (P6) was found to be poorly implemented in practice. Planned value and earned value are calculated based on the resource-loaded schedule (Fleming and Koppelman 2002), and calculating EVM metrics without considering the project's resource-loaded schedule could render the EVM metrics inaccurate. A resource-loaded schedule acts as a reference to earn credit for performed work.

Changes are inevitable in the construction industry, and proper management of them can impact a project's success (Sun and Meng 2009). Implementation of systems to track and process changes (P17) was associated with relatively high levels of implementation, suggesting that the construction industry is investing in establishing change management systems. However, real-time incorporation of change into a project baseline was reported to be implemented less often (P18). One possible reason for this is that the change approval process is a time-consuming process; a comprehensive assessment of each change, including examining potential side effects on other activities and projects, is a laborious task that often delays the change approval process.

Implementation of management control points concept (P9 and P10), which are intermediate control points to control budget and schedule, is comparatively low. Many of these control points are at the intersection of the WBS and organizational breakdown structure and require administrative support to establish. The remainder of the surveyed practices were found to be moderately implemented in industry.

Survey data were categorized into industrial and non-industrial construction to investigate if differences in EVMS implementation between industrial and non-industrial construction exist. The average reported implementation score for industrial construction was significantly higher than non-industrial (i.e., 5.5 versus 4.6; n=54, 41; $P < 0.05$). Averaged responses for each practice are summarized in Figure B.5. For approximately half of practices (9 out of 19), significant differences between industrial and non-industrial construction were observed. For practices 12 to 16, which are primarily pertaining to the application of EVM for monitoring and forecasting duration and cost, industrial construction was associated with a higher implementation level compared to non-industrial construction projects ($P<0.05$; Figure 3.3). Industrial construction was also reported to be more likely to implement EVM regardless of contract requirements (P19) and more rigorous change management system (P17). This may be attributed to the complexity of industrial projects, which require well-established control methods for successful project delivery. Significantly higher implementation levels were also reported for predetermination of the EV measurement rules prior to the project execution (P8) and integration of project through the WBS (P7).

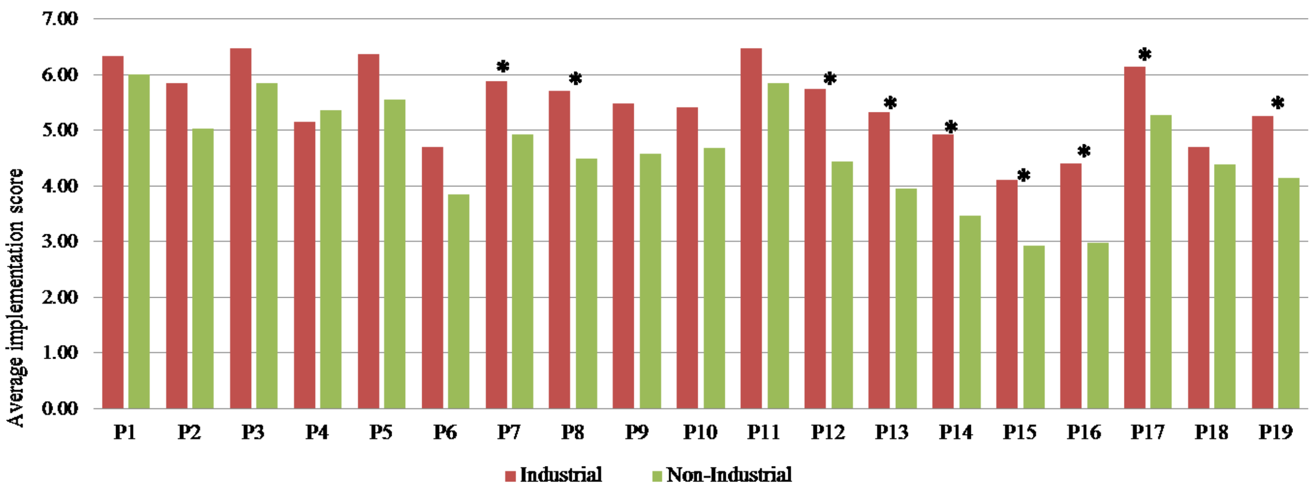

Figure B.5 Comparison between industrial and non-industrial implementation of EVMS practices. *P<0.05 versus industrial construction of corresponding practice.

A company's area of specialty is not the only factor affecting EVMS implementation. Company size can affect the implementation level, as industrial companies are often larger than non-industrial companies, as shown in Table 3.5.

To investigate the effect of company size on EVM practice, industrial construction responses were categorized into three groups based on the average revenue over the last three years. Figure B.6 summarizes EVM practice for each company's size category. Overall, larger industrial companies reported increased implementation of practices, compared to medium (5.69 vs. 4.91;

P<0.05) and small companies (5.69 vs. 4.24; P<0.05) due, perhaps, to the ability of larger companies to invest more revenue into management systems (Turner et al. 2009). No significant differences were observed between medium and small size industrial companies (P=0.10). Based on the average perceived severity scores, smaller the companies were less likely to implement EVM to forecast the duration of a project (P15) and detect sources of inefficiency (P16) (P<0.05; Figure B.6).

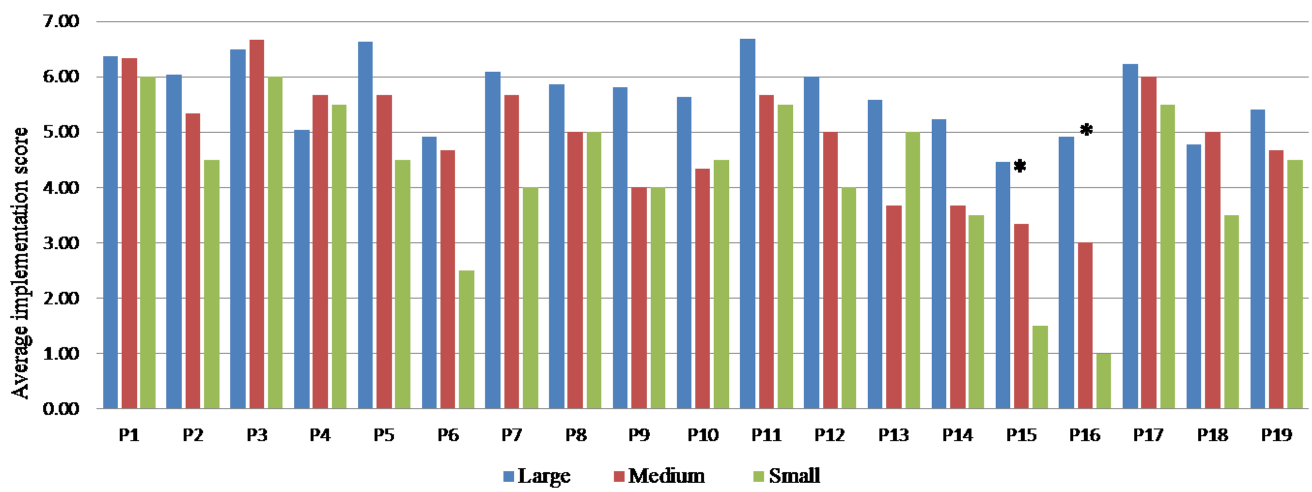

Figure B.6 EVMS practice implementation in industrial construction, categorized by company size. *P<0.05 versus industrial construction of corresponding practice.

B.2.2 Discussion

Least implemented practices included the use of resource-loaded schedules and challenges for keeping the schedule up-to-date (i.e., incorporating changes in a timely manner). Poor implementation of such practices can undermine the credibility of EVM metrics: out-of-date budget figures can result in lower *CPI* (i.e., for positive change values) because contractors cannot be credited for performed work, and a lack of resource-loaded schedule can render the calculation of earned and planned values more challenging since the budgeted amount for each task is unclear. Accordingly, it is recommended that a resource-loaded schedule be created early in the project when the project team is occupied with other duties (e.g., working with the client on permits, site mobilization, recruiting), and EVM metrics should be calculating using both budgeted (i.e., original budget plus approved changes) and anticipated (i.e., original budget plus unapproved change order amounts) values, which can be used as interim indicators along with budgeted metrics.

Comparing the implementation level between industrial and non-industrial construction demonstrated that industrial construction, on average, has a higher reported implementation level compared to the non-industrial sector. This may be a consequence of the complexity of industrial projects, which require stringent management systems for successful project delivery. The reported implementation of EVMS practices was also found to vary by company size. Larger companies reported increased implementation compared to medium and small firms. This may be due to the resources and specialized workforce capable of implementing complex, rigorous EVMS and practices at the larger companies.

Table B.1 Welch's t-test input data for industrial vs. nonindustrial construction practices

	P1	P2	P3	P4	P5	P6	P7	P8	P9	P10	P11	P12	P13	P14	P15	P16	P17	P18	P19
Avg. Industrial	6.33	5.85	6.48	5.15	6.37	4.70	5.89	5.70	5.48	5.41	6.48	5.74	5.33	4.93	4.11	4.41	6.15	4.70	5.26
Avg. Non-industrial	6.00	5.02	5.85	5.37	5.56	3.85	4.93	4.49	4.59	4.68	5.85	4.44	3.95	3.46	2.93	2.98	5.27	4.39	4.15
Count Industrial	54	54	54	54	54	54	54	54	54	54	54	54	54	54	54	54	54	54	54
Count Non-industrial	41	41	41	41	41	41	41	41	41	41	41	41	41	41	41	41	41	41	41
STD Industrial	1.73	2.23	1.86	2.00	1.78	2.61	2.03	2.56	2.27	2.38	1.82	2.30	2.64	2.51	2.81	2.84	2.01	2.49	2.59
STD Non-industrial	2.05	2.80	1.97	2.21	2.39	2.42	1.95	2.36	2.11	2.08	2.02	2.30	2.51	2.37	2.10	2.53	2.09	2.50	2.38
t	0.84	1.56	1.58	-0.49	1.82	1.64	2.33	2.40	1.98	1.58	1.57	2.73	2.60	2.91	2.35	2.59	2.07	0.61	2.17
v	77.70	74.70	83.61	81.52	71.39	89.24	87.96	89.53	89.24	91.15	81.22	86.21	88.30	88.66	92.99	90.51	84.64	86.15	89.50
P value	0.40	0.12	0.12	0.62	0.07	0.11	0.02	0.02	0.05	0.12	0.12	0.01	0.01	0.00	0.02	0.01	0.04	0.55	0.03
P 0.05							significant	significant				significant	significant	significant	significant	significant	significant		significant

Table B.2 Welch's t-test input data for industrial vs. nonindustrial construction shortcomings

	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	S12	S13
Avg. Industrial	4.15	4.15	2.96	4.33	3.59	3.70	4.67	4.52	3.74	4.70	5.04	4.22	4.74

Avg. Non-industrial	5.07	4.73	4.20	4.54	4.78	4.10	4.73	4.49	5.07	5.27	5.66	4.98	5.66
Count Industrial	54	54	54	54	54	54	54	54	54	54	54	54	54
Count Non-industrial	41	41	41	41	41	41	41	41	41	41	41	41	41
STD Industrial	2.82	2.72	1.97	2.05	2.65	2.44	2.43	2.46	2.46	2.27	2.68	2.42	2.67
STD Non-industrial	1.95	2.27	2.04	2.28	2.52	2.36	1.88	2.68	2.45	2.09	2.32	2.15	2.09
t	-1.88	-1.14	-2.96	-0.45	-2.22	-0.79	-0.15	0.06	-2.62	-1.26	-1.21	-1.60	-1.88
v	92.29	92.09	84.69	80.99	88.22	87.59	92.94	82.32	86.36	89.61	91.39	90.60	92.89
P value	0.06	0.26	0.00	0.65	0.03	0.43	0.88	0.95	0.01	0.21	0.23	0.11	0.06
P 0.05			significant		significant				significant				

Table B.3 Welch’s t-test input data comparing company sizes in industrial construction practices

	P1	P2	P3	P4	P5	P6	P7	P8	P9	P10	P11	P12	P13	P14	P15	P16	P17	P18	P19
Avg. Large	6.36	6.05	6.50	5.05	6.64	4.91	6.09	5.86	5.82	5.64	6.68	6.00	5.59	5.23	4.45	4.91	6.23	4.77	5.41
Avg. Medium	6.33	5.33	6.67	5.67	5.67	4.67	5.67	5.00	4.00	4.33	5.67	5.00	3.67	3.67	3.33	3.00	6.00	5.00	4.67
Avg. Small	6.00	4.50	6.00	5.50	4.50	2.50	4.00	5.00	4.00	4.50	5.50	4.00	5.00	3.50	1.50	1.00	5.50	3.50	4.50
Count	44.0	44.0	44.0	44.0	44.0	44.0	44.0	44.0	44.0	44.0	44.0	44.0	44.0	44.0	44.00	44.00	44.0	44.0	44.0

Large	0	0	0	0	0	0	0	0	0	0	0	0	0	0			0	0	0
Count Medium	6.00	6.00	6.00	6.00	6.00	6.00	6.00	6.00	6.00	6.00	6.00	6.00	6.00	6.00	6.00	6.00	6.00	6.00	6.00
Count Small	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00
STD Large	1.73	2.23	1.86	2.00	1.78	2.61	2.03	2.56	2.27	2.38	1.82	2.30	2.64	2.51	2.81	2.84	2.01	2.49	2.59
STD Medium	2.34	3.01	1.63	2.34	3.20	3.72	1.97	2.76	2.53	3.44	1.97	2.45	2.94	2.94	3.27	3.03	1.79	2.76	3.01
STD Small	2.31	3.42	2.83	1.91	1.91	2.52	3.65	3.46	3.65	2.52	3.79	3.27	3.83	3.42	1.91	1.15	1.91	2.52	1.91
Large VS Medium																			
t	0.03	0.56	-0.23	-0.62	0.73	0.15	0.49	0.73	1.67	0.90	1.20	0.94	1.52	1.24	0.80	1.46	0.29	-0.19	0.58
v	5.77	5.77	6.90	6.04	5.43	5.69	6.55	6.23	6.15	5.67	6.23	6.26	6.14	6.03	6.06	6.26	6.85	6.17	6.05
P	0.98	0.60	0.83	0.56	0.50	0.88	0.64	0.50	0.15	0.41	0.28	0.38	0.18	0.26	0.45	0.20	0.78	0.85	0.59
Significance																			
Large VS Small																			
t	0.31	0.89	0.35	-0.45	2.15	1.83	1.13	0.49	0.98	0.87	0.62	1.20	0.30	0.99	2.82	5.44	0.72	0.97	0.88
v	3.31	3.24	3.24	3.62	3.49	3.61	3.17	3.30	3.21	3.51	3.13	3.28	3.26	3.30	4.28	7.05	3.63	3.56	4.07
P	0.78	0.44	0.75	0.68	0.12	0.17	0.34	0.66	0.40	0.45	0.58	0.32	0.78	0.40	0.05	0.00	0.52	0.40	0.43
Significance															significant	significant			
Medium VS Small																			
t	0.22	0.40	0.43	0.12	0.72	1.10	0.84	0.00	0.00	-0.09	0.08	0.52	-0.59	0.08	1.12	1.46	0.42	0.89	0.11
v	6.64	5.95	4.35	7.49	7.98	7.97	4.18	5.48	4.92	7.84	4.10	5.23	5.33	5.85	7.96	6.87	6.24	7.02	8.00
P	0.83	0.71	0.69	0.91	0.50	0.31	0.45	1.00	1.00	0.93	0.94	0.62	0.58	0.94	0.30	0.19	0.69	0.40	0.92

Significance																			

Table B.4 Welch's t-test input data comparing company sizes in industrial construction shortcomings

	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	S12	S13
Avg. Large	4.00	4.45	2.91	4.27	3.64	3.50	4.50	4.50	3.68	4.86	5.14	4.18	4.68
Avg. Medium	5.67	2.67	3.00	4.67	3.67	4.00	5.67	5.33	3.33	3.67	4.33	4.67	5.67
Avg. Small	3.50	3.00	3.50	4.50	3.00	5.50	5.00	3.50	5.00	4.50	5.00	4.00	4.00
Count Large	44.00	44.00	44.00	44.00	44.00	44.00	44.00	44.00	44.00	44.00	44.00	44.00	44.00
Count Medium	6.00	6.00	6.00	6.00	6.00	6.00	6.00	6.00	6.00	6.00	6.00	6.00	6.00
Count Small	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00
STD Large	2.82	2.72	1.97	2.05	2.65	2.44	2.43	2.46	2.46	2.27	2.68	2.42	2.67
STD Medium	3.20	2.42	1.67	2.42	3.20	3.10	2.94	2.73	3.01	2.66	2.34	2.73	2.94
STD Small	1.91	2.00	3.00	1.91	1.15	2.52	2.58	1.91	1.15	1.91	2.58	2.83	2.31
Large VS Medium													

t	-1.21	1.67	-0.12	-0.38	-0.02	-0.38	-0.93	-0.71	0.27	1.05	0.77	-0.41	-0.78
v	6.11	6.84	7.04	6.01	5.97	5.88	5.96	6.16	5.94	6.04	6.93	6.11	6.18
P	0.27	0.15	0.91	0.72	0.98	0.72	0.40	0.51	0.80	0.33	0.47	0.69	0.47
Significance													
Large VS Small													
t	0.48	1.35	-0.39	-0.23	0.91	-1.53	-0.37	0.97	-1.92	0.36	0.10	0.12	0.56
v	4.29	4.08	3.24	3.65	6.44	3.53	3.50	3.96	5.91	3.81	3.62	3.41	3.77
P	0.66	0.25	0.72	0.84	0.40	0.22	0.73	0.40	0.11	0.74	0.93	0.91	0.62
Significance													
Medium VS Small													
t	1.34	-0.24	-0.30	0.12	0.47	-0.84	0.38	1.25	-1.23	-0.58	-0.42	0.37	1.00
v	7.98	7.46	4.26	7.61	6.71	7.52	7.21	7.92	6.89	7.87	6.09	6.41	7.64
P	0.22	0.82	0.78	0.91	0.66	0.43	0.72	0.25	0.27	0.58	0.69	0.72	0.35
Significance													

Appendix C: Hypothetical projects detailed data for Monte Carlo simulation

In this appendix, detailed information about the Monte Carlo simulation model and output of the model are presented respectively.

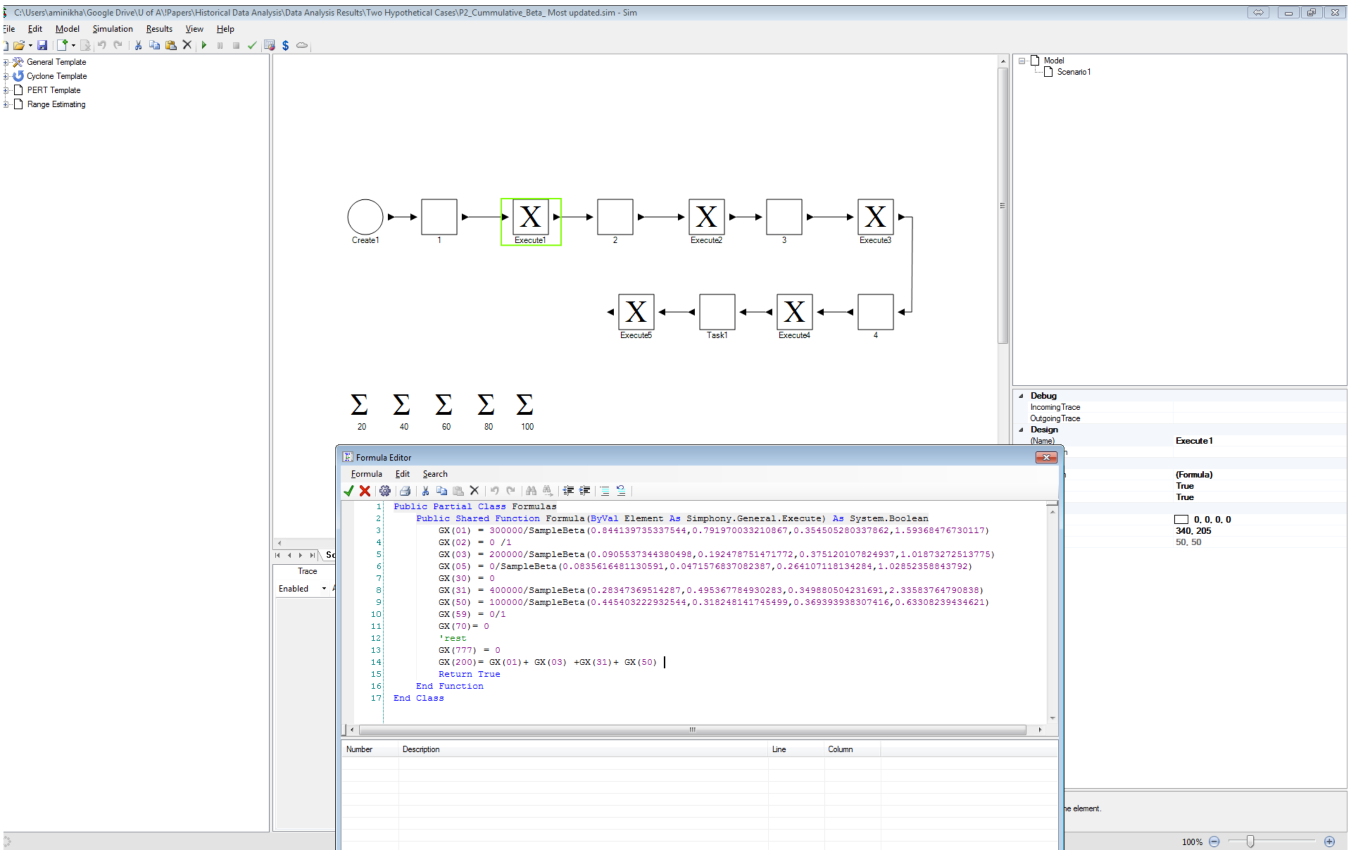

Figure C.1 Simphony.NET simulation model and sample code for 20% completion point forecast

Table C.1 forecasted projects actual cost

% Complete	EV	Project 1		Project 2	
		Average Cost	*CPI*	Average Cost	*CPI*
20%	$ 1,000,000	$ 1,214,005	0.82	$ 1,469,151	0.68
40%	$ 2,500,000	$ 2,835,643	0.88	$ 2,539,118	0.98
60%	$ 5,000,000	$ 4,664,339	1.07	$ 4,280,991	1.17
80%	$ 6,500,000	$ 5,966,305	1.09	$ 5,612,557	1.16
100%	$ 7,500,000	$ 7,179,655	1.04	$ 6,783,141	1.11

