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Designing a Framework to Improve Time Series Data of Construction Projects: Application of a Simulation Model and Singular Spectrum Analysis

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Abstract: During a construction project life cycle, project costs and time estimations contribute greatly to baseline scheduling. Besides, schedule risk analysis and project control are also influenced by the above factors. Although many papers have offered estimation techniques, little attempt has been made to generate project time series data as daily progressive estimations in different project environments that could help researchers in generating general and customized formulae in further studies. This paper, however, is an attempt to introduce a new simulation approach to reflect the data regarding time series progress of the project, considering the specifications and the complexity of the project and the environment where the project is performed. Moreover, this simulator can equip project managers with estimated information, which reassures them of the execution stages of the project although they lack historical data. A case study is presented to show the usefulness of the model and its applicability in practice. In this study, singular spectrum analysis has been employed to analyze the simulated outputs, and the results are separated based on their signal and noise trends. The signal trend is used as a point-of-reference to compare the outputs of a simulation employing S-curve technique results and the formulae corresponding to earned value management, as well as the life of a given project.

Keywords: project management; project progress simulation; singular spectrum analysis; S-curve technique; earned value management

1. Introduction

Research in the field of Project scheduling mainly consisting of mathematical operations dates back to the late 1950s, and was used to approximately predict the times on when to start and when to finish activities of the project in terms of priority and constraints in resources, while simultaneously pursuing to achieve a particular optimized project objective. Subsequently, a stockpile of research was conducted, accounting for scheduling and planning of projects in different areas (see, for example [1–4]).

While extensive research has been carried out during the last two decades resulting in models of project scheduling with different features, the bulk of research has mainly focused on fundamental principles of project scheduling. This limitation can possibly be explained by the project schedule failure, due to limited capability, to overcome the uncertainty and different risks which characterize the actual and practical execution of the project.

However, as a significant role in a project life cycle and in its failure or success, project scheduling (in combination with other new techniques) can improve the results [5]. In other words, a construction

project schedule has to be considered as a predictive model that can be used with other techniques such as Earned Value (EV) indices to improve resource efficiency calculations, risk analysis, project planning and control and performance measurement.

For more than fifty years, managers have been using Earned Value Management Systems (EVMS) to cope with the complicated task of controlling and adjusting project schedule baseline as the project is being executed, according to total project budget, timed delivery, and account project scope. There is a general consensus over using this well-known management system to use indices like Cost Performance Index (CPI) and Schedule Performance Index (SPI) to account for cost, schedule and technical performance integratively. Besides, this system allows for the calculation of costs, performance indices, schedule variances, forecast project costs and schedule duration. Cioffi proposed previous and new formalism as well as a new notation to be used in earned value analysis [6].

Research in this area has grown slightly, while forecasting techniques and their applications in areas such as price forecasting have grown rapidly. It seems that the lack or inaccessibility of project data is a major barrier to utilizing new forecasting techniques in project management. Applying new forecasting methods requires periodic, progressive time series data, as well as sufficient historical data from similar projects. Hence, in many construction projects, this data is not sufficient to apply forecasting methods and risk analysis. Refer to [5,7,8] for more details.

This paper contributes to serve two objectives. First, it mainly intends to review the literature on project management control research using earned value management and efforts to investigate project time and cost estimates. Although a large number of papers have proposed estimation methods, little attempt has been made to apply these methods to generate project time series data as daily progressive estimations in different project environments. Therefore, a new simulation approach as a novel framework is offered here to reflect the data regarding time-series progress of the project, considering the specifications and the complexity of the project and the environment where the project is performed.

The output can explain the future progress and financial situation of the project at different time scale. This simulator is a powerful tool that can provide daily progressive estimated information which reassures project managers of execution stages of the project although they lack historical data that could help researchers in generating general and customized formulae in further studies.

Secondly, the additional aim of this paper is to use both fictitious and empirical data to obtain and then validate results by using Singular Spectrum Analysis (SSA) and S-Curve techniques. Specifications of this simulator are extracted from the literature or arise from the author's experiences. Thus, researchers can both adjust their ideas to generally investigate project estimations by setting their inputs and study the outputs of the simulator.

This paper has been structured to include the following sections: Section 2 gives brief reviews on project estimates and controls which refer to sources as significant research studies in the related literature; further details are offered on their usage in the experiments related to simulation. In the first subsection, the most important parameters employed in Earned Value Management (EVM) are briefly reviewed, and some resources on the latest literature concerning time and cost performance measurement are displayed. A second subsection deals with the basic concept of SSA approach to analysis and forecast nonparametric time series. The third subsection surveys simulations techniques with reference to previous research studies in the field of project management and its recent advances. Section 3 describes the methodology, the new proposed framework and input and output descriptions and introduces the validation method in three subsections. The simulator has two main inputs described in Section 4. The following section calculates results containing construction project information which are fictitious project data and empirical data. Finally, Section 6 draws conclusions and paves the ground for future research.

2. Literature Review

In this section, we start with a short review of project estimates and controls with references to the earlier most important studies conducted in the literature. The subsections that follow offer further details about the simulation experiments presented in this study, specifically on their usage.

Plans and project schedules are usually developed for each project to make sure that activities are conducted to meet the specifications of the quality expected along with the budget and the allowed time. Many projects lose substantial financial resources every year due to delays in their progress and require additional time and costs for implementation or to reach completion. One of the main concerns of project managers is to fulfill a project within a pre-determined schedule and allocated budget. When differences between planned and actual work performances become considerable, extra management of tasks would be required to bring indices back on course to stay on the planned schedule and budget. During the implementation phase, project progress should be frequently monitored and checked against the planned project schedule so that we can identify and measure any divergences. Exact control of a project depends on suitable and timely access to the project's information, such as the cost and time status of the project.

2.1. EVM

In 1967, the U.S. Federal Government agencies played a significant role in introducing EVM for the first time and using it in programs like large acquisition ones [9]. The U.S. Federal Government was also able to successfully take advantage of EVM in its widespread projects. Project managers could benefit from EVM the most as it keeps them informed of the early indications and procedures of a project's execution and alerts them to eventual corrective action if needed. A large number of research investigations have been devoted to this area, as shown in [5,10], since EVM was introduced. Although EVM was employed to investigate time and cost both, the cost aspect has been the center of attention in most research studies. In a study, EVM was discussed from a price tag perspective [11]. In a later study, it is focused on predicting how long an activity takes by proposing a reliable methodology and using SPI [12] and a formula for estimating project time according to (EDAC) is proposed, i.e., Estimate of Duration at Completion.

During the life cycle of a project, a point of reference is needed for EVM to measure the project's execution periodically. This fixed reference point is supplied by its project's baseline schedule. In order to obtain the time and costs of a project performance, the three key parameters of EVM must be compared to each other and the time and cost performance measures as below:

- Budgeted Cost of Work scheduled (BCWS)
- Actual Costs Work Performed (ACWP)
- Budgeted Cost of Work Performed (BCWP)
- Earned schedule (ES)
- Schedule Variance ($SV = BCWP - BCWS$)
- Schedule Performance Index ($SPI = \frac{BCWP}{BCWS}$)
- Cost Variance ($CV = BCWP - ACWP$)
- Cost Performance Index ($CPI = \frac{BCWP}{ACWP}$)
- $EDAC = PD/SPI$

Lipke questioned the classic metrics of SV and SPI previously used since they failed to reliably forecast ending point of time of a project [10]. In this study, however, a time-based measure was designed to cope with false and unreliable behavior, which is dependent on similar principles to those of earned value method, but which renders the money-related metrics into a time aspect. He transformed the time performance metrics SV and SPI to $SV(t)$ and $SPI(t)$ and indicated that they show consistent and reliable behavior throughout the project life cycle.

EVM was also used for forecasting project duration, comparing the indicators of previous earned value performance, namely SV and SPI, with the recently developed indicators of earned schedule performance SV(t) and SPI(t) and later compared them with the results of time performance measured through the three methods of obtaining time performance in a project [13]. Their results indicated that a general schedule forecasting formula could apply to various project situations. Later, it was tried to evaluate EV-based methods by reviewing them as they are commonly used to forecast total duration of a project [14]. They delicately controlled the uncertainty level of project to conduct an extensive simulation survey in which they tried to account for the accuracy of forecasts as influenced by the network structure of project, and the reliable and accurate results obtained from the EV-based measures within time perspective. In their study, they investigated the capability of a newly designed method, and the schedule method earned, which hones the relationship between EV metrics and duration forecasts of the project.

A new formula to calculate the (EAC) is presented [15], i.e., Estimate At Completion, of projects to hone EVMS. Their new method contains a formula which is composed of four variables: SPI, Scheduled Percent Complete by Duration (SPCD), Actual Percent Complete by Duration (APCD), and Sum of Durations to Due Time (SDDT).

Studies measuring time performance of the project and/or the concept of earned schedule have been the focus of some publications issued in the popular and academic literature. Empirical data was manipulated by using statistical procedures involved in validation of time performance indices and stability investigations [10].

After all, sensitivity or risk analysis and EVM (whose results were validated using a simulator) were concepts already studied and examined in previous research investigations [5,14,16].

In conclusion, although research in this area has increased only minimally, there is still widespread interest in the need to introduce new indices and formulae into forecasting. Additionally, the use of simulation techniques and simulators has emerged as an effective tool to generate varied experiments.

2.2. SSA

SSA is a component of the more inclusive classification of methods called Principal Component Analysis (PCA), is a powerful technique used to analyze and predict non-parametric time series that include non-stationarity data elements with complex seasonal components and is superior to classical techniques. On the other hand, SSA is a technique used for the analysis of time series that are observed, and it is capable of exposing the main features of the predictability of time series.

The traditional models, namely ARMA, ARIMA, Box–Jenkins and artificial intelligence, such as fuzzy models, etc., demand certain assumptions as restrictive distributional, structural ones and adequate historical data. A new method inspired by genetic colonial theory is introduced to forecast and filter time series [17]. This method has many similarity with SSA. However, SSA does not use any statistical assumptions, namely the series stationarity or residuals normality, and it need not rely on any parametric model to find out the trend or oscillations. Moreover, contrary to many other methods, it is independent of sample size, even small sample sizes.

