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A New Approach for Project Control under Uncertainty. Going Back to the Basics.

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Abstract

In this paper we propose a new methodology for project control under uncertainty. In particular, we integrate Earned Value Methodology (EVM) with project risk analysis. The methodology helps project managers to know whether the project deviations from planned values are within the "expected" deviations derived from activity planned variability. Although the methodology is new and innovative, we only go back to the fundamentals of project simulation to generate the "universe" of possible projects, according to the assumed variability of project activities. Then we organize and gather the information in order to make the data coherent with EVM. We explain the steps to implement the methodology and we show three case studies. The methodology makes explicit that the schedule and budget resulting from traditional methods like PERT is statistically very optimistic.

Keywords: Project Management, Earned Value Management, Project Control, Monte Carlo Simulation, Project Risk Management.

1. Introduction.

Project control consists on the comparison of a plan or baseline with the actual results of the project to identify deviations and activate early corrective actions if needed. Earned Value Management (EVM) is a widely used project management methodology for project control, as it integrates scope, time and cost control under the same framework (Abba and Niel, 2010, Anbari, 2003, Blanco, 2013, Burke, 2003, Cioffi, 2006, Fleming and Koppelman, 2005, Henderson, 2003, Henderson, 2004, Jacob, 2003, Jacob and Kane, 2004, Kim et al., 2003, Lipke, 2003, Lipke, 2004b, Lipke, 1999, McKim et al., 2000).

Anbari (2003), Fleming & Koppelman (2005) and PMI (2005) explain the main features of the methodology and how to implement it. Several authors have improved the traditional EV by enhancing its capability in evaluating and monitoring project progress (Naeni et al., 2011, Navon, 2005, Vanhoucke and Vandevoorde, 2007, Warburton, 2011). It is not surprising that EV has been applied to many different disciplines and projects (Al-Jibouri, 2003, Chen and Zhang, 2012, Gowan et al., 2006, Hanna, 2012, Kwak and Anbari, 2012, Naderpour and Mofid, 2011)

Succinctly, EVM is based on the representation of three measures: First, the budgeted cost for work scheduled (BCWS) also called planned value (PV); second, the actual cost for work performed (ACWP) also called actual cost (AC); and finally, the budgeted cost for work performed (BCWP) or earned value (EV).

The earned value management indicators are derived from the three previous values: Cost Variance (CV = EV-AC) and Schedule Variance (SV = EV-PV). A positive variance indicates in the case of CV that the project is under budget and in the case of SV, ahead of schedule. On the other hand, a negative variance might be a warning of a problematic situation, showing that project is behind schedule or exceeding the planned budget. In order to compare projects with different size, the Performance Indexes are defined: Cost Performance Index (CPI = EV / AC) and Schedule Performance Index (SPI = EV /PV). Performance Indexes are below 1 whenever the variances are below 0. Variables and variances can be represented graphically (see figure 1), helping project managers to monitor project evolution. The graphical representation of PV is the project cost baseline.

Insert figure 1 around here.

Lipke (2003, 2004a) introduced a new measure, the Earned Schedule (ES), defined as the date when the current earned value should have been achieved. ES is calculated by projecting the EV on the PV curve. Once ES is determined, time-based indicators can be easily derived from SV(t)= ES-AT and the corresponding ratio measure SPI(t)=ES/AT, where AT is the actual time defined as the elapsed time since the beginning of the project.

Given the non-repetitive nature of projects, uncertainty and risk are at the very core of Project Management, and project managers are used to face project delays (and over-costs) beyond the planned values; consequently project managers need methodologies to take decisions under project uncertainty. The typical way to incorporate this uncertainty in project modeling is by means of stochastic networks where activity costs and durations are not deterministic but follow certain probability distributions.

But traditional EVM assumes certainty about the durations and costs of project activities. For this reason, EVM reports the project manager whether the project has overruns (costs, delays) or it is running better than planned, but the methodology does not specify whether the deviation from planned values is within (or not) the possible deviations derived from the expected variability of the project. In other words, perhaps the project is delayed from planned values (computed, for instance, by means of CPM (Kelley, 1961, Kelley and Walker, 1989) or PERT (Fazar, 1959, Malcolm et al., 1959) methodologies), but the delay could remain within the possible (and most probable) range of delays, taking into account the intrinsic variability of activities. Alternatively, the project delay (or over-cost) could be higher than the possible values of delay, so that some changes have taken place in the project and some conditions have changed from the planned conditions of activities variability.

