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Enhancing Project on Time Within Budget Performance by Implementing Proper Control Routines

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Prevalent control routines are generally based on traditional deterministic models that in situations of short time float and scanty budgets are often unable to deliver complex projects "on time within budget." Because it does not take uncertainties into consideration, the deterministic approach grossly misleads management into thinking that the likelihood of delivery on time within budget is very good, when in reality it is very poor. We propose a stochastic control routine that enables the attainment of project deliveries "on time" and, as much as possible, "within budget," in many situations where prevalent control routines cannot provide the same results.

Keywords: Project management; control routines; time-cost tradeoffs; Monte Carlo methods.

1. Introduction

Project management focuses on the technical specifications of a project and how those specifications can be met within the cost, profit, time, safety, and quality constraints that the contract with the client has imposed on the enterprise (Clark & Colling, 2005). Large projects are often characterized by a combination of uncertainty and ambiguity related to goals and tasks, as well as the complexities that emanate from their size and the numerous dependencies between different activities and the environment. Among the factors likely to change the existing plan are the revisions of work content estimates, changes in technical specifications, technical difficulties, delivery failures, weather conditions, and labor unrest. Research has proved that routines, even if cost-effective, do not work well in situations of high uncertainty. For example, the studies of Van de Ven et al., (1976) and Keller (1994) show that most routines work properly in low uncertainty situations, and Kraut & Streeter (1995) have clarified that under high uncertainty the control routine used in routine production environments may not suffice. Turner (1993) and Pinto (2007) clarify that risk management has a positive effect on project success in terms of delivery of contractual commitments on time and within budget.

Control and coordination are closely intertwined concepts in classic organization theory (Parker, 1984). Recent findings confirm that the implementation of a control routine and coordination system influences task completion competency and thus, project management performance (Liu et al., 2010). A control routine involves: 1) monitoring that serves to establish the need to control the tendency to deviate from the planned trajectory while there is still time to take corrective actions (Lock, 1987), 2) analyzing the situations at each inspection point using present views, and 3) deciding which corrective actions should be implemented if reestablishment of project targets is required. Sacks et al., (2005) claimed that the control of time, cost, and quality is performed almost exclusively manually, with the result that it is expensive, approximate, and commonly delivered with a time lag that does not allow an effectively closed control loop. The chances of successfully achieving the time and cost objectives during the course of implementation of a project are slim indeed, unless an adequate level of control followed by coordination, if required, is exercised throughout its lifecycle. Packendorf (1995), Kerzner (1998), Thiry (2004) and many others claimed that effective project management requires extensive inspection and internal coordination.

Project management is a complex decision-making process that typically involves continuous budgeting and scheduling decisions under pressures of time and cost. A project with ample time and a generous budget, especially when supported by an appropriate control routine, can usually be accomplished on time and within budget. But, in a situation of a short time float and a scanty budget, simultaneously attaining both time and cost targets might be extremely difficult, because time and cost are in a tradeoff relationship. In practice, the prevalent choice is the attainment of the time target first, while the satisfaction of the cost target is secondary. Thus, coordination should be mainly considered when the present view indicates missing the time target, or, when the indication is that the time target is attainable but the cost objective is not. The coordination for reestablishing the project time target can be obtained by possible pruning of activities, by detailing activities, by redistributing workloads in order to perform more activities in parallel (Laslo et al., 2008), and mostly by regulating the activity execution modes (using, for example, the critical path method (CPM) proposed by Kelley & Walker (1959) and Kelley (1961)).

Control systems must be flexible in accepting information, instantaneous in terms of response, comprehensive in terms of the range of functions they support, and intelligent in terms of analysis and overview of information throughout the project lifecycle. Project managers seek control systems that can actually be used throughout the project lifecycle, making subsequent controls easier and cheaper. But, contrary to the deterministic models, using stochastic models may place onerous requirements on users because they require multiple duration estimates whose production may be time-consuming. Nevertheless, the question is whether is it worthwhile to replace control routines that are based on a simplified deterministic approach with routines that are based on a complicated stochastic approach?

This study was designed to compare control routines based on alternative procedures, all seeking to provide deliveries that are on time within budget. The on time target in the experiment was determined as a constraint, while the within budget target was determined as a desired goal, but this goal was subject to the satisfaction of the time constraint. For comparing the performance of the control routines based on the different approaches, we performed "what if?" analyses on a real project that had renewable resources.

Indeed, project control routines may deal with limited capacities of project resources that require solution of multi-mode resource-constrained scheduling optimization problems. But, the availability of some non-renewable resources that are required within realistic execution-windows of project activities cannot be guaranteed when scheduling those execution-windows is subject to uncertainty. From the standpoint of practicality, it is worthwhile to convert the complicated multi-mode resource-constrained scheduling optimization problem into a problem with renewable resources and "earliest start" activity scheduling, which can be resolved as a time-cost tradeoff optimization problem.

This article will first provide a survey of literature in the context of project inspection points with our proposal for their definition. This is followed by the description of a generalized model for a multi-mode execution of activities for supporting the solution of time-cost tradeoff optimization problems. Then, the authors will provide the studied project on which the "what if"? analyses will be performed. Next, deterministic and stochastic simulation procedures of control processes will be described and implemented. The empirical portion of the paper concludes with a set of insights. Finally, a summary closes the article.

2. Project inspection points

Intelligent determination of inspection points throughout the project lifecycle is crucial for its effective control. The literature of recent decades has been challenged by several unresolved issues that have traditionally precluded the installation of sophisticated control systems.

One issue is the breadth of inspection (time only, cost only, time and cost, and so on). The earned value method implementations for large or complex projects include features such as indicators and forecasts of cost performance and schedule performance. However, the most basic requirement of an earned value system is that it quantifies progress using the present view and the earned value. Lipke et al., (2009) proposed an application of statistical methods to earned value management and earned schedule performance indices. Pajares & López–Paredes (2011) proposed two metrics that combine earned value management and project risk management for a project's control routine. Naeni et al. (2011) proposed a fuzzy-based earned value model with the advantage of developing and analyzing the earned value indices, with completion uncertainty affecting time and cost estimates.

