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The S-curve envelope as a tool for monitoring and control of projects

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Abstract

Monitoring and controlling the progress of projects is always indispensable to project manager's mission because it can help to produce updated pictures of how the project is progressing. Even with a target progress derived from a detailed project schedule, the actual progress, under the influence of many factors, may deviate significantly from the target, which requires to take corrective actions/control. A project monitoring and control system must provide the required information to answer the following questions: What is the difference between the planned and actual work performance? How is the project progressing in terms of completion of activities? How much ahead or behind schedule is the project? What is the efficiency of the time utilized on the project? In this paper, the concept of S-curve envelope is introduced. This S-curve envelope consists of two curves. The upper curve corresponds to the curve of the earliest times whereas the lower curve corresponds to the curve of the latest times. This S-curve envelope can be used as an early warning system to determine whether the S-curve from the actual progress data is reasonable or needs to be revised. If, when comparing the S-curve based on actual progress to the scheduled-based S-curve envelope, the project is running outside the envelope, appropriate action must be taken depending on whether the actual S-curve is below or above the envelope.

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Keywords: Project Management; S-Curves envelope; Project Monitoring

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1. Introduction

Projects are highly unlikely to proceed according to plan. In order to be able to identify and measure the differences between the plan and the actual work performance, progress on the project is required to be controlled and monitored. Monitoring and controlling the progress of projects is always indispensable to project manager's mission because it can help to produce updated pictures of how the project is progressing in terms of completion of activities, consumption of resources, delays, to improve and/or correct initial estimates adopted from the scheduling phase, etc.

Even with a target progress derived from a detailed project schedule, the actual progress during construction under the influence of many factors may deviate significantly from the target, which requires to take corrective actions/control. The common monitoring method of project progress is to compare the difference of real performed progress against contract/scheduled progress of the project[1]. Monitoring project performance involves making measurements as the project proceeds and comparing these measurements with the desired or expected values. Small deviations between plan and actual performance may be seen as being within the limits of uncertainty of the model building process. Larger differences may require control action to try to bring the actual performance on course within the desired state of the plan[2].

In order to characterize the status of a project, the concept of project envelope is introduced in this paper. This project envelope consists of two curves. The upper curve corresponds to the curve of the earliest times whereas the lower curve corresponds to the curve of the latest times. The project envelope indicates, for a specific time, the upper and lower cumulative expenses (costs) that should have been paid. The paper is organized as follows. In the next section a literature review on S-curves is presented. Next, the methodology utilized to construct the S-curve envelope is given. An application of this methodology is presented in section 4, and finally, there is a concluding section with the main findings of the paper.

2. S-curves

It is assumed that the profile of the cumulative cost versus elapsed time in projects takes the shape of an S-curve. Based on its appearance, the guide to Project Management Body of Knowledge[3] defines the S-curve as: graphic display of cumulative cots, labour hours, percentage of work, or other quantities, plotted against time. The name S-curve derives from the S-like shape of the curve, flatter at the beginning and end, steeper in the middle. The reason is that `projects start slowly when resources need to set up, and then projects start to accelerate once all resources have been acquired'[4,5]. Even the largest projects start with an initially number of tasks, but soon start to tackle multiple activities simultaneously. These parallel, interconnected activities increase the spending greatly compared to the work at the beginning. S-curves have become a requisite tool for project planning and control and for overall progress evaluation during the execution phase. Owners, managers and contractors commonly use the S-curve for project planning and control as it provides the basis for forecasting cash flows and thus making financial arrangements before construction. S-curves can be used for several purposes, as a target against which the actual progress of a project can be evaluated at any point in time to monitor whether the project is on schedule[6], to forecast the likely duration of a project once the contract price and cumulative expenditure are known, to manage cash flow, current performance status, future necessary costs/duration, etc. for running projects[1-7,9].

In the literature review on the topic we can find different methods to construct S-curves. Murmis[10] showed how to construct a curve numerically by building it from a normal distribution and forcing it through the fixed point of 5 percent progress at 10 percent of project duration. Skitmore[11] utilized three approaches, analytic, synthetic, and hybrid, in combination with six alternative models to determine the best approach/model combination for the available data and forecasts for future expenditure flows. Kaka[4] used a stochastic model based on historical data with logit transformation technique to incorporate variability and inaccuracy in their forecasts and decision-making. Barraza et al.,[8] developed stochastic S-curves to provide probability distributions of budgeted cost and planned elapsed time for a given percentage of progress in order to evaluate cost and time variations. Hwee and Tiong[12] developed an S-curve profile model from cost-schedule integration equipped with progressive construction-data feedback mechanisms. Mavrotas et al.,[13] modelled cash flows based on a bottom-up approach from a single contract to the entire organization with an S-curve based on a conventional non-linear regression model. Blyth and Kaka[9] proposed a model that standardized activities to produce an individual S-curve for an individual project using a multiple linear regression model. Chao and Chien[14] proposed an empirical method for estimating project S-curves that combined a succinct cubic polynomial function and a neural network model based on existing S-curve formulas and attributes of the project. Cheng and Roy[15] proposed an evolutionary fuzzy decision model for cash flow prediction using time-dependent support vector machines and S-curves. Cheng et al.,[6] proposed a progress payment forecasting approach using S-curves for the construction phase. The authors improve the traditional grey prediction model by applying the golden section and bisection method to build a short-interval cost-forecasting model. Maravas and Pantouvakis[16] developed an S-surface cash flow model based on fuzzy set theory to predict the working capital requirements of projects and Lin et al.,[1] proposed a construction project progress forecasting approach which combines the grey dynamic prediction model and the residual modified model to forecast the current project progress during the construction phase. Chen et al.,[17] estimated project's profitability at completion using a multivariate robust regression model to test how well the key variables in project initiation and planning phases predict project profitability.