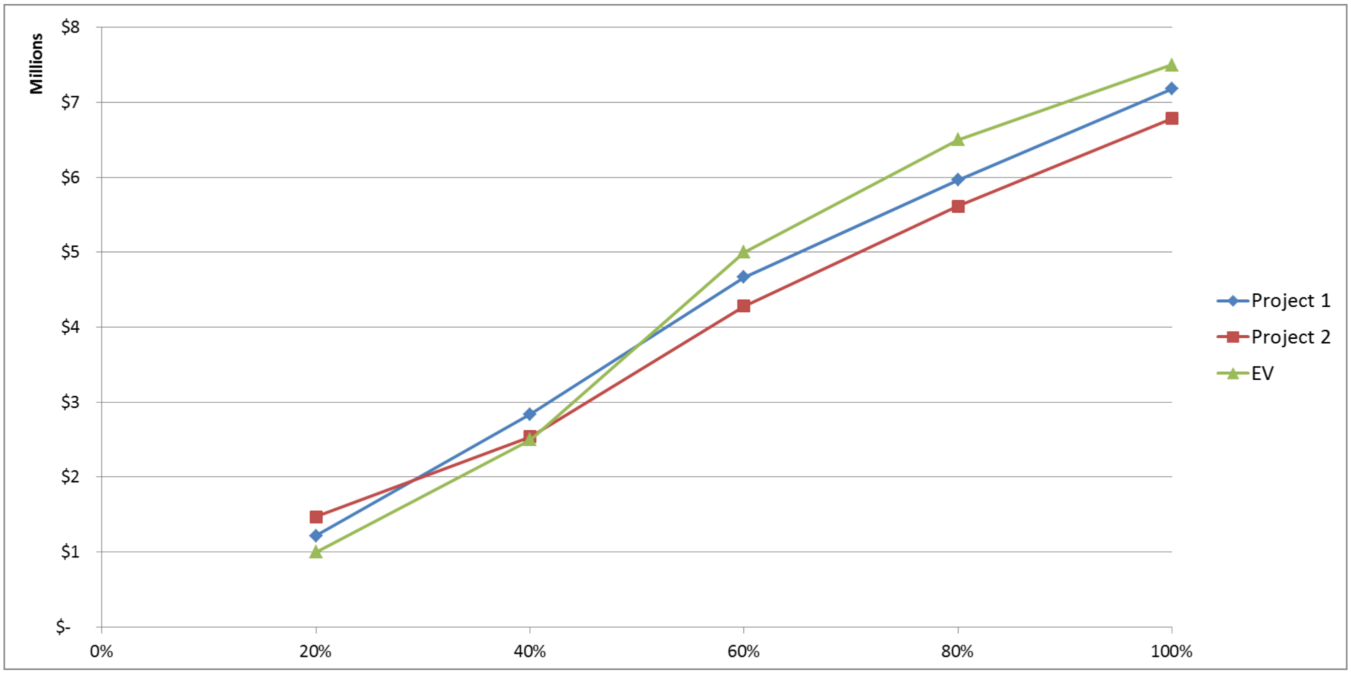

Figure C.2 forecasted project cost for the hypothetical project 1 and 2

Appendix D: Implementation of the Makov-Baysian approach in Simphony.NET

D.1 Codes for storing the read Markov transition matrices

```
Public Partial Class Formulas
      Public Shared Function Formula(ByVal Element As
Simphony.General.Execute) As System.Boolean
            'Defines for each function code
            Dim Dis as Int16
            DIS=0100


            'Iinitail Alpha values for A
                  GX(7770001+DIS)  = LX(01)
                  GX(7770002+DIS)  = LX(02)
                  GX(7770003+DIS)  = LX(03)
                  GX(7770004+DIS)  = LX(04)
                  GX(7770005+DIS)  = LX(05)
                  GX(7770006+DIS)  = LX(06)

                  'Iinitail Alpha values for B
                  GX(7770007+DIS)  = LX(07)
                  GX(7770008+DIS)  = LX(08)
                  GX(7770009+DIS)  = LX(09)
                  GX(7770010+DIS)  = LX(10)
                  GX(7770011+DIS)  = LX(11)
                  GX(7770012+DIS)  = LX(12)


                  'Iinitail Alpha values for C
                  GX(7770013+DIS)  = LX(13)
                  GX(7770014+DIS)  = LX(14)
                  GX(7770015+DIS)  = LX(15)
                  GX(7770016+DIS)  = LX(16)
                  GX(7770017+DIS)  = LX(17)
                  GX(7770018+DIS)  = LX(18)


                  'Iinitail Alpha values for D
                  GX(7770019+DIS)  = LX(19)
                  GX(7770020+DIS)  = LX(20)
                  GX(7770021+DIS)  = LX(21)
                  GX(7770022+DIS)  = LX(22)
                  GX(7770023+DIS)  = LX(23)
                  GX(7770024+DIS)  = LX(24)


                  'Iinitail Alpha values for E
                  GX(7770025+DIS)  = LX(25)
                  GX(7770026+DIS)  = LX(26)
                  GX(7770027+DIS)  = LX(27)
                  GX(7770028+DIS)  = LX(28)
                  GX(7770029+DIS)  = LX(29)
```

```
                  GX(7770030+DIS) = LX(30)

                  'Iinitail Alpha values for F
                  GX(7770031+DIS) = LX(31)
                  GX(7770032+DIS) = LX(32)
                  GX(7770033+DIS) = LX(33)
                  GX(7770034+DIS) = LX(34)
                  GX(7770035+DIS) = LX(35)
                  GX(7770036+DIS) = LX(36)




            Return True
      End Function
End Class
```

D.2 Codes for storing net PV values

```
Public Partial Class Formulas
      Public Shared Function Formula(ByVal Element As
Simphony.General.Execute) As System.Boolean
            GX(0100)=LX(1)
            GX((0200))=LX(2)
            GX((0300))=LX(3)
            GX((0500))=LX(5)
            GX((1400))=LX(14)
            GX((2000))=LX(20)
            GX((2600))=LX(26)
            GX((3000))=LX(30)
            GX((3100))=LX(31)
            GX((5000))=LX(50)
            GX((5900))=LX(59)
            GX((7000))=LX(70)
            GX((8000))=LX(80)

            Return True
      End Function
End Class
```

D.3 Codes for sampling from the Dirichlet distribution and updating transition matrices

```
Imports Simphony.Mathematics
Imports Simphony.General
Public Partial Class Formulas
      Public Shared Function Formula(ByVal Element As
Simphony.General.Execute) As System.Boolean
            Dim MarkovModel As MarkovModel = Scenario.GetElement(Of
MarkovModel)("M_A")
                  Dim MarkovChain As MarkovChain = MarkovModel.MarkovChain
                  Dim DIS as Int16 = 0100

                  'GX(777XX) for Alpha Values
                  'GX(888XX) for Yi value
                  'GX(999XX) for Dirichlet probability
                  'Sample from Gamma for different Alpha values


                  Dim A as Double
                  'Sample from Gamma for each Alpha value
                  A= SampleUniform(0,1)
                  GX(8880001+DIS)=
Gamma.QuantileFunction(GX(7770001+DIS),1,A)
                  GX(8880002+DIS)=
Gamma.QuantileFunction(GX(7770002+DIS),1,A)
                  GX(8880003+DIS)=
Gamma.QuantileFunction(GX(7770003+DIS),1,A)
                  GX(8880004+DIS)=
Gamma.QuantileFunction(GX(7770004+DIS),1,A)
                  GX(8880005+DIS)=
Gamma.QuantileFunction(GX(7770005+DIS),1,A)
                  GX(8880006+DIS)=
Gamma.QuantileFunction(GX(7770006+DIS),1,A)

                  'Sample from Dirichlet using sampled Gamma values
                  GX(19990000+DIS)=
GX(8880001+DIS)+GX(8880002+DIS)+GX(8880003+DIS)+GX(8880004+DIS)+GX(8880005+DI
S)+GX(8880006+DIS)
                  GX(9990001+DIS)  = GX(8880001+DIS)/GX(19990000+DIS)
                  GX(9990002+DIS)  = GX(8880002+DIS)/GX(19990000+DIS)
                  GX(9990003+DIS)  = GX(8880003+DIS)/GX(19990000+DIS)
                  GX(9990004+DIS)  = GX(8880004+DIS)/GX(19990000+DIS)
                  GX(9990005+DIS)  = GX(8880005+DIS)/GX(19990000+DIS)
                  GX(9990006+DIS)  = GX(8880006+DIS)/GX(19990000+DIS)
                  'Update MarkovChain Uisng values from the Dirichlet Dist.
                  MarkovChain.Transitions("A", "A").Probability =
GX(9990001+DIS)
                  MarkovChain.Transitions("A", "B").Probability =
GX(9990002+DIS)
                  MarkovChain.Transitions("A", "C").Probability =
GX(9990003+DIS)
                  MarkovChain.Transitions("A", "D").Probability =
GX(9990004+DIS)
                  MarkovChain.Transitions("A", "E").Probability =
GX(9990005+DIS)
```

```
                    MarkovChain.Transitions("A", "F").Probability = 1-
GX(9990001+DIS)-GX(9990002+DIS)-GX(9990003+DIS)-GX(9990004+DIS)-
GX(9990005+DIS)



                    'Sample from Gamma for each Alpha value

                    GX(8880007+DIS)=
Gamma.QuantileFunction(GX(7770001+DIS),1,A)
                    GX(8880008+DIS)=
Gamma.QuantileFunction(GX(7770002+DIS),1,A)
                    GX(8880009+DIS)=
Gamma.QuantileFunction(GX(7770003+DIS),1,A)
                    GX(8880010+DIS)=
Gamma.QuantileFunction(GX(7770004+DIS),1,A)
                    GX(8880011+DIS)=
Gamma.QuantileFunction(GX(7770005+DIS),1,A)
                    GX(8880012+DIS)=
Gamma.QuantileFunction(GX(7770006+DIS),1,A)

                    'Sample from Dirichlet using sampled Gamma values
                    GX(29990000+DIS)=
GX(8880007+DIS)+GX(8880008+DIS)+GX(8880009+DIS)+GX(8880010+DIS)+GX(8880011+DI
S)+GX(8880012+DIS)
                    GX(9990007+DIS) = GX(8880007+DIS)/GX(29990000+DIS)
                    GX(9990008+DIS) = GX(8880008+DIS)/GX(29990000+DIS)
                    GX(9990009+DIS) = GX(8880009+DIS)/GX(29990000+DIS)
                    GX(9990010+DIS) = GX(8880010+DIS)/GX(29990000+DIS)
                    GX(9990011+DIS) = GX(8880011+DIS)/GX(29990000+DIS)
                    GX(9990012+DIS) = GX(8880012+DIS)/GX(29990000+DIS)
                    'Update MarkovChain Uisng values from the Dirichlet Dist.
                    MarkovChain.Transitions("B", "A").Probability =
GX(9990007+DIS)
                    MarkovChain.Transitions("B", "B").Probability =
GX(9990008+DIS)
                    MarkovChain.Transitions("B", "C").Probability =
GX(9990009+DIS)
                    MarkovChain.Transitions("B", "D").Probability =
GX(9990010+DIS)
                    MarkovChain.Transitions("B", "E").Probability =
GX(9990011+DIS)
                    MarkovChain.Transitions("B", "F").Probability = 1-
GX(9990007+DIS)-GX(9990008+DIS)-GX(9990009+DIS)-GX(9990010+DIS)-
GX(9990011+DIS)



                    'Sample from Gamma for each Alpha value

                    GX(8880013+DIS)=
Gamma.QuantileFunction(GX(7770013+DIS),1,A)
                    GX(8880014+DIS)=
Gamma.QuantileFunction(GX(7770014+DIS),1,A)
                    GX(8880015+DIS)=
Gamma.QuantileFunction(GX(7770015+DIS),1,A)
                    GX(8880016+DIS)=
Gamma.QuantileFunction(GX(7770016+DIS),1,A)
```

```
                    GX(8880017+DIS)=
Gamma.QuantileFunction(GX(7770017+DIS),1,A)
                    GX(8880018+DIS)=
Gamma.QuantileFunction(GX(7770018+DIS),1,A)

                    'Sample from Dirichlet using sampled Gamma values
                    GX(39990000+DIS)=
GX(8880013+DIS)+GX(8880014+DIS)+GX(8880015+DIS)+GX(8880016+DIS)+GX(8880017+DI
S)+GX(8880018+DIS)
                    GX(9990013+DIS) = GX(8880013+DIS)/GX(39990000+DIS)
                    GX(9990014+DIS) = GX(8880014+DIS)/GX(39990000+DIS)
                    GX(9990015+DIS) = GX(8880015+DIS)/GX(39990000+DIS)
                    GX(9990016+DIS) = GX(8880016+DIS)/GX(39990000+DIS)
                    GX(9990017+DIS) = GX(8880017+DIS)/GX(39990000+DIS)
                    GX(9990018+DIS) = GX(8880018+DIS)/GX(39990000+DIS)
                    'Update MarkovChain Uisng values from the Dirichlet Dist.
                    MarkovChain.Transitions("C", "A").Probability =
GX(9990013+DIS)
                    MarkovChain.Transitions("C", "B").Probability =
GX(9990014+DIS)
                    MarkovChain.Transitions("C", "C").Probability =
GX(9990015+DIS)
                    MarkovChain.Transitions("C", "D").Probability =
GX(9990016+DIS)
                    MarkovChain.Transitions("C", "E").Probability =
GX(9990017+DIS)
                    MarkovChain.Transitions("C", "F").Probability = 1-
GX(9990013+DIS)-GX(9990014+DIS)-GX(9990015+DIS)-GX(9990016+DIS)-
GX(9990017+DIS)


                    'Sample from Gamma for each Alpha value

                    GX(8880019+DIS)=
Gamma.QuantileFunction(GX(7770019+DIS),1,A)
                    GX(8880020+DIS)=
Gamma.QuantileFunction(GX(7770020+DIS),1,A)
                    GX(8880021+DIS)=
Gamma.QuantileFunction(GX(7770021+DIS),1,A)
                    GX(8880022+DIS)=
Gamma.QuantileFunction(GX(7770022+DIS),1,A)
                    GX(8880023+DIS)=
Gamma.QuantileFunction(GX(7770023+DIS),1,A)
                    GX(8880024+DIS)=
Gamma.QuantileFunction(GX(7770024+DIS),1,A)

                    'Sample from Dirichlet using sampled Gamma values
                    GX(49990000+DIS)=
GX(8880019+DIS)+GX(8880020+DIS)+GX(8880021+DIS)+GX(8880022+DIS)+GX(8880023+DI
S)+GX(8880024+DIS)
                    GX(9990019+DIS) = GX(8880019+DIS)/GX(49990000+DIS)
                    GX(9990020+DIS) = GX(8880020+DIS)/GX(49990000+DIS)
                    GX(9990021+DIS) = GX(8880021+DIS)/GX(49990000+DIS)
                    GX(9990022+DIS) = GX(8880022+DIS)/GX(49990000+DIS)
                    GX(9990023+DIS) = GX(8880023+DIS)/GX(49990000+DIS)
                    GX(9990024+DIS) = GX(8880024+DIS)/GX(49990000+DIS)
                    'Update MarkovChain Uisng values from the Dirichlet Dist.
```

```
                    MarkovChain.Transitions("D", "A").Probability =
GX(9990019+DIS)
                    MarkovChain.Transitions("D", "B").Probability =
GX(9990020+DIS)
                    MarkovChain.Transitions("D", "C").Probability =
GX(9990021+DIS)
                    MarkovChain.Transitions("D", "D").Probability =
GX(9990022+DIS)
                    MarkovChain.Transitions("D", "E").Probability =
GX(9990023+DIS)
                    MarkovChain.Transitions("D", "F").Probability = 1-
GX(9990019+DIS)-GX(9990020+DIS)-GX(9990021+DIS)-GX(9990022+DIS)-
GX(9990023+DIS)



                    'Sample from Gamma for each Alpha value

                    GX(8880025+DIS)=
Gamma.QuantileFunction(GX(7770025+DIS),1,A)
                    GX(8880026+DIS)=
Gamma.QuantileFunction(GX(7770026+DIS),1,A)
                    GX(8880027+DIS)=
Gamma.QuantileFunction(GX(7770027+DIS),1,A)
                    GX(8880028+DIS)=
Gamma.QuantileFunction(GX(7770028+DIS),1,A)
                    GX(8880029+DIS)=
Gamma.QuantileFunction(GX(7770029+DIS),1,A)
                    GX(8880030+DIS)=
Gamma.QuantileFunction(GX(7770030+DIS),1,A)

                    'Sample from Dirichlet using sampled Gamma values
                    GX(59990000+DIS)=
GX(8880025+DIS)+GX(8880026+DIS)+GX(8880027+DIS)+GX(8880028+DIS)+GX(8880029+DI
S)+GX(8880030+DIS)
                    GX(9990025+DIS) = GX(8880025+DIS)/GX(59990000+DIS)
                    GX(9990026+DIS) = GX(8880026+DIS)/GX(59990000+DIS)
                    GX(9990027+DIS) = GX(8880027+DIS)/GX(59990000+DIS)
                    GX(9990028+DIS) = GX(8880028+DIS)/GX(59990000+DIS)
                    GX(9990029+DIS) = GX(8880029+DIS)/GX(59990000+DIS)
                    GX(9990030+DIS) = GX(8880030+DIS)/GX(59990000+DIS)
                    'Update MarkovChain Uisng values from the Dirichlet Dist.
                    MarkovChain.Transitions("E", "A").Probability =
GX(9990025+DIS)
                    MarkovChain.Transitions("E", "B").Probability =
GX(9990026+DIS)
                    MarkovChain.Transitions("E", "C").Probability =
GX(9990027+DIS)
                    MarkovChain.Transitions("E", "D").Probability =
GX(9990028+DIS)
                    MarkovChain.Transitions("E", "E").Probability =
GX(9990029+DIS)
                    MarkovChain.Transitions("E", "F").Probability = 1-
GX(9990025+DIS)-GX(9990026+DIS)-GX(9990027+DIS)-GX(9990028+DIS)-
GX(9990029+DIS)
```

```
                    'Sample from Gamma for each Alpha value

                    GX(8880031+DIS)=
Gamma.QuantileFunction(GX(7770031+DIS),1,A)
                    GX(8880032+DIS)=
Gamma.QuantileFunction(GX(7770032+DIS),1,A)
                    GX(8880033+DIS)=
Gamma.QuantileFunction(GX(7770033+DIS),1,A)
                    GX(8880034+DIS)=
Gamma.QuantileFunction(GX(7770034+DIS),1,A)
                    GX(8880035+DIS)=
Gamma.QuantileFunction(GX(7770035+DIS),1,A)
                    GX(8880036+DIS)=
Gamma.QuantileFunction(GX(7770036+DIS),1,A)

                    'Sample from Dirichlet using sampled Gamma values
                    GX(69990000+DIS)=
GX(8880031+DIS)+GX(8880032+DIS)+GX(8880033+DIS)+GX(8880034+DIS)+GX(8880035+DI
S)+GX(8880036+DIS)
                    GX(9990031+DIS) = GX(8880031+DIS)/GX(69990000+DIS)
                    GX(9990032+DIS) = GX(8880032+DIS)/GX(69990000+DIS)
                    GX(9990033+DIS) = GX(8880033+DIS)/GX(69990000+DIS)
                    GX(9990034+DIS) = GX(8880034+DIS)/GX(69990000+DIS)
                    GX(9990035+DIS) = GX(8880035+DIS)/GX(69990000+DIS)
                    GX(9990036+DIS) = GX(8880036+DIS)/GX(69990000+DIS)
                    'Update MarkovChain Uisng values from the Dirichlet Dist.
                    MarkovChain.Transitions("F", "A").Probability =
GX(9990031+DIS)
                    MarkovChain.Transitions("F", "B").Probability =
GX(9990032+DIS)
                    MarkovChain.Transitions("F", "C").Probability =
GX(9990033+DIS)
                    MarkovChain.Transitions("F", "D").Probability =
GX(9990034+DIS)
                    MarkovChain.Transitions("F", "E").Probability =
GX(9990035+DIS)
                    MarkovChain.Transitions("F", "F").Probability = 1-
GX(9990031+DIS)-GX(9990032+DIS)-GX(9990033+DIS)-GX(9990034+DIS)-
GX(9990035+DIS)



             Return True
      End Function
End Class
```

D.4 Codes for quantifying *CPI* and calculating EAC

```
Imports Simphony.General
Public Partial Class Formulas
      Public Shared Function Formula(ByVal Element As
Simphony.General.Execute) As System.Boolean

            Dim MarkovModel As MarkovModel = Scenario.GetElement(Of
MarkovModel)("M_A")

            Dim DIS as Int16 = 0100

            If GetMarkovState(MarkovModel.Name) = "A" Then
                  GX(110000+DIS)= SampleUniform(1.4, 1.7)
                  Elseif GetMarkovState(MarkovModel.Name) = "B" Then
                  GX(110000+DIS)= SampleUniform(1.2, 1.4)
                  Elseif GetMarkovState(MarkovModel.Name) = "C" Then
                  GX(110000+DIS)= SampleUniform(1.0, 1.2)
                  Elseif GetMarkovState(MarkovModel.Name) = "D" Then
                  GX(110000+DIS)= SampleUniform(0.8, 1.0)
                  Elseif GetMarkovState(MarkovModel.Name) = "E" Then
                  GX(110000+DIS)= SampleUniform(0.6, 0.8)
                  Elseif GetMarkovState(MarkovModel.Name) = "F" Then
                  GX(110000+DIS)= SampleUniform(0.3, 0.6)
            END IF
            GX(-DIS)=GX(DIS)/GX(110000+DIS)+GX(-DIS)
            'Traceline(GetMarkovState(MarkovModel.Name))



            Return True
      End Function
End Class
```

Appendix E: Randomly generated projects raw data

Table E.1 Net monthly performance data for randomly generated projects in discipline 01

Project		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
P1	PV	120	95	114	84	96	143	146	153	134	147	149	126	131	154	141	159	127	126	151	136	86	81	107	83
	EV	120	95	114	84	96	143	146	153	134	147	149	126	131	154	141	159	127	126	151	136	86	81	107	83
	AC	148	185	122	129	108	249	150	184	173	282	213	219	162	242	279	234	168	208	149	129	151	103	157	144
P2	PV	110	111	82	104	114	159	131	130	147	139	129	154	140	157	150	147	122	126	140	138	120	90	98	85
	EV	110	111	82	104	114	159	131	130	147	139	129	154	140	157	150	147	122	126	140	138	120	90	98	85
	AC	117	101	118	101	112	216	168	164	272	188	240	180	133	226	155	179	146	202	209	273	204	155	132	89
P3	PV	98	112	103	105	96	141	151	134	140	122	131	145	151	130	155	157	125	141	149	149	95	109	110	80
	EV	98	112	103	105	96	141	151	134	140	122	131	145	151	130	155	157	125	141	149	149	95	109	110	80
	AC	153	214	200	149	168	235	184	263	270	139	259	216	230	133	250	184	229	197	280	264	182	177	175	81
P4	PV	111	89	97	84	118	158	150	154	141	125	155	148	140	120	138	124	148	125	159	147	99	108	81	80
	EV	111	89	97	84	118	158	150	154	141	125	155	148	140	120	138	124	148	125	159	147	99	108	81	80
	AC	190	139	96	98	138	156	254	188	207	135	229	157	179	212	276	234	154	144	289	257	104	164	100	160
P5	PV	116	87	115	104	81	129	128	142	158	128	146	140	149	140	160	144	148	122	133	145	90	91	90	96
	EV	116	87	115	104	81	129	128	142	158	128	146	140	149	140	160	144	148	122	133	145	90	91	90	96
	AC	193	92	130	185	79	222	242	168	171	221	134	182	294	206	294	223	243	128	266	222	104	169	96	123
P6	PV	84	102	88	117	115	125	153	158	128	159	126	125	147	121	152	120	122	134	160	130	118	86	106	94
	EV	84	102	88	117	115	125	153	158	128	159	126	125	147	121	152	120	122	134	160	130	118	86	106	94
	AC	119	203	151	152	208	210	257	207	182	261	129	218	244	225	141	178	221	190	317	182	113	117	166	104
P7	PV	92	91	108	93	100	144	137	126	139	148	138	142	160	158	147	132	136	130	140	148	99	97	84	91
	EV	92	91	108	93	100	144	137	126	139	148	138	142	160	158	147	132	136	130	140	148	99	97	84	91
	AC	160	96	149	110	139	166	226	212	243	148	213	266	187	316	137	240	269	218	150	296	178	146	162	164
P8	PV	95	91	116	82	98	158	127	156	156	135	136	120	157	153	133	157	157	123	126	120	113	99	83	102
	EV	95	91	116	82	98	158	127	156	156	135	136	120	157	153	133	157	157	123	126	120	113	99	83	102

	AC	145	149	144	92	189	245	189	259	309	180	150	114	292	237	251	250	199	186	165	184	107	191	107	128
P9	PV	81	119	86	107	99	152	146	160	148	137	150	141	139	124	128	121	154	153	135	124	83	97	95	101
	EV	81	119	86	107	99	152	146	160	148	137	150	141	139	124	128	121	154	153	135	124	83	97	95	101
	AC	141	124	119	125	131	198	288	173	136	170	192	226	200	218	255	221	199	191	258	207	100	182	102	92
P10	PV	89	95	102	101	119	138	132	132	121	128	157	122	129	139	150	146	142	160	148	143	93	94	110	108
	EV	89	95	102	101	119	138	132	132	121	128	157	122	129	139	150	146	142	160	148	143	93	94	110	108
	AC	115	127	174	159	183	273	168	242	183	211	184	166	201	129	290	204	214	282	274	189	133	180	188	130
P11	PV	86	90	109	115	104	139	149	120	128	124	127	135	156	125	139	149	135	144	154	152	104	83	80	82
	EV	86	90	109	115	104	139	149	120	128	124	127	135	156	125	139	149	135	144	154	152	104	83	80	82
	AC	115	102	190	120	155	271	188	128	155	186	123	219	256	166	156	279	173	181	180	290	153	81	134	113
P12	PV	85	90	116	120	83	123	133	133	152	142	145	122	122	151	146	126	123	158	129	133	108	91	100	120
	EV	85	90	116	120	83	123	133	133	152	142	145	122	122	151	146	126	123	158	129	133	108	91	100	120
	AC	167	133	158	238	139	199	247	205	201	192	278	228	142	294	250	159	159	164	184	130	125	96	169	162
P13	PV	85	82	108	119	116	138	126	122	127	160	140	159	132	154	140	125	146	144	127	146	92	97	112	107
	EV	85	82	108	119	116	138	126	122	127	160	140	159	132	154	140	125	146	144	127	146	92	97	112	107
	AC	125	116	180	202	187	148	249	122	188	307	154	296	218	194	164	233	228	144	211	231	132	106	104	146
P14	PV	90	100	95	98	86	127	138	156	131	134	142	120	147	144	149	125	153	134	130	132	117	90	93	94
	EV	90	100	95	98	86	127	138	156	131	134	142	120	147	144	149	125	153	134	130	132	117	90	93	94
	AC	86	110	180	170	89	178	157	198	204	135	176	119	182	215	197	165	171	214	200	170	204	167	157	112
P15	PV	87	105	104	80	113	127	130	148	124	123	158	126	124	145	154	156	149	141	153	123	94	89	87	111
	EV	87	105	104	80	113	127	130	148	124	123	158	126	124	145	154	156	149	141	153	123	94	89	87	111
	AC	171	197	116	132	192	230	179	249	198	182	313	241	205	241	263	193	244	133	168	151	125	129	163	192
P16	PV	88	111	111	96	97	135	160	155	122	158	134	130	157	141	125	126	126	133	152	148	113	110	92	82
	EV	88	111	111	96	97	135	160	155	122	158	134	130	157	141	125	126	126	133	152	148	113	110	92	82
	AC	118	108	196	94	184	221	298	178	172	177	232	148	270	255	216	166	210	174	258	229	208	169	149	122
P17	PV	116	90	97	116	93	128	135	155	151	134	137	150	132	129	149	143	139	151	153	145	81	84	108	92
	EV	116	90	97	116	93	128	135	155	151	134	137	150	132	129	149	143	139	151	153	145	81	84	108	92
	AC	115	92	142	160	103	198	139	257	211	244	133	204	164	237	158	167	132	143	162	283	99	152	192	121
P18	PV	113	84	90	102	86	152	160	137	120	125	130	150	144	159	148	140	120	149	154	131	88	108	111	109
	EV	113	84	90	102	86	152	160	137	120	125	130	150	144	159	148	140	120	149	154	131	88	108	111	109
	AC	123	119	95	168	125	210	203	171	151	180	212	207	156	313	181	190	155	252	262	217	153	139	219	196