The second issue is the determination of the inspection frequency. In the literature, the problem of proper inspection frequency is mostly avoided by considering a pre-established total number of inspection points. However, there is scant research addressing this issue, mostly in the context of possible reduction of the total number of the inspection points (Friedman et al., 1989; Golenko-Ginzburg & Gonik, 1997; Golenko-Ginzburg & Laslo, 2001). For example, Golenko-Ginzburg & Laslo (2001) proposed an optimization procedure that can be realized with different execution modes. At each inspection point the model faces a stochastic optimization problem where the objective is to minimize the number of inspection points, subject to a chance-constrained completion deadline. Decision-making on the activity execution modes and the next inspection point are determined through extensive simulation at each routine inspection point. Tareghian & Salari (2009) argued that the number of project inspection points has an upper bound beyond which no significant benefits can be attained, but they did not state how to determine an adequate number of inspection points.

The third issue is the determination of inspection timing. The traditional optimal control models (Lefkowitz, 1977; Elsayed & Boucher, 1985; Linn & Wysk, 1990) deal with fully automated systems where the output is continuously measured on line. The temporary nature of a project allows us to monitor its advancement only at pre-determined inspection points, as it is impossible to perform measures continuously. Anyhow, the inability to continuously conduct inspection during the course of a project's advancement is the crux of project management. Partovi & Burton (1993) carried out a simulation study to compare the effectiveness of five inspection timing policies: 1) no inspection; 2) completely random inspection; 3) inspection at equal intervals; 4) beginning with more frequent and ending with less frequent inspection (front loading); and 5) beginning with less frequent and ending with more frequent inspection (end loading). Their results did not introduce significant differences. They recommended investigating the effects of density, network size, and other characteristics of the program evaluation and review technique (PERT) network on the performance of different inspection mechanisms. De Falco & Macchiaroli (1998) argued that because projects can follow different patterns, this makes clear the need for different allocations of inspection points. They proposed a framework to make decisions concerning the timing and frequency of inspection actions based on the definition of an effort function, which incorporates activity intensity and schedule slack aspects, and the premise that inspection intensity is distributed according to a bell-shaped curve around the point of maximum effort. Raz & Erel (2000) presented an analytical framework for determining the inspection timing throughout the project lifecycle. The authors' approach was based on maximizing the total amount of information generated by the inspection points, which depends on the intensity of the activities carried out since the last inspection point, and on the time elapsed since their execution. They compared the optimal amount of information to the amount of information obtained with two simpler policies—inspection at equal time intervals and inspection at equal activity intervals.

The fourth issue is concerned with auditing techniques such as monitoring based on data collection, written reports, formal or informal sessions with the project team, and on-site visits. Communication throughout the project lifecycle is hindered by the large amount and the wide variety of information that is involved in the project. However, in traditional control systems, manual data collection, improper data sharing, and the gap between inspection points usually result in late identification of deviations in project performance. This subsequently leads to late corrective actions, which often result in cost and schedule overruns. Unlike common document-based systems, advanced systems that facilitate project information management and communication focus on demonstrating the potential of data-centric web databases to enhance the communication process during the project lifecycle (Chassiakos & Sakellaropoulos, 2008). Azimi et al. (2011) presented an automated data acquisition system integrated with computer simulation. Their system provides a reliable platform for an automated and integrated control framework that facilitates decision-making by enabling project managers to take corrective actions immediately after deviations occur.

It seems that there is a wide consensus that the focus of inspection should be concentrated upon time and cost. It is also agreed upon that automated data acquisition systems integrated with computer simulations can provide control in real time with negligible cost. Thus, the issue of inspection frequency becomes irrelevant. Meredith & Mantel (1995) argue that control points should be linked to the actual plans of the project and to the occurrence of events as reflected in the plan, and not only to the calendar. Indeed, predetermined timing of inspection points is useless in situations with uncertainty. The timing of each inspection point should be triggered by an occurrence of a perceptible event when conclusive performance input is contributed. Thus, we suggest that only perceptible events of accomplishing project activity, or events in which a consequent project activity becomes eligible for processing (i.e., all its precedence activities are accomplished), should be considered as adequate inspection triggers. It is obvious that any unfolding event such as technological failures and specification redefinitions should be inspection triggers as well, but the appearance of such events is impossible to foretell. Because implementation of coordination in an ongoing activity is complicated and expensive, or even impossible, coordination should only involve non-started activities. Because the coordination has an immediate effect only on the activities that are eligible for processing, events that do not release additional activities that are eligible for execution can be precluded from being inspection triggers.

3. Generalized model for multi-mode execution of activities

Despite the fact that uncertainty is the crux of the problem in achieving the time and cost targets of projects, and especially research and development projects, practitioners are generally unaware of the inaccuracy inherent in implementing deterministic models in situations where projects are under the influence of significant uncertainty. PERT (Malcolm et al., 1959) was originally developed for planning and controlling projects where there is uncertainty. Such uncertainty mainly concerns the time and the cost required by each activity. PERT uses logic diagrams to analyze activity durations, focuses on the project events and estimates the probability of meeting specified completion dates, assuming that activity durations vary. The random activity durations obstruct the definition of critical paths. Thus, PERT determines the probability of meeting the contractual due date by way of a quantified risk assessment.

The process of identification, analysis, and assessment of possible project risks greatly benefits the project manager in developing risk mitigation and contingency plans for complex projects (Charette, 1996). PERT provides less unbiased estimates of the project completion expectations than deterministic methods such as CPM (Moder & Rodgers, 1968). Moreover, PERT provides a greater level of information to be analyzed, which allows us to evaluate the risks of missing the project time and cost targets. But, an analysis based on random activity durations along a single path may skew the results if there are multiple critical paths on the project (Ang et al., 1975). For this reason, PERT requires mathematical calculations that are tremendously complex (Moder et al., 1983). Moreover, the analytical evaluation of project completion time and total cost under uncertainty must be based on assumptions that impair the authenticity of results. Because it is infeasible or impossible to compute an exact result with a , Monte Carlo (MC) simulations can quantify the effects of risk and uncertainty in project schedules and budgets.

Dealing with activity durations in the context of PERT, Laslo (2003) and Elmaghraby (2005) defined two types of duration uncertainty—the “internal uncertainty” and the “external uncertainty.” The first (internal uncertainty) type derives from revision of work content, changes in technical specifications, technical difficulties, and so on, and is typical for some types of tasks such as research and development. Laslo (2003) showed that when the extreme dominance belongs to the internal uncertainty’s share, the coefficient of variation of the activity duration is kept. The second (external uncertainty) type derives from delivery failures, weather conditions, labor unrest, and so on, and is typical of other types of tasks such as production and construction. Thus, when the external uncertainty has an extremely dominant share within the accumulative uncertainty of the activity duration, the standard deviation of the activity duration is kept during the crashing of the activity duration.