The theoretical underpinnings and practical background of the SSA technique were introduced by Golyandina et al. in 2001 [18] and further by Hassani [19,20] and Viljoen for common time series [21]. The applications of this technique are many and various, for example, in meteorology, physics, economics, and financial mathematics. In recent years, SSA has been designed and employed to various practical problems, for instance, in industrial production [22], by Afshar et al. [23] to load forecasting in the electricity market as well as other markets, for forecasting CO₂ emissions [24], and for signal extraction in a genetics related application [25]. Moreover, a forecasting method was presented with Artificial Neural Network and SSA [26] and a hybrid model Coupled with SSA was used to forecast rainfall [27]. Finally, SSA is introduced and reviewed the separability techniques and window length [28].

The SSA technique is composed of two steps that are complementary to each other, decomposition and reconstruction.

Figure 1 presents, the standard SSA, which includes two main stages and four subsets. By reconstructing the original series after decomposition, it is possible to remove noise.

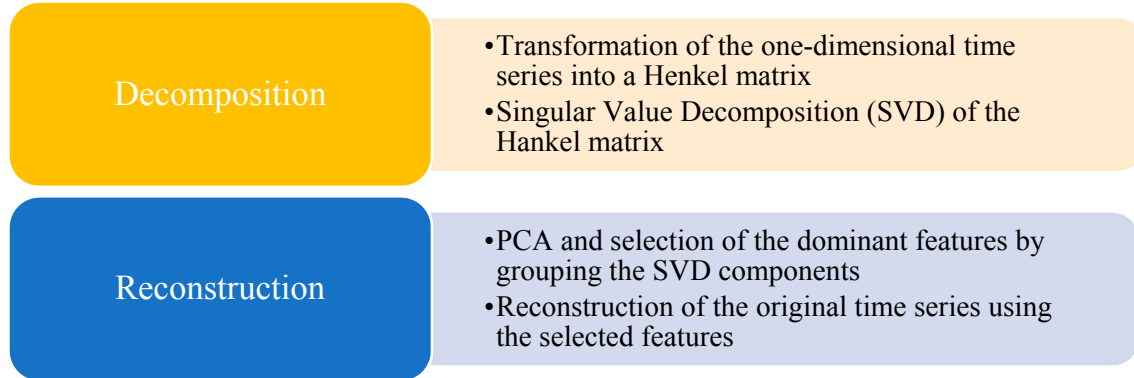


Figure 1. The standard Singular Spectrum Analysis (SSA) steps.

The first stage is the decomposition stage, which has two steps:

Step 1, embedding:

Embedding is similar to mapping and can be regarded as a form of mapping. This form of mapping, i.e., embedding, turns a time series that is one-dimensional, $Y_T = (y_1, y_2, \dots, y_T)$, into series that are multi-dimensional, X_1, X_2, \dots, X_k , using vectors, $X_i = (y_i, \dots, y_{i+L-2}) \in R^L$.

$$X = \begin{pmatrix} y_0 & \cdots & y_{K-1} \\ \vdots & \ddots & \vdots \\ y_{L-1} & \cdots & y_{T-1} \end{pmatrix}$$

Embedding has certain assumptions: $K = T - L + 1$; the window length, L , as the single parameter or an integer that should be $2 \leq L \leq T$. Besides, the L or window length must be big enough. This step results in a matrix called a Hankel matrix, $H = (X_1, \dots, X_K)$, which has equal elements on the diagonal, and the linear space that is spanned by columns of H is called the trajectory.

Step 2, SVD:

The second step is called the SVD step, which sums up elementary matrices of rank-one bi-orthogonal to obtain the singular value decomposition of the trajectory, $X = E_1 + \dots + E_d$, where $E_i = \sqrt{\lambda_i} U_i V_i^T$ and λ_i and U_i are eigenvalues and eigenvectors of matrix, XX^T , $V_i = X^T U_i / \sqrt{\lambda_i}$ and $\lambda_1 \geq \lambda_2 \geq \dots \geq \lambda_L \geq 0$. The set (λ_i, U_i, V_i) is referred to as a value of the matrix X called the i -th eigentriple, in which s_i represents the singular value of X or its i -th value (whose value is equal to the square root of the i -th eigenvalue of matrix XX^T); U_i is the i -th left singular vector of X (equivalent to the i -th eigenvector of XX^T); and V_i is the i -th right singular vector of X (equivalent to the i -th eigenvector of $X^T X$). A group of r eigenvectors determines an r -dimensional hyperplane in the L -dimensional space, RL of vectors, X_j .

The second stage is the reconstruction stage, which consists of two steps: grouping and diagonal averaging. The grouping step refers to dividing the elementary matrices, X_i , into some categories and adding the matrices in each group. Imagine that $I = \{i_1, \dots, i_p\}$ is a set of indices i_1, \dots, i_p . Therefore, the matrix, X_I , related to the set I , is presented as $X_I = i_1 + \dots + i_p$. The decomposition of the set of

indices, $J = 1, \dots, d$, into the disjoint subsets, I_1, \dots, I_m , corresponds to the matrix called X , which is represented by $X = X_{I_1} + \dots + X_{I_m}$. Eigentriple grouping is the process of selecting the sets I_1, \dots, I_m .

Diagonal averaging turns every single matrix I into a time series. A time series is an element commonly added to the initial series Y_T . If z_{ij} represents a component of a matrix Z , then the k -th term of the obtained series is calculated by averaging z_{ij} over all I, j in such a way that $i + j = k + 2$. The above procedure is known as diagonal averaging or, to put it differently, the Hankelization of the matrix Z . By applying diagonal averaging or the Hankelization procedure to all matrix elements of X_{I_1}, \dots, X_{I_m} , another expansion is achieved: $X = \widetilde{X}_{I_1} + \dots + \widetilde{X}_{I_m}$. This expansion is equal to the decomposition of the first original series $Y_T = (y_1, y_2, \dots, y_T)$ into a total m series: $y_t = \sum_{k=1}^m \widetilde{y}_t^{(k)}$, where $\widetilde{Y}_T^{(k)} = (\widetilde{y}_1^{(k)}, \dots, \widetilde{y}_T^{(k)})$ matches the matrix X_{I_k} .

Two parameters are needed for the SSA method: the number of elementary matrices r and the window length L . It is necessary that we choose an appropriate window length L since it is essential for improving the accuracy of the SSA. If the points of different vectors, X_i and X_j ($i \neq j$) are linearly independent, then the value of L is calculated. The structure of the data and how we perform the analysis determine our choice of these parameters following particular selection rules.

2.3. Simulation Project Techniques

Simulation is also one of the most useful and effective techniques to analyze a complex and dynamic project, which helping the decision maker to recognize the effect of various dependent variables and complex scenarios on the project's behavior. Furthermore, project simulation can be used in different aspects of project management, can help researchers to gain many accurate and realistic outputs according to set inputs and also to investigate different scenarios as summarized below.

As described in Section 2.1, the use of simulation techniques and simulators has emerged as an effective tool to generate varied experiments in this area. A method called Special Purpose Simulation (SPS) is utilized [29] which is a tool to optimize workforce forecast loading and leveling resources. SPS is a simulation model manages to optimize resource supplies and requirements for conducting a petrochemical project, considering standard discipline necessities and involvements. A project model has been designed [30] which simulates the developmental process of the project in a realistic manner and produces information concerning three different monitoring systems. In this paper, factors influencing the total cost and performance of project are also accounted for by changes occurring in the project plan and rates of inflation. In a similar vein, a research framework was developed to enable project managers to approximately calculate completion time of the project and dive deep into the main factors which influence the estimation for complex engineering projects being executed concurrently [31]. Their proposed framework is composed of three main procedures: data gathering, simulation, and data analysis with ANOVA.

A number of studies have been developed to scrutinize various factors affecting project cost estimations. Akintoye focused on understanding different factors influencing project contractors' cost estimating practices [32]. In this study, 24 factors were identified by conducting a comparative study analyzing 84 UK contractors categorized into four classes ranging from very small, small, medium to large firms. Bashir and Thomson presented a thorough quantitative estimation approach which can offer initial along with updated project estimates from manageability or feasibility study until project completion [33]. A dynamic simulation-based crashing methodology was introduced to assess project networks and determine the optimum crashing configuration that reduces the average project cost to a minimum level because of delayed penalties and crashing costs [34]. Their dynamic method allows us to assess the project network to design a crashing strategy at the very onset of the project execution and also during the time that the project is being performed.

As described in Section 2.2, EVM concepts were used as a basis to analyze simulation techniques in a number of research investigations. In a study, the efficiency of controlling a project was analyzed [5]. A Monte-Carlo simulation was used to validate the project data of the study whether fictitious or empirical. Upon noticing warning control parameters, we must take corrective actions to put the

project back into the correct path whenever a problem occurs. This set of information offered by the Schedule Risk Analyses (SRA) along with EVM information which is mostly the sensitivity information is obtained during project control. The effects of different activities on risk and the expected completion time of the project were described [8].

In another study, Elshaer used Planned Value Management (PVM), Earned Duration Management (EDM) and Earned Schedule Management (ESM) as the three earned value methods to study the prediction of project duration in EVM [16].

In conclusion, it can be seen that, to a considerable degree, these studies were conducted with the aim of designing a project simulator. In many cases, simulation studies have been used to validate project scheduling solutions or to estimate project specification in some part of the project, for instance project completion cost and time estimations or risk measurements. However, none of the prior studies has considered daily project information as a time series. On this basis, the purpose of this paper is to design a novel project progress simulator that can convert the project into its time series as efficient information, which can help other researchers to generate new formulae.