P19	PV	104	97	113	111	104	130	126	132	139	135	146	158	143	155	147	135	134	151	121	133	99	112	106	106
	EV	104	97	113	111	104	130	126	132	139	135	146	158	143	155	147	135	134	151	121	133	99	112	106	106
	AC	174	103	155	122	139	200	242	195	199	163	197	270	176	220	154	224	174	227	188	165	190	118	196	122
P20	PV	81	86	84	107	109	137	149	122	154	125	141	121	134	122	146	122	143	129	120	121	100	92	101	101
	EV	81	86	84	107	109	137	149	122	154	125	141	121	134	122	146	122	143	129	120	121	100	92	101	101
	AC	97	131	102	119	155	144	210	207	259	133	197	148	198	215	185	203	286	248	203	206	129	84	198	126
P21	PV	87	120	88	84	116	137	128	123	158	152	132	152	121	124	160	138	154	136	142	135	90	120	103	112
	EV	87	120	88	84	116	137	128	123	158	152	132	152	121	124	160	138	154	136	142	135	90	120	103	112
	AC	149	224	175	163	215	207	119	130	294	239	261	198	207	211	250	217	256	154	133	162	154	160	149	178
P22	PV	100	85	118	92	117	126	130	139	124	138	128	130	144	151	133	128	146	139	138	157	81	95	83	97
	EV	100	85	118	92	117	126	130	139	124	138	128	130	144	151	133	128	146	139	138	157	81	95	83	97
	AC	122	128	151	170	213	184	252	157	195	268	150	217	174	294	196	198	172	277	210	179	81	89	165	144
P23	PV	89	89	98	99	103	156	129	120	135	154	152	143	131	158	135	151	123	123	142	138	83	85	104	118
	EV	89	89	98	99	103	156	129	120	135	154	152	143	131	158	135	151	123	123	142	138	83	85	104	118
	AC	85	95	139	144	145	168	239	133	270	273	272	230	131	188	228	151	122	143	178	171	78	87	152	190
P24	PV	99	116	98	92	87	140	159	125	160	132	153	140	135	131	124	145	140	160	158	132	103	87	114	117
	EV	99	116	98	92	87	140	159	125	160	132	153	140	135	131	124	145	140	160	158	132	103	87	114	117
	AC	125	212	153	169	169	260	313	154	189	224	268	277	261	134	179	155	150	157	144	149	112	148	122	167
P25	PV	117	91	81	97	87	152	134	153	152	157	152	154	136	154	126	154	131	124	136	151	114	113	102	82
	EV	117	91	81	97	87	152	134	153	152	157	152	154	136	154	126	154	131	124	136	151	114	113	102	82
	AC	136	90	133	190	108	211	149	151	252	173	304	159	257	214	183	179	156	186	193	258	115	186	151	139
P26	PV	102	103	116	118	114	127	136	138	154	147	130	146	128	152	128	132	121	151	130	151	86	91	88	106
	EV	102	103	116	118	114	127	136	138	154	147	130	146	128	152	128	132	121	151	130	151	86	91	88	106
	AC	159	133	111	119	193	168	136	261	160	154	198	178	243	231	230	248	213	214	211	285	106	148	145	127
P27	PV	88	96	110	83	115	145	129	150	125	125	126	153	150	132	144	140	160	133	140	154	111	110	92	114
	EV	88	96	110	83	115	145	129	150	125	125	126	153	150	132	144	140	160	133	140	154	111	110	92	114
	AC	99	169	179	88	106	236	222	209	171	245	131	217	158	173	207	238	194	146	143	193	208	117	98	225
P28	PV	107	85	104	112	109	135	158	136	157	134	131	150	152	122	137	154	158	134	136	158	114	112	98	120
	EV	107	85	104	112	109	135	158	136	157	134	131	150	152	122	137	154	158	134	136	158	114	112	98	120
	AC	141	116	120	123	174	196	300	199	262	236	197	291	293	177	234	219	231	189	223	316	117	166	161	227
P29	PV	108	91	99	92	110	134	150	132	160	155	124	149	131	132	123	126	159	130	153	136	80	89	101	97

	EV	108	91	99	92	110	134	150	132	160	155	124	149	131	132	123	126	159	130	153	136	80	89	101	97
	AC	134	87	107	152	144	194	288	213	302	152	118	191	204	161	139	203	205	164	168	234	136	145	131	110
P30	PV	102	81	81	110	103	129	139	131	134	157	126	147	132	147	143	142	151	125	138	136	112	94	117	89
	EV	102	81	81	110	103	129	139	131	134	157	126	147	132	147	143	142	151	125	138	136	112	94	117	89
	AC	100	133	141	106	103	121	164	139	146	246	215	175	216	147	150	141	198	226	126	152	175	175	160	90
P31	PV	90	115	101	110	106	146	151	159	158	130	145	148	141	150	140	146	134	138	127	157	110	103	96	103
	EV	90	115	101	110	106	146	151	159	158	130	145	148	141	150	140	146	134	138	127	157	110	103	96	103
	AC	136	187	193	166	133	172	246	161	164	153	183	147	231	219	181	238	224	210	124	171	193	197	137	127
P32	PV	113	115	82	119	106	148	137	138	126	125	148	148	133	151	148	122	121	123	140	135	111	117	106	109
	EV	113	115	82	119	106	148	137	138	126	125	148	148	133	151	148	122	121	123	140	135	111	117	106	109
	AC	201	161	126	208	198	284	274	196	252	149	263	176	261	222	147	173	175	244	150	244	203	220	121	215
P33	PV	96	95	116	112	95	155	154	132	121	142	155	125	133	123	155	137	133	149	154	127	117	83	100	98
	EV	96	95	116	112	95	155	154	132	121	142	155	125	133	123	155	137	133	149	154	127	117	83	100	98
	AC	160	138	147	127	150	260	200	211	151	278	242	119	192	143	270	227	227	174	290	245	172	88	141	162
P34	PV	110	118	94	86	91	133	122	138	120	156	152	131	125	146	127	127	140	126	125	148	120	80	117	101
	EV	110	118	94	86	91	133	122	138	120	156	152	131	125	146	127	127	140	126	125	148	120	80	117	101
	AC	134	232	179	142	106	247	120	144	178	268	207	172	218	291	207	236	179	234	154	209	124	119	219	157
P35	PV	99	87	83	84	98	121	160	129	126	158	123	148	135	137	142	156	141	153	135	141	87	88	81	103
	EV	99	87	83	84	98	121	160	129	126	158	123	148	135	137	142	156	141	153	135	141	87	88	81	103
	AC	111	124	125	97	138	166	314	119	145	280	177	243	123	186	251	192	254	295	166	251	97	175	92	153
P36	PV	84	101	100	100	100	156	160	157	123	122	137	127	125	156	132	158	141	140	160	133	90	102	82	120
	EV	84	101	100	100	100	156	160	157	123	122	137	127	125	156	132	158	141	140	160	133	90	102	82	120
	AC	166	121	136	180	189	282	280	181	239	228	218	180	133	200	234	262	209	223	157	138	158	144	135	208
P37	PV	100	99	84	107	89	142	157	151	149	120	148	153	130	131	123	131	138	149	144	134	107	100	104	88
	EV	100	99	84	107	89	142	157	151	149	120	148	153	130	131	123	131	138	149	144	134	107	100	104	88
	AC	93	167	147	195	89	224	242	293	282	178	249	164	168	203	165	193	135	192	177	249	185	164	111	100
P38	PV	91	90	109	94	96	136	126	143	155	156	159	156	120	144	156	136	132	138	157	128	87	89	114	120
	EV	91	90	109	94	96	136	126	143	155	156	159	156	120	144	156	136	132	138	157	128	87	89	114	120
	AC	124	146	168	181	128	243	188	183	217	296	315	189	173	180	204	268	197	215	300	166	144	165	107	178
P39	PV	117	105	93	118	84	140	143	157	129	120	131	141	151	131	129	124	157	146	157	120	81	101	91	89
	EV	117	105	93	118	84	140	143	157	129	120	131	141	151	131	129	124	157	146	157	120	81	101	91	89

	AC	200	188	137	159	113	197	226	187	170	174	124	274	243	238	169	134	286	213	209	131	137	123	88	126
P40	PV	106	118	94	84	116	124	129	146	143	126	124	143	135	157	142	131	127	152	139	131	108	107	90	97
	EV	106	118	94	84	116	124	129	146	143	126	124	143	135	157	142	131	127	152	139	131	108	107	90	97
	AC	175	113	162	158	172	159	213	261	250	118	171	225	189	151	163	143	206	195	256	131	125	120	156	179
P41	PV	102	88	90	105	80	129	127	159	140	126	134	155	131	137	139	155	144	120	133	143	84	106	108	102
	EV	102	88	90	105	80	129	127	159	140	126	134	155	131	137	139	155	144	120	133	143	84	106	108	102
	AC	158	106	86	107	94	146	150	232	181	192	197	239	215	177	272	189	148	133	193	267	140	149	156	168
P42	PV	117	91	93	90	85	137	127	132	128	158	142	128	128	139	150	130	157	159	146	129	93	119	112	88
	EV	117	91	93	90	85	137	127	132	128	158	142	128	128	139	150	130	157	159	146	129	93	119	112	88
	AC	218	105	151	97	168	234	147	172	186	220	210	219	169	234	222	131	312	301	253	119	140	228	221	119
P43	PV	89	110	106	104	111	141	146	134	149	155	123	125	154	138	150	145	150	156	136	152	115	81	89	113
	EV	89	110	106	104	111	141	146	134	149	155	123	125	154	138	150	145	150	156	136	152	115	81	89	113
	AC	91	213	134	164	142	166	136	208	159	161	138	216	148	142	296	283	249	261	237	228	113	104	86	158
P44	PV	84	98	105	102	110	129	122	139	148	160	143	120	133	121	131	146	151	152	150	127	99	91	100	116
	EV	84	98	105	102	110	129	122	139	148	160	143	120	133	121	131	146	151	152	150	127	99	91	100	116
	AC	116	196	102	181	161	228	122	268	210	237	216	134	253	229	208	285	290	160	210	166	196	87	106	140
P45	PV	119	111	90	87	112	152	148	124	124	152	151	148	147	157	132	140	123	151	123	138	104	95	116	112
	EV	119	111	90	87	112	152	148	124	124	152	151	148	147	157	132	140	123	151	123	138	104	95	116	112
	AC	201	148	95	172	177	266	148	191	201	216	204	225	140	262	253	190	193	222	180	243	129	131	182	122
P46	PV	109	91	116	113	115	145	150	149	135	125	142	120	127	123	154	148	130	131	139	150	87	86	92	91
	EV	109	91	116	113	115	145	150	149	135	125	142	120	127	123	154	148	130	131	139	150	87	86	92	91
	AC	122	92	188	146	116	215	206	168	186	136	142	221	211	145	196	266	228	140	227	275	111	168	97	86
P47	PV	95	81	94	98	111	126	155	144	139	122	155	140	154	121	123	132	130	134	140	138	81	113	104	84
	EV	95	81	94	98	111	126	155	144	139	122	155	140	154	121	123	132	130	134	140	138	81	113	104	84
	AC	101	147	129	183	193	242	293	261	231	166	287	220	308	148	218	156	172	196	258	159	92	199	182	119
P48	PV	99	118	88	97	104	156	125	157	155	134	152	159	149	130	122	128	138	146	137	132	118	113	86	120
	EV	99	118	88	97	104	156	125	157	155	134	152	159	149	130	122	128	138	146	137	132	118	113	86	120
	AC	162	186	113	187	120	190	178	305	161	163	205	181	240	159	179	136	196	273	212	227	149	157	81	240
P49	PV	107	106	83	84	113	127	149	148	141	154	121	152	134	143	157	153	123	121	151	134	91	98	114	98
	EV	107	106	83	84	113	127	149	148	141	154	121	152	134	143	157	153	123	121	151	134	91	98	114	98
	AC	173	165	125	156	107	210	225	290	272	305	231	277	226	137	248	222	141	144	302	161	162	125	112	129

P50	PV	105	119	104	94	115	146	128	122	126	136	152	122	132	125	150	156	150	149	132	148	101	83	94	117
	EV	105	119	104	94	115	146	128	122	126	136	152	122	132	125	150	156	150	149	132	148	101	83	94	117
	AC	107	228	157	159	161	203	243	192	189	167	176	239	247	126	219	234	141	195	185	272	97	129	101	201
P51	PV	81	118	84	87	95	140	139	129	120	141	123	130	145	147	128	130	129	129	134	156	84	83	119	83
	EV	81	118	84	87	95	140	139	129	120	141	123	130	145	147	128	130	129	129	134	156	84	83	119	83
	AC	111	171	133	173	114	171	200	181	215	272	234	226	244	247	252	226	155	191	263	175	102	133	156	152
P52	PV	113	85	91	107	120	136	129	133	144	128	146	121	143	121	122	159	148	131	160	120	108	98	120	120
	EV	113	85	91	107	120	136	129	133	144	128	146	121	143	121	122	159	148	131	160	120	108	98	120	120
	AC	166	130	157	169	161	219	224	205	266	173	190	196	186	137	209	164	250	238	285	130	168	192	170	154
P53	PV	104	117	85	120	96	152	126	136	126	153	136	139	128	157	158	145	158	154	127	130	101	107	111	115
	EV	104	117	85	120	96	152	126	136	126	153	136	139	128	157	158	145	158	154	127	130	101	107	111	115
	AC	159	159	135	172	111	170	136	237	183	205	254	186	174	290	262	144	182	253	185	228	182	148	189	190
P54	PV	107	119	114	88	97	159	149	152	133	140	139	134	148	140	121	140	120	152	136	135	109	90	83	112
	EV	107	119	114	88	97	159	149	152	133	140	139	134	148	140	121	140	120	152	136	135	109	90	83	112
	AC	103	209	176	127	98	192	161	284	261	258	263	201	184	241	165	164	144	223	249	189	147	168	120	118
P55	PV	108	88	80	100	114	160	143	135	144	160	137	127	160	149	125	160	148	125	132	158	95	119	112	91
	EV	108	88	80	100	114	160	143	135	144	160	137	127	160	149	125	160	148	125	132	158	95	119	112	91
	AC	205	111	126	187	152	318	177	181	203	307	159	245	195	155	233	162	255	134	210	310	112	182	111	163
P56	PV	104	85	89	88	83	129	140	139	146	127	134	134	142	159	132	135	154	131	153	139	118	113	96	91
	EV	104	85	89	88	83	129	140	139	146	127	134	134	142	159	132	135	154	131	153	139	118	113	96	91
	AC	145	97	116	172	157	152	209	272	239	226	151	174	260	165	260	200	146	255	282	254	117	175	176	175
P57	PV	102	82	91	113	96	153	131	137	121	124	125	127	133	125	138	130	158	133	120	142	100	105	101	81
	EV	102	82	91	113	96	153	131	137	121	124	125	127	133	125	138	130	158	133	120	142	100	105	101	81
	AC	132	112	132	147	95	295	250	260	177	217	144	253	219	195	239	161	295	193	173	266	200	111	137	134
P58	PV	120	102	115	111	83	125	150	150	120	152	155	159	123	120	121	153	148	144	139	141	91	104	110	106
	EV	120	102	115	111	83	125	150	150	120	152	155	159	123	120	121	153	148	144	139	141	91	104	110	106
	AC	122	111	133	158	153	153	296	195	158	143	192	318	171	118	127	278	138	246	182	257	153	176	177	207
P59	PV	81	83	84	105	101	133	130	147	148	147	154	129	127	135	139	145	152	127	124	134	108	99	95	88
	EV	81	83	84	105	101	133	130	147	148	147	154	129	127	135	139	145	152	127	124	134	108	99	95	88
	AC	112	81	121	145	198	184	228	216	206	253	249	224	206	221	196	222	188	204	213	236	102	141	89	131
P60	PV	119	116	106	101	107	122	134	126	155	145	138	127	152	123	154	131	143	146	148	129	109	80	104	119

	EV	119	116	106	101	107	122	134	126	155	145	138	127	152	123	154	131	143	146	148	129	109	80	104	119
	AC	175	190	195	189	170	159	230	146	274	207	242	254	255	240	166	153	253	248	277	217	191	93	192	108
P61	PV	112	111	83	102	87	159	129	155	129	151	146	155	139	130	148	156	122	149	148	160	96	104	93	120
	EV	112	111	83	102	87	159	129	155	129	151	146	155	139	130	148	156	122	149	148	160	96	104	93	120
	AC	132	214	147	112	166	172	182	298	170	211	188	152	247	137	289	239	145	273	155	160	169	154	102	192
P62	PV	116	93	97	115	108	148	135	157	140	142	146	127	129	151	135	129	132	158	150	156	115	110	101	108
	EV	116	93	97	115	108	148	135	157	140	142	146	127	129	151	135	129	132	158	150	156	115	110	101	108
	AC	107	149	159	169	187	229	184	250	140	249	213	212	221	288	216	190	135	273	137	254	183	208	197	138
P63	PV	99	113	98	87	80	144	152	150	156	129	127	123	153	145	160	157	130	123	143	152	104	108	114	105
	EV	99	113	98	87	80	144	152	150	156	129	127	123	153	145	160	157	130	123	143	152	104	108	114	105
	AC	153	141	166	79	142	238	205	260	204	205	184	221	245	207	224	226	247	138	225	299	132	175	220	107
P64	PV	104	94	97	97	88	121	136	141	122	153	127	137	130	142	137	155	122	140	131	150	112	81	109	98
	EV	104	94	97	97	88	121	136	141	122	153	127	137	130	142	137	155	122	140	131	150	112	81	109	98
	AC	108	126	169	184	99	125	218	245	137	260	166	271	168	216	240	152	216	127	136	261	187	84	131	149
P65	PV	116	120	106	85	89	139	138	120	136	141	159	141	150	136	134	129	120	146	120	144	106	98	102	118
	EV	116	120	106	85	89	139	138	120	136	141	159	141	150	136	134	129	120	146	120	144	106	98	102	118
	AC	191	209	200	105	169	204	156	144	146	138	243	282	233	249	226	177	127	274	179	156	107	131	99	122
P66	PV	85	116	87	116	98	143	158	148	140	138	138	159	148	147	160	146	128	142	150	129	102	114	82	115
	EV	85	116	87	116	98	143	158	148	140	138	138	159	148	147	160	146	128	142	150	129	102	114	82	115
	AC	109	117	105	193	108	142	311	163	167	157	225	296	243	228	272	197	188	203	284	186	158	228	132	217
P67	PV	85	84	98	107	118	146	138	160	153	148	152	143	123	127	128	154	134	131	149	156	105	115	112	98
	EV	85	84	98	107	118	146	138	160	153	148	152	143	123	127	128	154	134	131	149	156	105	115	112	98
	AC	140	166	181	112	181	234	127	274	260	181	263	139	218	251	212	306	196	212	218	242	144	183	159	117
P68	PV	118	93	114	104	92	137	143	122	150	125	145	159	138	150	156	124	133	121	128	145	88	94	118	91
	EV	118	93	114	104	92	137	143	122	150	125	145	159	138	150	156	124	133	121	128	145	88	94	118	91
	AC	224	127	133	193	147	166	220	161	254	220	254	301	265	165	151	200	132	200	234	138	94	126	212	131
P69	PV	92	117	93	84	86	138	129	135	146	141	123	156	155	142	150	136	128	148	132	145	84	114	117	89
	EV	92	117	93	84	86	138	129	135	146	141	123	156	155	142	150	136	128	148	132	145	84	114	117	89
	AC	104	209	113	164	121	208	232	140	193	162	246	204	152	166	287	258	184	152	194	209	151	125	142	94
P70	PV	108	104	93	113	113	120	150	145	160	125	121	122	135	132	123	130	143	159	132	129	103	83	117	93
	EV	108	104	93	113	113	120	150	145	160	125	121	122	135	132	123	130	143	159	132	129	103	83	117	93

	AC	111	114	181	172	200	138	270	270	218	126	162	221	161	214	187	228	256	146	154	197	133	120	116	98
P71	PV	112	107	110	116	118	146	135	151	159	126	145	152	135	131	120	155	121	145	148	157	89	108	109	96
	EV	112	107	110	116	118	146	135	151	159	126	145	152	135	131	120	155	121	145	148	157	89	108	109	96
	AC	205	165	164	154	175	263	150	205	213	242	191	296	225	141	187	146	212	149	231	171	154	208	154	116
P72	PV	118	97	120	119	90	155	158	129	135	146	133	125	144	135	151	130	128	138	160	147	109	102	85	113
	EV	118	97	120	119	90	155	158	129	135	146	133	125	144	135	151	130	128	138	160	147	109	102	85	113
	AC	144	130	157	115	116	217	270	123	176	140	129	241	199	221	181	225	239	219	285	160	218	141	137	123
P73	PV	118	80	105	89	119	143	148	138	141	130	139	135	150	159	137	152	132	158	123	126	94	108	116	98
	EV	118	80	105	89	119	143	148	138	141	130	139	135	150	159	137	152	132	158	123	126	94	108	116	98
	AC	195	108	100	156	130	242	170	246	162	209	186	217	192	210	182	196	223	308	155	195	141	132	144	125
P74	PV	111	118	81	83	85	137	126	137	145	160	140	151	158	145	127	145	141	132	138	158	94	92	119	84
	EV	111	118	81	83	85	137	126	137	145	160	140	151	158	145	127	145	141	132	138	158	94	92	119	84
	AC	161	170	160	165	81	148	185	138	154	278	214	180	188	160	169	218	159	190	275	182	123	89	200	113
P75	PV	109	94	95	102	115	122	156	148	137	148	133	125	129	136	153	158	130	156	121	147	89	86	87	120
	EV	109	94	95	102	115	122	156	148	137	148	133	125	129	136	153	158	130	156	121	147	89	86	87	120
	AC	156	184	104	122	202	163	211	238	193	151	237	159	120	144	148	215	190	243	184	225	178	110	87	152
P76	PV	89	120	104	96	112	156	137	158	148	123	133	120	121	156	150	122	120	136	147	135	84	80	80	96
	EV	89	120	104	96	112	156	137	158	148	123	133	120	121	156	150	122	120	136	147	135	84	80	80	96
	AC	137	198	158	161	187	298	186	273	204	133	124	167	220	262	287	199	188	196	162	188	154	75	106	108
P77	PV	94	86	84	81	104	149	149	150	123	120	159	158	141	121	158	131	120	135	143	123	84	118	94	120
	EV	94	86	84	81	104	149	149	150	123	120	159	158	141	121	158	131	120	135	143	123	84	118	94	120
	AC	107	138	133	106	134	295	235	230	133	188	291	297	248	221	164	170	192	162	207	153	119	159	163	152
P78	PV	111	92	96	95	83	142	154	121	140	123	127	153	155	152	125	153	148	157	130	158	98	118	84	101
	EV	111	92	96	95	83	142	154	121	140	123	127	153	155	152	125	153	148	157	130	158	98	118	84	101
	AC	178	136	132	113	90	180	240	207	176	231	229	177	301	214	129	231	158	195	259	172	145	144	90	166
P79	PV	120	86	108	120	106	132	122	133	129	132	148	160	124	159	124	129	157	127	143	155	92	110	120	105
	EV	120	86	108	120	106	132	122	133	129	132	148	160	124	159	124	129	157	127	143	155	92	110	120	105
	AC	191	89	206	239	120	255	135	181	178	236	240	213	187	221	229	139	212	175	225	164	119	164	199	108
P80	PV	98	102	106	111	84	125	159	156	156	154	155	146	132	149	160	141	137	136	154	144	106	91	96	92
	EV	98	102	106	111	84	125	159	156	156	154	155	146	132	149	160	141	137	136	154	144	106	91	96	92
	AC	135	201	106	188	162	224	226	197	211	202	178	164	253	258	306	130	251	238	209	151	187	92	146	108