Furthermore, in the current environment of rapid change, costs are typically subject to fluctuations owing to project uncertainty (Chou, 2011). Laslo & Gurevich (2013a) defined two types of cost uncertainty—the “duration-deviation-independent cost uncertainty” and the “duration-deviation-dependent cost uncertainty.” The former (duration-deviation-independent) cost uncertainty derives from an inaccurate estimate of prices, materials, and wages. The standard deviation of the duration-deviation-independent cost uncertainty is proportional to the budget allocated in order to provide the desired execution mode, i.e., its coefficient of variation is preserved. In cases of self-performed activities or outsourced activities under cost-price terms, the random deviation from the duration target has an impact on the activity cost (deviations of salaries paid for random effective hours caused by internal uncertainty and salaries paid for random idle periods caused by external uncertainty). Therefore, the latter (duration-deviation-dependent) cost uncertainty should be considered for such cases. Obviously, the duration-deviation-dependent cost uncertainty is not typical of a case of outsourced activity under fixed-cost terms because in such a case the activity cost is related to the target duration but is not affected by the actual duration. That is, there is no dependency between the activity cost uncertainty and the activity duration uncertainty. The random duration-deviation-dependent cost has mostly been considered as a linear function of the random activity duration (Arisawa & Elmaghraby, 1972; Britney, 1976; Tavares et al., 1998). Thus, we assume that the standard deviation of the duration-deviation-dependent cost distribution is equal to the standard deviation of the total duration distribution multiplied by the execution cost-per-time unit. The initial execution cost-per-time unit is mainly related to normal performance and varies during the crashing of the duration. The execution cost-per-time unit during the shortening of the activity duration is proportional to the change in the allocated budget, and inversely proportional to the change in the expected duration (in the case of outsourced activity under fixed price terms, duration randomness has no impact on the actual cost because the execution cost-per-time unit is considered to be zero).

In a manner similar to that described by Laslo & Gurevich (2013a) we formulate a generalized activity time-cost model that is applicable for any activity pattern with any execution mode. Each possible activity execution mode, M, with the target effective execution duration, $E\left(Q^{\mathsf{M}}\right)$, requires the allocation of budget b^{M}.

The random activity duration T^{M} related to its execution mode is composed of the following random time components:

1. The random effective execution duration, Q^{M}, related to its execution mode and affected by the activity's internal uncertainty:

$$Q^{\mathsf{M}} = E(Q^{\mathsf{M}}) + \Delta Q^{\mathsf{M}}, \tag{1}$$

where:

- the duration-budget tradeoffs curve (allocated budget versus target effective execution duration, $E\left(Q^{\mathsf{M}}\right)$) is considered as a pre-given continuous function, with its estimated edge points corresponding to the normal (minimal) and the crash (maximal) budgets, $b^{¥}$ and $b^{£}$ respectively, related to the normal and crash execution modes,
- ΔQ^{M} is a random component that reflects the internal uncertainty; this variable is related to the relevant execution mode, has zero expectation and a standard deviation proportional to the target effective execution duration, and $\sigma(Q^{¥})$ is a known standard deviation of the effective execution duration related to the normal execution mode.

2. The random wasted time caused by disturbances, R:

$$R = E(R) + \Delta R \quad ,(2)$$

where:

- $E(R)$ is considered as a known positive value,
- ΔR is a random component that reflects the external uncertainty; the distribution of this variable does not depend on the execution mode, has zero expectation, and a known standard deviation $\sigma(R)$.

Thus, the random activity duration related to the execution mode is defined as:

$$T^{\mathsf{M}} = Q^{\mathsf{M}} + R = E\left(T^{\mathsf{M}}\right) + \Delta Q^{\mathsf{M}} + \Delta R . \tag{3}$$

The random activity cost, C^{M}, that is related to its execution mode, is composed of the following components:

1) the determined budget allocated to the activity, b^{M}, that is associated with its execution mode,

2) a random variable that reflects the duration-deviation-independent cost uncertainty, ΔS^{M}. This variable is related to the execution mode, has zero expectation, and a standard deviation proportional to the allocated budget, $\sigma(\Delta S^{¥})$ is a known standard deviation of the duration–deviation–independent cost related to the normal execution mode,

3) a random component that reflects the duration-deviation-dependent cost uncertainty equal to the deviation from the target duration, $T^{M} - E(T^{M})$ multiplied by the activity execution cost-per-time unit related to b^{M}, v^{M}. The execution cost-per-time unit related to the execution mode is $v^{M} = (b^{M} / b^{¥}) \cdot \left(E(Q^{¥}) / E(Q^{M})\right) \cdot v^{¥}$, where $v^{¥}$ is a known execution cost-per-time unit that is related to the normal execution mode.

Thus, the random activity cost related to the execution mode is defined as:

$$C^{M} = b^{M} + \Delta S^{M} + v^{M} \cdot (\Delta Q^{M} + \Delta R). \tag{4}$$

Assuming some distributions for ΔQ^{M}, ΔR, and ΔS^{M}, the generalized model for activity duration and cost allows for obtaining the simulated activity time and cost performances related to each execution mode.

4. The studied project

The study is based on a project with renewable resources that was accomplished in an electronics company that develops and produces test and measurement equipment. The project network is described in Figure 1. The project lead-time determined for this project was 260 work days and the budget allocated to this project was $1,840K.