3. Methodology

The methodology employed in the computational and conceptual experiment includes a new framework in order to generate project progress time series data, thereby introducing valuable information about projects and preparing an appropriate context for introducing new indices and formulae, varied experiments and further research. In the following subsections, the framework structure, its components and sources and why and how these sources (project progress simulator and SSA) can be used together in project control are explained.

3.1. Project Progress Generator Framework

Computer-assisted simulation is a powerful method to analyze complex and dynamic projects by analyzing large data size, and this precise and flexible technique has been used in much of the research in the field of project management (see, for example, [14,29]). Simulation software can predict the set of expected costs and the duration of the project, depending on input parameters. These inputs control activity duration, cost estimation and the effect of risks when producing cost estimates.

However, as mentioned before, the idea of generating project progress simulators has not been mentioned in the prior studies. Therefore, the aim of this paper is to introduce this simulator and to optimize the resulting time series with SSA. The combination of simulation techniques and SSA analysis with different inputs will help project managers to obtain a realistic estimation of project cost and time in different sectors of the project and will reduce the delay risks. Furthermore, insight is gained into project progress behavior, deviations during project execution, the appropriate use of EAC formulas and identifying areas for additional research.

The important aspect of the SSA is that it has two advantages over other methods, which makes it more beneficial in project control. One feature of the SSA is that it can be applied to series with small sample sizes. The other important aspect is that, unlike other methods, the SSA does not need any statistical assumptions, such as the stationarity of the series or the normality of the residuals. The basic concepts of the project progress generator have been shown by Iranmanesh and Tavassoli [15]. In this paper, the well-developed model with more details is presented. The project progress generator framework has four main steps (as shown in Figure 2). The process starts with the project entry, which can be a given project or selected from a fictitious database and scheduling baseline.

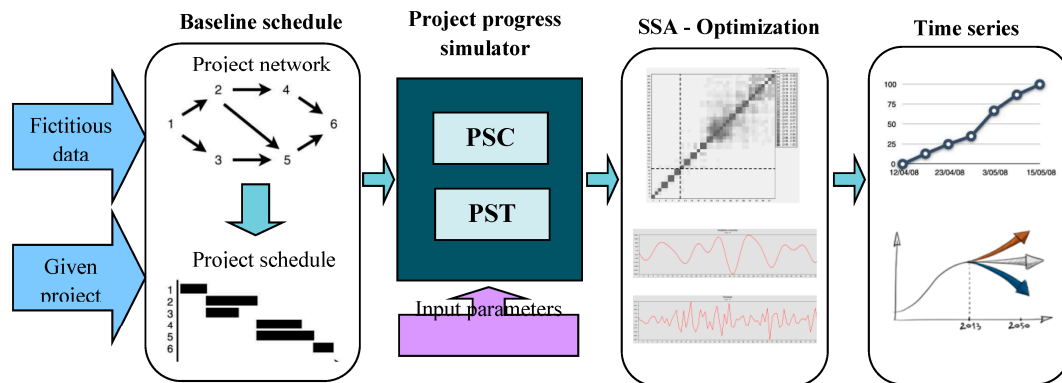


Figure 2. Project progress generator framework and its steps. PSC, Progress Simulation for Time; PST, Progress Simulation for Time.

The project progress with the proposed simulator can be considered from two main perspectives:

- Progress Simulation for Time (PST): PST calculates different indices in various time sections and focuses on time parameters to simulate the progress of projects.

PST consists of the following steps:

- Determining the input project and parameters;
 - Constructing project scheduling;
 - Updating the project's progress daily;
 - Computing the project's actual progress daily, based on the set inputs. Suppose \aleph represents the random impact of risk overall, then $\aleph \in (0, 1]$. The impact of risk events, X , integrated with the above task progress is shown as follows:

$$(X_i)_j = (X_i)_{j-1} + (P_i)_s * D_i * (\aleph_i)_j$$
 where i and j represent the number of tasks and days, respectively. The random overall impact, $(\aleph_i)_j$, shows the risk of each task in each day from its start to finish. Furthermore, $(P_i)_s$ and D_i are daily scheduled progress in a planned day, s , and experts' proposed status for the task, i .
 - Calculating different measurement indices (i.e., EVM measurements);
 - Continuing until the project is entirely completed.
- Progress Simulation for Cost (PSC): PSC simulates the progress of projects via cost progress during project execution, calculates different indices in different time sections and focuses on cost parameters. PSC is developed mainly based on the PST structure and focuses on the cost parameters. The following is a list of other principles of PSC.
 - Determining the input costing parameters;
 - Calculating planned cost progress based on a general specification (i.e., inflation rate) and each task's specifications (i.e., costs of resources);
 - The daily cost of each task is calculated based on resource consumption of the task on that day and other costing parameters;
 - The daily project cost is calculated until the project is finished.

The simulator outputs are time and cost time series that indicate the progressive behavior of the project's cost and time. These outputs are then used as inputs of the SSA method. SSA analyzes these inputs and separates the main trend from noise, then identifies if there is any special trend in

the time series, such as seasonal behaviors. The output, or “trend time series”, can be used for further estimations if the project is repeated or not completed.

3.2. Input Parameters

The proposed simulator considers several parameters that are identified as affecting the project’s progress. Hence, these parameters are presented as samples for the designed model, and many others can be considered in this framework with different types of projects. These input parameters, which should be fed to the simulator by the user, are as follows:

Input project type: As mentioned before, the input project can be a fictitious project or a given one.

Project discipline: In regard to project management, the concept of ‘discipline’ is defined as an area of work or activity that demands enormous knowledge. It peculiarly corresponds to the area of work or focus where unique and static sets of rules and regulations need to be closely followed in the processes of the conduct and completion of that work or activity.

As Figure 3 presents, the project structure is divided into some separated disciplines, and each discipline comprises certain tasks, each of which utilizes project resources to be accomplished.

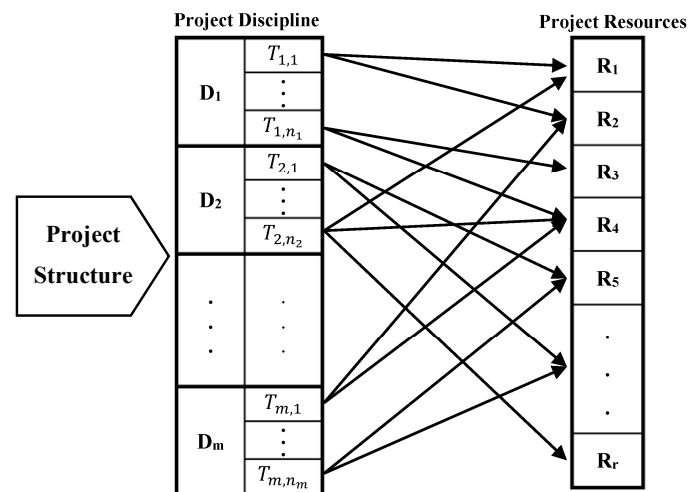


Figure 3. Project disciplines and their relations to project resources.

Disciplines’ work contour: The work contour is a kind of property that demonstrates how every single task is spread over the assignment duration. In this research, it is assumed that all tasks in each discipline have the same work contour property, named back-loaded. The shape of different work contours is pointed out in the different behaviors of tasks and disciplines during the project.

Expert’s comments: To generate actual information, some task specifications are needed. As a case in point, each task’s progress status is needed in order to process whether the task progress has overtaken the plan and to determine the degree of variation existing between them. This simulator is a powerful tool for project managers. Therefore, they are the main users of this system, and they should enter their comments about how projects can progress in their environments.

Inflation rate: Inflation rates are assumed to be linear and fixed during the project.

3.3. Output Validation

S-Curve displays accumulated efforts or costs of a project and represents the function of time or cost. In fact, this curve was employed to control and check progress in a set of projects related to each other. Moreover, it is showed that this is possible to characterize the progression of the overall cost of any project [35]. The results of the study inductively concluded that the rising slope in the S-curve, and the point of time when half of the total funds have been consumed, are two numbers that represent this curve.

In the absence of data, we can characterize an equation to illustrate project S-curves with three parameters:

- The total cost of the project (Y_1);
- The total life time of the project (t_1);
- The point of time when the project has spent half of its total funds ($t_{1/2}$).

Estimating the three above parameters, an S-curve equation that can specify in what way labor or funds could be represented during the project at the start of any project can be established for project management purposes.

Define β as the proportion $\beta = t/t_1$, and term the specific β where $Y = 0.5Y_1$ as $\beta_{1/2}$ where Y indicates the project cost, given the condition that $0 < \beta_{1/2} < 1$. If a project whose distribution is front-loaded, where the funds are spent earlier rather than later, $\beta_{1/2}$ will be nearer to the beginning of the project. Other projects tend to have this time closer to the middle ($\beta_{1/2} = 0.5$). For back-loaded projects, in which funds are disbursed nearer to the end of the project, $\beta_{1/2}$ would be greater than 0.7.

A gentle rise, a steep slope and a gradual path to the asymptote are the three parts of a typical S-curve. Suppose that the steep slope in the middle portion includes two-thirds of the rise from point $Y = 0$ to $Y = Y_\infty$, where Y_∞ is the highest level of the project cost. One-third of the rise remaining takes place over the two gently rising portions. Factor r is defined as a parameter that displays the large size of the rise in the third middle and enables the project manager to freely select an approximation to this central slope, and $r_{0.67}$ is defined through:

$$r = \frac{2}{3}r_{0.67}$$

Assume that the project manager selected desired β and $r_{0.67}$, so the value of γ through Equation (1) can be calculated. The project manager can then plot the project's S-curve using Equation (2).

$$\ln(\gamma + 2) = 8\beta_{1/2}r_{0.67} \quad (1)$$

Finally, the S-curve equation, in regard to the ratio $y = Y/Y_1$, is defined as follows:

$$y(\beta) = y_\infty \frac{1 - \exp(-8r_{0.67}\beta)}{1 + \gamma \exp(-8r_{0.67}\beta)} \quad (2)$$

where $y_\infty = Y_\infty/Y_1 > 1$. Theoretically, $y = 1$ shows that the project is complete, and at $\beta = \beta_{1/2}$, $y = \frac{Y_\infty}{2}$.