P81	PV	99	95	104	89	114	121	140	129	146	156	150	132	128	144	135	147	153	137	155	159	97	86	95	109
	EV	99	95	104	89	114	121	140	129	146	156	150	132	128	144	135	147	153	137	155	159	97	86	95	109
	AC	107	189	167	158	163	207	242	169	237	173	140	259	143	262	132	238	158	178	271	146	90	164	136	154
P82	PV	83	114	94	112	115	136	151	145	144	137	129	160	136	126	131	152	147	143	140	137	118	82	109	106
	EV	83	114	94	112	115	136	151	145	144	137	129	160	136	126	131	152	147	143	140	137	118	82	109	106
	AC	82	161	166	193	222	267	248	218	282	156	179	213	224	222	261	155	229	252	207	153	127	93	166	141
P83	PV	93	92	120	95	92	124	123	120	140	155	160	132	135	144	147	151	135	120	132	152	92	98	115	119
	EV	93	92	120	95	92	124	123	120	140	155	160	132	135	144	147	151	135	120	132	152	92	98	115	119
	AC	171	92	157	123	103	115	130	178	218	146	286	224	174	145	137	196	124	143	170	231	117	131	192	143
P84	PV	86	112	99	106	108	145	129	157	141	137	150	147	126	125	138	160	123	128	149	149	113	102	92	81
	EV	86	112	99	106	108	145	129	157	141	137	150	147	126	125	138	160	123	128	149	149	113	102	92	81
	AC	156	213	133	160	106	280	206	196	259	215	222	218	236	144	255	157	135	120	221	153	224	135	105	76
P85	PV	116	90	89	97	105	142	126	151	145	122	154	126	146	152	147	145	127	120	120	145	115	85	95	114
	EV	116	90	89	97	105	142	126	151	145	122	154	126	146	152	147	145	127	120	120	145	115	85	95	114
	AC	122	152	89	161	149	183	164	273	157	159	145	238	133	181	281	136	180	220	142	174	170	115	161	131
P86	PV	108	111	116	110	112	150	144	133	133	134	153	142	128	138	146	122	128	137	126	157	112	108	92	108
	EV	108	111	116	110	112	150	144	133	133	134	153	142	128	138	146	122	128	137	126	157	112	108	92	108
	AC	216	171	130	189	186	227	168	266	227	245	190	203	224	229	242	160	227	258	251	217	111	156	91	178
P87	PV	110	100	119	111	119	130	149	155	152	123	137	135	129	133	159	132	129	148	126	136	85	111	84	92
	EV	110	100	119	111	119	130	149	155	152	123	137	135	129	133	159	132	129	148	126	136	85	111	84	92
	AC	215	184	199	131	228	120	212	277	299	237	181	255	209	239	308	147	188	212	159	147	153	222	106	86
P88	PV	88	120	80	105	118	138	127	153	151	139	154	142	130	152	159	124	152	124	152	125	118	92	110	101
	EV	88	120	80	105	118	138	127	153	151	139	154	142	130	152	159	124	152	124	152	125	118	92	110	101
	AC	159	120	144	152	170	230	179	205	275	188	277	210	198	141	272	134	246	153	223	120	107	114	175	126
P89	PV	117	112	115	99	118	133	160	150	152	120	120	149	135	121	134	143	125	134	130	140	87	116	86	106
	EV	117	112	115	99	118	133	160	150	152	120	120	149	135	121	134	143	125	134	130	140	87	116	86	106
	AC	161	200	171	158	221	211	312	167	152	184	139	148	255	208	252	282	175	265	202	176	165	135	90	199
P90	PV	95	115	89	115	118	137	144	129	146	148	155	152	151	128	131	145	159	125	137	122	110	114	106	95
	EV	95	115	89	115	118	137	144	129	146	148	155	152	151	128	131	145	159	125	137	122	110	114	106	95
	AC	174	169	161	109	207	249	190	217	180	277	177	152	291	154	250	244	149	135	134	145	197	115	99	182
P91	PV	91	114	111	104	112	160	160	135	128	160	122	130	129	126	146	139	138	155	140	136	100	86	80	97

	EV	91	114	111	104	112	160	160	135	128	160	122	130	129	126	146	139	138	155	140	136	100	86	80	97
	AC	152	116	145	111	174	302	192	162	216	259	145	241	137	120	146	259	272	274	169	201	170	102	120	136
P92	PV	94	120	98	91	104	143	150	147	157	143	150	135	120	134	155	152	124	145	127	151	111	100	84	94
	EV	94	120	98	91	104	143	150	147	157	143	150	135	120	134	155	152	124	145	127	151	111	100	84	94
	AC	111	136	109	137	135	162	257	204	306	203	291	255	114	125	268	213	156	158	199	216	128	149	119	141
P93	PV	115	97	95	90	97	129	159	151	142	139	148	135	150	152	151	153	125	135	152	131	98	107	116	84
	EV	115	97	95	90	97	129	159	151	142	139	148	135	150	152	151	153	125	135	152	131	98	107	116	84
	AC	174	148	119	88	162	138	146	172	207	217	138	150	210	149	217	145	246	208	246	199	121	119	188	105
P94	PV	81	88	105	120	104	152	121	158	160	146	123	131	124	145	155	124	147	134	156	128	118	117	120	88
	EV	81	88	105	120	104	152	121	158	160	146	123	131	124	145	155	124	147	134	156	128	118	117	120	88
	AC	134	119	159	209	172	144	110	240	314	251	121	174	233	196	251	179	245	166	231	169	228	112	210	95
P95	PV	108	107	89	91	89	130	127	132	135	152	149	128	122	158	133	136	150	146	155	153	99	116	91	119
	EV	108	107	89	91	89	130	127	132	135	152	149	128	122	158	133	136	150	146	155	153	99	116	91	119
	AC	163	164	145	122	162	147	133	170	262	292	255	129	193	278	246	215	212	276	198	300	119	223	95	170
P96	PV	99	102	106	113	95	150	149	135	144	158	130	132	157	137	152	121	159	159	154	138	120	117	117	107
	EV	99	102	106	113	95	150	149	135	144	158	130	132	157	137	152	121	159	159	154	138	120	117	117	107
	AC	127	154	149	216	86	198	136	266	256	149	191	207	289	169	140	115	216	261	246	239	119	158	211	202
P97	PV	113	118	111	92	114	148	128	125	126	140	155	145	142	156	150	130	154	159	159	137	110	113	117	118
	EV	113	118	111	92	114	148	128	125	126	140	155	145	142	156	150	130	154	159	159	137	110	113	117	118
	AC	131	152	114	94	112	263	119	146	229	161	243	178	281	190	228	254	194	297	259	160	154	202	117	113
P98	PV	102	108	97	92	80	147	132	149	156	148	143	151	130	144	124	129	152	133	147	123	111	88	112	96
	EV	102	108	97	92	80	147	132	149	156	148	143	151	130	144	124	129	152	133	147	123	111	88	112	96
	AC	179	119	104	166	115	272	193	265	279	141	197	178	118	143	201	157	144	198	150	226	109	146	142	126
P99	PV	83	105	106	118	89	136	147	154	124	156	136	147	146	134	152	121	122	121	130	146	107	87	107	111
	EV	83	105	106	118	89	136	147	154	124	156	136	147	146	134	152	121	122	121	130	146	107	87	107	111
	AC	96	186	116	111	166	196	185	171	216	218	175	209	209	261	271	152	140	114	254	162	134	149	213	183
P100	PV	90	83	99	92	117	140	150	140	151	122	154	140	160	141	129	142	131	156	134	144	118	80	118	93
	EV	90	83	99	92	117	140	150	140	151	122	154	140	160	141	129	142	131	156	134	144	118	80	118	93
	AC	111	77	140	177	165	223	204	221	205	133	222	186	154	161	203	217	148	270	213	235	171	118	139	98

Table E.2 Net monthly performance data for randomly generated projects in discipline 02

Project		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
P1	PV	84	89	80	94	110	151	139	153	136	159	123	121	132	134	150	159	133	134	147	152	91	80	90	119
	EV	84	89	80	94	110	151	139	153	136	159	123	121	132	134	150	159	133	134	147	152	91	80	90	119
	AC	159	61	78	133	177	153	100	233	114	130	146	184	224	155	270	127	242	87	106	281	115	144	147	102
P2	PV	91	86	100	109	108	142	139	147	157	145	120	143	133	134	160	123	122	140	125	143	119	88	88	91
	EV	91	86	100	109	108	142	139	147	157	145	120	143	133	134	160	123	122	140	125	143	119	88	88	91
	AC	76	147	60	106	90	160	88	222	308	128	89	132	223	243	296	242	216	200	195	255	146	112	165	176
P3	PV	117	97	98	98	119	155	120	135	138	160	135	123	138	154	122	151	157	137	153	121	80	101	100	115
	EV	117	97	98	98	119	155	120	135	138	160	135	123	138	154	122	151	157	137	153	121	80	101	100	115
	AC	230	150	139	194	137	225	140	267	91	192	99	169	94	202	170	151	151	104	116	185	118	75	182	86
P4	PV	117	94	89	95	114	143	144	157	158	125	142	126	131	132	123	121	132	123	142	151	91	120	109	109
	EV	117	94	89	95	114	143	144	157	158	125	142	126	131	132	123	121	132	123	142	151	91	120	109	109
	AC	136	62	138	109	164	257	186	243	278	173	176	103	138	219	135	115	148	81	220	160	121	227	76	204
P5	PV	83	96	96	85	107	128	143	130	133	155	156	131	124	125	149	138	145	132	134	159	89	107	112	87
	EV	83	96	96	85	107	128	143	130	133	155	156	131	124	125	149	138	145	132	134	159	89	107	112	87
	AC	87	72	109	162	131	183	199	99	141	146	94	164	149	218	259	112	116	144	110	100	138	140	140	127
P6	PV	117	110	111	113	118	148	156	133	138	134	137	124	121	155	131	129	158	142	144	149	94	104	111	107
	EV	117	110	111	113	118	148	156	133	138	134	137	124	121	155	131	129	158	142	144	149	94	104	111	107
	AC	131	160	181	141	104	271	284	168	219	196	159	145	162	109	198	197	237	189	200	185	87	171	188	112
P7	PV	108	80	114	110	108	121	149	152	160	146	130	157	152	138	154	147	160	133	125	151	107	107	99	104
	EV	108	80	114	110	108	121	149	152	160	146	130	157	152	138	154	147	160	133	125	151	107	107	99	104
	AC	99	70	202	146	160	167	219	242	280	140	170	124	109	255	128	182	160	194	131	171	154	184	83	150
P8	PV	81	83	87	118	100	135	148	135	156	133	143	135	160	150	156	157	135	122	134	143	109	86	95	86
	EV	81	83	87	118	100	135	148	135	156	133	143	135	160	150	156	157	135	122	134	143	109	86	95	86
	AC	76	126	133	139	127	147	219	93	95	192	276	104	208	90	298	275	236	72	109	140	80	126	147	151
P9	PV	107	104	93	87	119	127	145	123	144	158	135	150	148	128	149	155	159	121	156	145	83	114	84	111
	EV	107	104	93	87	119	127	145	123	144	158	135	150	148	128	149	155	159	121	156	145	83	114	84	111
	AC	107	200	70	87	81	112	161	200	151	147	176	260	203	136	136	107	227	168	123	183	96	122	68	155
P10	PV	118	111	110	81	117	137	154	146	147	145	122	140	156	140	137	158	145	154	136	133	117	83	102	94

	EV	118	111	110	81	117	137	154	146	147	145	122	140	156	140	137	158	145	154	136	133	117	83	102	94
	AC	169	91	116	131	209	178	105	292	159	173	216	169	195	231	152	204	173	105	140	225	206	133	107	156
P11	PV	90	114	93	88	119	123	142	157	150	139	123	121	146	141	122	126	128	148	138	147	91	80	117	89
	EV	90	114	93	88	119	123	142	157	150	139	123	121	146	141	122	126	128	148	138	147	91	80	117	89
	AC	118	211	86	81	205	205	125	105	297	278	235	132	93	124	161	78	97	152	92	178	116	103	142	130
P12	PV	81	97	86	102	82	152	143	148	120	158	124	159	131	160	140	158	136	122	152	152	106	82	85	116
	EV	81	97	86	102	82	152	143	148	120	158	124	159	131	160	140	158	136	122	152	152	106	82	85	116
	AC	155	188	153	122	130	278	270	87	78	95	200	272	212	133	232	272	87	205	281	184	88	130	76	75
P13	PV	116	97	93	114	80	139	126	157	131	149	145	159	125	149	138	138	146	138	127	155	94	110	120	108
	EV	116	97	93	114	80	139	126	157	131	149	145	159	125	149	138	138	146	138	127	155	94	110	120	108
	AC	146	145	165	79	102	207	131	188	107	207	277	122	130	224	275	257	137	200	77	310	182	139	150	98
P14	PV	101	96	112	106	80	141	131	124	120	155	124	125	136	157	150	152	153	133	138	149	89	93	84	97
	EV	101	96	112	106	80	141	131	124	120	155	124	125	136	157	150	152	153	133	138	149	89	93	84	97
	AC	130	112	114	112	53	155	166	87	187	291	112	170	186	105	179	275	93	226	192	168	85	122	135	98
P15	PV	85	108	97	98	111	149	126	129	153	121	158	150	157	149	143	139	154	133	129	139	96	114	86	99
	EV	85	108	97	98	111	149	126	129	153	121	158	150	157	149	143	139	154	133	129	139	96	114	86	99
	AC	89	76	169	155	209	106	134	172	292	81	93	282	104	170	169	85	226	106	83	150	171	141	162	76
P16	PV	106	97	99	100	84	156	139	143	120	131	131	155	145	126	139	160	130	135	142	160	102	89	87	106
	EV	106	97	99	100	84	156	139	143	120	131	131	155	145	126	139	160	130	135	142	160	102	89	87	106
	AC	111	186	190	86	60	234	235	186	131	236	115	184	112	77	136	106	260	174	231	174	193	141	130	110
P17	PV	91	80	118	83	94	151	149	144	141	141	126	141	120	134	124	156	137	146	135	151	91	109	92	104
	EV	91	80	118	83	94	151	149	144	141	141	126	141	120	134	124	156	137	146	135	151	91	109	92	104
	AC	86	114	116	166	176	291	125	153	189	224	140	203	166	249	102	289	93	99	240	257	109	148	117	72
P18	PV	115	106	106	107	84	142	120	153	130	151	122	155	122	121	135	137	143	156	151	123	103	97	82	87
	EV	115	106	106	107	84	142	120	153	130	151	122	155	122	121	135	137	143	156	151	123	103	97	82	87
	AC	109	106	212	186	151	195	73	132	203	187	137	277	106	103	126	211	225	167	148	118	117	125	62	146
P19	PV	90	89	84	92	95	160	123	149	153	121	130	139	159	136	128	129	156	158	141	156	87	85	93	112
	EV	90	89	84	92	95	160	123	149	153	121	130	139	159	136	128	129	156	158	141	156	87	85	93	112
	AC	164	105	132	170	80	174	162	182	251	82	77	261	275	185	141	237	285	103	147	176	73	110	89	169
P20	PV	91	83	86	100	82	141	155	137	147	126	146	142	145	148	160	154	142	128	147	158	86	105	114	111
	EV	91	83	86	100	82	141	155	137	147	126	146	142	145	148	160	154	142	128	147	158	86	105	114	111

	AC	99	100	72	140	154	226	102	166	134	229	108	132	265	240	147	176	220	136	119	245	148	161	176	211
P21	PV	104	106	118	114	82	145	160	151	123	132	155	128	123	140	155	158	138	137	129	141	90	100	112	103
	EV	104	106	118	114	82	145	160	151	123	132	155	128	123	140	155	158	138	137	129	141	90	100	112	103
	AC	157	148	181	170	48	241	301	267	207	259	268	110	223	218	251	199	142	123	250	179	73	65	185	182
P22	PV	100	99	96	85	87	120	133	136	148	130	158	160	151	133	122	148	148	151	139	130	109	81	82	107
	EV	100	99	96	85	87	120	133	136	148	130	158	160	151	133	122	148	148	151	139	130	109	81	82	107
	AC	83	182	64	160	119	229	84	189	138	134	226	309	195	188	201	258	213	246	117	78	84	158	118	133
P23	PV	105	96	108	113	92	123	146	155	156	131	147	134	133	143	140	156	127	123	136	149	81	117	99	114
	EV	105	96	108	113	92	123	146	155	156	131	147	134	133	143	140	156	127	123	136	149	81	117	99	114
	AC	165	120	200	131	116	134	185	206	306	206	165	157	126	156	241	276	226	156	227	283	161	176	70	156
P24	PV	90	104	87	100	84	155	142	133	133	154	123	156	128	144	156	120	125	158	138	149	81	102	98	99
	EV	90	104	87	100	84	155	142	133	133	154	123	156	128	144	156	120	125	158	138	149	81	102	98	99
	AC	54	120	128	187	91	302	175	250	158	219	140	153	220	200	300	127	163	223	230	246	103	125	83	100
P25	PV	83	111	94	109	96	157	148	157	152	122	153	139	120	156	136	139	127	126	157	132	103	112	84	95
	EV	83	111	94	109	96	157	148	157	152	122	153	139	120	156	136	139	127	126	157	132	103	112	84	95
	AC	52	194	83	112	153	229	263	292	108	133	211	108	118	187	166	278	201	188	248	143	109	129	134	141
P26	PV	110	87	106	82	91	146	122	148	125	149	147	127	160	146	144	122	155	156	157	138	110	115	101	104
	EV	110	87	106	82	91	146	122	148	125	149	147	127	160	146	144	122	155	156	157	138	110	115	101	104
	AC	176	124	93	107	177	133	159	135	98	106	228	211	213	162	284	181	282	167	126	273	161	116	94	64
P27	PV	95	113	86	113	96	124	154	146	141	133	143	149	149	157	146	142	123	138	138	132	105	91	89	115
	EV	95	113	86	113	96	124	154	146	141	133	143	149	149	157	146	142	123	138	138	132	105	91	89	115
	AC	129	171	53	189	75	136	134	168	188	174	123	264	101	236	152	138	219	168	229	214	154	129	160	151
P28	PV	87	97	88	97	106	120	126	158	159	124	123	133	157	149	130	123	134	128	153	126	101	96	115	82
	EV	87	97	88	97	106	120	126	158	159	124	123	133	157	149	130	123	134	128	153	126	101	96	115	82
	AC	106	127	82	95	194	110	197	267	262	231	234	105	146	283	168	181	157	243	194	101	177	182	112	76
P29	PV	80	87	104	88	112	125	131	122	123	141	146	153	134	145	152	128	147	128	126	160	100	88	98	117
	EV	80	87	104	88	112	125	131	122	123	141	146	153	134	145	152	128	147	128	126	160	100	88	98	117
	AC	74	147	98	157	170	111	151	198	229	220	140	129	180	203	211	172	125	134	76	149	114	78	185	74
P30	PV	95	83	85	89	120	123	150	153	153	139	132	132	158	142	128	135	144	155	130	145	102	86	120	114
	EV	95	83	85	89	120	123	150	153	153	139	132	132	158	142	128	135	144	155	130	145	102	86	120	114
	AC	57	77	151	128	112	87	237	109	208	146	96	194	107	226	248	213	236	259	242	239	189	169	160	206

P31	PV	97	83	99	103	103	157	148	140	136	131	141	159	159	122	136	141	138	149	145	133	85	93	115	117
	EV	97	83	99	103	103	157	148	140	136	131	141	159	159	122	136	141	138	149	145	133	85	93	115	117
	AC	106	104	110	156	67	104	127	230	165	236	100	110	202	221	233	114	272	204	197	170	87	169	225	228
P32	PV	105	120	102	84	106	152	124	128	160	144	130	140	135	124	133	122	144	137	122	149	80	102	98	103
	EV	105	120	102	84	106	152	124	128	160	144	130	140	135	124	133	122	144	137	122	149	80	102	98	103
	AC	84	184	98	91	175	274	165	210	253	268	81	164	115	193	237	200	157	177	170	107	62	204	136	142
P33	PV	93	103	98	114	89	130	149	134	125	126	129	136	134	125	139	126	129	141	129	120	93	120	92	114
	EV	93	103	98	114	89	130	149	134	125	126	129	136	134	125	139	126	129	141	129	120	93	120	92	114
	AC	79	110	72	187	116	133	112	122	135	251	257	190	197	159	149	168	168	233	182	89	170	150	97	70
P34	PV	117	84	107	113	80	149	144	155	136	124	142	160	144	132	136	150	138	134	131	139	107	94	94	81
	EV	117	84	107	113	80	149	144	155	136	124	142	160	144	132	136	150	138	134	131	139	107	94	94	81
	AC	230	55	209	157	57	185	215	271	209	139	234	246	199	222	205	138	233	121	79	239	111	71	124	90
P35	PV	108	92	103	118	101	127	151	139	128	125	160	141	121	140	122	149	131	129	155	139	88	118	82	86
	EV	108	92	103	118	101	127	151	139	128	125	160	141	121	140	122	149	131	129	155	139	88	118	82	86
	AC	181	69	131	229	155	154	287	170	197	105	139	178	129	238	233	182	88	205	113	153	148	236	63	155
P36	PV	84	92	118	91	106	158	148	148	122	150	153	131	158	125	127	153	144	156	140	143	97	118	112	114
	EV	84	92	118	91	106	158	148	148	122	150	153	131	158	125	127	153	144	156	140	143	97	118	112	114
	AC	163	151	133	154	95	111	296	252	222	159	249	81	311	210	132	101	95	217	258	262	110	198	151	164
P37	PV	92	99	90	116	86	155	134	156	133	121	158	121	128	148	149	151	134	157	133	136	107	114	105	115
	EV	92	99	90	116	86	155	134	156	133	121	158	121	128	148	149	151	134	157	133	136	107	114	105	115
	AC	142	64	167	157	127	236	139	165	231	230	218	172	81	126	186	184	243	155	255	109	101	120	104	131
P38	PV	88	104	94	109	119	148	122	132	120	160	136	137	123	152	123	141	139	133	157	155	106	116	89	95
	EV	88	104	94	109	119	148	122	132	120	160	136	137	123	152	123	141	139	133	157	155	106	116	89	95
	AC	99	158	160	199	177	203	227	256	115	126	103	100	107	292	157	172	171	138	303	140	201	99	118	83
P39	PV	91	120	92	98	101	130	144	137	121	139	150	157	155	143	151	131	147	153	141	155	98	114	80	85
	EV	91	120	92	98	101	130	144	137	121	139	150	157	155	143	151	131	147	153	141	155	98	114	80	85
	AC	79	209	178	124	102	138	261	123	225	147	255	207	124	245	116	102	290	109	144	171	112	95	75	54
P40	PV	97	106	110	116	85	157	153	139	120	128	139	131	154	133	133	121	148	120	144	134	112	83	87	120
	EV	97	106	110	116	85	157	153	139	120	128	139	131	154	133	133	121	148	120	144	134	112	83	87	120
	AC	136	98	119	74	118	107	254	140	139	152	175	115	229	251	238	103	123	205	184	146	103	56	97	170
P41	PV	102	84	90	85	96	127	152	129	150	154	120	125	120	127	158	142	146	140	136	160	84	88	85	111