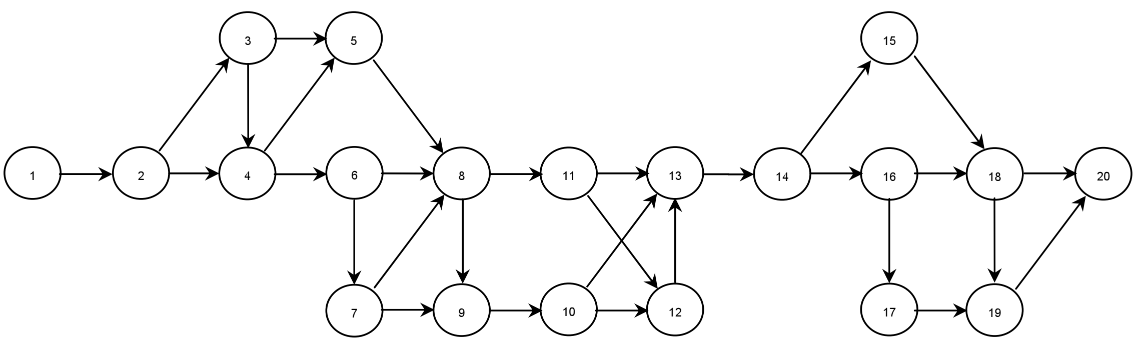

Figure 1: The AOA PERT-type project network

A detailed evaluation of project activity duration and cost distribution characteristics corresponding to the time and cost uncertainty sources had been prepared beforehand (Laslo & Gurevich, 2013b). For each project activity the expected effective execution duration is assumed to be a continuous linear function of the allocated budget (time-cost tradeoffs curve). This function, which represents possible execution mode alternatives, had been estimated. The distribution characteristics of each project activity at the edge points of this function, which are the normal and the crash execution modes, are presented in Table 1, where:

- the expected effective execution duration related to the normal mode (estimated), denoted by $E\left(Q^{¥}\right)$,

- the standard deviation of the effective execution duration related to the normal mode (estimated), denoted by $\sigma\left(Q^{¥}\right)$,
- the expected wasted time caused by disturbances (estimated), denoted by $E(R)$,
- the standard deviation of the wasted time caused by disturbances (estimated), denoted by $\sigma(R)$,
- the expected duration of activity related to the normal mode, $E\left(T^{¥}\right)=E\left(Q^{¥}\right)+E(R)$,
- the required budget for execution under the normal mode, denoted by $b^{¥}$,
- the standard deviation of the duration-deviation-independent cost related to the normal mode (estimated), denoted by $\sigma\left(\Delta S^{¥}\right)$,
- the execution cost-per-time unit related to the normal execution mode, denoted by $v^{¥}$,
- the expected effective execution duration related to the crash mode (estimated), denoted by $E\left(Q^{£}\right)$,
- the expected activity duration related to the crash mode, $E\left(T^{£}\right)=E\left(Q^{£}\right)+E(R)$,
- the required budget for the implementation of the crash execution mode, denoted by $b^{£}$.

Table 1: Initial estimation of duration and cost distribution characteristics related to normal and crash execution modes

Activity	Normal execution mode								Crash execution mode		
(i, j)	$E(Q^{¥})$	$\sigma(Q^{¥})$	$E(R)$	$\sigma(R)$	$E(T^{¥})$	$b^{¥}$	$\sigma(\Delta S^{¥})$	$v^{¥}$	$E(Q^{£})$	$E(T^{£})$	$b^{£}$
(1,2)	16	3.46	9	3.00	25	96	0.66	6.0	11	20	97
(2,3)	14	3.00	5	1.41	19	49	0.00	3.5	11	16	53
(2,4)	18	4.00	7	2.24	25	72	0.84	4.0	16	23	74
(3,4)	4	0.00	1	0.00	5	12	0.67	3.0	3	4	14
(3,5)	11	2.24	1	0.00	12	33	0.94	3.0	11	12	33
(4,5)	5	1.00	1	0.00	6	15	0.74	3.0	5	6	15
(4,6)	22	4.80	4	1.00	26	77	0.91	3.5	18	22	80
(5,8)	49	10.86	3	1.00	52	147	0.97	3.0	44	47	165
(6,7)	4	0.00	1	0.00	5	6	0.69	1.5	4	5	6
(6,8)	26	5.74	1	0.00	27	130	1.10	5.0	21	22	134
(7,8)	21	4.58	2	0.00	23	21	0.73	1.0	21	23	21
(7,9)	28	6.16	1	0.00	29	70	0.68	2.5	28	29	70
(8,9)	6	1.00	5	1.41	11	18	0.77	3.0	5	10	23
(8,11)	29	6.40	3	1.00	32	116	0.96	4.0	23	26	121
(9,10)	10	2.00	2	0.00	12	30	0.75	3.0	9	11	37
(10,12)	14	3.00	5	1.41	19	35	0.82	2.5	14	19	35
(10,13)	37	8.19	3	1.00	40	111	1.04	3.0	33	36	116
(11,12)	7	1.41	2	0.00	9	21	0.00	3.0	6	8	24
(11,13)	18	4.00	6	2.00	24	90	0.99	5.0	18	24	90
(12,13)	16	3.46	1	0.00	17	48	0.00	3.0	13	14	50
(13,14)	6	1.00	1	0.00	7	12	0.00	2.0	4	5	13
(14,15)	18	4.00	3	1.00	21	63	0.82	3.5	14	17	64
(14,16)	22	4.80	2	0.00	24	55	0.76	2.5	20	22	67
(15,18)	24	5.29	1	0.00	25	60	0.75	2.5	19	20	62
(16,17)	13	2.83	2	0.00	15	65	0.86	5.0	13	15	65
(16,18)	24	5.29	3	0.00	27	72	0.00	3.0	22	25	80
(17,19)	26	5.74	1	0.00	27	65	0.00	2.5	26	27	65
(18,19)	18	4.00	2	0.00	20	45	0.00	2.5	16	18	48
(18,20)	17	3.74	5	1.41	22	68	0.77	4.0	14	19	69
(19,20)	4	0.00	1	0.00	5	12	0.00	3.0	4	5	12

Because this project was an internal venture outside the framework of contractual commitments, the executive considered the cost target more important that the time target. The minimal budget for accomplishing the project was calculated as the expected sum of all project activity costs associated with the activity normal execution modes, and was found to be equal to $1,714K. The completion time according to activity's normal execution modes was considered by the project manager as the time length of the critical path. The longest expected time length was found as 254 work days on the 1–2–4–5–8–9–10–13–14–16–18–19–20 path, with a variance of 130. Thus, the project manager argued that by performing each of the project activities according to its normal execution mode, the risk of not accomplishing the project on time (260 work days) was approximately 30% (here the normal distribution for the project's completion time was assumed). Despite this conspicuous level of tardiness risk, the executive confirmed the consistent policy of normal execution modes. According to this policy, inspection points were otiose because investment of additional budget for regulation of activity execution modes should not be on the agenda, even when deviations from the planned trajectory endanger the meeting of the planned due date.