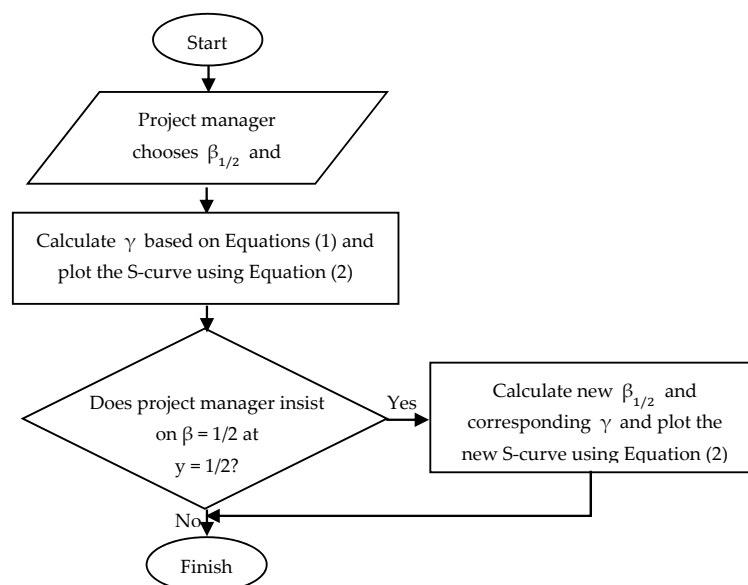


Figure 4. S-curve technique flowchart.

If the manager is willing to say that $y = 1/2$ at $\beta = 1/2$, conducting the $\hat{\beta}$ calculation will obtain a new $\beta_{1/2}$ that will meet the desired situation. Figure 4 represents the flowchart for using this technique to plot a project's S-curve.

In the next section, the behavior of simulator results is compared to project life cycle trends, using an S-curve trend to verify these results.

4. Data Description

As mentioned before, the framework has two project data sources: fictitious and given projects. In this subsection, we describe both fictitious and empirical project data and their specifications.

4.1. Fictitious Project Data

As there has been great progress in the models and methods of project scheduling (especially intelligent approaches), the need for data instances to evaluate the solution procedure increases. Therefore, a large number of research studies on project scheduling during the past several years has been attempting to focus on designing and developing benchmark series of project networks to equip users and researchers with successful project planning and evaluating equipment to visualize various projects and to benchmark solution procedures for single and multi-mode project scheduling problems that are resource-constrained.

Generally, if we want to employ intelligent forecasting methods to predict the time and cost of projects, it is essential that we generate basic time series as the scientific representations of various projects. These representations, referred to as standard datasets, are always formed based on the known concept of project networks, explaining the activities, characteristics and precedence constraints of each project using a directed non-cyclic connected graph to prove that the project is manageable.

Comprehensive surveys of these datasets and comparisons between them can be found in [23,25–27]. In the current study, we use the ProGen standard dataset. The simulator was used in 480 projects with 92 tasks and 4 resources [36].

As mentioned before, the purpose of this study is to introduce a project progressive simulator framework and generate project time series data. Hence, structural network parameters such as the topological structure, the criticality of a network or resources are not investigated in this study. On this basis, fictitious project data are used just as an input project.

4.2. Empirical Project Data

Javadieh is one of the areas situated in the southwest of Tehran in Iran. An underpass project was conducted in Javadieh. This project includes two bridges, one overpass measuring 90 m in length and 8.20 m in width and one underpass of 80 m in length and 8.20 m in width. Besides, two entry ramps and one exit ramp meet this railway, which cross with the northern city network (Shoosh Avenue) and southern city network (Noori Street).

Engineering, procurement, destruction and construction are the four main disciplines employed in the whole project. The construction discipline consists of some main sub-disciplines, namely excavation, formwork, concreting, waterproofing, embankment, pavement and other minor work activities, like curbs, signs, signaling and lighting.

This project was estimated to be completed within six months with 223 tasks over the four mentioned disciplines. The price agreed for this contract was fixed, approximately 66,869,542,003 Rials (equal to \$2.3 million at writing). The project network was thought to be an activity-on-the-node project network whose project data determined the precedence relations between the tasks. The project was scheduled from 24 April 2013 to 20 October 2013; after five months, only 60% of the project had been completed, and the delays made them reschedule the project. Therefore, it was necessary for them to continuously analyze the project condition, measurement factors and daily progress status in order to evaluate the project's efficiency and risk effects. That way, the project can be rescheduled in a realistic way, since this monitoring and controlling equipment enabled the project manager to measure the remaining project cost and time, to provide adequate resources and to take other factors, such as control risks, into account.

5. Simulation Result

The progress simulator is demonstrated as a software program including PSC and PST concepts by the use of Visual Basic for Application (VBA) in the environment of Microsoft Project 2010 (MSP) and SSA method using CaterPillar SSA 3.40 to analyze the results [37].

In this section, the results of a randomly selected project from the ProGen dataset and a given project are presented. The selected project is just used for presenting the methodology, and this technique can be applied on several projects. Moreover, simulating several runs with different input parameters can help project managers to forecast precisely different situations. The results are then compared to the S-curve technique and SSA, based on the simulator output. The influences of input parameters are then examined in different circumstances. Section 5.1 presents the steps of generating fictitious project progress time series and Section 5.2 demonstrates the simulated results for a given project.

5.1. Fictitious Project Results

Figure 5 shows the results of the simulator on one randomly selected project from the ProGen dataset. In this diagram, the daily progresses of physical and actual percent completion were compared. The S-curve shape can be seen in these two diagrams; however, this simulated project includes a delay of 56 days. This project has 92 tasks and is scheduled for 87 days, and it is simulated by these input parameters:

- The project has four disciplines comprising 20%, 10%, 40% and 30% of all of the tasks, and back-loaded, flat, front-loaded and bell are their work contours, respectively.
- Eighty percent of task delays are in the range of 10% of scheduled progress.
- The project was simulated with a 20% inflation rate for the last six months.

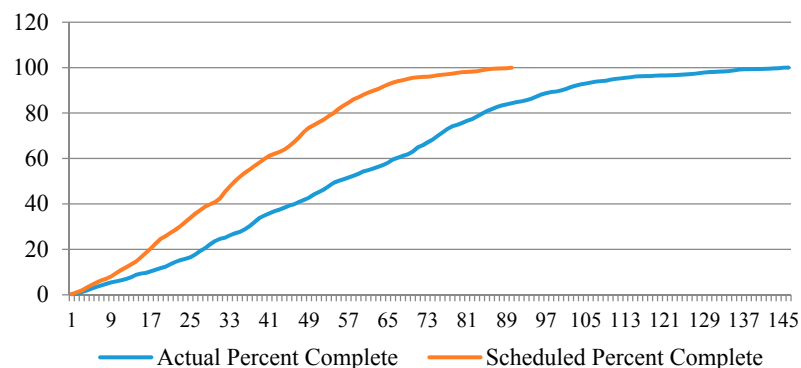


Figure 5. Percent completion of the simulated project.

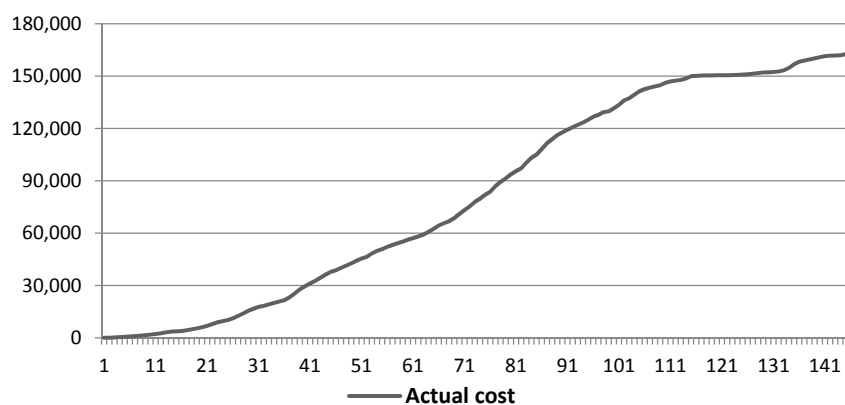


Figure 6. Actual cost S-curve.

To validate the simulator, another randomly selected project from the ProGen dataset is used, taking the results and comparing them to the S-curve technique's results. The simulator inputs are set, as all tasks are in one discipline with a normal distribution, a 20% inflation rate for last six months and 80% of task delays in the range of 10% of scheduled progress. Figure 6 shows the actual cost S-curve.

This actual time series is now used as an example to illustrate the selection of the SSA parameters and to show the reconstruction of the original series in detail.

- Selection of the window length L :

At the decomposition stage, the window length L is a single parameter that has to be chosen and achieving sufficient separation of the components is crucial in selecting L . As stated above, the window length is the dimension of the Euclidean space that the time series is developed. Moreover, in literature considerable attempt and various methods have been presented for choosing the optimal value of L , for example, $L = T/4$ as a recommended one and L can be larger but not larger than $T/2$ [19]. More recently, the selection of L was optimized based on the minimization of a loss function [38]. Larger value of L leads to a more detailed decomposition and resolving longer period oscillations so L has been set at a larger value ($L = T/2$) in these analyses. In this example $L = 38$.

- Selection of r :

In this method, some auxiliary information and diagrams generated by Caterpillar SSA could be applied to select the parameters L and r . Here, there is a brief explanation of the method which might be beneficial in separating the signal from noise in the time series, which is offered by controlling breaks in the eigenvalue spectra. Furthermore, a pure noise series typically generates a gradually reducing sequence of singular values. It is noteworthy that there are alternate methods for the selection of r , refer to Hassani et al. (2016) for instance [20].