	EV	102	84	90	85	96	127	152	129	150	154	120	125	120	127	158	142	146	140	136	160	84	88	85	111
	AC	179	81	119	82	179	229	216	240	273	213	227	121	227	122	95	115	126	120	201	221	67	98	75	81
P42	PV	92	84	97	101	97	150	153	128	137	145	160	152	143	136	151	145	125	160	133	157	101	116	86	106
	EV	92	84	97	101	97	150	153	128	137	145	160	152	143	136	151	145	125	160	133	157	101	116	86	106
	AC	98	78	133	123	137	255	243	168	237	133	96	236	272	95	133	138	105	304	215	283	104	217	95	100
P43	PV	87	91	87	80	88	146	143	130	149	152	152	128	130	134	149	150	135	130	125	143	81	96	88	99
	EV	87	91	87	80	88	146	143	130	149	152	152	128	130	134	149	150	135	130	125	143	81	96	88	99
	AC	99	182	171	147	142	197	235	215	97	254	201	188	254	158	262	210	166	194	98	270	161	84	168	156
P44	PV	105	107	84	111	118	154	146	160	159	130	145	144	137	151	141	135	122	139	155	140	97	97	89	102
	EV	105	107	84	111	118	154	146	160	159	130	145	144	137	151	141	135	122	139	155	140	97	97	89	102
	AC	65	148	132	123	116	286	207	179	261	260	128	281	126	146	133	100	244	152	96	192	88	143	66	179
P45	PV	105	86	93	109	106	154	152	146	133	128	124	158	158	133	137	134	147	152	140	127	94	119	85	108
	EV	105	86	93	109	106	154	152	146	133	128	124	158	158	133	137	134	147	152	140	127	94	119	85	108
	AC	65	51	94	140	209	296	149	197	86	193	94	196	216	226	206	123	138	152	263	150	171	184	141	78
P46	PV	100	112	112	85	89	153	133	156	134	129	122	157	123	137	130	141	159	143	125	150	101	110	109	118
	EV	100	112	112	85	89	153	133	156	134	129	122	157	123	137	130	141	159	143	125	150	101	110	109	118
	AC	81	88	172	156	134	162	114	184	82	214	172	184	92	262	192	234	97	107	164	162	111	149	216	164
P47	PV	99	91	109	116	109	132	140	131	146	124	126	124	124	155	133	122	148	121	160	158	97	109	80	97
	EV	99	91	109	116	109	132	140	131	146	124	126	124	124	155	133	122	148	121	160	158	97	109	80	97
	AC	149	104	155	97	209	210	279	126	127	188	141	128	77	140	255	178	117	108	218	180	104	197	136	176
P48	PV	115	116	87	104	108	123	139	131	152	153	147	138	150	147	133	129	150	146	133	120	92	93	102	100
	EV	115	116	87	104	108	123	139	131	152	153	147	138	150	147	133	129	150	146	133	120	92	93	102	100
	AC	183	169	74	142	70	220	153	232	122	141	266	166	188	218	148	190	212	101	105	229	136	183	175	161
P49	PV	89	95	81	84	95	152	132	130	125	137	154	127	128	133	152	134	129	132	124	137	99	106	98	95
	EV	89	95	81	84	95	152	132	130	125	137	154	127	128	133	152	134	129	132	124	137	99	106	98	95
	AC	70	117	79	146	87	90	253	260	191	129	240	110	124	94	125	260	103	213	190	223	96	81	104	148
P50	PV	97	87	111	85	117	156	140	156	147	145	127	148	160	148	143	156	148	155	155	144	101	99	109	94
	EV	97	87	111	85	117	156	140	156	147	145	127	148	160	148	143	156	148	155	155	144	101	99	109	94
	AC	69	98	133	81	194	192	262	293	237	226	138	184	166	92	179	162	258	287	175	130	178	63	87	117
P51	PV	111	108	114	114	87	148	140	121	157	138	144	140	133	132	140	128	122	121	156	150	103	108	119	107
	EV	111	108	114	114	87	148	140	121	157	138	144	140	133	132	140	128	122	121	156	150	103	108	119	107

	AC	88	179	163	135	170	167	140	168	102	84	145	256	162	187	99	92	111	127	209	234	193	201	190	72
P52	PV	105	110	90	91	97	154	126	140	130	144	140	126	131	136	151	132	127	150	146	126	95	113	102	106
	EV	105	110	90	91	97	154	126	140	130	144	140	126	131	136	151	132	127	150	146	126	95	113	102	106
	AC	166	174	149	86	119	251	218	113	198	171	179	103	200	113	149	218	156	96	137	122	72	211	130	80
P53	PV	97	96	100	105	98	136	136	144	143	158	121	139	153	149	148	147	145	138	136	147	107	80	95	91
	EV	97	96	100	105	98	136	136	144	143	158	121	139	153	149	148	147	145	138	136	147	107	80	95	91
	AC	189	186	160	114	185	204	84	246	217	300	241	200	184	148	111	196	106	91	159	241	64	70	138	138
P54	PV	92	111	98	118	101	145	159	143	128	160	145	153	140	131	124	146	137	120	150	125	87	85	96	96
	EV	92	111	98	118	101	145	159	143	128	160	145	153	140	131	124	146	137	120	150	125	87	85	96	96
	AC	154	125	90	176	121	270	254	124	204	248	115	150	209	262	135	88	199	95	122	83	145	60	83	162
P55	PV	97	81	111	95	86	126	133	129	130	147	152	142	153	160	156	143	155	151	156	145	91	80	120	112
	EV	97	81	111	95	86	126	133	129	130	147	152	142	153	160	156	143	155	151	156	145	91	80	120	112
	AC	150	91	155	126	92	251	189	123	185	160	286	89	144	186	259	179	237	113	150	178	71	160	158	95
P56	PV	103	80	89	116	84	130	159	131	120	158	145	122	121	135	151	155	122	148	156	121	114	115	112	108
	EV	103	80	89	116	84	130	159	131	120	158	145	122	121	135	151	155	122	148	156	121	114	115	112	108
	AC	122	90	151	123	70	209	251	127	216	289	175	133	86	243	230	239	167	281	103	225	163	200	118	171
P57	PV	109	109	108	108	116	158	137	131	131	154	160	144	149	131	133	127	133	141	140	124	90	120	105	82
	EV	109	109	108	108	116	158	137	131	131	154	160	144	149	131	133	127	133	141	140	124	90	120	105	82
	AC	179	111	173	100	84	128	270	162	128	177	312	207	97	94	223	191	253	265	102	185	96	119	81	91
P58	PV	112	91	95	120	102	159	152	120	135	151	148	156	126	160	128	125	143	137	153	133	117	86	99	86
	EV	112	91	95	120	102	159	152	120	135	151	148	156	126	160	128	125	143	137	153	133	117	86	99	86
	AC	181	156	67	197	121	138	111	186	178	178	253	181	165	298	108	105	113	121	184	226	208	60	178	152
P59	PV	81	110	119	81	100	145	138	142	125	151	139	129	149	160	133	121	135	144	134	130	92	113	120	100
	EV	81	110	119	81	100	145	138	142	125	151	139	129	149	160	133	121	135	144	134	130	92	113	120	100
	AC	129	160	71	119	105	248	174	236	244	279	218	85	234	267	138	93	238	96	117	241	102	221	106	198
P60	PV	108	120	115	110	90	148	144	127	148	138	131	147	146	155	151	156	142	146	145	159	115	80	110	118
	EV	108	120	115	110	90	148	144	127	148	138	131	147	146	155	151	156	142	146	145	159	115	80	110	118
	AC	168	90	154	133	111	290	238	183	133	145	173	91	111	288	107	273	224	101	242	245	87	154	217	151
P61	PV	102	111	88	89	106	138	154	138	132	137	143	132	129	131	141	129	125	150	141	139	84	118	113	91
	EV	102	111	88	89	106	138	154	138	132	137	143	132	129	131	141	129	125	150	141	139	84	118	113	91
	AC	163	193	76	161	187	188	191	170	79	212	153	252	253	215	113	255	86	197	233	140	167	218	107	173

P62	PV	97	103	106	102	97	130	153	128	132	133	135	130	135	131	155	135	136	124	121	155	113	97	92	87
	EV	97	103	106	102	97	130	153	128	132	133	135	130	135	131	155	135	136	124	121	155	113	97	92	87
	AC	131	191	105	171	94	126	127	87	223	259	169	172	186	228	228	209	166	239	198	253	168	186	117	110
P63	PV	115	114	113	93	90	126	123	136	136	130	150	148	143	135	157	131	123	144	131	129	85	81	96	93
	EV	115	114	113	93	90	126	123	136	136	130	150	148	143	135	157	131	123	144	131	129	85	81	96	93
	AC	140	164	145	119	124	140	232	196	146	221	279	101	190	109	253	186	187	86	255	159	108	104	178	151
P64	PV	108	102	94	81	91	160	120	136	146	150	154	142	122	147	134	154	152	155	147	152	112	94	89	87
	EV	108	102	94	81	91	160	120	136	146	150	154	142	122	147	134	154	152	155	147	152	112	94	89	87
	AC	151	120	79	81	87	142	233	136	107	251	182	116	145	132	125	168	239	307	272	261	185	147	78	59
P65	PV	87	119	94	117	106	143	123	123	145	150	159	129	145	134	121	135	127	143	150	132	88	105	89	101
	EV	87	119	94	117	106	143	123	123	145	150	159	129	145	134	121	135	127	143	150	132	88	105	89	101
	AC	91	143	101	214	198	104	187	95	165	120	94	255	278	90	237	189	145	119	294	186	72	66	158	184
P66	PV	102	110	114	85	106	129	136	152	128	128	135	153	125	158	135	134	137	151	144	129	82	90	102	106
	EV	102	110	114	85	106	129	136	152	128	128	135	153	125	158	135	134	137	151	144	129	82	90	102	106
	AC	186	85	148	56	209	142	248	128	237	198	193	220	184	269	80	163	251	159	266	254	133	155	170	108
P67	PV	96	87	84	99	105	132	144	130	128	130	155	148	151	129	145	125	155	154	123	146	111	111	87	107
	EV	96	87	84	99	105	132	144	130	128	130	155	148	151	129	145	125	155	154	123	146	111	111	87	107
	AC	63	169	71	102	180	226	187	165	173	91	149	292	160	93	91	163	274	116	209	261	79	150	171	175
P68	PV	84	94	102	104	81	142	160	134	133	151	154	133	129	139	140	157	146	159	126	127	118	115	92	81
	EV	84	94	102	104	81	142	160	134	133	151	154	133	129	139	140	157	146	159	126	127	118	115	92	81
	AC	152	177	106	72	70	195	267	117	219	125	297	170	227	100	122	254	171	316	228	104	195	152	170	65
P69	PV	82	115	100	88	92	133	153	122	129	130	123	153	144	126	158	146	156	135	123	132	94	89	109	95
	EV	82	115	100	88	92	133	153	122	129	130	123	153	144	126	158	146	156	135	123	132	94	89	109	95
	AC	62	174	107	152	156	142	200	123	79	109	80	214	147	96	258	266	220	216	177	230	181	95	179	177
P70	PV	94	115	90	87	108	150	153	125	139	138	120	124	135	135	134	146	127	150	126	145	81	115	110	87
	EV	94	115	90	87	108	150	153	125	139	138	120	124	135	135	134	146	127	150	126	145	81	115	110	87
	AC	168	160	122	90	140	219	280	188	143	229	125	242	257	104	260	212	86	290	207	102	156	144	144	107
P71	PV	92	88	115	82	118	154	143	132	141	147	156	152	135	124	152	130	121	136	151	132	109	87	92	98
	EV	92	88	115	82	118	154	143	132	141	147	156	152	135	124	152	130	121	136	151	132	109	87	92	98
	AC	123	91	122	119	117	216	107	244	271	128	190	257	220	197	135	92	77	193	148	255	194	103	87	172
P72	PV	99	101	87	116	108	133	147	149	132	120	124	127	127	124	127	153	120	157	132	141	80	91	105	85

	EV	99	101	87	116	108	133	147	149	132	120	124	127	127	124	127	153	120	157	132	141	80	91	105	85
	AC	162	95	88	218	151	165	159	109	129	222	136	248	168	112	180	132	140	99	116	213	90	99	85	111
P73	PV	81	91	91	92	108	121	132	146	144	152	127	148	136	120	135	130	127	137	155	154	103	108	81	88
	EV	81	91	91	92	108	121	132	146	144	152	127	148	136	120	135	130	127	137	155	154	103	108	81	88
	AC	117	167	155	69	130	167	140	270	284	251	123	271	180	80	107	168	217	244	206	217	63	85	49	156
P74	PV	83	113	80	83	82	123	126	158	145	123	149	135	129	157	126	158	144	138	128	141	116	108	92	112
	EV	83	113	80	83	82	123	126	158	145	123	149	135	129	157	126	158	144	138	128	141	116	108	92	112
	AC	126	153	94	95	49	85	83	107	235	90	271	135	130	297	186	107	239	168	79	145	152	205	173	185
P75	PV	108	98	96	96	117	150	156	133	125	135	158	146	130	160	120	147	126	148	126	159	80	91	108	116
	EV	108	98	96	96	117	150	156	133	125	135	158	146	130	160	120	147	126	148	126	159	80	91	108	116
	AC	91	146	112	60	227	111	108	262	94	146	221	140	111	246	190	151	89	226	96	105	88	74	170	179
P76	PV	100	112	85	103	118	140	137	146	146	139	123	122	140	131	141	125	121	132	136	123	81	98	80	80
	EV	100	112	85	103	118	140	137	146	146	139	123	122	140	131	141	125	121	132	136	123	81	98	80	80
	AC	200	148	111	148	225	223	133	142	161	209	224	124	260	151	142	136	180	260	112	165	91	171	90	68
P77	PV	104	109	99	102	115	139	148	140	126	152	139	158	150	133	127	148	137	141	130	134	114	99	80	118
	EV	104	109	99	102	115	139	148	140	126	152	139	158	150	133	127	148	137	141	130	134	114	99	80	118
	AC	159	111	97	174	181	199	107	192	141	202	214	311	150	262	119	212	177	128	114	91	72	81	146	207
P78	PV	109	105	120	102	92	124	156	143	134	154	121	152	149	152	156	140	157	153	126	138	81	113	83	81
	EV	109	105	120	102	92	124	156	143	134	154	121	152	149	152	156	140	157	153	126	138	81	113	83	81
	AC	193	68	163	71	86	166	111	107	102	240	236	254	171	226	129	238	129	277	97	139	54	96	58	143
P79	PV	85	82	81	100	84	157	147	133	139	126	146	143	158	122	151	160	137	145	152	157	82	82	101	93
	EV	85	82	81	100	84	157	147	133	139	126	146	143	158	122	151	160	137	145	152	157	82	82	101	93
	AC	78	117	147	89	127	192	163	105	149	95	133	282	216	239	225	294	166	223	254	135	144	75	189	96
P80	PV	94	95	107	80	101	154	126	151	123	120	151	134	146	134	140	141	147	120	135	139	104	92	82	103
	EV	94	95	107	80	101	154	126	151	123	120	151	134	146	134	140	141	147	120	135	139	104	92	82	103
	AC	167	177	71	133	128	183	203	278	116	150	252	129	140	92	111	224	103	180	240	121	152	120	120	88
P81	PV	114	120	103	111	84	130	157	141	154	153	131	145	145	126	121	135	133	145	147	144	89	114	120	115
	EV	114	120	103	111	84	130	157	141	154	153	131	145	145	126	121	135	133	145	147	144	89	114	120	115
	AC	89	150	199	210	158	260	221	255	185	95	115	87	232	238	172	225	211	132	172	282	74	74	77	209
P82	PV	80	111	116	115	93	121	129	156	159	133	145	124	144	124	146	124	130	153	135	129	111	119	95	81
	EV	80	111	116	115	93	121	129	156	159	133	145	124	144	124	146	124	130	153	135	129	111	119	95	81

	AC	152	65	231	209	80	163	231	214	299	78	170	229	256	211	254	222	81	101	108	147	79	203	164	158
P83	PV	107	85	118	86	97	126	122	144	132	160	143	122	128	126	145	121	155	140	132	138	97	118	115	119
	EV	107	85	118	86	97	126	122	144	132	160	143	122	128	126	145	121	155	140	132	138	97	118	115	119
	AC	73	117	138	90	118	200	162	186	211	134	142	82	147	204	267	160	172	171	95	132	58	163	147	175
P84	PV	106	114	89	101	83	120	129	144	157	136	121	153	131	160	135	133	120	154	127	154	91	118	120	99
	EV	106	114	89	101	83	120	129	144	157	136	121	153	131	160	135	133	120	154	127	154	91	118	120	99
	AC	170	227	143	86	132	190	95	202	290	178	144	174	157	157	142	172	125	137	144	259	126	194	230	168
P85	PV	99	98	111	84	104	126	141	155	122	138	137	140	138	124	127	124	146	121	136	150	94	110	103	91
	EV	99	98	111	84	104	126	141	155	122	138	137	140	138	124	127	124	146	121	136	150	94	110	103	91
	AC	99	96	99	76	126	152	224	219	111	109	258	179	229	145	236	162	239	207	105	185	133	151	133	79
P86	PV	119	81	84	86	114	143	131	140	139	134	132	125	153	143	125	128	143	120	134	145	103	97	117	98
	EV	119	81	84	86	114	143	131	140	139	134	132	125	153	143	125	128	143	120	134	145	103	97	117	98
	AC	179	123	90	82	120	249	198	181	260	90	129	80	101	275	95	151	222	172	182	215	159	76	151	111
P87	PV	82	108	116	113	120	155	131	142	142	134	148	155	143	155	132	120	160	147	126	132	80	91	101	110
	EV	82	108	116	113	120	155	131	142	142	134	148	155	143	155	132	120	160	147	126	132	80	91	101	110
	AC	77	199	176	86	133	163	168	178	185	235	93	293	182	299	191	133	242	144	247	82	139	137	70	133
P88	PV	97	113	89	107	118	156	124	145	138	123	132	147	151	153	128	135	142	153	140	135	85	109	100	88
	EV	97	113	89	107	118	156	124	145	138	123	132	147	151	153	128	135	142	153	140	135	85	109	100	88
	AC	159	217	152	170	94	275	110	173	207	210	83	221	291	104	253	223	133	304	203	269	131	75	125	161
P89	PV	114	89	101	87	102	134	131	137	158	155	135	145	128	147	138	146	134	137	156	160	107	89	119	109
	EV	114	89	101	87	102	134	131	137	158	155	135	145	128	147	138	146	134	137	156	160	107	89	119	109
	AC	108	53	100	148	157	91	155	216	254	245	265	116	82	294	189	177	106	263	158	170	81	158	157	130
P90	PV	97	108	85	118	110	120	121	143	147	144	134	122	148	133	131	150	133	134	126	141	106	108	119	83
	EV	97	108	85	118	110	120	121	143	147	144	134	122	148	133	131	150	133	134	126	141	106	108	119	83
	AC	163	82	73	231	201	163	200	167	122	235	265	195	221	233	242	99	230	162	241	279	199	116	232	74
P91	PV	84	113	82	87	113	129	156	134	125	158	147	154	135	142	125	128	135	122	144	141	90	92	92	88
	EV	84	113	82	87	113	129	156	134	125	158	147	154	135	142	125	128	135	122	144	141	90	92	92	88
	AC	135	166	70	158	176	195	225	235	113	169	241	126	263	108	94	189	257	216	147	266	74	83	155	146
P92	PV	86	99	87	87	80	157	137	125	120	147	154	159	159	157	157	131	152	154	136	147	87	102	82	107
	EV	86	99	87	87	80	157	137	125	120	147	154	159	159	157	157	131	152	154	136	147	87	102	82	107
	AC	128	191	104	114	122	242	160	230	202	115	228	148	293	236	96	186	275	106	196	94	155	197	80	141

P93	PV	107	96	118	91	90	131	141	135	151	141	120	123	125	145	150	160	136	127	133	146	101	110	82	89
	EV	107	96	118	91	90	131	141	135	151	141	120	123	125	145	150	160	136	127	133	146	101	110	82	89
	AC	141	107	186	171	102	249	140	111	300	258	224	117	173	186	104	290	267	175	108	145	81	81	86	135
P94	PV	98	97	120	110	88	160	146	139	150	155	142	140	139	138	122	160	145	142	160	130	107	80	104	89
	EV	98	97	120	110	88	160	146	139	150	155	142	140	139	138	122	160	145	142	160	130	107	80	104	89
	AC	153	189	130	205	151	138	226	203	218	237	274	169	117	161	73	291	200	212	251	196	154	105	182	56
P95	PV	114	104	105	119	114	160	143	141	148	145	133	136	132	147	135	150	147	147	131	145	93	99	87	96
	EV	114	104	105	119	114	160	143	141	148	145	133	136	132	147	135	150	147	147	131	145	93	99	87	96
	AC	128	82	124	143	90	275	103	113	181	102	266	166	207	112	154	299	253	263	207	260	114	104	101	75
P96	PV	117	81	109	98	103	155	144	143	124	145	159	143	130	145	136	146	144	127	132	144	102	119	111	103
	EV	117	81	109	98	103	155	144	143	124	145	159	143	130	145	136	146	144	127	132	144	102	119	111	103
	AC	91	52	123	103	195	231	285	107	200	97	122	192	91	239	238	91	98	235	172	166	91	205	191	119
P97	PV	113	93	92	101	87	147	144	134	130	145	126	139	123	135	144	149	147	125	125	139	107	88	110	97
	EV	113	93	92	101	87	147	144	134	130	145	126	139	123	135	144	149	147	125	125	139	107	88	110	97
	AC	127	186	69	71	82	147	281	80	113	144	125	132	149	182	200	116	256	140	123	261	199	109	118	146
P98	PV	87	108	112	83	98	132	159	143	155	147	139	147	156	129	120	138	149	148	153	120	104	96	110	98
	EV	87	108	112	83	98	132	159	143	155	147	139	147	156	129	120	138	149	148	153	120	104	96	110	98
	AC	144	183	112	148	178	242	176	232	285	241	164	179	106	248	208	221	153	144	228	89	89	71	79	178
P99	PV	120	111	109	86	88	131	127	157	146	158	120	149	145	128	157	143	121	122	139	133	95	89	108	92
	EV	120	111	109	86	88	131	127	157	146	158	120	149	145	128	157	143	121	122	139	133	95	89	108	92
	AC	210	114	177	153	76	107	141	148	124	174	193	177	145	184	268	90	192	159	220	89	159	62	141	55
P100	PV	97	87	114	117	117	135	152	139	122	142	139	141	124	125	159	131	149	134	128	152	99	91	98	102
	EV	97	87	114	117	117	135	152	139	122	142	139	141	124	125	159	131	149	134	128	152	99	91	98	102
	AC	155	55	197	174	152	88	237	104	224	202	153	266	191	169	122	215	174	196	142	144	113	176	60	187

Table E.3 Net monthly performance data for randomly generated projects in discipline 03

Project		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
P1	PV	97	99	85	105	94	143	123	124	153	134	126	128	120	150	144	130	120	133	156	132	100	116	93	98
	EV	97	99	85	105	94	143	123	124	153	134	126	128	120	150	144	130	120	133	156	132	100	116	93	98
	AC	67	96	94	114	74	132	82	98	132	96	113	125	106	111	150	105	106	100	117	98	96	103	86	107
P2	PV	118	114	100	98	92	154	123	150	130	134	135	143	146	124	137	141	157	152	152	152	89	98	87	113
	EV	118	114	100	98	92	154	123	150	130	134	135	143	146	124	137	141	157	152	152	152	89	98	87	113
	AC	101	117	98	105	62	156	107	123	101	139	90	133	139	133	149	142	127	141	137	112	68	75	86	105
P3	PV	120	114	95	100	112	153	153	146	124	149	140	135	160	123	154	143	131	138	120	121	97	109	93	99
	EV	120	114	95	100	112	153	153	146	124	149	140	135	160	123	154	143	131	138	120	121	97	109	93	99
	AC	92	104	73	77	86	141	170	152	123	153	140	122	162	93	123	129	136	123	127	125	69	102	98	87
P4	PV	102	97	81	82	112	125	121	154	123	122	129	140	131	122	157	123	147	134	134	121	104	103	109	80
	EV	102	97	81	82	112	125	121	154	123	122	129	140	131	122	157	123	147	134	134	121	104	103	109	80
	AC	106	80	80	61	83	101	90	163	103	98	89	101	128	87	129	92	122	105	137	110	100	84	86	65
P5	PV	110	94	94	94	117	130	137	126	132	148	120	135	133	127	144	158	135	125	122	130	96	113	85	99
	EV	110	94	94	94	117	130	137	126	132	148	120	135	133	127	144	158	135	125	122	130	96	113	85	99
	AC	117	92	99	68	129	137	101	93	94	136	92	119	141	110	154	161	101	85	100	118	90	98	62	69
P6	PV	84	105	96	82	85	160	143	157	122	125	151	149	125	160	137	138	130	133	137	160	92	118	110	87
	EV	84	105	96	82	85	160	143	157	122	125	151	149	125	160	137	138	130	133	137	160	92	118	110	87
	AC	63	90	95	91	91	138	137	126	127	130	134	139	115	147	125	112	92	93	100	157	98	101	103	70
P7	PV	84	92	101	115	114	147	152	159	154	145	148	160	138	134	121	132	143	130	140	147	104	84	82	83
	EV	84	92	101	115	114	147	152	159	154	145	148	160	138	134	121	132	143	130	140	147	104	84	82	83
	AC	71	89	92	128	79	118	149	122	165	146	158	144	150	141	104	94	106	92	154	115	112	82	71	59
P8	PV	110	113	92	100	109	155	144	121	149	156	141	138	154	124	145	130	159	156	156	137	117	91	89	112
	EV	110	113	92	100	109	155	144	121	149	156	141	138	154	124	145	130	159	156	156	137	117	91	89	112
	AC	113	110	83	80	86	129	130	87	128	112	154	135	137	130	116	134	170	154	167	151	125	99	70	78
P9	PV	89	105	105	86	89	144	153	126	138	132	148	159	157	128	124	146	159	127	136	145	117	91	85	109
	EV	89	105	105	86	89	144	153	126	138	132	148	159	157	128	124	146	159	127	136	145	117	91	85	109
	AC	80	82	108	84	61	117	139	120	152	141	112	124	144	114	86	147	107	116	131	106	129	86	79	118
P10	PV	103	85	98	106	109	150	136	151	128	126	153	120	132	142	148	122	131	131	122	148	99	105	91	85