The project was performed according to the normal execution modes policy; work on the project started in March 2011 and was completed in May 2012. The project lasted 279 work days, and its actual total cost was $1,847.8K. A detailed analysis of the sources of time and cost deviations versus the initial planning was performed as described in Table 2, where:

- t^* is the actual activity duration (as executed under the normal mode) with deviation $t^* - E(T^*)$ from the estimated duration that is composed of the actual estimated value of the deviation of the effective execution duration, denoted by Δq^* and the actual estimated value of the deviation of the wasted time caused by disturbances, denoted by Δr,

- c^* is the actual activity cost (as executed under the normal mode) with deviation $c^* - b^*$ from the allocated budget that is composed of the actual value of the duration-deviation-dependent cost uncertainty, $v^* \cdot (\Delta q^* + \Delta r)$, and the actual value of the duration-deviation-independent cost uncertainty, denoted by $\Delta s^* = \left(c^* - b^*\right) - v^* \cdot (\Delta q^* + \Delta r)$.

Table 2: Normal execution mode: the performace and the analyzed sources of time and cost deviations vs. the initial planning

Activity	Planning			Performance				
(i, j)	$E(T^*)$	b^*	v^*	t^*	Δq^*	Δr	c^*	Δs^*
(1,2)	25	96	6.0	33	4	4	144.5	0.47
(2,3)	19	49	3.5	25	4	2	70.0	0.00
(2,4)	25	72	4.0	17	-5	-3	39.0	-1.02
(3,4)	5	12	3.0	5	0	0	12.5	0.51
(3,5)	12	33	3.0	15	3	0	43.3	1.32
(4,5)	6	15	3.0	5	-1	0	11.3	-0.71
(4,6)	26	77	3.5	32	5	1	99.2	1.22
(5,8)	52	147	3.0	40	-11	-1	112.4	1.41
(6,7)	5	6	1.5	5	0	0	6.6	0.58
(6,8)	27	130	5.0	33	6	0	158.2	-1.81
(7,8)	23	21	1.0	27	4	0	25.7	0.68
(7,9)	29	70	2.5	35	6	0	85.6	0.55
(8,9)	11	18	3.0	9	-1	-1	12.8	0.82
(8,11)	32	116	4.0	39	6	1	145.4	1.39
(9,10)	12	30	3.0	10	-2	0	23.2	-0.76
(10,12)	19	35	2.5	22	2	1	43.5	0.95
(10,13)	40	111	3.0	33	-6	-1	88.4	-1.62
(11,12)	9	21	3.0	10	1	0	24.0	0.00
(11,13)	24	90	5.0	28	3	1	111.5	1.47
(12,13)	17	48	3.0	19	2	0	54.0	0.00

Activity	Planning			Performance				
(i, j)	$E(T^*)$	b^*	v^*	t^*	Δq^*	Δr	c^*	Δs^*
(13,14)	7	12	2.0	6	-1	0	10.0	0.00
(14,15)	21	63	3.5	24	2	1	72.5	-0.96
(14,16)	24	55	2.5	21	-3	0	48.3	0.79
(15,18)	25	60	2.5	28	3	0	68.2	0.74
(16,17)	15	65	5.0	16	1	0	71.1	1.07
(16,18)	27	72	3.0	24	-3	0	63.0	0.00
(17,19)	27	65	2.5	30	3	0	72.5	0.00
(18,19)	20	45	2.5	18	-2	0	40.0	0.00
(18,20)	22	68	4.0	25	2	1	79.2	-0.8
(19,20)	5	12	3.0	5	0	0	12.0	0.00
Project	**254**	**1714**		**279**			**1848**	

The project was accomplished with an absence of unfolding events, and, as previously mentioned, its implementation was consistent according to normal activity execution modes policy, without carrying on any corrective actions. Although the implementation of the project was not supported by any control system, the obtained time performance indicates that the accomplishment of the project on time within budget is a challenging mission. Thus, a sophisticated decision-making procedure should be considered for the coordination routine throughout the implementation of this project. The availability of initial estimates and performance data makes this scenario appropriate for a "what if?" analysis that should be conducted for the purpose of evaluating stochastic versus deterministic reestablishment of time and cost project targets. Because the presented scenario does not ensure that both the time and cost targets of the project can be attainable simultaneously, a determination of a hierarchy between these targets is required. As is customary with most practitioners, the time target in this study is defined as the primary target and the cost target as the secondary.

5. Simulation of the control processes

Here we present in detail control processes, one based on the deterministic approach and the other with several pre-determined time probability levels on the stochastic approach, in order to demonstrate their implementation on our studied project. We presume that the project is considered before its actual realization, and simulate its execution accompanied by the control routines. We also assume the generalized model (3)-(4) for durations and costs of the project activities. Because an implementation of a control process at each inspection point generally leads to reconsideration of execution modes of the non-started activities, we presume that the simulated time and cost deviations versus initial planning of these activities correspond to their real values, adjusted for the changed execution mode, i.e., $\Delta q^{\text{M}} = \Delta q^{\text{¥}} \cdot E(Q^{\text{M}}) / E(Q^{\text{¥}})$, $\Delta s^{\text{M}} = \Delta s^{\text{¥}} \cdot b^{\text{M}} / b^{\text{¥}}$,

$$t^{\text{M}} = E\left(T^{\text{M}}\right) + \Delta q^{\text{M}} + \Delta r \quad .(5)$$

$$c^{\text{M}} = b^{\text{M}} + \Delta s^{\text{M}} + v^{\text{M}} \cdot (\Delta q^{\text{M}} + \Delta r) \quad (6)$$

5.1 Simulation of the control process with the deterministic procedure

By considering the activity duration and cost means as deterministic parameters, the deterministic approach ostensibly allows one to define one or more of the project's critical paths that seemingly determine the project completion time. The project cost can be easily calculated by summing up the costs of all the project activities. Siemens (1971) proposed a simple iterative optimization procedure named the Siemens Approximation Method (SAM) for crashing PERT projects which has been the most prevalent crashing procedure in practice during the last decades. Additional budgets are economically allocated for shortening all critical paths by one unit of time at each iteration, until the length of each critical path satisfies the time target. The simulation of the deterministic approach is composed of the following steps as detailed in Algorithm 1.