With these accomplished results, the principal components are attained from SVD. Choosing $L = 38$ and performing SVD of the trajectory matrix X , we get 38 eigentriples, organized by the share they contribute to the decomposition. Figure 6 depicts the plan of the logarithms of the 38 singular values. In Figure 7, an enormous decrease in values takes place close to Element 9, which can be taken as the beginning of the noise floor.

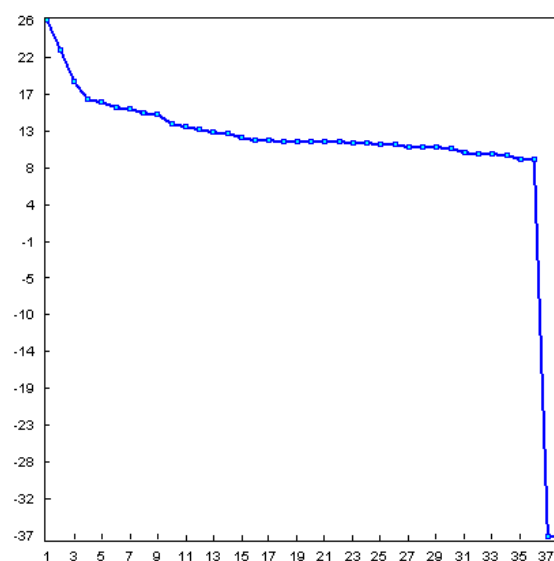


Figure 7. Logarithms of the 38 eigenvalues.

Grouping the major elements can be done by another technique in which we analyze the w -correlations of the matrix of the absolute values. Figure 8 represents the w -correlations for

the 38 reconstructed elements in a 20-grade grey scale from white to black corresponding to the absolute values of correlations from zero to one. According to this information, the first nine eigentriples (r value) are chosen for the reconstruction of the original series, and the remaining are considered as noise.

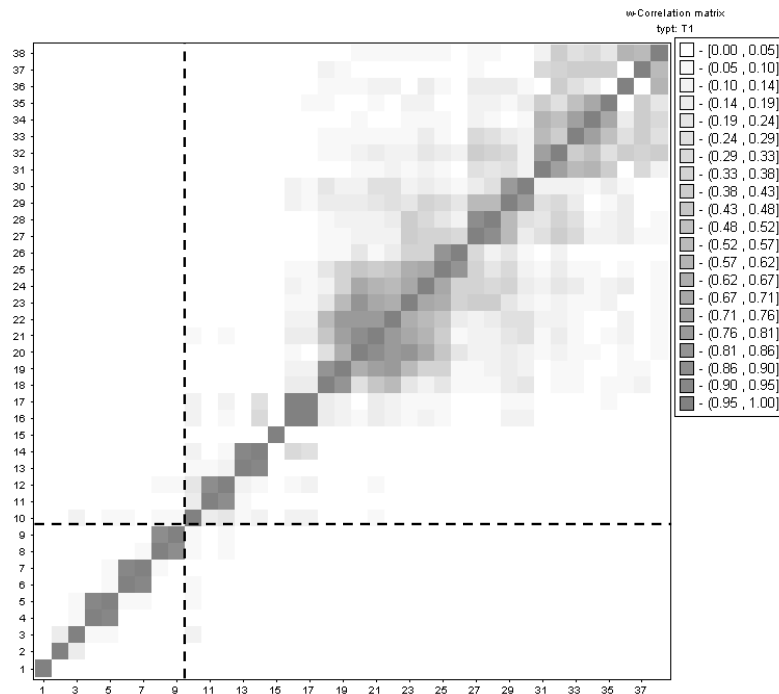


Figure 8. Matrix of w -correlations for the 38 reconstructed components.

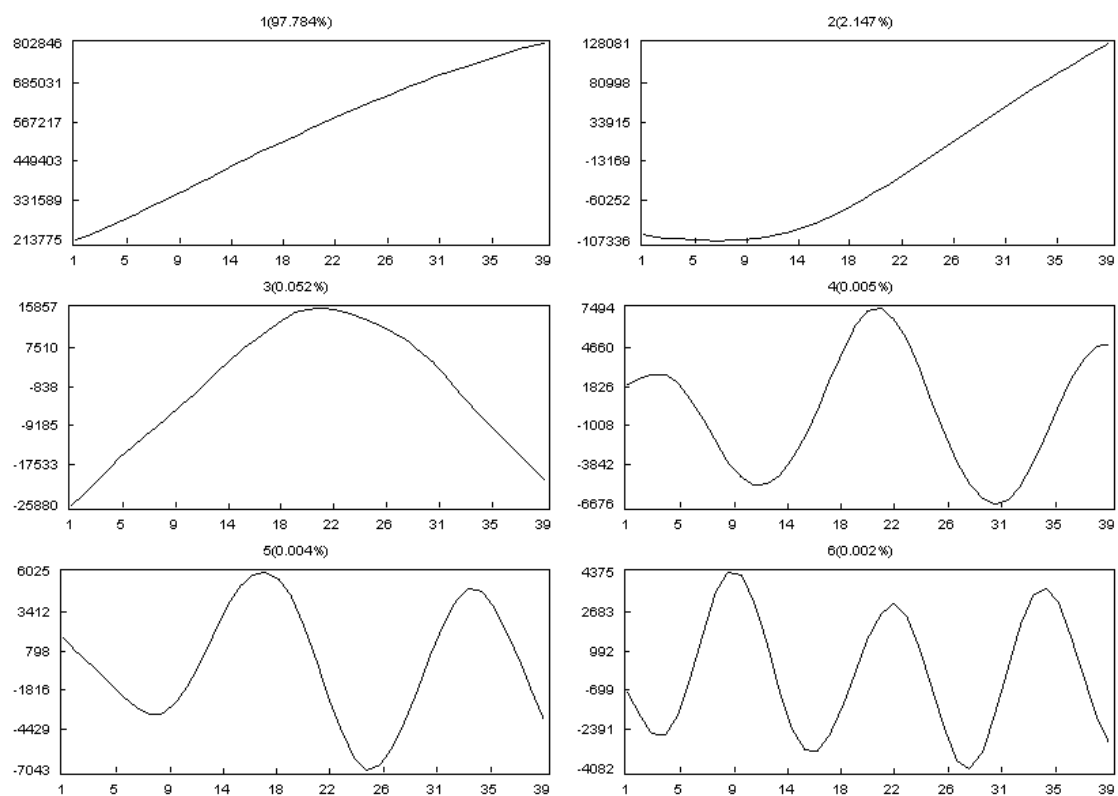


Figure 9. The first six principal components.

Figure 9 shows the first main elements plotted as time series. Practically, the singular values of the two eigentriples of a harmonic series are usually very near to one another, and this makes the visual identification of the harmonic components easy. A close look at pairwise scatterplots of the singular vectors enables us to visually distinguish those eigentriples that match the harmonic elements of the series, given that these components can be separated from the residual component. Figure 10 presents scatterplots, accompanied by lines joining consecutive points, of the first nine paired major elements.

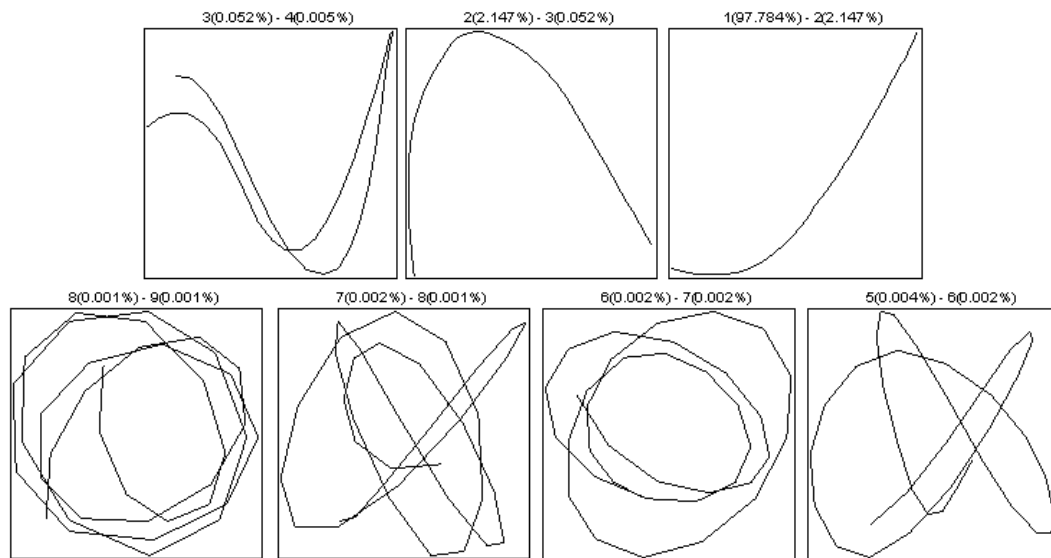


Figure 10. Scatterplots corresponding to the first nine paired principal components.

The trend is a gradual change in the element of a time series that does not include oscillatory components. Thus, to distinguish a trend in the series, one must search for gradually-changing eigenvectors. Figure 11 depicts the trend, which is extracted from the eigentriples 1 to 9. This curve explicitly shows the general tendency in the series.

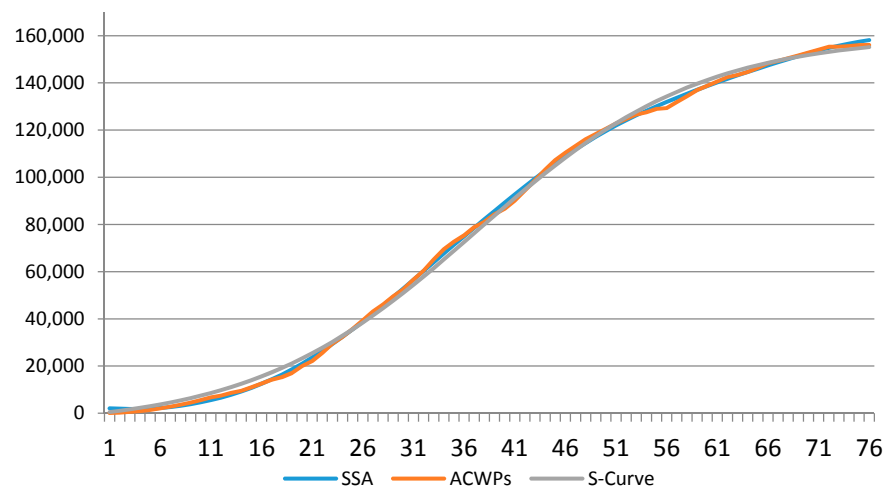


Figure 11. Reconstructed trend from the eigentriples 1 to 9 compared with ACWP and S-Curve.