	EV	103	85	98	106	109	150	136	151	128	126	153	120	132	142	148	122	131	131	122	148	99	105	91	85
	AC	91	88	107	111	121	131	122	168	108	126	167	119	96	131	164	109	144	115	111	157	105	106	63	93
P11	PV	105	83	102	102	83	151	142	124	159	121	125	130	138	153	130	143	150	123	124	135	117	83	82	106
	EV	105	83	102	102	83	151	142	124	159	121	125	130	138	153	130	143	150	123	124	135	117	83	82	106
	AC	93	74	81	109	79	121	153	94	154	121	103	143	130	164	87	136	137	89	134	90	80	64	71	71
P12	PV	102	80	113	113	114	134	155	124	157	127	142	136	145	132	155	158	122	149	121	158	114	81	93	108
	EV	102	80	113	113	114	134	155	124	157	127	142	136	145	132	155	158	122	149	121	158	114	81	93	108
	AC	100	82	103	77	80	143	126	138	157	85	152	135	131	135	150	119	101	146	108	111	124	62	102	120
P13	PV	91	95	118	82	87	136	132	125	143	136	153	123	151	141	141	120	145	127	127	152	100	115	106	95
	EV	91	95	118	82	87	136	132	125	143	136	153	123	151	141	141	120	145	127	127	152	100	115	106	95
	AC	68	72	109	78	97	144	123	84	142	140	113	114	165	107	157	102	132	99	136	111	68	77	108	103
P14	PV	112	109	96	83	101	150	141	150	131	160	153	134	145	158	133	159	150	145	160	121	94	104	80	117
	EV	112	109	96	83	101	150	141	150	131	160	153	134	145	158	133	159	150	145	160	121	94	104	80	117
	AC	93	82	100	84	68	131	106	156	128	120	122	95	116	147	138	159	138	154	155	102	97	81	57	87
P15	PV	99	115	118	111	81	132	146	144	133	138	143	128	127	130	144	143	134	121	157	145	102	88	92	89
	EV	99	115	118	111	81	132	146	144	133	138	143	128	127	130	144	143	134	121	157	145	102	88	92	89
	AC	69	82	131	84	64	144	117	150	89	128	104	129	100	125	101	159	142	123	132	97	103	83	94	89
P16	PV	81	84	92	91	101	138	127	127	139	123	149	154	137	159	141	147	139	136	146	143	101	88	109	104
	EV	81	84	92	91	101	138	127	127	139	123	149	154	137	159	141	147	139	136	146	143	101	88	109	104
	AC	87	61	89	101	110	102	122	110	136	87	165	140	141	114	107	138	103	99	130	137	75	66	84	112
P17	PV	118	94	103	119	111	130	145	148	131	151	135	137	129	153	146	138	127	132	158	153	89	107	105	82
	EV	118	94	103	119	111	130	145	148	131	151	135	137	129	153	146	138	127	132	158	153	89	107	105	82
	AC	123	95	91	98	84	137	106	108	88	168	107	114	143	144	128	131	117	127	158	162	71	104	81	86
P18	PV	85	97	100	103	92	147	131	138	136	146	121	145	120	127	132	134	139	134	128	133	93	97	119	97
	EV	85	97	100	103	92	147	131	138	136	146	121	145	120	127	132	134	139	134	128	133	93	97	119	97
	AC	61	81	103	110	88	156	101	117	116	155	127	104	82	118	145	130	139	149	114	101	90	106	112	102
P19	PV	103	107	98	100	95	153	137	141	123	140	120	125	152	151	160	131	155	131	160	157	88	100	88	111
	EV	103	107	98	100	95	153	137	141	123	140	120	125	152	151	160	131	155	131	160	157	88	100	88	111
	AC	76	109	109	105	77	110	140	117	112	95	133	99	161	160	134	132	138	119	173	108	97	105	86	79
P20	PV	90	108	115	82	88	144	157	160	120	154	136	125	137	120	123	160	145	139	124	127	89	88	118	105
	EV	90	108	115	82	88	144	157	160	120	154	136	125	137	120	123	160	145	139	124	127	89	88	118	105

	AC	97	92	92	59	62	118	132	141	127	142	128	139	142	108	133	110	97	103	122	102	84	80	103	86
P21	PV	97	98	83	110	101	130	156	153	146	145	134	137	151	131	131	134	132	137	145	138	119	96	105	87
	EV	97	98	83	110	101	130	156	153	146	145	134	137	151	131	131	134	132	137	145	138	119	96	105	87
	AC	67	103	91	99	92	112	106	147	110	149	141	151	148	143	102	96	129	136	160	131	94	82	84	89
P22	PV	95	105	90	119	106	122	136	155	120	154	133	145	141	152	138	130	147	143	139	160	120	85	81	86
	EV	95	105	90	119	106	122	136	155	120	154	133	145	141	152	138	130	147	143	139	160	120	85	81	86
	AC	76	107	80	88	87	126	131	155	114	162	89	113	100	155	132	87	140	134	99	170	98	76	87	94
P23	PV	108	88	80	91	103	160	131	131	125	130	147	160	159	129	152	160	155	121	133	129	117	82	102	111
	EV	108	88	80	91	103	160	131	131	125	130	147	160	159	129	152	160	155	121	133	129	117	82	102	111
	AC	91	78	86	85	114	158	89	141	103	103	115	152	118	126	126	110	161	94	124	143	101	84	105	115
P24	PV	97	106	83	111	90	142	140	134	147	131	152	121	138	138	148	131	157	131	120	157	103	118	111	113
	EV	97	106	83	111	90	142	140	134	147	131	152	121	138	138	148	131	157	131	120	157	103	118	111	113
	AC	73	91	59	101	85	138	115	129	107	109	146	133	141	131	142	114	146	110	122	141	102	107	102	80
P25	PV	98	95	105	119	81	130	159	137	120	158	149	123	123	136	147	140	149	133	158	124	87	98	98	116
	EV	98	95	105	119	81	130	159	137	120	158	149	123	123	136	147	140	149	133	158	124	87	98	98	116
	AC	76	99	86	118	69	121	127	99	115	156	112	122	114	120	143	147	155	126	167	87	76	95	88	106
P26	PV	109	100	101	93	114	150	143	129	127	135	142	147	151	135	122	133	132	152	120	154	93	107	87	92
	EV	109	100	101	93	114	150	143	129	127	135	142	147	151	135	122	133	132	152	120	154	93	107	87	92
	AC	85	106	109	82	98	150	154	137	98	119	125	163	131	128	90	106	137	116	131	137	77	119	97	65
P27	PV	83	89	89	111	95	127	154	121	148	150	130	158	143	141	157	123	147	154	155	141	115	104	89	117
	EV	83	89	89	111	95	127	154	121	148	150	130	158	143	141	157	123	147	154	155	141	115	104	89	117
	AC	57	60	84	123	70	97	168	102	101	111	108	156	117	130	151	128	141	123	152	96	93	90	78	84
P28	PV	93	88	115	97	87	129	134	143	152	133	154	133	123	122	136	151	128	125	155	133	107	110	103	83
	EV	93	88	115	97	87	129	134	143	152	133	154	133	123	122	136	151	128	125	155	133	107	110	103	83
	AC	75	72	115	76	69	94	133	152	114	112	157	128	113	109	94	101	136	94	144	118	72	81	69	70
P29	PV	116	102	94	101	82	156	129	134	148	123	133	160	141	157	148	153	134	135	158	132	86	117	85	83
	EV	116	102	94	101	82	156	129	134	148	123	133	160	141	157	148	153	134	135	158	132	86	117	85	83
	AC	96	90	101	69	89	126	107	130	110	128	140	110	135	126	160	158	98	101	163	141	74	111	84	64
P30	PV	109	114	106	86	83	146	128	143	141	122	145	159	156	134	121	122	141	130	152	160	104	105	109	81
	EV	109	114	106	86	83	146	128	143	141	122	145	159	156	134	121	122	141	130	152	160	104	105	109	81
	AC	78	119	82	69	92	121	132	153	120	105	152	153	112	135	102	112	131	118	117	139	111	79	77	64

P31	PV	91	112	82	107	80	139	125	160	140	123	127	150	128	149	125	138	145	149	144	145	83	113	99	117
	EV	91	112	82	107	80	139	125	160	140	123	127	150	128	149	125	138	145	149	144	145	83	113	99	117
	AC	73	124	78	118	88	96	113	114	116	106	132	101	132	148	94	121	112	104	154	120	79	87	104	112
P32	PV	94	80	110	101	99	139	158	160	128	135	126	120	126	148	150	149	151	157	139	137	100	98	101	104
	EV	94	80	110	101	99	139	158	160	128	135	126	120	126	148	150	149	151	157	139	137	100	98	101	104
	AC	98	74	77	76	91	117	123	114	91	142	129	121	140	130	135	165	157	163	128	107	97	89	88	97
P33	PV	88	103	97	119	112	151	126	146	148	149	154	135	140	128	148	136	125	150	150	139	119	119	95	111
	EV	88	103	97	119	112	151	126	146	148	149	154	135	140	128	148	136	125	150	150	139	119	119	95	111
	AC	64	97	66	108	88	106	113	158	138	124	128	135	140	87	127	91	88	122	144	117	84	123	69	91
P34	PV	111	87	91	102	84	148	158	123	159	131	120	147	153	144	120	153	156	134	126	130	107	115	100	102
	EV	111	87	91	102	84	148	158	123	159	131	120	147	153	144	120	153	156	134	126	130	107	115	100	102
	AC	81	64	90	88	59	127	166	137	119	143	101	141	161	148	102	138	129	126	100	122	100	127	98	70
P35	PV	90	85	96	82	83	145	141	158	132	121	120	127	156	149	155	130	153	126	152	146	112	99	117	113
	EV	90	85	96	82	83	145	141	158	132	121	120	127	156	149	155	130	153	126	152	146	112	99	117	113
	AC	95	94	64	85	56	113	130	175	140	88	91	102	133	107	135	105	164	84	106	143	110	74	96	89
P36	PV	114	89	117	111	116	156	129	137	157	157	137	124	125	133	155	155	142	133	127	126	98	82	115	111
	EV	114	89	117	111	116	156	129	137	157	157	137	124	125	133	155	155	142	133	127	126	98	82	115	111
	AC	113	68	116	119	87	122	98	92	152	141	129	103	96	132	171	104	107	98	91	108	100	83	98	115
P37	PV	92	86	97	93	120	125	135	150	135	128	144	139	144	125	132	127	133	141	147	140	119	99	118	81
	EV	92	86	97	93	120	125	135	150	135	128	144	139	144	125	132	127	133	141	147	140	119	99	118	81
	AC	65	72	86	81	95	128	113	131	111	123	144	129	135	119	147	127	129	123	154	132	105	74	80	59
P38	PV	110	91	115	87	83	150	121	148	149	126	133	120	144	127	157	128	146	154	135	139	120	102	87	116
	EV	110	91	115	87	83	150	121	148	149	126	133	120	144	127	157	128	146	154	135	139	120	102	87	116
	AC	117	64	106	86	59	161	88	130	106	126	105	109	150	113	166	122	102	146	142	107	116	85	90	94
P39	PV	87	109	107	107	90	158	138	130	127	155	156	130	157	124	146	147	123	142	131	126	92	91	98	81
	EV	87	109	107	107	90	158	138	130	127	155	156	130	157	124	146	147	123	142	131	126	92	91	98	81
	AC	65	104	105	108	97	150	110	103	140	150	164	135	154	136	162	112	82	126	144	116	62	93	76	90
P40	PV	84	85	114	116	107	148	151	155	138	139	150	145	130	153	148	148	144	154	153	128	108	81	89	88
	EV	84	85	114	116	107	148	151	155	138	139	150	145	130	153	148	148	144	154	153	128	108	81	89	88
	AC	58	86	101	110	108	99	168	124	152	145	119	141	96	129	158	161	96	154	170	124	84	58	69	95
P41	PV	113	117	97	88	97	149	137	127	157	132	149	135	131	121	123	142	122	155	159	140	89	120	84	80

	EV	113	117	97	88	97	149	137	127	157	132	149	135	131	121	123	142	122	155	159	140	89	120	84	80
	AC	87	116	81	80	99	113	103	86	113	110	109	139	138	88	86	104	88	163	162	116	94	90	74	66
P42	PV	92	98	100	99	111	136	138	122	155	157	138	123	143	127	148	132	145	147	145	127	82	90	120	114
	EV	92	98	100	99	111	136	138	122	155	157	138	123	143	127	148	132	145	147	145	127	82	90	120	114
	AC	73	91	90	92	94	99	101	87	105	135	152	116	156	95	126	147	158	104	158	88	65	62	100	83
P43	PV	109	83	119	103	110	145	147	158	127	143	157	122	146	140	121	132	143	138	149	141	106	97	82	114
	EV	109	83	119	103	110	145	147	158	127	143	157	122	146	140	121	132	143	138	149	141	106	97	82	114
	AC	90	77	115	102	99	139	128	114	141	106	121	126	136	111	83	98	123	106	122	110	110	82	62	90
P44	PV	102	80	108	112	98	160	156	152	148	132	139	154	158	144	137	126	122	155	124	151	114	86	106	108
	EV	102	80	108	112	98	160	156	152	148	132	139	154	158	144	137	126	122	155	124	151	114	86	106	108
	AC	98	56	107	104	78	109	170	157	141	92	108	159	119	114	129	136	123	124	117	151	120	77	84	117
P45	PV	116	88	86	82	90	157	142	146	125	143	125	157	138	120	141	160	127	130	146	160	110	110	87	90
	EV	116	88	86	82	90	157	142	146	125	143	125	157	138	120	141	160	127	130	146	160	110	110	87	90
	AC	115	62	77	72	77	124	135	128	95	119	88	126	137	120	102	126	131	87	143	141	121	102	78	97
P46	PV	83	111	101	105	108	140	156	134	146	155	155	146	137	144	146	123	126	141	146	129	85	88	110	84
	EV	83	111	101	105	108	140	156	134	146	155	155	146	137	144	146	123	126	141	146	129	85	88	110	84
	AC	85	101	112	87	111	133	153	111	99	135	133	153	152	109	158	111	98	128	155	108	75	65	106	86
P47	PV	113	110	105	86	119	152	131	130	135	137	160	121	136	147	135	128	156	136	126	160	110	120	87	97
	EV	113	110	105	86	119	152	131	130	135	137	160	121	136	147	135	128	156	136	126	160	110	120	87	97
	AC	80	122	74	58	83	150	98	104	143	130	173	111	141	156	108	132	164	150	96	139	96	101	72	99
P48	PV	80	102	106	119	110	140	130	133	134	124	134	121	133	122	146	149	150	153	142	143	99	98	93	93
	EV	80	102	106	119	110	140	130	133	134	124	134	121	133	122	146	149	150	153	142	143	99	98	93	93
	AC	61	82	114	107	114	151	142	105	105	120	117	88	101	104	134	107	104	156	146	129	89	87	70	89
P49	PV	81	92	95	102	96	134	130	139	158	127	127	155	143	155	120	130	148	152	147	146	95	109	96	83
	EV	81	92	95	102	96	134	130	139	158	127	127	155	143	155	120	130	148	152	147	146	95	109	96	83
	AC	59	74	67	94	77	115	140	135	122	85	135	122	143	126	128	126	117	169	154	118	76	93	91	59
P50	PV	96	90	107	96	92	143	155	159	145	138	149	130	120	136	120	146	149	152	134	132	115	90	89	99
	EV	96	90	107	96	92	143	155	159	145	138	149	130	120	136	120	146	149	152	134	132	115	90	89	99
	AC	98	72	87	93	66	104	130	111	113	95	146	138	91	146	80	98	162	137	94	90	82	66	96	90
P51	PV	101	89	108	109	100	146	160	137	147	133	158	120	130	127	144	140	120	149	139	142	120	103	102	116
	EV	101	89	108	109	100	146	160	137	147	133	158	120	130	127	144	140	120	149	139	142	120	103	102	116

	AC	70	62	81	86	98	110	163	151	128	101	139	131	113	132	122	115	120	146	126	107	107	113	69	126
P52	PV	96	89	100	120	107	133	133	140	137	158	128	129	129	137	140	153	140	160	141	141	94	84	117	101
	EV	96	89	100	120	107	133	133	140	137	158	128	129	129	137	140	153	140	160	141	141	94	84	117	101
	AC	80	95	104	121	110	145	144	151	125	167	140	86	112	116	119	122	101	122	149	128	76	81	97	83
P53	PV	91	110	84	105	85	156	123	146	150	158	130	158	129	139	121	137	126	141	134	159	106	90	100	106
	EV	91	110	84	105	85	156	123	146	150	158	130	158	129	139	121	137	126	141	134	159	106	90	100	106
	AC	74	112	78	113	69	122	90	124	105	155	130	156	130	108	87	138	96	116	102	175	102	86	93	86
P54	PV	81	105	90	95	96	136	150	132	147	154	149	152	158	160	160	139	158	132	137	122	98	119	100	80
	EV	81	105	90	95	96	136	150	132	147	154	149	152	158	160	160	139	158	132	137	122	98	119	100	80
	AC	70	107	73	95	71	110	134	102	121	125	116	166	174	149	107	129	107	112	95	90	109	83	104	85
P55	PV	117	83	92	107	96	122	153	144	139	133	160	126	150	129	158	150	126	155	133	145	119	88	112	110
	EV	117	83	92	107	96	122	153	144	139	133	160	126	150	129	158	150	126	155	133	145	119	88	112	110
	AC	89	56	77	118	72	104	124	138	126	90	165	108	153	99	169	159	125	113	106	109	84	74	121	94
P56	PV	101	100	118	90	83	157	130	155	153	140	132	131	143	156	155	160	129	150	123	153	92	105	94	110
	EV	101	100	118	90	83	157	130	155	153	140	132	131	143	156	155	160	129	150	123	153	92	105	94	110
	AC	103	73	106	65	71	122	129	141	107	95	102	128	110	142	140	114	103	146	119	161	72	90	90	121
P57	PV	112	97	102	96	104	155	148	156	151	126	142	153	153	138	123	151	159	137	123	134	99	86	98	104
	EV	112	97	102	96	104	155	148	156	151	126	142	153	153	138	123	151	159	137	123	134	99	86	98	104
	AC	105	95	99	70	85	161	129	115	124	91	148	116	121	113	98	131	122	112	98	102	86	89	85	77
P58	PV	84	89	97	92	84	150	134	132	121	124	142	138	147	134	128	132	150	121	148	149	99	116	116	104
	EV	84	89	97	92	84	150	134	132	121	124	142	138	147	134	128	132	150	121	148	149	99	116	116	104
	AC	58	81	70	63	86	138	118	144	102	104	138	137	159	149	92	114	105	104	149	119	110	94	109	75
P59	PV	115	95	105	114	115	126	123	152	160	157	121	157	139	126	148	125	158	142	133	147	95	110	88	86
	EV	115	95	105	114	115	126	123	152	160	157	121	157	139	126	148	125	158	142	133	147	95	110	88	86
	AC	99	98	110	103	120	115	134	134	178	121	88	121	146	139	161	103	134	95	97	162	83	78	62	91
P60	PV	100	111	111	82	119	154	157	148	155	158	144	149	135	133	133	133	143	153	131	131	87	97	119	104
	EV	100	111	111	82	119	154	157	148	155	158	144	149	135	133	133	133	143	153	131	131	87	97	119	104
	AC	83	95	107	76	106	168	133	152	116	107	128	134	135	140	114	97	122	121	126	97	77	81	94	109
P61	PV	114	103	111	80	106	131	136	152	133	137	133	122	154	157	149	137	138	128	146	132	86	103	116	104
	EV	114	103	111	80	106	131	136	152	133	137	133	122	154	157	149	137	138	128	146	132	86	103	116	104
	AC	100	79	89	84	100	136	133	120	100	101	112	89	103	165	103	96	149	142	145	117	58	99	125	85

P62	PV	120	80	95	88	92	160	156	120	122	155	138	125	125	151	160	120	146	129	127	150	108	83	89	90
	EV	120	80	95	88	92	160	156	120	122	155	138	125	125	151	160	120	146	129	127	150	108	83	89	90
	AC	109	74	67	87	74	163	167	86	134	105	132	110	134	109	112	104	124	106	98	138	105	73	88	98
P63	PV	104	107	94	106	93	151	128	123	148	131	148	123	155	135	154	160	129	131	156	153	112	106	102	111
	EV	104	107	94	106	93	151	128	123	148	131	148	123	155	135	154	160	129	131	156	153	112	106	102	111
	AC	110	90	91	101	82	162	137	116	111	132	142	119	110	92	129	141	119	102	112	156	113	87	84	95
P64	PV	97	95	116	111	90	126	148	159	141	126	144	145	154	136	140	137	153	158	159	157	115	101	117	82
	EV	97	95	116	111	90	126	148	159	141	126	144	145	154	136	140	137	153	158	159	157	115	101	117	82
	AC	88	65	93	91	72	136	148	116	100	102	144	144	131	109	153	126	129	166	162	113	128	71	112	66
P65	PV	104	111	89	116	99	157	134	149	123	137	150	125	137	150	136	158	141	159	150	151	95	113	114	87
	EV	104	111	89	116	99	157	134	149	123	137	150	125	137	150	136	158	141	159	150	151	95	113	114	87
	AC	114	95	69	93	92	163	102	130	112	95	117	125	114	117	118	139	145	157	155	154	72	78	82	63
P66	PV	86	102	81	103	84	150	158	160	136	122	140	146	123	158	134	160	128	121	130	148	95	107	90	116
	EV	86	102	81	103	84	150	158	160	136	122	140	146	123	158	134	160	128	121	130	148	95	107	90	116
	AC	58	103	57	76	70	150	149	114	101	89	125	152	114	109	115	160	88	102	120	123	105	88	87	96
P67	PV	102	81	111	94	93	157	149	138	130	157	155	141	135	134	153	157	132	135	160	126	80	118	97	114
	EV	102	81	111	94	93	157	149	138	130	157	155	141	135	134	153	157	132	135	160	126	80	118	97	114
	AC	113	71	118	83	63	163	100	128	144	170	121	106	149	113	124	141	104	105	152	134	76	125	96	114
P68	PV	97	89	104	87	99	148	122	152	146	154	138	160	149	159	124	142	156	126	130	126	93	96	105	91
	EV	97	89	104	87	99	148	122	152	146	154	138	160	149	159	124	142	156	126	130	126	93	96	105	91
	AC	90	78	104	77	68	148	112	147	124	126	116	146	125	161	95	141	105	95	91	120	66	78	85	64
P69	PV	113	91	89	93	94	145	129	149	154	124	123	153	146	132	147	125	128	155	131	144	96	82	94	83
	EV	113	91	89	93	94	145	129	149	154	124	123	153	146	132	147	125	128	155	131	144	96	82	94	83
	AC	115	85	81	63	67	155	138	148	109	125	106	132	117	119	126	85	140	124	90	148	70	63	84	86
P70	PV	112	90	86	104	89	154	123	136	137	135	134	133	156	154	143	150	128	156	154	151	96	115	99	105
	EV	112	90	86	104	89	154	123	136	137	135	134	133	156	154	143	150	128	156	154	151	96	115	99	105
	AC	85	69	94	80	81	117	86	144	141	104	122	93	170	139	122	165	92	154	105	149	70	86	82	92
P71	PV	98	96	118	105	108	132	149	123	153	135	144	153	154	149	156	157	144	137	153	127	90	118	117	90
	EV	98	96	118	105	108	132	149	123	153	135	144	153	154	149	156	157	144	137	153	127	90	118	117	90
	AC	66	68	120	107	84	147	124	109	168	92	112	115	151	115	109	171	151	107	141	133	86	86	128	89
P72	PV	101	119	117	110	107	151	121	160	149	148	142	128	121	137	159	121	145	120	160	139	81	87	110	83