Algorithm 1: The simulation steps of the deterministic approach

Step 1	Identify the current set of all the paths by lexicographic scanning.
Step 2	Start the procedure at the project's source event which is the initial inspection point by considering a normal execution mode and the related expected activity duration for each of the project activities.
Step 3	Identify the set of the project's critical paths by taking into consideration: • the simulated durations (calculated according to Equation (5)) as durations of the accomplished activities; • the expected durations related to the current execution modes as durations of the other activities.
Step 4	Check if the project time target is attainable by considering the expected length of one or more critical paths as the project completion time; if the time target is attainable continue to Step 5; otherwise, go to Step 6.
Step 5	Check whether the project cost target is attainable by taking into consideration: • the simulated costs (calculated according to Equation (6)) as costs of the accomplished activities; • the expected costs related to the current execution modes as costs of the other activities; if the cost target is attainable continue to Step 7; otherwise, go to Step 6.
Step 6	6.1 Identify the set of the project's critical paths by taking into consideration: • the simulated durations (calculated according to Equation (5)) as durations of the accomplished activities; • the expected durations related to the current execution modes as durations of the ongoing activities; • the expected durations related to the normal execution modes as durations of the non-started activities. 6.2 Regulate the execution modes so that each critical path being considered is shortened by one unit of time by allocating an economically additional budget to a set of non-started activities lying on that critical path (the cost of shortening the duration of each of these activities by one unit of time is the slope of its time-cost tradeoffs curve). 6.3 Identify the current set of the project's critical paths and calculate the current project cost after the last regulation of the execution modes (Step 6.2); if the project's time target is unattainable or the project cost is below the cost target continue to Step 6.4; otherwise, go to Step 7. 6.4 Check whether at least one of the current critical paths where the current execution mode of all its non-started activities is the crash mode; if any such critical path exists continue to step 7 (premature halt of the project crashing procedure); otherwise, return to step 6.2.
Step 7	Convert the status of the activities that are eligible for processing into ongoing activities and then calculate their simulated durations (according to Equation (5)). Calculate their simulated completion time by summing up the timing of the current inspection point (their earliest common execution start) and the simulated duration of each of them.
Step 8	Find the timing of the earliest coming event in which consequent project activity becomes eligible for processing, i.e., all its precedence activities are accomplished), and define it as the current inspection point. Then, convert the status of each ongoing activity with a simulated completion time that precedes or meets the timing of this inspection point, into the status of accomplished activity. If all the activities are accomplished the simulation is accomplished, otherwise; return to Step 3.

At each inspection point the actual cost is calculated by summing up the simulated costs of the accomplished activities and the partial simulated costs of the ongoing activities. Partial simulated cost of each ongoing activity is calculated as its simulated cost multiplied by the ratio between its duration until the inspection point and its simulated duration.
The initial naïve project's expected completion time related to the most economic execution ($1,714K) was 254 work days and the project's simulated performance as a result of implementing the control system with the deterministic procedure showed completion time of 272 work days with the cost of $1,875K.

5.2. Simulation of control processes with stochastic procedures

The evaluation of the project completion time under uncertainty is very complicated. Moreover, project managers often erroneously consider the maximum of expected project path completion times as an expected project completion time. This handicap is troublesome in complex networks where there are many parallel paths with project activities lying on several of them. The implementation of MC methods for evaluating the realistic distribution of the project completion time and cost, heuristics that are not concerned with erroneous assumptions, has been recommended for preventing impaired accuracy of results. Golenko–Ginzburg (1993) proposed an iterative semi-stochastic optimization procedure where the additional budget required for shortening the activity duration by one unit of time is allocated according to the activity criticality, i.e., the activity with the highest probability of lying on critical paths. Laslo & Gurevich (2013a) introduced a stochastic optimization procedure based on MC methods, with the purpose of minimizing a chance-constrained cost under a chance-constrained completion time, and demonstrated its superiority using broad MC comparisons versus the deterministic and the semi-stochastic procedures for crashing the project completion time. Assuming the known distributions for durations and costs of project activities, the stochastic approach allows for estimating the expected project completion time and cost as well as the $1-\alpha$ fractile of the project completion time. These estimations are based on MC methods where samples of 10,000 observations are generated from the duration and cost distributions of the project activities. Then, for each sample of observations from the duration distributions of the project activities, we calculate the observation from the distribution of the project's completion time as the length of the project's critical paths. Thus, utilizing 10,000 observations from the project's completion time distribution we define a MC expected project completion time as a mean of these 10,000 observations and a MC $1-\alpha$ fractile of the project completion time as such value that 9,500 observations are less than or equal to it and 500 observations are greater than or equal to it. In a similar way, we calculate the observation from the project cost distribution by summing up the costs of all the project activities for each sample of observations from the cost distributions of the project activities. Then, utilizing 10,000 observations from the project's cost distribution we define a MC expected project cost as a mean of these 10,000 observations. Assuming normal distributions for durations and costs of the project activities, the simulation of the stochastic approach is composed of the following steps as detailed in Algorithm 2.