3. Methodology

Various mathematical formula forms for estimating S-curves have also been developed over the years. For example, the polynomical and exponential functions in Gates and Scarpa[18], Peer[19], Tucker[7], Miskawi[20], Khosrumshahi[21] and the logit transformation approach proposed by Kenley and Wilson[5] to build individual construction project cash flows model. Comparisons made by Skitmore[11] and Navon[22] show that the best closeness of fit is achieved by the logit transformation formula, which has been widely preferred to be other researchers[23]. Other methods have been based on classifying projects into groups and producing a standard curve for each group simply by fitting one curve into historical data using the multiple linear regression technique[4,11,24].

In this paper we adopt the approach suggested by Brandewinder[25] analysing products that when entering the market follow an S-Curve. The equation for the S-curve is given by:

$$f(x) = \frac{1}{1+e^{-x}} \tag{1}$$

In order to control when the growth happens and its speed, we transform the curve adding two parameters

$$f(x) = \frac{1}{1+e^{-\propto(t-T_0)}} \tag{2}$$

where T_0 is the t-value of the sigmoid's midpoint (the time at which the project has used half of its total funds) and $\propto$ indicates the steepness of the curve. When $\propto = 1$ and $T_0 = 0$, Eq. 1 is the standard logistic function. Parameter $\propto$ stretches or compresses time and adjusts the slope of the curve. Parameter T_0 adjusts the position of the maximum slope and shifts the timeline of the curve. As it increases it moves the maximum slope towards the origin of the *t*-axis. Small values of T_0 imply late payments while greater values mean early payments.

Now, given two values, f_1 and f_2 and two dates t_1 and t_2, we want to find the value of the two parameters $\propto$ and T_0 such that $f_1 = t_1$ and $f_2 = t_2$. Substituting $f_1 = t_1$ into Eq. (2) yields the following:

$$\frac{1}{1+e^{-\propto(t_1-T_0)}} = f_1 \rightarrow e^{-\propto(t_1-T_0)} = \frac{1}{f_1} - 1 \rightarrow -\propto (t_1 - T_0) = \ln\left(\frac{1}{f_1} - 1\right) \tag{3}$$

Performing the same operation on $f_2 = t_2$, the following system of two linear equations is obtained:

$$\begin{cases} \propto (t_1 - T_0) = \ln\left(\frac{1}{f_1} - 1\right) \\ \propto (t_2 - T_0) = \ln\left(\frac{1}{f_2} - 1\right) \end{cases} \tag{4}$$

Solving the system gives us the following values for $\propto$ and T_0:

$$\propto = \frac{\ln\left(\frac{1}{f_1} - 1\right) - \ln\left(\frac{1}{f_2} - 1\right)}{t_2 - t_1} \tag{5}$$

$$T_0 = \frac{\ln\left(\frac{1}{f_1} - 1\right)}{\propto} + t_1 \tag{6}$$

In order to find the value of the two parameters, $\propto$ and T_0, two points of the curve, i.e., 25 percent and 75 percent; 20 percent and 80 percent of the duration of the project must be taken from the project data.

4. Application

The purpose of this section is to illustrate the use of the proposed model, which can be a useful tool for project managers in controlling and revising the actual S-curve during the course of a project. Table 1 shows the data of the project and Tables 2 and 3 show the Earliest Start (ES), Earliest Finish (EF), Latest Start (LS), Latest Finish (LF), and Slacks when performing the activities of the project at normal and crash time.

Table 1. Data of the project.

Task	Predecessors	Normal time (months)	Normal cost (€*10^6)	Crash time (months)	Crash cost (€*10^6)
Start	-	0	0	0	0
A	-	0.5	2.5	.0.25	5
B	A	1.5	7.5	0.75	15
C	-	1.25	1.25	0.8	2.5
D	C	1.75	1.75	1.2	3.5
E	B, D	1.25	2.5	0.42	5
F	E	1.75	3.5	0.58	7
G	D	1	1.5	0.75	2.5
H	G	3	4.5	2.25	7.5
Finish	F, H	0	0	0	0

Table 2. Slacks, normal time.