	EV	101	119	117	110	107	151	121	160	149	148	142	128	121	137	159	121	145	120	160	139	81	87	110	83
	AC	87	108	85	90	82	146	91	157	162	108	115	138	99	149	145	123	102	120	157	145	78	80	77	88
P73	PV	99	105	120	116	109	141	141	144	143	133	143	160	140	149	149	122	120	137	135	144	112	93	81	95
	EV	99	105	120	116	109	141	141	144	143	133	143	160	140	149	149	122	120	137	135	144	112	93	81	95
	AC	69	116	122	118	116	152	114	135	96	105	103	128	134	161	140	112	127	125	105	131	85	96	86	67
P74	PV	104	96	96	90	110	150	121	123	120	146	144	128	155	126	128	134	125	149	157	152	97	101	114	106
	EV	104	96	96	90	110	150	121	123	120	146	144	128	155	126	128	134	125	149	157	152	97	101	114	106
	AC	105	70	105	86	92	122	87	85	133	146	154	109	150	100	93	149	104	152	108	147	96	83	99	80
P75	PV	114	107	86	92	89	142	146	145	136	147	150	122	133	159	145	127	154	124	157	151	101	106	109	104
	EV	114	107	86	92	89	142	146	145	136	147	150	122	133	159	145	127	154	124	157	151	101	106	109	104
	AC	124	80	73	80	72	116	127	106	121	125	119	133	105	116	97	113	166	123	171	163	108	78	75	70
P76	PV	81	104	80	107	116	138	150	130	149	123	132	139	158	142	135	131	131	153	148	135	98	82	101	87
	EV	81	104	80	107	116	138	150	130	149	123	132	139	158	142	135	131	131	153	148	135	98	82	101	87
	AC	62	93	88	102	96	102	101	99	101	124	108	143	172	136	103	140	98	156	161	146	73	62	109	82
P77	PV	81	83	84	82	112	146	158	124	145	157	146	143	131	142	121	153	143	157	138	132	80	90	114	117
	EV	81	83	84	82	112	146	158	124	145	157	146	143	131	142	121	153	143	157	138	132	80	90	114	117
	AC	69	72	58	68	124	107	160	117	148	107	112	120	113	107	86	164	146	107	92	120	66	74	109	113
P78	PV	120	120	99	108	104	139	151	153	132	151	147	123	128	156	159	148	126	131	142	149	117	106	80	84
	EV	120	120	99	108	104	139	151	153	132	151	147	123	128	156	159	148	126	131	142	149	117	106	80	84
	AC	103	100	83	86	103	140	122	165	116	162	125	124	127	128	122	121	129	121	114	143	94	74	55	65
P79	PV	91	107	117	86	107	156	145	129	152	143	124	135	154	125	123	147	148	142	125	154	90	111	88	84
	EV	91	107	117	86	107	156	145	129	152	143	124	135	154	125	123	147	148	142	125	154	90	111	88	84
	AC	75	81	97	82	95	122	157	124	157	114	129	97	139	128	116	115	102	138	111	125	80	89	92	92
P80	PV	105	115	95	86	91	151	138	152	125	141	144	144	132	151	137	136	151	132	122	135	105	119	113	110
	EV	105	115	95	86	91	151	138	152	125	141	144	144	132	151	137	136	151	132	122	135	105	119	113	110
	AC	88	95	64	83	84	148	92	155	99	106	120	115	141	146	108	121	146	139	128	104	76	93	118	91
P81	PV	101	90	93	90	84	131	159	147	150	125	156	148	138	144	134	154	146	143	135	145	117	95	85	91
	EV	101	90	93	90	84	131	159	147	150	125	156	148	138	144	134	154	146	143	135	145	117	95	85	91
	AC	92	71	79	72	56	143	114	157	122	135	119	135	145	137	118	126	162	116	93	136	96	67	61	92
P82	PV	93	109	105	94	101	144	148	144	136	130	149	159	156	133	129	121	154	158	156	120	90	86	81	101
	EV	93	109	105	94	101	144	148	144	136	130	149	159	156	133	129	121	154	158	156	120	90	86	81	101

	AC	83	73	113	102	102	99	114	137	99	144	146	153	123	97	139	100	168	147	145	104	88	95	60	108
P83	PV	109	102	102	102	111	144	142	136	143	159	153	156	124	151	139	125	130	142	144	151	87	94	103	113
	EV	109	102	102	102	111	144	142	136	143	159	153	156	124	151	139	125	130	142	144	151	87	94	103	113
	AC	116	70	112	112	99	105	133	116	114	138	145	162	114	162	120	99	87	145	130	107	73	72	83	110
P84	PV	103	100	89	87	91	134	143	125	131	135	129	122	147	142	126	156	158	134	146	151	96	90	116	85
	EV	103	100	89	87	91	134	143	125	131	135	129	122	147	142	126	156	158	134	146	151	96	90	116	85
	AC	72	109	93	73	78	95	130	125	118	150	135	95	100	108	136	148	144	146	152	124	99	68	89	94
P85	PV	102	91	102	119	110	156	138	146	133	120	125	128	149	151	121	146	132	138	157	129	84	112	111	102
	EV	102	91	102	119	110	156	138	146	133	120	125	128	149	151	121	146	132	138	157	129	84	112	111	102
	AC	74	91	111	123	114	158	123	112	130	100	139	111	146	134	122	143	111	99	135	119	79	122	93	86
P86	PV	104	87	113	104	107	121	152	144	121	144	155	149	148	145	132	141	156	157	139	150	98	80	118	111
	EV	104	87	113	104	107	121	152	144	121	144	155	149	148	145	132	141	156	157	139	150	98	80	118	111
	AC	113	76	115	108	109	134	155	102	113	115	167	152	126	116	137	99	158	141	138	107	98	54	81	101
P87	PV	103	83	98	109	94	147	140	133	123	130	144	132	123	127	141	156	121	152	124	129	109	120	115	108
	EV	103	83	98	109	94	147	140	133	123	130	144	132	123	127	141	156	121	152	124	129	109	120	115	108
	AC	82	85	100	98	77	107	127	126	118	108	122	128	114	130	148	150	108	103	105	135	119	130	79	110
P88	PV	108	103	97	88	97	152	159	138	126	134	150	160	125	151	121	126	142	146	155	132	111	86	110	84
	EV	108	103	97	88	97	152	159	138	126	134	150	160	125	151	121	126	142	146	155	132	111	86	110	84
	AC	103	107	104	91	90	109	118	95	116	149	161	147	90	145	113	125	119	159	119	112	78	87	116	76
P89	PV	120	86	115	105	97	120	149	133	137	136	143	123	143	121	136	138	121	155	157	140	109	80	91	108
	EV	120	86	115	105	97	120	149	133	137	136	143	123	143	121	136	138	121	155	157	140	109	80	91	108
	AC	125	65	77	95	81	85	162	100	105	135	119	135	106	125	143	109	110	157	121	136	99	54	77	119
P90	PV	101	94	80	99	96	156	130	121	152	142	148	144	143	138	136	123	133	121	151	127	119	96	104	120
	EV	101	94	80	99	96	156	130	121	152	142	148	144	143	138	136	123	133	121	151	127	119	96	104	120
	AC	108	104	87	110	84	161	109	110	155	136	145	132	127	145	131	106	118	129	116	103	125	68	92	100
P91	PV	93	115	98	107	116	134	150	120	137	151	133	155	136	157	151	150	126	125	159	121	106	104	114	93
	EV	93	115	98	107	116	134	150	120	137	151	133	155	136	157	151	150	126	125	159	121	106	104	114	93
	AC	74	124	71	78	123	137	152	110	100	139	93	104	102	160	153	134	105	105	124	105	100	108	109	68
P92	PV	115	88	83	114	85	157	125	153	144	128	154	153	144	129	139	154	158	137	120	128	88	107	112	113
	EV	115	88	83	114	85	157	125	153	144	128	154	153	144	129	139	154	158	137	120	128	88	107	112	113
	AC	79	82	65	97	68	115	109	158	154	141	132	165	98	97	114	156	125	145	116	92	75	110	90	87

P93	PV	106	93	100	80	96	147	157	127	150	151	142	142	150	135	139	141	149	148	142	134	100	84	88	112
	EV	106	93	100	80	96	147	157	127	150	151	142	142	150	135	139	141	149	148	142	134	100	84	88	112
	AC	95	94	72	85	66	138	159	107	102	107	155	122	120	146	115	109	119	124	104	134	90	86	89	92
P94	PV	120	106	93	91	110	131	136	123	122	132	137	160	122	127	129	133	137	134	145	153	95	93	111	102
	EV	120	106	93	91	110	131	136	123	122	132	137	160	122	127	129	133	137	134	145	153	95	93	111	102
	AC	109	109	90	82	80	103	112	135	84	100	99	150	129	113	88	94	125	94	161	103	72	69	94	84
P95	PV	88	92	119	96	96	122	144	125	160	157	134	124	132	143	147	157	140	144	126	129	88	98	101	116
	EV	88	92	119	96	96	122	144	125	160	157	134	124	132	143	147	157	140	144	126	129	88	98	101	116
	AC	64	86	130	74	89	133	102	101	110	108	110	92	132	112	113	163	126	107	92	114	96	82	106	103
P96	PV	112	109	81	92	120	140	157	142	144	158	155	143	159	142	128	160	123	150	131	150	93	105	98	90
	EV	112	109	81	92	120	140	157	142	144	158	155	143	159	142	128	160	123	150	131	150	93	105	98	90
	AC	106	83	78	96	119	132	146	122	137	111	110	140	170	156	119	149	125	165	131	114	91	107	106	93
P97	PV	94	96	85	101	108	146	132	150	132	156	128	143	148	122	124	132	139	128	127	138	94	118	90	84
	EV	94	96	85	101	108	146	132	150	132	156	128	143	148	122	124	132	139	128	127	138	94	118	90	84
	AC	64	98	66	80	89	115	103	167	115	156	100	134	114	87	83	112	150	142	88	117	70	100	76	71
P98	PV	84	118	93	89	112	125	138	138	144	151	126	122	138	130	129	139	129	130	156	132	120	85	104	88
	EV	84	118	93	89	112	125	138	138	144	151	126	122	138	130	129	139	129	130	156	132	120	85	104	88
	AC	89	126	100	99	94	91	97	102	101	157	129	94	141	135	139	135	112	108	133	143	122	66	87	81
P99	PV	118	81	86	91	99	120	160	122	127	125	139	131	137	132	142	121	137	122	147	146	110	80	114	90
	EV	118	81	86	91	99	120	160	122	127	125	139	131	137	132	142	121	137	122	147	146	110	80	114	90
	AC	89	78	61	84	97	108	165	101	112	104	93	118	142	132	132	113	115	129	144	131	116	75	86	68
P100	PV	82	108	117	86	92	138	154	145	157	154	146	141	153	127	143	160	141	122	148	154	116	101	87	88
	EV	82	108	117	86	92	138	154	145	157	154	146	141	153	127	143	160	141	122	148	154	116	101	87	88
	AC	69	100	124	64	101	115	163	133	129	128	112	152	118	114	103	117	120	122	111	149	119	82	62	87

Table E.4 Net monthly performance data for randomly generated projects in discipline 04

Project		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
P1	PV	87	111	106	105	112	143	148	137	153	138	133	143	153	145	158	151	120	135	144	151	88	107	105	113
	EV	87	111	106	105	112	143	148	137	153	138	133	143	153	145	158	151	120	135	144	151	88	107	105	113
	AC	87	94	129	119	87	126	123	96	147	142	149	127	158	144	96	162	142	122	95	183	106	79	114	124
P2	PV	106	94	92	84	94	147	141	156	148	124	148	152	129	160	123	125	120	160	154	130	107	120	89	95
	EV	106	94	92	84	94	147	141	156	148	124	148	152	129	160	123	125	120	160	154	130	107	120	89	95
	AC	76	73	57	71	78	104	176	120	107	131	157	128	106	181	132	133	113	138	156	125	109	128	111	73
P3	PV	89	97	99	110	85	133	126	140	131	160	155	160	141	153	147	152	145	121	122	124	89	87	104	116
	EV	89	97	99	110	85	133	126	140	131	160	155	160	141	153	147	152	145	121	122	124	89	87	104	116
	AC	83	85	81	74	80	149	129	85	123	163	143	130	166	125	122	137	117	125	77	100	72	61	124	96
P4	PV	95	117	80	111	107	126	120	160	128	142	137	150	145	127	149	142	141	141	122	120	97	102	81	83
	EV	95	117	80	111	107	126	120	160	128	142	137	150	145	127	149	142	141	141	122	120	97	102	81	83
	AC	95	131	54	121	112	115	91	110	104	102	95	126	173	124	106	119	127	151	135	84	86	72	88	96
P5	PV	101	100	115	110	107	133	134	150	144	131	121	131	132	158	127	131	124	141	145	151	89	114	120	104
	EV	101	100	115	110	107	133	134	150	144	131	121	131	132	158	127	131	124	141	145	151	89	114	120	104
	AC	63	96	115	95	128	102	88	141	107	143	91	97	125	166	109	121	87	158	113	177	102	74	106	70
P6	PV	111	101	85	97	118	128	136	149	156	122	135	151	157	136	123	149	147	124	159	138	92	111	108	97
	EV	111	101	85	97	118	128	136	149	156	122	135	151	157	136	123	149	147	124	159	138	92	111	108	97
	AC	122	118	78	74	83	84	106	148	139	93	163	153	159	107	82	137	140	154	154	116	111	113	118	118
P7	PV	85	112	102	94	94	155	149	137	126	141	146	135	157	139	142	142	143	123	142	145	119	108	85	103
	EV	85	112	102	94	94	155	149	137	126	141	146	135	157	139	142	142	143	123	142	145	119	108	85	103
	AC	104	73	79	110	89	96	134	152	118	131	178	108	104	138	142	159	146	89	146	129	136	116	62	117
P8	PV	84	105	109	113	102	148	139	129	135	156	132	136	126	134	151	154	136	152	155	146	96	108	114	97
	EV	84	105	109	113	102	148	139	129	135	156	132	136	126	134	151	154	136	152	155	146	96	108	114	97
	AC	77	129	97	123	85	167	160	139	126	162	79	122	127	92	187	112	80	187	93	174	58	116	83	86
P9	PV	82	89	116	110	80	128	146	137	129	158	137	133	132	132	122	136	125	155	157	141	82	120	91	106
	EV	82	89	116	110	80	128	146	137	129	158	137	133	132	132	122	136	125	155	157	141	82	120	91	106
	AC	77	66	106	81	68	82	158	112	80	174	81	105	128	152	90	126	118	152	113	142	102	77	111	92
P10	PV	103	114	92	118	119	152	139	139	130	145	146	135	143	126	151	150	160	143	120	157	113	84	108	89

	EV	103	114	92	118	119	152	139	139	130	145	146	135	143	126	151	150	160	143	120	157	113	84	108	89
	AC	110	133	92	133	132	112	117	122	120	139	161	111	132	81	98	126	149	140	110	108	141	81	64	101
P11	PV	83	113	86	98	97	136	138	151	144	144	132	158	137	124	157	134	147	132	139	124	88	102	119	111
	EV	83	113	86	98	97	136	138	151	144	144	132	158	137	124	157	134	147	132	139	124	88	102	119	111
	AC	53	86	87	98	119	106	99	130	125	176	95	179	158	97	181	92	181	111	103	108	99	65	146	123
P12	PV	101	82	96	119	120	124	151	133	122	142	144	121	141	140	130	156	136	142	155	130	111	107	93	98
	EV	101	82	96	119	120	124	151	133	122	142	144	121	141	140	130	156	136	142	155	130	111	107	93	98
	AC	65	57	99	77	150	94	156	78	90	116	132	150	113	139	156	195	152	124	183	92	128	116	108	71
P13	PV	120	95	101	105	112	139	137	125	152	120	144	128	156	135	132	157	159	123	120	132	120	110	85	111
	EV	120	95	101	105	112	139	137	125	152	120	144	128	156	135	132	157	159	123	120	132	120	110	85	111
	AC	124	80	77	93	115	125	103	128	109	91	166	134	173	127	116	174	146	92	148	84	137	125	97	90
P14	PV	107	96	83	108	81	132	158	153	125	126	135	124	133	127	121	159	127	156	148	138	106	116	89	90
	EV	107	96	83	108	81	132	158	153	125	126	135	124	133	127	121	159	127	156	148	138	106	116	89	90
	AC	102	100	77	118	71	128	179	133	125	115	86	113	146	110	115	137	122	179	99	119	64	110	68	102
P15	PV	120	118	108	81	99	143	133	125	155	158	126	157	135	144	149	148	121	152	122	126	97	80	93	95
	EV	120	118	108	81	99	143	133	125	155	158	126	157	135	144	149	148	121	152	122	126	97	80	93	95
	AC	95	116	67	70	113	172	160	118	118	164	154	171	113	176	186	144	99	184	148	154	98	87	113	105
P16	PV	106	111	109	96	95	158	131	130	141	126	157	131	135	149	144	130	126	154	129	142	114	91	99	119
	EV	106	111	109	96	95	158	131	130	141	126	157	131	135	149	144	130	126	154	129	142	114	91	99	119
	AC	120	89	110	103	61	136	100	103	148	158	122	103	90	92	120	138	118	97	121	175	138	109	117	108
P17	PV	101	98	82	101	119	149	156	128	126	155	130	158	150	131	153	158	122	138	130	150	103	118	93	89
	EV	101	98	82	101	119	149	156	128	126	155	130	158	150	131	153	158	122	138	130	150	103	118	93	89
	AC	86	74	84	73	124	152	158	82	91	127	133	106	98	103	191	147	106	138	140	150	93	70	91	110
P18	PV	108	114	95	107	119	143	152	134	137	143	137	158	125	123	124	138	156	120	146	155	113	89	88	105
	EV	108	114	95	107	119	143	152	134	137	143	137	158	125	123	124	138	156	120	146	155	113	89	88	105
	AC	92	114	114	110	144	160	94	139	125	159	140	185	121	130	104	110	126	139	161	192	88	73	91	110
P19	PV	116	113	101	81	115	133	141	135	160	158	133	135	148	125	142	159	133	144	123	154	113	120	89	117
	EV	116	113	101	81	115	133	141	135	160	158	133	135	148	125	142	159	133	144	123	154	113	120	89	117
	AC	102	71	92	66	115	125	118	167	181	194	81	100	110	99	126	122	132	163	114	146	101	136	108	111
P20	PV	101	101	106	85	82	132	124	160	141	134	121	150	159	152	141	156	122	135	144	133	100	114	92	101
	EV	101	101	106	85	82	132	124	160	141	134	121	150	159	152	141	156	122	135	144	133	100	114	92	101

	AC	80	72	65	62	97	139	77	110	155	127	113	125	176	167	149	195	96	111	164	156	93	72	76	88
P21	PV	101	110	90	88	94	149	143	159	137	159	144	141	126	137	121	152	123	150	130	125	91	117	119	96
	EV	101	110	90	88	94	149	143	159	137	159	144	141	126	137	121	152	123	150	130	125	91	117	119	96
	AC	102	138	83	95	89	116	160	167	116	176	147	142	149	137	85	102	103	171	98	126	112	83	88	57
P22	PV	104	102	120	84	116	150	151	144	124	140	145	122	146	133	144	124	128	125	134	120	98	99	120	111
	EV	104	102	120	84	116	150	151	144	124	140	145	122	146	133	144	124	128	125	134	120	98	99	120	111
	AC	119	126	85	94	142	119	133	89	117	155	164	89	112	82	107	103	111	89	139	95	88	106	116	131
P23	PV	113	85	85	112	95	157	125	134	142	129	124	149	153	125	156	142	123	156	142	140	85	108	115	87
	EV	113	85	85	112	95	157	125	134	142	129	124	149	153	125	156	142	123	156	142	140	85	108	115	87
	AC	125	50	73	72	67	122	155	103	89	101	141	180	145	105	165	88	91	192	116	158	53	122	133	104
P24	PV	108	111	103	86	91	137	156	141	150	139	156	155	131	129	130	149	128	130	148	135	81	102	87	111
	EV	108	111	103	86	91	137	156	141	150	139	156	155	131	129	130	149	128	130	148	135	81	102	87	111
	AC	117	70	122	52	98	147	159	96	89	121	108	93	134	148	78	170	99	99	164	95	72	80	57	74
P25	PV	113	117	82	102	117	145	157	145	159	135	137	129	128	148	140	137	126	130	134	141	105	81	85	80
	EV	113	117	82	102	117	145	157	145	159	135	137	129	128	148	140	137	126	130	134	141	105	81	85	80
	AC	80	96	75	103	95	120	159	180	143	82	129	90	129	178	168	116	115	142	91	99	119	64	71	64
P26	PV	89	108	87	102	117	135	122	155	137	148	147	143	142	153	138	146	120	127	146	146	101	87	120	119
	EV	89	108	87	102	117	135	122	155	137	148	147	143	142	153	138	146	120	127	146	146	101	87	120	119
	AC	93	127	53	77	90	104	153	96	158	176	112	116	152	190	84	136	104	122	153	172	78	70	95	104
P27	PV	114	84	113	99	101	141	137	158	151	143	144	150	159	129	129	149	160	122	131	149	101	119	95	96
	EV	114	84	113	99	101	141	137	158	151	143	144	150	159	129	129	149	160	122	131	149	101	119	95	96
	AC	124	67	115	96	75	121	123	112	125	170	135	170	191	94	160	152	130	82	100	176	123	143	63	91
P28	PV	100	105	94	88	83	144	137	121	125	143	137	156	142	152	136	159	141	129	143	149	103	81	86	112
	EV	100	105	94	88	83	144	137	121	125	143	137	156	142	152	136	159	141	129	143	149	103	81	86	112
	AC	106	71	111	62	54	104	133	113	124	104	130	126	163	106	87	170	152	159	114	116	66	58	99	131
P29	PV	93	97	88	108	82	135	128	158	153	142	151	128	138	154	159	124	157	160	136	147	90	91	87	108
	EV	93	97	88	108	82	135	128	158	153	142	151	128	138	154	159	124	157	160	136	147	90	91	87	108
	AC	110	92	68	126	91	134	87	190	168	142	107	122	135	191	159	131	185	171	163	143	109	77	86	70
P30	PV	94	112	88	83	80	131	140	156	122	146	121	156	152	139	136	130	124	143	147	141	87	100	83	89
	EV	94	112	88	83	80	131	140	156	122	146	121	156	152	139	136	130	124	143	147	141	87	100	83	89
	AC	55	120	87	91	61	156	97	95	78	149	88	170	114	168	169	100	114	164	103	159	101	67	68	99

P31	PV	120	114	102	111	89	146	132	159	146	151	155	148	124	132	152	147	147	148	126	151	106	104	98	113
	EV	120	114	102	111	89	146	132	159	146	151	155	148	124	132	152	147	147	148	126	151	106	104	98	113
	AC	102	111	126	83	106	166	87	164	104	145	164	112	122	104	167	107	123	110	81	184	85	114	64	133
P32	PV	119	119	103	80	87	144	135	143	141	154	128	135	130	129	148	140	122	132	145	132	96	112	95	95
	EV	119	119	103	80	87	144	135	143	141	154	128	135	130	129	148	140	122	132	145	132	96	112	95	95
	AC	114	144	118	90	104	161	111	129	173	100	134	103	96	138	110	125	106	116	138	129	96	102	61	86
P33	PV	107	107	115	110	97	154	152	154	149	158	145	134	126	140	157	154	130	125	160	136	88	88	98	112
	EV	107	107	115	110	97	154	152	154	149	158	145	134	126	140	157	154	130	125	160	136	88	88	98	112
	AC	68	76	107	101	88	108	134	188	180	125	145	165	115	111	168	148	127	143	122	135	82	66	100	134
P34	PV	111	86	97	114	90	138	153	124	146	158	130	155	156	148	143	140	146	157	151	130	94	113	108	116
	EV	111	86	97	114	90	138	153	124	146	158	130	155	156	148	143	140	146	157	151	130	94	113	108	116
	AC	138	65	73	115	86	128	174	74	164	109	151	124	165	111	99	95	137	168	163	103	108	84	73	121
P35	PV	103	117	97	84	103	121	150	125	145	141	140	132	132	142	155	145	145	142	158	122	98	110	105	93
	EV	103	117	97	84	103	121	150	125	145	141	140	132	132	142	155	145	145	142	158	122	98	110	105	93
	AC	91	140	113	68	99	86	95	88	132	158	172	165	124	119	105	162	149	131	136	121	79	88	72	61
P36	PV	94	94	110	93	97	154	160	133	133	132	136	158	149	141	134	151	134	158	147	146	108	97	95	113
	EV	94	94	110	93	97	154	160	133	133	132	136	158	149	141	134	151	134	158	147	146	108	97	95	113
	AC	86	101	133	112	62	156	146	84	144	120	169	193	128	175	119	148	154	122	134	172	132	104	100	67
P37	PV	116	119	88	119	93	154	139	121	149	143	146	132	135	124	138	137	132	131	139	134	116	102	94	116
	EV	116	119	88	119	93	154	139	121	149	143	146	132	135	124	138	137	132	131	139	134	116	102	94	116
	AC	137	70	70	121	106	139	121	120	162	97	112	121	109	140	138	125	140	152	157	102	129	105	70	71
P38	PV	101	98	118	82	113	121	129	124	142	138	154	123	128	159	125	124	127	149	138	121	117	93	90	82
	EV	101	98	118	82	113	121	129	124	142	138	154	123	128	159	125	124	127	149	138	121	117	93	90	82
	AC	106	120	114	57	92	85	130	83	143	149	131	112	77	151	106	100	145	118	135	77	91	73	99	87
P39	PV	111	90	111	104	116	129	131	126	142	143	149	154	136	152	146	148	137	139	140	137	115	83	80	85
	EV	111	90	111	104	116	129	131	126	142	143	149	154	136	152	146	148	137	139	140	137	115	83	80	85
	AC	124	97	133	108	126	134	160	132	102	140	165	91	99	166	136	120	88	128	134	125	140	98	80	57
P40	PV	106	108	113	86	88	152	136	153	128	141	123	154	131	139	152	126	155	140	144	139	88	113	98	106
	EV	106	108	113	86	88	152	136	153	128	141	123	154	131	139	152	126	155	140	144	139	88	113	98	106
	AC	119	111	108	71	86	157	165	133	115	157	140	140	147	111	169	97	186	123	160	124	83	89	67	77
P41	PV	94	88	113	86	118	128	140	122	129	146	123	139	149	144	124	151	149	156	120	150	90	89	102	100