Figure 12 represents the selected harmonic components (4 to 9) and clearly shows the harmonic behavior of the original series. Therefore, we can categorize the remaining components of the eigentriples (10 to 38) as noise. Figure 13 displays the residuals extracted from these eigentriples.

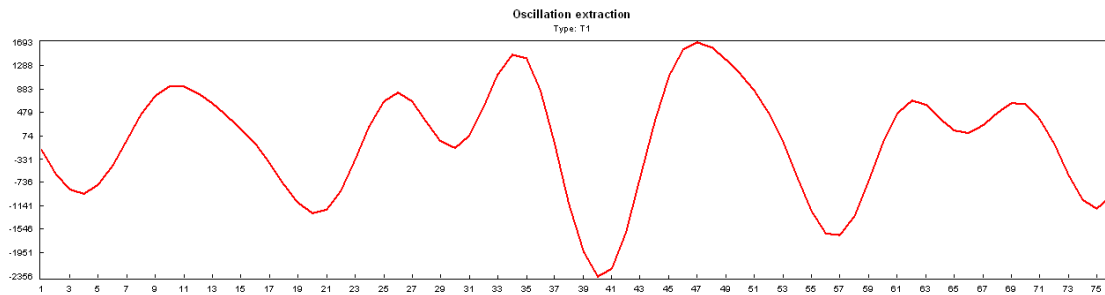


Figure 12. Harmonic from the eigentriples 4 to 9.

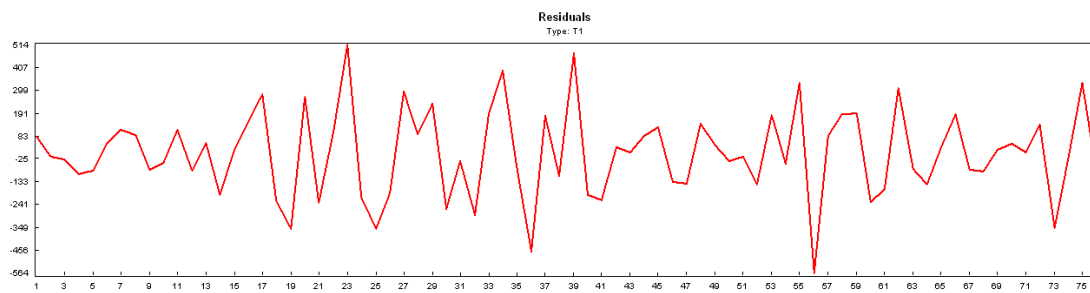


Figure 13. The residuals from the eigentriples 10 to 38.

Finally, as is described in Section 3.3, with chosen values $B_{1/2}$ and $r_{0.67}$, the parameter γ can be obtained from Equation (1), and Equation (2) can plot the desired evolution S-curve. To fit this curve with an actually simulated curve (the generated time series from the selected fictitious project), we set required parameters as $Y_0 = 100$, $Y_\infty = 160,000$ and project duration = 77 days. To fulfill the other desired conditions, we set $B_{1/2} = 0.49$, $\gamma = 29.02$ and $\delta = 0.09$.

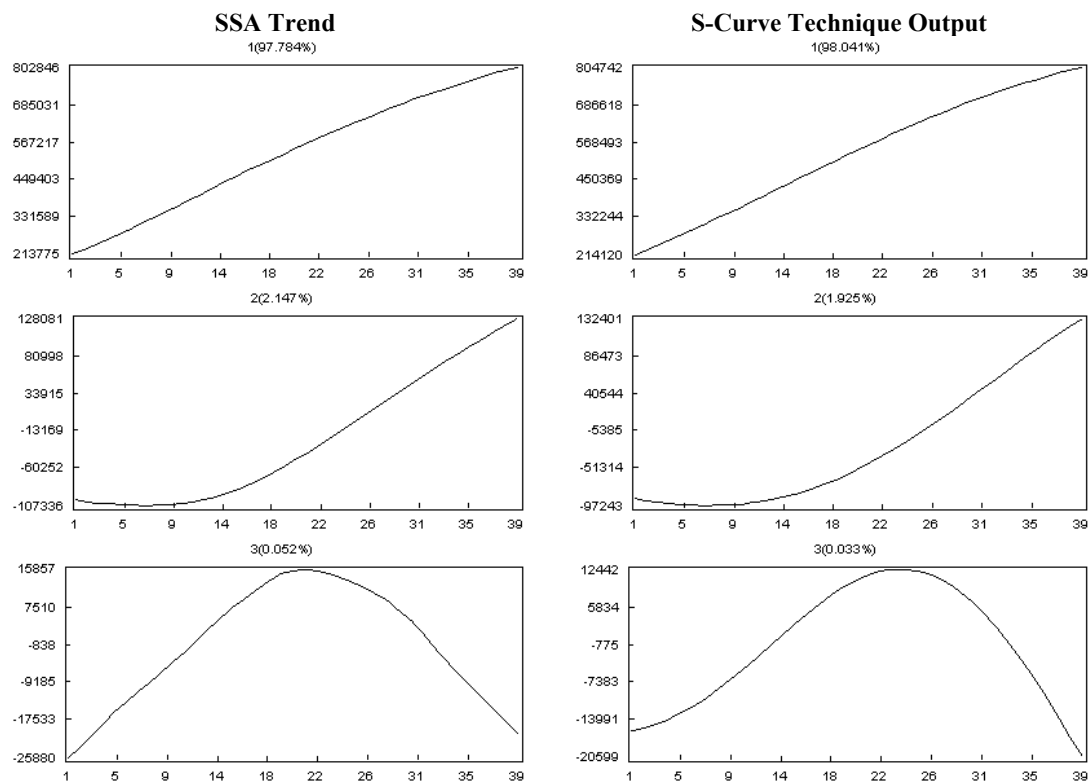


Figure 14. Principal components related to the first three eigentriples.

In the next step, the analysis of the S-curve technique time series was implemented similarly to the previously mentioned selected project by SSA method. To show the similarity of these two time series, principal components of two time series, simulator output and S-curve technique output are extracted and compared. The most important components concerning the first three eigentriples, for both the simulator and S-curve technique series, are shown in Figure 14. As shown, these two series have quite similar components. Accordingly, we can conclude that the simulator and S-curve technique time series have the same structure, and this verifies the accuracy of the simulator result.

The deviations between the trend of simulated results (SSA trend) and the S-curve technique with the first generated time series are shown in Figure 15. Clearly, these two deviations have the same behavior over time, with the exception of the start and end points. However, SSA results show a lower change range. Generally, these two deviations are near to one another, which results in the fact that the simulated fictitious results have a high accuracy and that this accuracy can be confirmed by similar tests on empirical data.

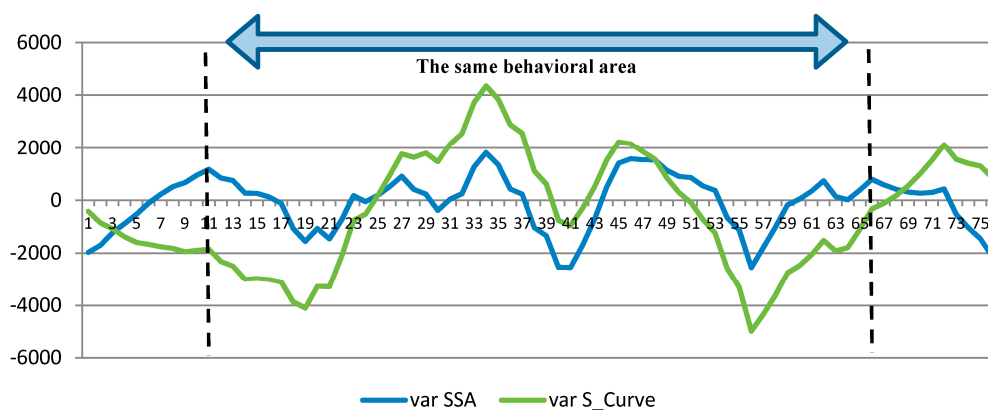


Figure 15. Deviations between the SSA trend and the S-curve method with the generated time series.

To validate deviations between SSA and the S-curve method, two measures, RMSE and R, are employed that assess the quality of the generated time series. These two measures, R and RMSE, are used to determine the extent to which the model fits the data and are calculated as below:

$$R = \frac{\sum (y_i - \bar{y}_i) (\hat{y}_i - \bar{\hat{y}}_i)}{\sqrt{\sum (y_i - \bar{y}_i)^2 \sum (\hat{y}_i - \bar{\hat{y}}_i)^2}} \quad RMSE = \sqrt{\frac{1}{N} \sum (y_i - \hat{y}_i)^2} \quad (3)$$

Table 1 presents the results of the two measures for SSA trend and the S-curve method with the generated time series. These two measures prove that the generated time series fit the actual trend better than the standard S-curve. Both RMSE values are less than 5% of the maximum member of each series that prove the validity of estimated time series. RMSE of the SSA trend is less than half of the S-curve one. Although the R measure is perfect in both, SSA is judged slightly better.

Table 1. Deviations between SSA trend and the S-curve method with the generated time series.