The inclusion of project variability in control methodologies in general, and EVM in particular is becoming an interesting research topic within academics.

Barraza et al. (2004) applied stochastic S-curves to determine forecasted project estimates. Later, Barraza and Bueno (2007) introduced a probabilistic project control concept by extending the performance control limit curves to derive an acceptable forecast of final project performance.

The implications of this stochastic approach in EVM have been recently incorporated by means of fuzzy approaches (Naeni et al., 2011). They developed fuzzy control charts to monitor several EV indices, and provided a transformation method based on fuzzified indices. Leu and Lin (2008) improved the performance of traditional EV by implementing the statistical quality control charts. They implemented individual control charts to monitor project performance data, and provided a log transformation method. Finally, Aliverdi et al (2013) apply statistical quality control charts to monitor earned value indices.

Vanhoucke (2011) suggested monitoring projects with two approaches: top-down, based on earned value metrics; and bottom-up, based on the schedule risk analysis method. Vanhoucke (2012) studied the reasons why EVM and Schedule Risk Analysis give better results in some projects than in others. Hazir & Shtub (2011) explored the relation between information presentation and project control and they developed a simulation software to face with uncertain environments.

By means of Monte Carlo simulation, we can compute the statistical distribution functions of project cost and duration when the project is finished. Therefore, at the end of the project, we can know, within a particular confidence level, whether the project finished or not within the “expected variability” (project under control), and, as a consequence, we can compute buffers for the project to be under control at the end of the project. However, project managers do not want to wait until the end of the project to know whether the project is under control: They need to know it during project runtime, in order to take decisions and corrective actions whenever delays (or over-costs) are out of the expected values.

In order answer the former question, Pajares & López Paredes (2011) suggested to split the final project buffer into small buffers for every time interval, being the interval buffers proportional to the risk reduced at the particular time interval. To this aim, they defined the concept of risk baseline as the *"the evolution of 'project risk value' through project execution lifecycle. The risk of the project at any given time is calculated as the risk of the project pending tasks (those not yet completed), assuming that the project has performed as planned until that given time*" (statistical variance can be used as a measure of risk, both for duration and cost). The risk reduced at any particular interval can be computed as the difference between the values of the risk baseline within the interval.

Pajares & López-Paredes (Pajares and López-Paredes, 2011) linked the interval buffers to EVM methodology by comparing cumulative buffers with cost and time variances at any time. They define two new control indexes that showed whether the project was under control (cost, time) or not. Finally, using these indicators, Acebes et al (2013) propose a graphical framework where represent the schedule and cost control indexes to monitor and control projects with uncertainty.

In this paper, we propose an extremely different approach. We go back to the fundamentals and we use Monte Carlo simulation to obtain the "*universe*" of possible different project runs (at least a significant quantity). Then, for every "possible" project j (every simulation), we define triads (x, T_{xj}, C_{xj}), where x is the percentage of completion, $C_{xj} = x*C_j$ is the money spent when the project has been completed x %

(within simulation j); T_{xj} is the time when the cost C_{xj} was achieved and C_j is the total project cost in the j-th simulation.

For the particular case of x=1, we obtain the set of points (the distribution functions) of cost and duration at the end of the project (project 100 % completed). Therefore, our methodology is an extension of the traditional one, with different percentages of project completion, so that we obtain the distribution functions (and confidence intervals) of cost and duration at any percentage of project completion.

In order to make the use of the methodology easier, we split the triad into a couple of two dimensional graphs (time, x) and (x, cost). When the project is running, we represent within these graphs where the project is, so that we can know whether project cost or duration is under control at any time for a given level of confidence.

The methodology is coherent with EVM, and the data and variances from EVM can be easily translated into the graphs. Indeed, this new approach does not need more data than the information provided by EVM and the variability of project activities. And computations are easily implemented by means of common software.

