Increasing project control and guidance efficiency through a time-frame simulation approach

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Abstract. Nowadays projects dynamicity and complexity make the control process highly critical. The existing planning and control techniques have frequently proved inadequacy to manage the present challenge. The paper proposes a simulative approach to managing with more efficiency projects life cycles. The appositely built simulation model is populated with both deterministic and stochastic elements: the formers come from the project plan; the stochastic elements have been introduced in order to consider the probabilistic nature of activities duration. In the planning phase the model generates a "baseline pencil" that gives a more confident estimation of the time to complete the project. During the execution phase the model is able to store the data related to the ongoing activities and updates in real-time the estimation of the project completion. Contemporary, it allows the calculation of specific performance indexes which permit to signal in real-time possible occurring "warnings" to users and suggest potential solutions.

Keywords: Project Management; Project control process; Simulation; Stochastic network project; Uncertainty management

1 Introduction

The flexibility required by tasks coordination as well as the multiple feedback processes and non-linear relationships involved during nowadays projects execution make them highly dynamic and complex. Moreover, the uncertainty and variability due to the lack of knowledge about most factors and variables, especially at the beginning stage, has to be opportunely managed, since projects performances (in terms of reliability and timeliness) principally depend on it. Technical, schedule, cost and political changes as well as mistakes that naturally occur during project execution make aleatory the duration of each activity of the network.

The stricter time boundaries, the lack of information and the high impact of mistakes point out the criticality of the project control process. In these circumstances, the expression "project control" assumes the prevailing meaning of "steering" the dynamic system towards planned targets rather than monitoring its progressive achievement. To control a project means to evaluate the project, identify the required changes and plan interventions. It therefore implies dynamic, active and continuous interactions within the "project system" and it consequentially causes an increasing of complexity and uncertainty to be managed [1].

Moreover, the growing need for faster projects advancement requires a closer integration between executing and planning phases and, therefore, it implies the search for new tools able to support the project throughout its whole life cycle.

These observations highlight the inadequacy to manage the present challenges of the existing planning and control techniques, which have not been modified substantially for several decades. Particularly, the deterministic assumptions of the Critical Path Method (CPM) [2] ignore the complexities associated to the uncertainty of the activities. In its turn, the Program Evaluation and Review Technique (PERT) [3] is based on a probabilistic approach but it fails because it reduces the solution space to a single critical path through the network, ignoring the effects of the complex interactions created by dependent sub-paths.

During the executive phase, project plans are periodically revaluated over time as soon as new information become available. This creates a dynamic probabilistic problem whose final solution is a series of partially implemented plans, each one based on the best available information at the moment of the relative evaluation.

The simplifying hypotheses on which the analytical probabilistic approaches are generally based often compromise their reliability degree in the representation of the real problem. In these cases, turning to a simulative approach may result a valid alternative.

Simulation is defined as the manipulation and observation of a synthetic model (which can be described through logical-mathematical functions) representative of a real design that, for technical or economic reasons (such as time boundaries), is not susceptible to direct experimentation. The simulation model is developed to represent the essential characteristics of the real system and omits many minor details [4].

Moreover, adopting a simulative approach in projects management consents to consider different characteristics of the networks which can not be otherwise considered: statistical dependences between the durations of activities; alternative ways to follow up depending on significant events occurring during project execution; time-cost links for each activity of the network.

The present paper proposes a simulative approach to managing projects during their whole life cycles. This study incorporates the activities duration uncertainty into the classical analysis of time-costs tradeoffs in project schedules in order to increase the efficiency of the project control and guidance process.

2. A Simulative Approach to Managing Projects

As previously mentioned, the aim of this paper is to propose a simulative approach to managing the whole projects life cycle able to overcome the weaknesses of the existing project management techniques in order to reach an increase in efficiency of the guidance and control processes.

A simulation model has been appositely built through the combination of the Rockwell Software's Arena, the Microsoft's Excel spreadsheet application and the

Microsoft's Project. The model is populated with both deterministic and stochastic elements.

The deterministic inputs come from the project plan realized through the commonly used Microsoft's Project software and include a network diagram, a Gantt chart and a cost function defined for each project activity (as the CPM analysis requires). These data are automatically stored in Microsoft's Excel spreadsheets which are opportunely linked with the Arena software, where the simulation is actually performed.