	MAX	RMSE	R
ACWP	156,015.81		
SSA	158,153.98	1050.64	0.92
S-Curve	155,155.24	2166.50	0.93

5.1.1. Effect of Input Parameters on the Simulator Results

The sensitivity analysis of some important input parameters is presented in this section. Resource constraints, work contours and changes in the progress status are considered as changing factors, and their effects on simulator outputs are studied.

- Effect of Resource Constrains:

Taking into consideration resource constraints, both the project time and cost will increase. Figure 16 shows the resulting S-curve of the project for both with and without resource leveling.

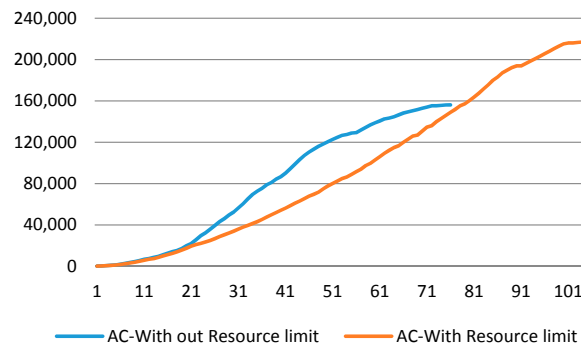


Figure 16. Simulator output with and without resource leveling. AC, Actual Cost.

Resource leveling lengthens the project completion time 40 days and increase the project cost by about \$9500. Moreover, simulator output in the case of resource leveling fluctuates considerably. These two time series have been analyzed by SSA. The window length is set to half of the project duration ($L = 53$). Figure 17 shows the principal components related to the first three eigentriples of the resulting time series.

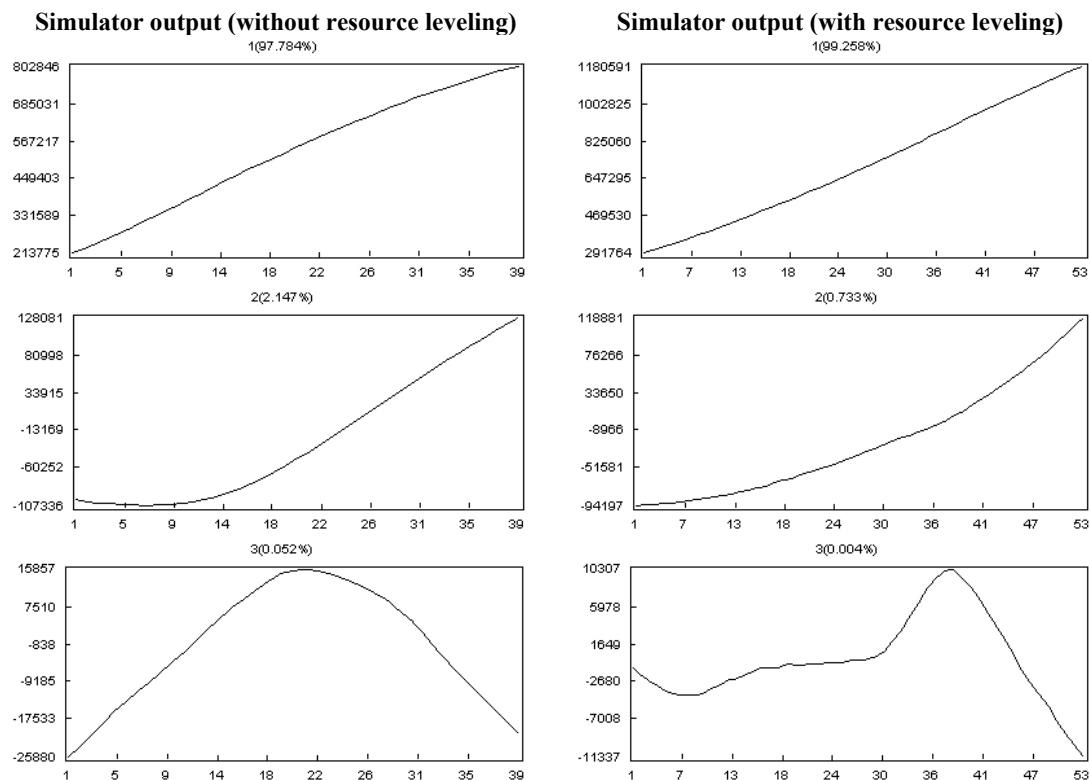


Figure 17. Principal components related to the first three eigentriples.

The two first principal components have approximately the same behavior, and in fact, both series have a similar trend. However, the third principle components of new time series have a different structure due to the high fluctuation of the series. In the case of resource leveling, based on w-correlations analysis, no harmonic components are detected in the resulting time series and residuals, which are obtained by the eigentriples 4 to 53 fluctuating more.

- Effect of discipline and work contour:

In this section, the simulator is run in two different settings of work contour: front loaded and back loaded and with the assumption of resource leveling. Principal components related to the first three eigentriples of the resulting time series are presented in Figure 18.

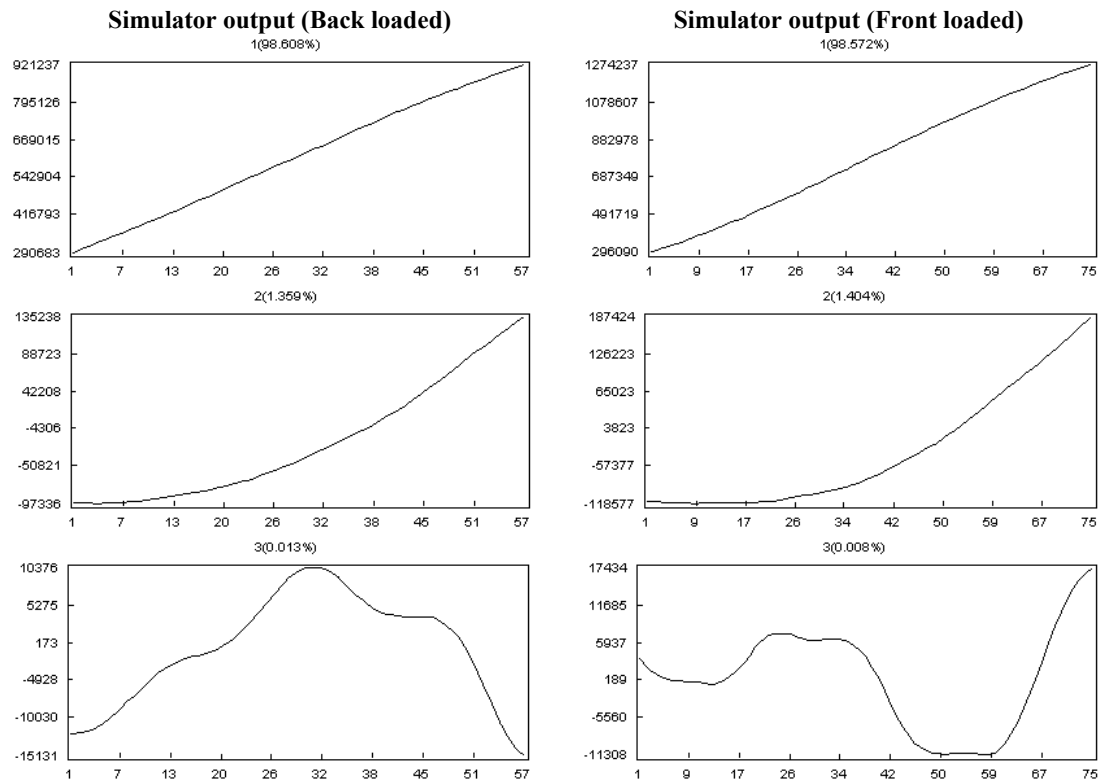


Figure 18. Principal components related to the first three eigentriples of the time series in two different settings: front-loaded and back-loaded work contour.

In this case, the two first components of the resulted series are similar, but the third component has a different shape. Besides, the third component has more fluctuation in the front-loaded work contour setting than the back-loaded one.

Although the residuals of these time series have various behaviors and structures, these series have a similar harmonic component, as well.

- Effect of the changes in the progress status:

To evaluate the impacts of activities' progress status on actual progress and the simulator output, the simulator is run in two various statuses:

- The actual progress of tasks fluctuates ± 0.2 of their plan progress.
- The actual progress of tasks fluctuates ± 0.3 of their plan progress.

Moreover, it is assumed that the project has a flat work contour and resource leveling. When the interval range increases, project completion time and cost raise, while project progress fluctuates more.

Figure 19 presents the first three eigentriple components of the resulting time series. The increase of this range results in a large fluctuation in the time series. This is apparent in the second and third principle components. However, the first principle component of the two series has approximately the same structure, and therefore, the two series have generally similar trends.

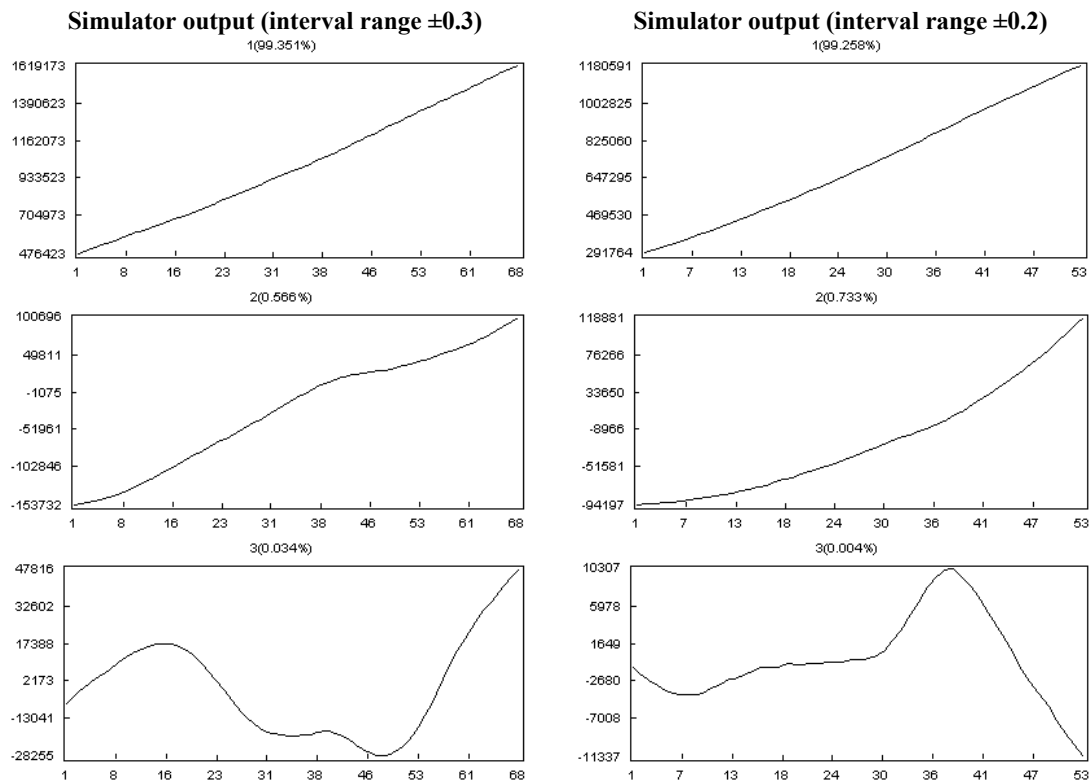


Figure 19. Principal components related to the first three eigentriples of the time series for two different interval ranges.