	EV	94	88	113	86	118	128	140	122	129	146	123	139	149	144	124	151	149	156	120	150	90	89	102	100
	AC	106	53	97	108	97	155	161	95	130	181	107	149	94	117	131	113	115	103	92	99	89	93	60	116
P42	PV	113	88	98	102	90	136	136	131	124	128	133	129	120	146	159	137	135	137	136	123	117	91	98	96
	EV	113	88	98	102	90	136	136	131	124	128	133	129	120	146	159	137	135	137	136	123	117	91	98	96
	AC	130	64	89	98	56	80	87	157	154	119	138	102	86	171	97	93	93	93	102	82	91	76	117	79
P43	PV	97	114	105	80	111	155	135	155	159	148	149	124	153	148	156	145	126	152	147	160	90	96	106	119
	EV	97	114	105	80	111	155	135	155	159	148	149	124	153	148	156	145	126	152	147	160	90	96	106	119
	AC	61	68	118	78	111	102	144	177	134	121	122	140	92	129	98	157	140	181	159	101	84	66	120	105
P44	PV	119	103	90	97	115	135	142	139	142	140	139	145	128	159	147	131	134	140	129	138	85	103	103	116
	EV	119	103	90	97	115	135	142	139	142	140	139	145	128	159	147	131	134	140	129	138	85	103	103	116
	AC	93	100	106	91	127	107	89	125	155	111	153	93	159	191	172	153	159	84	160	159	105	122	126	125
P45	PV	82	97	112	106	106	150	154	124	148	120	146	147	140	147	158	158	134	142	151	159	97	96	119	116
	EV	82	97	112	106	106	150	154	124	148	120	146	147	140	147	158	158	134	142	151	159	97	96	119	116
	AC	49	68	80	108	130	132	102	128	175	73	172	123	148	93	177	190	162	153	106	102	114	101	93	78
P46	PV	115	101	87	93	113	129	139	147	132	127	147	121	124	136	151	156	148	122	138	149	113	115	107	95
	EV	115	101	87	93	113	129	139	147	132	127	147	121	124	136	151	156	148	122	138	149	113	115	107	95
	AC	124	105	89	97	84	108	111	143	90	108	176	71	129	133	154	183	169	90	139	113	88	122	129	67
P47	PV	102	81	105	91	118	159	159	121	132	132	120	151	153	157	159	154	120	148	148	131	91	110	81	105
	EV	102	81	105	91	118	159	159	121	132	132	120	151	153	157	159	154	120	148	148	131	91	110	81	105
	AC	97	77	86	86	106	127	164	139	117	96	106	184	158	138	107	97	90	105	145	92	107	73	100	125
P48	PV	89	102	102	96	117	150	128	140	120	132	149	144	158	137	131	154	122	160	126	138	116	105	98	100
	EV	89	102	102	96	117	150	128	140	120	132	149	144	158	137	131	154	122	160	126	138	116	105	98	100
	AC	75	64	99	66	92	164	154	115	114	124	173	114	128	126	143	106	113	173	154	139	88	81	109	94
P49	PV	97	114	101	95	103	155	125	144	151	154	147	131	146	149	125	135	121	126	140	132	105	103	91	91
	EV	97	114	101	95	103	155	125	144	151	154	147	131	146	149	125	135	121	126	140	132	105	103	91	91
	AC	119	88	75	101	115	119	100	166	160	191	121	115	117	168	148	155	90	141	83	107	69	64	109	97
P50	PV	97	103	98	110	97	153	147	160	158	141	133	126	134	148	133	140	129	126	140	148	117	118	88	106
	EV	97	103	98	110	97	153	147	160	158	141	133	126	134	148	133	140	129	126	140	148	117	118	88	106
	AC	91	74	106	135	118	115	141	179	167	97	120	155	114	121	153	134	114	146	106	144	85	84	75	83
P51	PV	86	87	100	86	94	128	138	155	138	150	136	152	144	135	150	127	143	129	151	137	108	89	102	85
	EV	86	87	100	86	94	128	138	155	138	150	136	152	144	135	150	127	143	129	151	137	108	89	102	85

	AC	88	108	82	59	84	77	149	119	91	164	95	106	164	116	176	93	104	137	139	114	81	61	125	62
P52	PV	94	82	88	83	86	123	131	124	143	131	133	122	139	132	152	126	141	157	129	156	120	94	113	86
	EV	94	82	88	83	86	123	131	124	143	131	133	122	139	132	152	126	141	157	129	156	120	94	113	86
	AC	110	75	97	94	101	116	113	77	126	144	149	150	114	100	144	149	144	148	137	131	136	103	132	55
P53	PV	107	117	108	93	103	126	121	150	153	120	136	139	155	125	120	133	150	158	160	153	120	113	111	85
	EV	107	117	108	93	103	126	121	150	153	120	136	139	155	125	120	133	150	158	160	153	120	113	111	85
	AC	95	91	120	81	98	103	138	171	95	127	147	107	96	124	74	148	134	164	150	147	90	124	130	94
P54	PV	84	114	81	116	111	134	159	153	157	120	144	152	141	156	146	155	156	129	145	137	99	101	104	83
	EV	84	114	81	116	111	134	159	153	157	120	144	152	141	156	146	155	156	129	145	137	99	101	104	83
	AC	96	89	63	87	110	106	130	107	119	132	173	138	120	162	114	183	129	116	132	147	123	114	68	64
P55	PV	117	120	115	87	87	137	131	157	130	143	134	120	158	127	135	159	148	146	147	148	98	112	104	102
	EV	117	120	115	87	87	137	131	157	130	143	134	120	158	127	135	159	148	146	147	148	98	112	104	102
	AC	102	110	81	70	107	163	164	122	125	139	96	134	182	90	155	143	141	130	162	121	59	74	103	80
P56	PV	81	93	115	81	113	140	145	147	148	129	139	135	150	135	135	151	139	153	153	147	120	81	109	112
	EV	81	93	115	81	113	140	145	147	148	129	139	135	150	135	135	151	139	153	153	147	120	81	109	112
	AC	91	101	99	85	140	148	142	97	147	85	95	153	179	116	146	145	107	159	119	91	125	55	117	90
P57	PV	108	100	105	85	115	135	126	144	139	155	146	154	125	145	149	129	138	144	158	133	99	89	114	98
	EV	108	100	105	85	115	135	126	144	139	155	146	154	125	145	149	129	138	144	158	133	99	89	114	98
	AC	90	118	75	87	71	107	142	170	107	116	92	160	103	132	130	116	168	96	107	105	113	60	127	68
P58	PV	82	108	91	118	88	139	159	137	141	160	123	130	141	144	141	134	133	151	132	149	81	97	85	108
	EV	82	108	91	118	88	139	159	137	141	160	123	130	141	144	141	134	133	151	132	149	81	97	85	108
	AC	66	122	69	133	102	89	135	148	144	174	111	91	175	145	162	141	118	113	158	137	89	71	56	97
P59	PV	120	112	118	107	100	129	122	137	120	138	136	134	139	157	132	140	130	143	151	131	91	110	114	106
	EV	120	112	118	107	100	129	122	137	120	138	136	134	139	157	132	140	130	143	151	131	91	110	114	106
	AC	91	123	103	121	59	130	96	116	88	148	88	113	152	188	158	140	147	146	100	103	112	65	129	65
P60	PV	83	97	98	94	87	123	146	140	138	134	144	132	125	152	126	144	138	146	158	134	109	86	102	106
	EV	83	97	98	94	87	123	146	140	138	134	144	132	125	152	126	144	138	146	158	134	109	86	102	106
	AC	64	68	67	91	64	144	164	157	99	121	120	114	150	125	95	130	144	168	131	88	114	67	81	121
P61	PV	104	110	118	105	87	141	145	159	144	154	156	156	151	145	160	145	128	142	132	155	95	105	87	101
	EV	104	110	118	105	87	141	145	159	144	154	156	156	151	145	160	145	128	142	132	155	95	105	87	101
	AC	98	94	89	83	58	124	141	178	89	160	187	193	91	170	141	165	105	170	120	98	91	99	61	79

P62	PV	107	98	103	97	85	139	137	126	135	127	136	124	142	123	121	130	127	127	132	147	111	81	86	87
	EV	107	98	103	97	85	139	137	126	135	127	136	124	142	123	121	130	127	127	132	147	111	81	86	87
	AC	106	105	88	113	82	83	171	100	134	90	170	105	124	109	106	87	145	86	107	115	78	69	78	98
P63	PV	90	90	105	111	113	148	121	153	127	140	157	148	136	156	160	138	123	159	146	157	86	120	89	95
	EV	90	90	105	111	113	148	121	153	127	140	157	148	136	156	160	138	123	159	146	157	86	120	89	95
	AC	55	60	111	98	141	108	134	159	122	101	185	126	146	112	187	146	76	130	120	93	88	77	59	77
P64	PV	113	107	104	112	108	148	138	141	142	139	130	149	127	159	142	134	134	128	137	121	111	108	84	91
	EV	113	107	104	112	108	148	138	141	142	139	130	149	127	159	142	134	134	128	137	121	111	108	84	91
	AC	98	87	124	132	116	166	81	106	118	140	155	183	107	122	109	157	138	118	141	132	88	92	70	88
P65	PV	84	89	102	100	88	125	135	153	160	157	125	160	122	146	149	154	126	135	152	133	98	81	100	115
	EV	84	89	102	100	88	125	135	153	160	157	125	160	122	146	149	154	126	135	152	133	98	81	100	115
	AC	81	76	75	119	106	85	113	161	98	162	151	168	96	99	145	188	103	154	102	90	65	51	93	92
P66	PV	102	86	83	109	118	130	153	122	123	157	145	154	158	130	127	143	131	153	156	147	107	93	84	114
	EV	102	86	83	109	118	130	153	122	123	157	145	154	158	130	127	143	131	153	156	147	107	93	84	114
	AC	96	60	70	78	114	103	135	146	73	144	97	193	155	105	142	129	85	113	101	179	126	115	85	136
P67	PV	90	112	117	99	99	132	145	127	129	150	132	139	122	120	159	139	143	157	136	143	83	96	103	80
	EV	90	112	117	99	99	132	145	127	129	150	132	139	122	120	159	139	143	157	136	143	83	96	103	80
	AC	96	105	95	121	72	161	119	112	132	161	143	140	129	130	175	132	122	137	80	160	56	120	72	49
P68	PV	106	114	93	90	103	135	124	123	159	146	158	158	124	155	124	133	131	150	139	153	91	93	114	115
	EV	106	114	93	90	103	135	124	123	159	146	158	158	124	155	124	133	131	150	139	153	91	93	114	115
	AC	125	129	55	54	73	147	89	73	173	130	128	139	123	194	109	166	100	161	138	188	88	60	136	108
P69	PV	81	115	105	112	113	120	141	141	141	147	125	148	136	141	150	155	150	144	125	141	120	103	117	88
	EV	81	115	105	112	113	120	141	141	141	147	125	148	136	141	150	155	150	144	125	141	120	103	117	88
	AC	96	69	64	119	140	122	103	89	90	179	98	166	150	111	135	157	143	164	126	118	112	69	105	58
P70	PV	100	89	81	113	116	146	122	146	143	148	126	135	122	151	130	145	121	127	150	132	85	106	82	90
	EV	100	89	81	113	116	146	122	146	143	148	126	135	122	151	130	145	121	127	150	132	85	106	82	90
	AC	121	77	70	128	140	92	87	123	146	138	127	104	132	148	103	142	133	98	183	84	89	103	51	84
P71	PV	112	118	115	99	86	133	147	126	160	158	156	120	135	152	130	156	149	127	149	131	97	80	89	103
	EV	112	118	115	99	86	133	147	126	160	158	156	120	135	152	130	156	149	127	149	131	97	80	89	103
	AC	74	145	77	68	103	120	88	137	160	131	134	83	104	160	78	190	143	118	168	164	84	88	86	67
P72	PV	112	101	87	102	92	120	151	136	149	158	145	151	123	129	153	125	139	132	154	152	97	83	114	88

	EV	112	101	87	102	92	120	151	136	149	158	145	151	123	129	153	125	139	132	154	152	97	83	114	88
	AC	94	112	105	77	84	79	89	118	158	139	165	122	128	89	93	98	95	144	156	125	65	86	111	84
P73	PV	102	104	85	89	110	151	147	132	140	140	144	159	156	132	139	131	127	129	151	123	86	84	103	88
	EV	102	104	85	89	110	151	147	132	140	140	144	159	156	132	139	131	127	129	151	123	86	84	103	88
	AC	95	129	98	80	125	165	162	112	104	119	151	126	109	121	93	101	88	90	172	74	85	86	82	80
P74	PV	96	80	89	99	95	144	143	160	125	133	141	124	145	133	157	121	153	130	147	141	117	88	87	115
	EV	96	80	89	99	95	144	143	160	125	133	141	124	145	133	157	121	153	130	147	141	117	88	87	115
	AC	59	58	96	78	103	148	120	182	155	108	111	136	126	82	113	93	125	100	98	166	71	97	80	141
P75	PV	114	86	109	101	96	132	150	157	153	137	159	140	147	133	123	152	158	157	133	139	84	103	105	94
	EV	114	86	109	101	96	132	150	157	153	137	159	140	147	133	123	152	158	157	133	139	84	103	105	94
	AC	120	83	113	65	77	165	95	113	155	99	138	150	97	149	91	99	114	97	93	117	61	72	62	59
P76	PV	83	120	98	92	88	138	139	135	133	129	120	125	151	157	127	140	136	149	153	124	108	100	88	95
	EV	83	120	98	92	88	138	139	135	133	129	120	125	151	157	127	140	136	149	153	124	108	100	88	95
	AC	85	109	121	84	70	139	172	131	98	124	128	124	146	108	146	95	125	107	176	129	69	117	104	85
P77	PV	87	92	108	116	97	149	124	121	123	131	123	132	126	126	151	159	153	134	124	155	94	102	108	96
	EV	87	92	108	116	97	149	124	121	123	131	123	132	126	126	151	159	153	134	124	155	94	102	108	96
	AC	94	63	130	79	67	165	145	103	98	160	84	102	156	120	91	116	151	114	114	149	101	80	83	112
P78	PV	120	85	93	103	99	122	146	124	141	150	132	137	143	157	149	129	136	125	121	158	80	111	119	114
	EV	120	85	93	103	99	122	146	124	141	150	132	137	143	157	149	129	136	125	121	158	80	111	119	114
	AC	143	92	107	99	116	92	145	151	120	146	128	158	89	152	110	137	116	90	109	100	56	67	84	96
P79	PV	89	96	104	120	91	135	151	158	152	147	153	154	146	132	136	156	144	127	149	131	103	88	102	118
	EV	89	96	104	120	91	135	151	158	152	147	153	154	146	132	136	156	144	127	149	131	103	88	102	118
	AC	84	59	129	113	57	108	92	190	105	169	96	134	128	88	83	123	99	107	139	94	91	68	110	80
P80	PV	96	91	103	83	82	121	132	134	134	125	129	156	140	158	140	141	125	124	133	146	101	81	104	107
	EV	96	91	103	83	82	121	132	134	134	125	129	156	140	158	140	141	125	124	133	146	101	81	104	107
	AC	57	88	103	88	51	74	162	91	113	94	98	186	157	98	101	114	121	124	161	91	68	93	128	129
P81	PV	94	92	81	116	107	136	138	121	146	154	151	124	147	140	154	128	154	159	148	129	101	93	82	91
	EV	94	92	81	116	107	136	138	121	146	154	151	124	147	140	154	128	154	159	148	129	101	93	82	91
	AC	98	115	70	132	81	110	87	148	133	156	149	131	131	147	160	109	166	170	118	110	61	73	85	105
P82	PV	115	96	119	88	103	144	126	123	151	158	126	144	127	148	158	146	135	133	126	124	99	119	89	104
	EV	115	96	119	88	103	144	126	123	151	158	126	144	127	148	158	146	135	133	126	124	99	119	89	104

	AC	121	117	89	79	90	167	105	113	124	96	141	112	154	164	93	117	127	144	110	130	98	79	79	129
P83	PV	99	86	86	106	99	123	132	130	150	132	123	134	154	153	140	148	149	139	120	123	107	103	102	120
	EV	99	86	86	106	99	123	132	130	150	132	123	134	154	153	140	148	149	139	120	123	107	103	102	120
	AC	58	60	79	124	111	109	131	124	125	99	114	149	183	148	111	126	146	140	143	101	71	87	73	122
P84	PV	111	91	101	119	116	155	151	124	140	159	151	158	158	140	122	139	142	145	127	134	86	119	116	108
	EV	111	91	101	119	116	155	151	124	140	159	151	158	158	140	122	139	142	145	127	134	86	119	116	108
	AC	113	76	108	74	81	161	115	135	108	116	131	93	141	147	85	121	89	161	159	138	57	126	118	75
P85	PV	85	95	102	118	81	130	125	136	156	140	136	156	158	158	152	148	120	125	152	146	116	102	95	84
	EV	85	95	102	118	81	130	125	136	156	140	136	156	158	158	152	148	120	125	152	146	116	102	95	84
	AC	82	62	122	81	70	77	121	116	128	162	91	183	167	152	117	173	74	141	120	127	115	115	85	58
P86	PV	91	91	113	93	90	125	131	135	124	122	125	120	137	123	121	141	156	135	155	138	100	91	98	108
	EV	91	91	113	93	90	125	131	135	124	122	125	120	137	123	121	141	156	135	155	138	100	91	98	108
	AC	62	106	71	82	96	146	81	109	99	122	91	112	129	117	111	154	162	88	121	92	74	91	102	121
P87	PV	114	90	99	88	113	124	142	140	138	130	129	135	123	144	152	138	128	149	136	152	86	83	91	85
	EV	114	90	99	88	113	124	142	140	138	130	129	135	123	144	152	138	128	149	136	152	86	83	91	85
	AC	100	89	96	59	140	150	168	153	101	137	119	119	124	124	147	168	129	176	95	184	101	56	92	96
P88	PV	111	107	82	111	105	128	130	143	139	132	141	120	139	124	139	145	147	134	156	129	120	93	91	110
	EV	111	107	82	111	105	128	130	143	139	132	141	120	139	124	139	145	147	134	156	129	120	93	91	110
	AC	122	92	53	94	70	110	125	174	124	90	118	95	82	144	101	112	132	135	137	130	125	110	105	111
P89	PV	119	104	91	80	83	136	150	150	143	133	125	152	130	157	132	128	158	141	147	159	104	111	100	94
	EV	119	104	91	80	83	136	150	150	143	133	125	152	130	157	132	128	158	141	147	159	104	111	100	94
	AC	81	104	75	59	90	82	185	167	133	137	130	185	92	107	92	152	106	135	150	191	126	124	125	92
P90	PV	81	83	100	91	112	151	121	139	154	154	126	125	143	151	158	144	132	143	156	122	91	118	101	93
	EV	81	83	100	91	112	151	121	139	154	154	126	125	143	151	158	144	132	143	156	122	91	118	101	93
	AC	65	100	68	107	77	149	120	117	136	128	97	129	107	130	125	130	82	119	148	121	104	104	120	88
P91	PV	111	89	103	108	89	159	150	146	149	148	128	155	159	123	126	126	134	152	124	134	81	86	85	111
	EV	111	89	103	108	89	159	150	146	149	148	128	155	159	123	126	126	134	152	124	134	81	86	85	111
	AC	87	91	90	95	64	143	101	124	134	160	97	107	148	79	97	117	143	160	136	151	92	106	78	139
P92	PV	113	90	110	86	89	141	144	154	147	144	149	133	159	135	135	147	145	142	132	146	105	100	100	116
	EV	113	90	110	86	89	141	144	154	147	144	149	133	159	135	135	147	145	142	132	146	105	100	100	116
	AC	68	95	75	65	85	113	174	182	88	127	146	101	169	86	131	98	144	138	144	105	66	98	92	131

P93	PV	85	103	81	117	83	131	136	129	151	148	155	145	124	154	146	138	142	150	154	141	102	96	109	93
	EV	85	103	81	117	83	131	136	129	151	148	155	145	124	154	146	138	142	150	154	141	102	96	109	93
	AC	52	97	94	116	64	136	120	124	184	158	119	158	153	128	115	116	142	188	185	117	128	93	82	107
P94	PV	88	109	94	92	120	130	130	133	142	138	151	160	123	150	145	137	126	147	150	149	114	97	113	91
	EV	88	109	94	92	120	130	130	133	142	138	151	160	123	150	145	137	126	147	150	149	114	97	113	91
	AC	96	95	80	102	82	157	81	80	115	160	125	187	95	107	180	110	113	91	176	133	136	103	101	90
P95	PV	82	89	118	100	84	130	148	136	155	134	135	131	156	132	122	143	121	140	155	146	113	108	112	115
	EV	82	89	118	100	84	130	148	136	155	134	135	131	156	132	122	143	121	140	155	146	113	108	112	115
	AC	73	68	94	81	81	146	105	82	172	88	128	131	131	150	93	169	86	92	130	172	73	99	82	113
P96	PV	94	111	86	90	94	135	157	130	143	149	149	145	126	134	147	126	156	128	132	148	89	114	101	92
	EV	94	111	86	90	94	135	157	130	143	149	149	145	126	134	147	126	156	128	132	148	89	114	101	92
	AC	64	114	62	102	67	130	187	114	153	170	103	174	117	129	143	139	162	154	78	185	79	140	102	100
P97	PV	86	99	88	96	119	133	143	153	158	137	149	160	131	123	132	129	131	121	128	139	82	95	82	81
	EV	86	99	88	96	119	133	143	153	158	137	149	160	131	123	132	129	131	121	128	139	82	95	82	81
	AC	62	106	95	79	118	93	156	106	153	160	137	181	98	90	104	99	148	137	154	88	89	116	49	53
P98	PV	113	93	119	100	112	136	146	159	154	123	145	132	148	150	122	135	156	134	126	136	81	102	87	118
	EV	113	93	119	100	112	136	146	159	154	123	145	132	148	150	122	135	156	134	126	136	81	102	87	118
	AC	85	71	131	113	113	87	137	172	156	102	86	120	96	170	106	135	111	165	129	112	88	116	108	70
P99	PV	103	85	104	118	86	137	131	138	127	149	148	146	148	139	134	136	128	134	152	143	87	101	105	84
	EV	103	85	104	118	86	137	131	138	127	149	148	146	148	139	134	136	128	134	152	143	87	101	105	84
	AC	96	64	127	91	60	170	145	106	152	142	104	136	173	128	83	156	84	80	160	122	72	100	81	77
P100	PV	104	102	114	92	81	148	125	145	159	135	157	133	137	159	140	146	135	153	151	138	118	84	83	96
	EV	104	102	114	92	81	148	125	145	159	135	157	133	137	159	140	146	135	153	151	138	118	84	83	96
	AC	92	83	105	85	96	148	145	109	199	135	97	165	89	107	90	180	80	90	184	171	129	80	85	73

	A	B	C	D	E	F
A	0	0	0	0	0	0
B	0	0	0	0	0	0
C	0	0	18	51	75	60
D	0	0	49	93	189	163
E	0	0	71	180	355	280
F	0	0	64	175	266	210

Figure E.1 Markov transition matrix for discipline 01

	A	B	C	D	E	F
A	20	19	28	31	58	61
B	18	15	26	34	49	51
C	28	25	40	50	63	70
D	35	37	53	64	119	94
E	61	51	59	141	187	155
F	56	45	66	82	174	134

Figure E.2 Markov transition matrix for discipline 02

	A	B	C	D	E	F
A	34	62	85	73	0	0
B	70	181	220	159	0	0
C	90	225	278	218	0	0
D	57	159	224	164	0	0
E	0	0	0	0	0	0
F	0	0	0	0	0	0

Figure E.3 Markov transition matrix for discipline 03

	A	B	C	D	E	F
A	76	71	111	158	0	0
B	75	76	108	169	0	0
C	102	111	146	219	0	0
D	167	175	204	331	0	0
E	0	0	0	0	0	0
F	0	0	0	0	0	0

Figure E.3 Markov transition matrix for discipline 04