The stochastic elements have been introduced in order to consider that activities durations can not be treated as deterministic but have to be more realistically modelled as probabilistic in order to consider their "natural uncertainty". For this reason the simulation model associates a duration probability function, appositely defined, to each activity of the network.

The definition of the cost functions necessary to carry out the CPM analysis needs a particular attention. The duration of each activity is assumed to be independent of the allocations to the other activities. Each cost function comes from the fitting of the available historical data and is assumed to be deterministic. These functions present a non-increasing trend over the time domain bounded by the normal activity duration T_N (associated to the minimum activity cost) and the crash activity duration T_C (associated to the maximum activity cost), and an increasing trend towards the maximum activity duration T_{MAX}. The latter time domain is not considered in the CPM analysis but it has been introduced in order to give completeness to the simulation model.

The figure that follows (Fig. 1) graphically represents the steps of the proposed simulative approach.

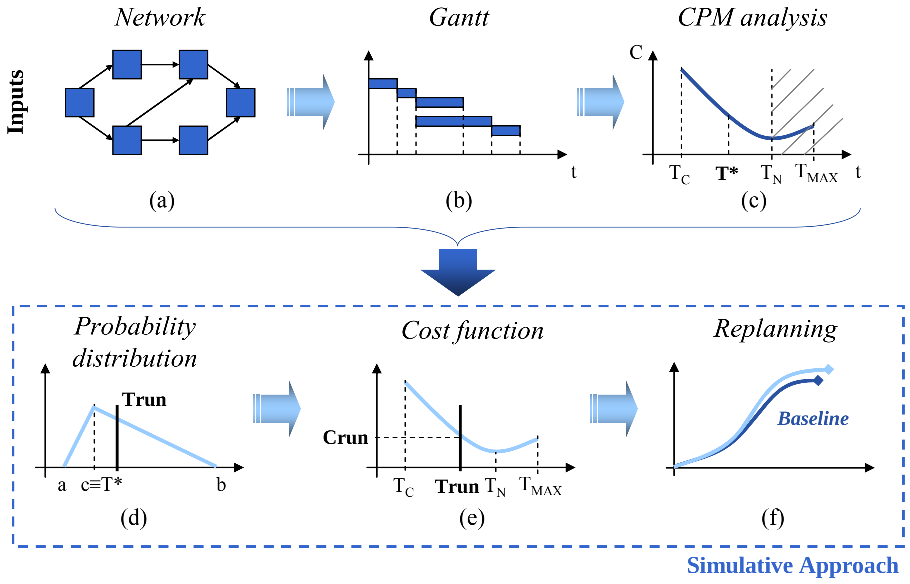

Fig. 1. The simulative approach steps.

As previously mentioned, the simulative approach starts from a series of input data coming from the use of the classical project management tools. Once the network diagram **(a)** and the consecutive Gantt chart **(b)** have been built, the CPM analysis can be carried out in order to identify, for each activity of the network, the specific duration (T* in the figure) which minimizes the total cost of the whole project **(c)**. The network associated to these durations allows the determination of a project baseline of reference for the simulation replications. In fact, the simulative approach is accomplished by introducing a variability to each duration T* through a specific probability distribution. In this way the intrinsic uncertainty of the activities duration can be fed into the approach. The choice of the probability distribution functions will be afterward explained in detail (see “Definition of the Probability Distribution Function”).

At each iteration, for each activity, a duration value is sampled from the probability distribution function **(d)** and the relative cost value is updated **(e)**. On the basis of these values the critical path and the whole project duration can be identified **(f)**. After a sufficient number of repetitions, determined according to the desired confidence degree for the output variables (see “Choice of the Number of Repetitions”), a “baseline pencil”, which portrays the variation field of the project time-cost binomial, can be obtained.

The baseline pencil enables the determination of a probability distribution for the whole project duration (see Section 3) and therefore the estimation of the probability of exceeding prefixed contractual due dates.

The proposed approach can be also used during the execution phase of the project. In this case, the data related to the completely performed activities are considered as deterministic inputs for the simulation model with the consequential reduction of the uncertainty associated to the project duration estimation.