Algorithm 2: The simulation steps of the stochastic approach

Step 1		Determine the desired probability confidence (chance constraint) of the project completion time, $0 < 1-\alpha < 1$.
Step 2		Start the procedure at the project's source event, which is the initial inspection point, by considering a normal execution mode and related duration and cost distributions for each of the project activities.
Step 3		Define the duration and cost of the accomplished activities as their simulated values (calculated according to Equations (5)-(6)). Then, from the duration and cost distributions of the other activities related to the normal execution modes, generate samples of 10,000 observations and, according to equations (3-4), calculate the MC $1-\alpha$ fractile of the project completion time and the MC expected project cost.
Step 4		Check whether the project time target is attainable with the predetermined confidence level. If the time target is attainable with the predetermined confidence level continue to Step 5; otherwise, go to Step 6.
Step 5		Check whether the project cost target is attainable (i.e., if the MC expected project cost is less than or equal to the allocated budget to the project). If the cost target is attainable continue to Step 7; otherwise, go to Step 6.
Step 6	6.1	Define the duration and cost of the accomplished activities as their simulated values (calculated according to Equations (5)-(6)). Adjust the duration and cost distributions of the ongoing activities related to the current execution modes by taking into consideration that these activities are executed during a known period of time since the previous inspection point, and are not yet accomplished (see Laslo & Gurevich (2013b) for details). Consider the duration and cost distributions of the non-started activities as related to the normal execution modes.
	6.2	Allocate one unit of budget to any one of the non-started project's activities that can be shortened (i.e., its current execution mode is not a crash mode), and update its duration distribution. Then, from the duration and cost distributions of all project activities, generate samples of 10,000 observations and, according to equations (3-4), calculate both the MC $1-\alpha$ fractile of the project completion time as well as the MC expected project completion time and cost.
	6.3	Repeat Step 6.2 for each of the non-started project's remaining activities that can be shortened; then continue with Step 6.4.
	6.4	Select the non-started activity to which the allocation of one unit of budget provides the minimal chance-constrained project completion time (i.e., the minimal MC $1-\alpha$ fractile of the project completion time). In case of several minimal chance-constrained project completion times, choose the activity to which the allocation of one unit of cost also provides the minimal MC expected project completion time. In the case of several minimal MC expected project completion times, choose one of such activities at random. Allocate one unit of budget to the chosen activity and update its duration distribution.
	6.5	Calculate the MC $1-\alpha$ fractile of the project completion time and the MC expected project cost, both being related to the current execution modes. If the project's time target is unattainable or if the project cost is below the cost target, continue to Step 6.6; otherwise, go to Step 7.
	6.6	Check whether at least one of the non-started project's activities can be shortened (i.e., its current execution mode is not a crash mode). If such activity exists return to step 6.2; otherwise, go to step 7.
Step 7		Convert the status of the activities that are eligible for processing, into ongoing activities and calculate their simulated durations (according to Equation (5)). Then calculate their simulated completion time by summing up the timing of the current inspection point (their earliest common execution start) and the simulated duration of each of them.
Step 8		Find the timing of the earliest coming event in which consequent project activity becomes eligible for processing (that is, all its precedence activities are accomplished), and define it as the current inspection point. Then, convert the status of each ongoing activity with a simulated completion time that precedes or meets the timing of this inspection point into the status of accomplished activity. If all the activities are accomplished, the simulation is accomplished; otherwise, return to Step 3.

At each inspection point the actual cost is calculated by summing up the simulated costs of the accomplished activities with the simulated cost of each of the ongoing activities, multiplied by the ratio between its duration until the inspection point and its simulated duration.

The initial simulated project's expected completion time related to the most economic execution ($1,714K) was 265 work days.

The first simulation of the control process using the stochastic procedure was performed for a .50 time confidence level (what many may incorrectly assume as equivalent to a procedure that is based on expected activity durations). The project's simulated performance as a result of implementing the control system with the stochastic procedure for a .50 time confidence level showed the completion time of 255 work days with the cost of $1,888K.

Because the simulation of the control process with the stochastic procedure for a .50 time confidence level showed earliness of the project's completion time but cost overflow, a simulation with the stochastic procedure for a .40 time confidence level was performed with the expectation that this would reduce the cost overflow and still satisfy the project's time target. The project's simulated performance as a result of implementing the control system with the stochastic procedure for a .40 time confidence level showed the completion time of 257 work days with the cost of $1,889K. The cost overflow was slightly expanded by $700, which indicated that contrary to expectations, the cost overflow was not reduced.

To ensure the project's completion at or before the contractual due dates, project managers will be rarely satisfied with a .50 time confidence level (i.e., at a risk of 50% for not accomplishing the project on time), and will aim for higher confidence levels. Therefore, simulations with the stochastic procedure for .60, .70, .80, and .90 time confidence levels were performed in order to learn about the possible effect of the time confidence level on the time and cost performances and on the control system's evolution as well. For example, the project's simulated performance as a result of implementing the control system with the stochastic procedure for a .90 time confidence level, which was chosen to represent the results of all the simulations with time confidence levels >.50, showed the completion time of 246 work days with the cost of $1,921K. We should note that the simulation results showed consistent trends of completion time reduction and cost overflow expansion in the course of raising the determined time confidence level.

6. Insights

The study is based on a single scenario. For this reason, the simulated performance results can mostly be considered only as indicators of possible outcomes of implementing each of the control routines. But, where the results are explainable they might be admissible as insights. These insights were exposed by tracing the evolution of the control process throughout the implementation of alternative control routines.

The analysis of the simulation results indicates that risk management in which the decision-making routine considers predetermined time confidence levels, as shown in Table 3, may allow the attainment of the on time target, while based on the deterministic approach does not. Moreover, the analysis shows that when we are seeking to attain the on time target we cannot consider that deterministic procedures, which are erroneously interpreted as a procedure with a .50 confidence level, are superior to stochastic procedures with confidence levels that are lower than .50. We can conclude as well that the implementation of stochastic procedures may allow the attainment of the on time within budget target where the implementation of the deterministic approach can attain only the within budget target. This can be illustrated by considering a less strict cost target (i.e., a cost target which is equal to or greater than $1,888K). As can be seen from Table 3, for the deterministic procedure, such a change of the cost target will not contribute to the attainment of the time target and will meet only the within budget target. However, for the stochastic procedure with a .50 completion time confidence level, such consideration will allow meeting both the "on time" and the "within budget" targets.

Initially, before any regulation of the activities' execution mode is performed, the deterministic procedure, as shown in Table 3, indicates early completion of the project, while the stochastic procedure with a .50 time confidence level indicates tardiness, which requires the reestablishment of the project's time target. The difference between these indications should be ascribed to the erroneous consideration of the maximum expected project path completion times as an expected project completion time. A naïve definition of critical paths, without taking into account the random nature of activity durations, omits the chance of each of the project's uncritical paths to be longer than the critical paths, and this acts to determine a later than expected completion of the project. Thus, except in the case of a project with a single path (an ordinal set of activities), the deterministic procedure shows that an underestimated expectation of the project's completion time acts to delay alerts; and these are alerts that should invoke coordination before the deviations from the planned trajectory endanger the meeting of the planned due date.