Task	ES	EF	LS	LF	Slack
Start	0	0	0	0	0
A	0	0.5	2	2.5	2
B	0.5	2	2.5	4	2
C	0	1.25	0	1.25	0
D	1.25	3	1.25	3	0
E	3	4.25	4	5.25	1
F	4.25	6	5.25	7	1
G	3	4	3	4	0
H	4	7	4	7	0
Finish	7	7	7	7	0

Table 3. Slacks, crash time.

Task	ES	EF	LS	LF	Slack
Start	0	0	0	0	0
A	0	0.25	3	3.25	3
B	0.25	1	3.25	4	3
C	0	0.8	0	0.8	0
D	0.8	2	0.8	2	0

E	2	2.42	4	4.42	2
F	2.42	3	4.42	5	2
G	2	2.75	2	2.75	0
H	2.75	5	2.75	5	0
Finish	5	5	5	5	0

Table 4. Slacks, crash time.

Earliest times		Latest times	
$t_1 = 0.25$	$f_1 = 12.0$	$t_1 = 1.75$	$f_1 = 11.28$
$t_1 = 4.25$	$f_2 = 94.8$	$t_1 = 4.25$	$f_2 = 75.99$

Solving the system of linear equations in Eq. (4) with the data presented in Table 4, the following Equations are obtained and used to construct the S-curve envelope shown in Figure 1.

$$f(x) = \frac{1}{1 + e^{-1.22(t-1.88)}}$$

$$f(x) = \frac{1}{1 + e^{-1.28(t-3.35)}}$$

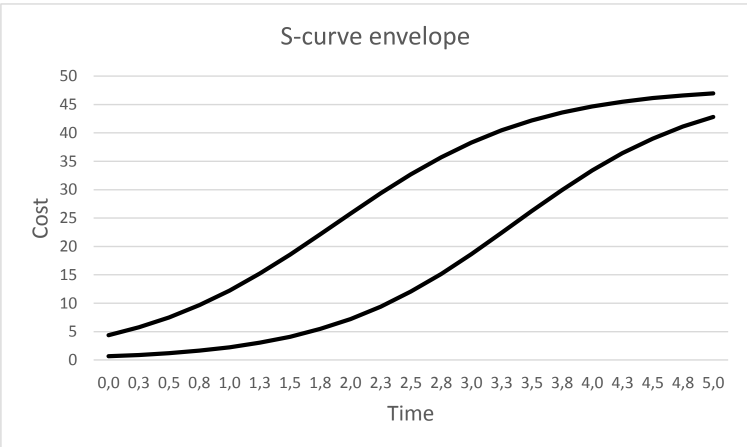

Figure 1. S-curve envelope

The advantages of the method presented here are various. The S-curve envelope allows to identify the status of the project comparing it with the plan and analyzing the deviations. Contrary to other methods based on classifying projects into groups and producing a standard S-curve for each group simply by fitting one curve into historical data using multiple linear regression techniques, the S-curve presented in this paper is built only with the data of the project to be undertaken. Specifically we only need two amounts of costs and the dates at which these amounts are consumed. For example, 10-90 or 15-85, 20-80 percent of the budget and the corresponding dates. The parameters of the model are also clearly identifiable with the parameters of the project. Parameter T_0 indicates the time at which 50 percent of the project budget will be consumed and parameter alpha is directly related with the cost escalation rate where lower values correspond to smother curves. Low (high) values for T_0 characterize projects that start with early (late) payments, or projects where activities start early (late). By increasing (decreasing) alpha, we are shrinking (stretching) the period of time during which a certain percentage of the project budget is consumed, which at the same time implies higher (lower) escalation rates.

4. Conclusions

In this paper, an S-curve envelope is introduced for monitoring and control of projects. This S-curve envelope consists of two curves. The upper curve corresponds to the curve of the earliest times whereas the lower curve corresponds to the curve of the latest times. The monitor and control process through the S-curve envelope can be used as an early warning system to determine whether the S-curve from the actual progress data is reasonable or needs to be revised. If, when comparing the S-curve based on actual progress to the scheduled-based S-curve envelope, the project is running outside the envelope, appropriate action must be taken depending on whether the actual S-curve is below or above the envelope. If the actual cumulative cost (PV, EV, contractor's payments…) is below the S-curve envelope, it means that the project is running with delay while if the actual cumulative cost is above the envelope the project is running too fast. Consequently, the monitor and control process through the project envelope can be used as an early warning system in every type of project, especially in projects under high levels of uncertainty or in projects where goals and objectives are unclear or not well defined.

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