As far as we understand, one of the main advantages of this new approach is that we combine two methodologies which are familiar to project managers: EVM and Monte Carlo Simulation. Combining both methodologies we integrate risk management with the EVM methodology, in other words, we integrate control and risk under the same framework.

Although we use Monte Carlo simulation to generate de “universe” of possible projects, the innovation of our approach is that we arrange the information in order to know whether the project are within the expected variability at any time. We also arrange the data, so that it is coherent with EVM variables”.

The rest of the paper is organized as follows. In section 2, we introduce the methodology, afterwards, in section 3 we illustrate the method with three case studies. We finally conclude summarizing the main contributions and requirements of the approach.

2. A new (and simple) approach to project control under uncertainty.

In the new approach, we go back to the fundamentals of project simulation by Monte Carlo methodology. We simulate to get the “universe” of possible projects realizations, and we group the information in terms of percentage of project completion.

Our aim is to know, whether the deviations (cost and durations) from planned values during project runtime are within the “planned” variability deducted from the variability of project activities. Assuming a particular statistical distribution function for the cost and duration of activities, we can compute the statistical functions of project duration and cost at the end of the project by means of Monte Carlo simulation (see figure 2). Although it could be evident, it can be useful for future explanations to realize that the output of the j-th simulation is a project finishing at time t_j and with a total cost of C_j, and it can be represented by a dot at figure 2, within the cost-time graph. If we consider thousands of project simulations, we get an “area” of possible project cost and duration, so that the statistical distributions can be computed, one for costs (the vertical distribution at the right side of figure 2) and durations (the horizontal one at the top). Once the distributions have been computed, it is possible to calculate confidence intervals and percentiles for cost (for example P_c90, P_c70, etc.) and duration (P_d90, P_d70, etc), and also mean values (d_{mean}, C_{mean}), etc., and any other statistical features, like the rectangular areas for a set of particular percentiles. For instance, in figure 2, we have represented a rectangle with the percentiles P_d90,P_d10, P_c90, P_c10 (bold rectangle) and P_d70,P_d30, P_c70, P_c30 (dot line rectangle) inside.

Insert figure 2 around here

In the same way we proceed for the end of the project, now we wonder about the resulting “area” of dots in figure 2 drawn when the projects are, for instance, at one half of its realization. This means that, for the j-th simulation, we need to compute the time when the project cost spent reached $0.5*C_j$.

In general, we define a triad (x, T_{xj}, C_{xj}), where x is the percentage of completion (measured in terms of cost), $C_{xj} = x*C_j$ is the money spent when the project has been completed x % (within simulation j); T_{xj} is the time when the cost C_{xj} was achieved and C_j is the total project cost in the j-th simulation. This definition of percentage completed is consistent with EVM methodology. It assumes that the cumulative planned cost of the performed tasks is an indicator of the development of the work. Since $EV = \sum_{Start}^{Current} PV(Completed)$, then the percentage can be measured as EV/BAC, where BAC refers to budget at completion. Given this approach, in each particular simulated instance of the project we can compute the planned total cost of the project and track the percentage of the project back forward measuring the cost of the tasks that have been completed at any intermediate instant of the simulation. For every x, we will obtain the “area” of dots representing the projects been at x % of realization and, therefore, we can compute the statistical distributions for cost and duration at x % of project completion, and the corresponding percentiles $P_{xc}90$, $P_{xc}70$, …., $P_{xd}90$, $P_{xd}70$, etc. (distributions and rectangle at the down-left side of figure 2). The particular case of x=1 represents the situation at the end of the project.

If we assume that some of the risks of the project come as consequence of uncertainty it is then important to figure out if the performance of the project is compatible with the random nature of the project or if on the contrary, divergences may be explained by means of the occurrence of unexpected events or the instability of the assumptions of the project planning stage. The methodology considers that the stochastic nature of the project can be modeled as probabilistic distributions of task duration and cost. The case studies used to illustrate the approach in this paper consider that task durations follow different distributions, and costs are function of duration, but the technique can be generalized for any dependent or independent random relations between cost and duration as long as time-accumulated cost trajectories can be simulated. Under these assumptions the approach allows us estimate intermediate cost and duration distributions of the project, and this fact is the basis to understand the control approach. We want to know how the performance of the project is when we take into account the "random expected variability of the project" into the monitoring process of the project through EVM methodology. If the project is within the limits and confidence intervals of the project we assume that the variances can be explained by normal stochastic variability, but if the project is out of these limits the project manager has objective reasons for considering that something out of planning may be happening. The appropriate limits to send warning signals and to apply corrective measures depend on the specific context of the project, for instance, strict deadlines and due dates may need smaller control buffers.