Definition of the Probability Distribution Function. The simulation model has been built considering two main hypotheses. The first – see (1) - allows the definition of the time segment Δ within which variations of the activity duration are admissible; the second hypothesis -see (4) - imposes the shape of the probability distribution function. As regards the first hypothesis, the variation range Δ for a generic T* has to be proportional to the time domain of the related activity duration (T_N-T_C) and, at the same time, inversely proportional to the acceleration cost associated to the activity duration C_a.

$$\textbf{H1:}\quad \Delta \propto \frac{T_N - T_C}{C_a}\,. \tag{1}$$

Moreover, the Δ time segment has to comply with the following conditions:

$$\begin{cases} \lim\limits_{C_a \to 0} \Delta = T_N - T_C \\ \lim\limits_{C_a \to \infty} \Delta = 0 \end{cases}\,. \tag{2}$$

Particularly, we have experimentally found the following analytical expression to calculate the time segment Δ for each activity of the project:

$$\Delta = \frac{T_N - T_C}{e^{k\frac{C_a}{C_C}}} \qquad \text{where} \qquad k = k_1\left(\frac{C_C - C_N}{C_N}\right). \tag{3}$$

where k_1 is a positive constant ($k_1>0$) and $(C_C-C_N)/C_N$ is the cost proportional increase of a generic project activity.

Figure 2 shows the trend of the time segment Δ for a fixed (TN-TC) by varying the acceleration cost Ca.

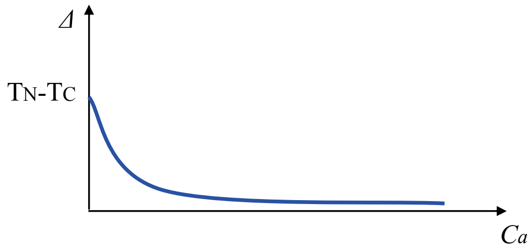

Fig. 2. Trend of the Δ time segment.

As regards the choice of the probability distribution for the activities durations (H2), the asymmetric triangular distribution seems to be the most appropriate. There is little in nature that has a triangular distribution. However, it is a good graphical and mathematical approximation to many events that occur in projects. Project management relies heavily on approximation for day-to-day practice. For instance, the approximate behaviour of schedule task durations can be modelled quite well with the triangular distribution.

The asymmetry reflects the imbalance between pessimistic and optimistic events: the pessimistic events (durations higher than T*) is surely more likely than the optimistic events (durations lower than T*) (see Fig. 3).

The triangular distribution parameters for each activity duration T* have been set by imposing the following conditions (4):

$$\textbf{H2:} \quad \begin{cases} \Delta = b - a \\ 2(c-a) = b - c \end{cases} \quad \Rightarrow \quad \begin{cases} a = c - \Delta/3 \\ b = c + 2/3\Delta \end{cases}. \tag{4}$$

The second condition reflects the choice to consider for each activity the pessimistic event more likely than the optimistic event with a two to one ratio.

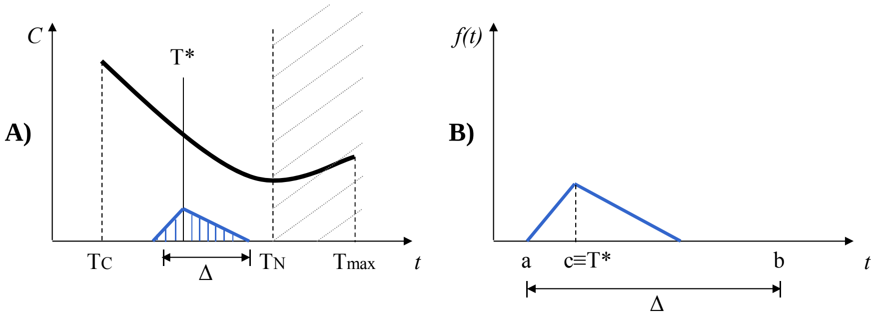

Fig. 3. The cost function (A) and the probability function associated to T* (B).

Choice of the Number of Repetitions. The results of the simulation model are the basis on which the change actions on the real system can be set up. This implies the necessity to know the inaccuracy degree of the reached results and, therefore, the necessity to conduct a strategic analysis in order to determine the number of replications of the simulation model and, consequentially, the size of the observation sample.