5.2. Case Study Results

Figure 20 simulates an experiment on a construction project whose project duration was six months, and its Budget at Completion (BAC) was = 66,869,542,003 Rials (around \$2.3 million at writing). About 34% of the project was not completed due to delays for about five months since the project started, and the project was executed under a situation with high risks; the inflation rate was estimated to be 30% for six months. As already stated, the project was supposed to follow the four main disciplines and seven sub-disciplines corresponding to the fourth main discipline. Here, we suppose that all tasks have a uniform (flat) distribution.

The baseline schedule is used when the project was planned at the very beginning, which is shown in the Gantt chart formed. In this paper, the simulation is conducted by the use of the project progress simulator described earlier. After all, other input parameters have been treated based on present actual information. After 150 days of the project have passed, the simulation begins to match the actual curve with actual project progress; thus, the completion trends can be forecasted and measured.

As seen in Figure 20, the project is scheduled to be completed in 306 days (about 10 months) with a cost overrun. As a result, the budget must rise from 66,869,542 to 100,750,109,952 Rials, i.e., by about 35%. Besides, Figure 20 displays the progress information of another project. Therefore, EVM calculations are now able to be measured daily.

The progress simulator equips us with forecast and control methods that lead to reliable results, and which make daily and completion date forecasting simple to a large extent. If these initial warning signals are appropriately analyzed properly in comparison with the project schedule, they pave the way for us to take corrective actions on those activities that are not on the right track (particularly, those tasks that are on the critical path).

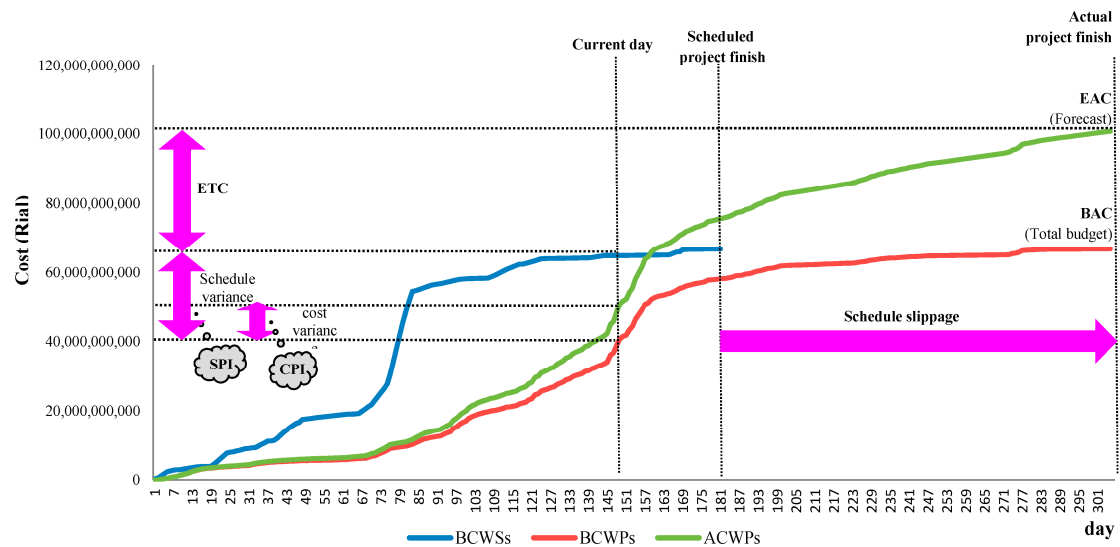


Figure 20. Simulation results for the given project. EAC, Estimate At Completion; BAC, Budget At Completion; SPI, Schedule Performance Index; CPI, Cost Performance Index.

As mentioned before, the generated time series can be used to extend formulae. Table 2 shows the time series analysis with EVM formulae in different time scales of the forecasted time series.

Table 2. Time series analysis with EVM formulae. EDAC, Estimate of Duration at Completion.

Time of Forecast	% Schedule Completed	% Work Completed	EDAC	ES	CV%
1/00	0/32	0/06	225/90	0/03	0
32/00	11/36	17/91	383.08	0/76	0/34
63/00	35/78	31/84	584.70	1/88	0/92
94/00	79/50	45/16	762.57	0/45	3/17
125/00	92/93	53/02	448.16	0/53	8/04
156/00	95/39	62/80	241.40	0/70	18/94
187/00	100/00	73/21			27/44

Figure 21 illustrates one sample of the usage of the simulator results. In this figure, the dynamic action threshold on the Schedule Performance Index (SPI(t)) is depicted.

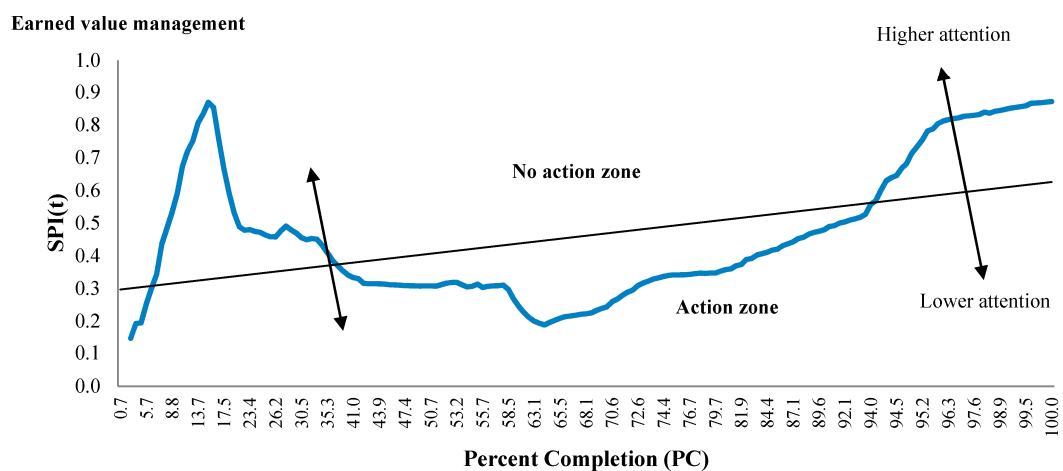


Figure 21. Corrective action during project control.

6. Conclusions

Construction project estimation and control as important parts of project management and performance measurement are not new to and have long been discussed in the academic research literature. Moreover, project time and cost estimation, especially at the beginning of projects, is one of the most significant processes of project management and, when performed well, results in project risk reduction.

Plenty of research has been completed to estimate project time and cost, most approaches of which are based on EVM techniques and indices, such as SPI, CPI and their combinations. However, applying new forecasting methods requires periodic and progressive time series data, as well as the availability of historical data from similar projects. In this regard, for many projects, the available data are not sufficient to apply forecasting methods.

In this paper, a new simulation approach as a novel framework is offered here to serve as an attempt to introduce a new simulation approach to reflect the data regarding the time series progress of the project, considering the specifications and the complexity of the project and the environment where the project is performed. This simulator is a powerful tool that can provide daily progressive estimated information for project managers to assist their monitoring of project performance, though they lack historical data that could help researchers in generating general and customized formulae in further research.

This simulator generates project time series with both the PSC and PST concepts and as a part of the presented framework, its outputs are analyzed by SSA. The application of the SSA technique in the area of project management and project control is presented for the first time by this research. The results of the analysis show the superiority of this technique in this field, the specifications of project time and cost curves and the effects on different situations. Furthermore, the results of one random project from the ProGen dataset (as a fictitious input) demonstrate the similarity of the first two components of each curve and other changes according to project specification change.

The simulator's validity is tested through comparison of its output with the results of the S-curve technique, using one of the most powerful tools of analyzing time series, SSA. This comparison demonstrates similar behavior within these tools.

Finally, the result of the simulator is shown with empirical data input. A given project is used as a simulator input, and its time series is then depicted in a similar process. The presented results show that the simulator can be used to forecast the actual costs and the duration of a project, in order to review the planning not only at the beginning, but also while the project is being executed and can help project managers to perform corrective actions. In addition, the project behavior can be investigated during different project periods.

Given the importance of understanding and improving project progress information and data estimations, future lines of research should be set up. The authors intend to focus on two research lines. First, the proposed simulators can be developed for an SPS through adding specific project characteristics, such as resource types. This method allows project managers to generate a more specific time series, which shows project features more precisely. Secondly, the proposed simulator uses other network generators' outputs to simulate a project. Since all datasets have been generated in the resource constraint environments and other assumptions limiting the structure of their networks, the general results cannot be evaluated. Therefore, adding a network simulator, which allows project managers to study network parameter effects on project time and cost, could also be a field of future study.

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