Table 3: Comparison of the simulated performance of the alternative control routines

	Completio n (days)	Cost ($K)
Project targets	260	1840
Without control routine		
Initial naïve expectation of performace related to the most economic execution	254 (-6)	1714 (-126)
Actual performance	279 (+19)	1848 (+8)
Control with naïve deteministic routine		
Initial naïve expectation of performace related to the most economic execution	254 (-6)	1714 (-126)
Simulated performance	272 (+12)	1875 (+35)
Control with stochastic routine with a 0.40 completion time confidence level		
Initial simulated expectation of performace related to the most economic execution	265 (+5)	1714 (-126)
Simulated performance	257 (-3)	1889 (+49)
Control with stochastic routine with a 0.50 completion time confidence level		
Initial simulated expectation of performace related to the most economic execution	265 (+5)	1714 (-126)
Simulated performance	255 (-5)	1888 (+48)
Control with stochastic routine with a 0.90 completion time confidence level		
Initial simulated expectation of performace related to the most economic execution	265 (+5)	1714 (-126)
Simulated performance	246 (-14)	1921 (+81)

Underestimated presentation of the project's completion time by the deterministic procedure in the first stages requires a more intensive effort in reestablishing the time target throughout the later stages. Thus, although the deterministic procedure continues to present overly optimistic completion times that are shorter than the more realistic completion times presented by the stochastic procedure with a .50 time confidence level, in the advanced stages the deterministic procedure required a more intensive effort in reestablishing the project's time target than did the stochastic procedure.

Notwithstanding the need for a more intensive effort in reestablishing the project's time target in the advanced stages, the deterministic procedure may prematurely halt the crashing of the project completion time. Such a premature halt comes about when at least one of the critical paths related to the current combination of the activity executions consists of only those activities the execution of which have been accelerated up to the crash execution mode. This mostly occurs before utilizing the crash execution mode of all project activities, which usually happens before attaining the desired expected or chance-constrained project completion time. That is, with the deterministic procedure, the rest of the available budget cannot be used for increasing the chance of accomplishing the project within the due date.

The simulation results indicate, as expected, that by increasing the predetermined time probability confidence in control routines based on the stochastic approach, project completion time is shortened. On the other hand, the results indicate that the outcome of doing so usually increases project costs. However, at low levels of probability confidence (mostly not predetermined in practice), this outcome may be doubtful. This phenomenon, typical of low levels of time probability confidence, may derive from economic execution modes throughout the earlier stages of the project lifecycle. Later in the lifecycle, they can cause significant tardiness, which requires intensive acceleration of execution modes, resulting in expenses that are greater than the budget savings attained throughout the earlier stages.

Summary

Improvement in the organization of project control is a major challenge facing project organizations today. In response, executives, in general, are taking stock of approaches to improve the organization of the project control. As the project and its environment become complex, being ever more subject to uncertainty, time, and money pressures, there is a greater need for efficient and smart control systems to support decision-making and manage project information.

Among network techniques recently, and widely, employed in project management, the critical path method is implemented for management assessment of the possibility to complete a project on time. But, if the project's network has multiple parallel paths with relatively equal means and large variances, the critical path method yields biased results. Our "what if?" analyses conclude that unrealistic and over-optimistic time performances are found within those control routines where the project's completion time is assumed to be the same as the length of the critical paths. By utilizing the deterministic approach in control routines the project manager will be grossly misled into thinking the chance to attain the time target is very good, when in reality it is very poor. Thus, such a routine falsifies the present views, and those are the views that should alert management to deviations from the planned trajectory, while there is still time to take corrective actions. Moreover, erroneous conclusions often result when the crashing of the project's completion time does not take into consideration that accelerating the execution of activities that are outside critical paths may improve as well the project's time performance. The acceleration of execution that is limited only to activities on critical paths may cause a premature halt of project completion time crashing, and thereby hinder utilization of the whole potential of the coordination. For these reasons, any control routine based on a deterministic approach is strongly discouraged.

The stochastic approach based on MC methods can be utilized to estimate the distribution of the project's completion time and guide the manager in appraising and controlling the chances of accomplishing the project on time. But, the supposition that a stochastic control routine with a higher predetermined time confidence level will always shorten the project's completion time might be false in those cases where the project's cost is constrained. An elevated time confidence level means speeding the execution modes of activities in the earlier stages of the project lifecycle although not all of them will later be found to be critical in the context of project's time target. Consequently, the wasted budget allocated for this purpose may hinder the budgeting of the speeded execution modes that are required for activities that will be found to be critical in the following stages. Thus, under cost constraint, a lavish control routine with a high time confidence level that was established for the purpose of shortening the project's completion time might miss the desired result and ultimately cause delayed completion, or sometimes even hinder the project's accomplishment. We should note that the stochastic procedures allow for pre-determining different confidence levels for attaining both the time target and the cost target (Laslo, 2003). By doing this, stochastic procedures provide a desired balance between the two targets. This possibility was not implemented in our experiment because we had anticipated in advance the lack of capability to simultaneously satisfy both time and cost targets. However, in our experiments the stochastic procedures were performed with varying time confidence levels and with a desired .50 cost confidence level, which is approximately equal to the expected cost.

Stochastic procedures introduce realistic time performances throughout the project lifecycle, while CPM introduces overly optimistic time performances. In view of this, in the context of time performance, the preference for the stochastic approach, when compared to the deterministic approach, is obvious. Thus, we can conclude from our study that control routines based on stochastic procedures may allow delivery on time, whereas those based on a deterministic approach cannot. We can also conclude that control routines based on stochastic procedures may allow delivery not only on time, but within budget, whereas those based on a deterministic approach can deliver the project only within budget. These conclusions are not limited to control routines based on the stochastic approach in which the predetermined time probability confidence is at least .50, which is mistakenly considered as equal to the expected completion time in the deterministic approach.

Thus, a control routine based on the stochastic approach as implemented in our experiments can be very useful in project management. We recommend using the stochastic approach because we infer that such a routine, supported by computing resources available to everyone, is, throughout the project lifecycle, flexible in accepting information, instantaneous in terms of response, comprehensive in terms of the range of functions it can support, and intelligent in terms of analysis and overview of information. Unfortunately, recommendations for a preferred pre-determined time probability confidence that will allow delivery on time in the most economical way cannot be given. This is because each project is unique, and decisions about time probability confidence depend on the partial order of the project activities, the duration and cost distribution of the activities, the project's time and cost slacks, and especially on luck, which cannot be forecasted. Yet, in projects with generous time and cost slacks, both time and cost targets can be protected simultaneously by increasing predetermined probability confidence levels, for both time and cost, to values in excess of .50.

To conclude, control routines based on a deterministic approach are absolutely inadequate for managing projects. Control routines based on a stochastic approach should always be preferred, although we cannot yet recommend which probability confidence level may serve us best. We do not believe that this question can currently be found a solution to, but future research may contribute additional insights and give us a more sophisticated outline for improving our choices in this context.

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