A sufficient number of replications of the simulation can be accomplished through the following formula [5]:

$$n = \frac{s^2 t^2_{n-1,1-\alpha/2}}{d^2}. \quad (5)$$

where s represents the system variability evaluated by considering a generic number of previously made iterations; t is the value for a t-distribution with (n-1) degrees of freedom for a range of one-sided critical regions; d represents the accuracy of the estimation, that is the biggest difference between the estimated and the real parameters.

Particularly, starting from 100 previously executed simulation replications, the system variability s and the respective value of the t-distribution t have been determined. Therefore, for a confidence interval $(1-\alpha)$ set on 95%, the congruous number of replications to be accomplished has been set on 250.

3 The "Baseline Pencil" to Increase Estimations Confidence

As stated in Section 1, a project "baseline pencil" and the related probability distribution for the project duration are generated by repeating the simulation a congruous number of time (Fig. 4).

The utilization of a project simulation model in the planning phase forces deeper analysis and understanding of the possible risks occurring during project execution and provides the opportunity to identify, test, and budget potential improvement strategies in advance. This determines a stronger consciousness of both the real and perceived potentials of the selected project proposal which therefore will be more likely to succeed in the subsequent executing phase.

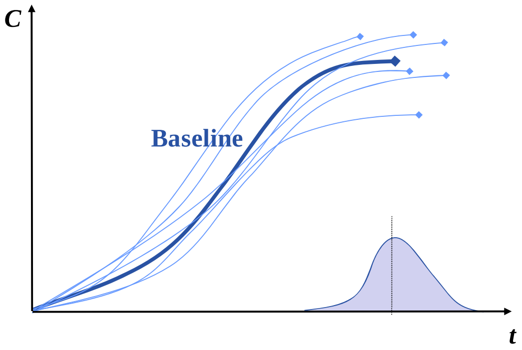

Fig. 4. The probability distribution function of the project completion time.

Furthermore, during the planning phase of the project the ability to determine a project length distribution function can provide the organization with competitive advantages when submitting proposals or negotiating contracts.

Frequently, time reserves are associated to each activity of the project in order to guarantee that the project plan stays on schedule. However, this solution in most cases turns out not to be competitive. Introducing uncertainty in the beginning phase of the project allows the introduction of more effective planning strategies. Particularly, an aggregate “time buffer” from which all the activities can draw time could be introduced. This buffer can be dimensioned by contemporary analysing the behaviour of the probability distribution function of the whole project duration and the probability distribution functions of the durations of each project activity.

4 Real-time Updating and Change Management

Once the project starts, the use of the proposed simulative approach guarantees a series of interesting advantages. The simulation model is able to store the data related to the ongoing activities and update in real-time the estimation of the project completion. As the project progresses, the data related to the completed activities are now considered as deterministic and a new baseline pencil is created on the updated information. The new baselines may include a set of options different from the not realised options of the baseline pencil identified in the planning phase. This variation may depend on the effects of any previously implemented expediting action, on the differences between expected and actual durations of the completed activities, and/or on changes brought about on the estimated durations of the remaining activities.

In addition, continuing to maintain awareness of the completion distribution function during the project execution phase, allows managers to intervene when required, to test intervention strategies, and to implement those strategies as required in order to improve project outcomes. The model, in fact, enables the calculation of specific performance indexes (based on the classical CPI and SPI indexes) which, compared with previously fixed threshold values, permit to signal in advance possible occurring “warnings” to users. Moreover, potential solutions are suggested on the basis of a particular matrix which links the feasible occurring warnings to appropriate corrective actions [6], [7]. Managers can choose the best solution and implement it by using Microsoft’s Project; the project progress curve will be simultaneously updated.

5 Conclusions and Future Research

The proposed simulative approach is characterized by a great flexibility thanks to the suitability of the simulation model to all kind of projects and allows a real-time re-planning together with an efficient change management.

Potential extensions to this research are numerous.

First of all, in this research the cost functions associated to each project activity have been assumed to be deterministic but in practice it is likely that the cost value related to a particular activity duration is considered variable according to a specific probability distribution that can be determined through historical data.

Another interesting extension would be to test the proposed approach in real projects, both to compare its results to more traditional techniques and evaluate users acceptance replies.

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