2.1. Projections into cost and time figures.

In order to make the methodology easy to use and coherent with the classical EVM, we split the representation of the triad (x, T_{xj}, C_{xj}) into a couple of graphs, one for time and other for cost. We can see the projection in figure 3. Figure 3a is the same than figure 2, emphasizing different rectangles representing different percentiles for several x.

In figure 3.c we represent the time projection. For a particular x, we compute the time corresponding with different percentiles $P_d D$, $D \in [0,100]$ (in the particular case of the figure 3.c we show the results for $P_d 90$, $P_d 70$, $P_d 30$, $P_d 10$). Then we join all the points for a particular percentile D, $P_d D$, for all $x \in [0,1]$, obtaining the curves in figure 3.c.

In figure 3.b. we represent the cost projection. In this case, cost is represented in the y-axis and percentage (x) in the x-axis. For every x, we compute the cost corresponding to different cost percentiles $P_c C$, $C \in [0,100]$ and then we join the points for a particular percentile $P_c C$ for all $x \in [0,1]$. As cost is proportional to percentage completed, now we obtain straight lines.

Insert figure 3 around here.

We should keep in mind that figures 3 are built up during the project planning phase. The inputs to build the figures are only the cost and duration distribution functions of the activities and its precedence relations, that is, the common information needed for project scheduling and budgeting in uncertain environments; no more.

In figure 4, we show a flow-chart that sketches and summarizes the methodology. For scheduling the project, we can use any of the typical methodologies as CPM or PERT. The cost of activities is usually related to duration, depending on direct and indirect costs relations. By means of Monte Carlo simulation we generate stochastically compatible instances of the project, being each instance a possible realization with its duration and cost. Once the process has been repeated for a large number of instances (n) we can compute the average cost and duration, variances and percentiles for each percentage x of work performed in the project.

Insert figure 4 around here.

2.2. Using the new framework during project runtime.

We first need to represent the Planned Value (Cost Baseline) in the graphical framework. The Planned Value (PV) can be represented directly in the cost-time plane (see figure 5a). To this aim, we project PV into the cost-x plane (figure 5b) and into the x-time plane (figure 5c). At any particular time t, the planned value is PV_t, and therefore $x_t=PV_t/BAC$, being BAC the budget at completion (total project budget or planned value at the end of the project). Therefore, we can represent the points (x_t, PV_t) in figure 5b and (t, x_t) in figure 5c.

Insert figure 5 around here.

During project runtime, we have to compute AC and EV as it is commonly done in EVM. For t=AT (Actual Time), the Actual Cost is AC_{AT} and $x_{AT}=EV_{AT}/BAC$. Therefore, we can draw the point (x_{AT}, AC_{AT}) in figure 5b and (AT, x_{AC}) in figure 5c. The definition of x_{AT} as the earned value divided by the budget at completion is at the very core of the assumptions of the Earned Value methodology and has been previously used in literature (Vanhoucke, 2011). Since EV represents the budgeted cost for work performed and BAC is the final budgeted cost for work scheduled, EV/BAC measures the percentage of completed project normalized by the budgeted cost. Moreover, this definition is equivalent to the approach adopted to compute the advance of the project when we define the concept triads in the simulation part of the method, and consequently both quantities are comparable.

The black line in figures 5 represents the AC curve (performance), and the pink one is the evolution of PV, as it is usually represented in EVM. Differences in time from planned values are expressed in time units, as it happens when we use Earned Schedule (ES).

At AT= 15, AC=10240 and x=75%. The project has over-costs, as the cost is higher that the PV projection at this time (figure 5b). But the project remains between the percentiles P_c90 and P_c70 (red and orange lines respectively), This means that, taking into account the assumed variability of the activity costs and durations, if we take a confidence interval of 90%, the project is under budget (remains under the 90 % of confidence value). But if we narrow the confidence interval to 70% (orange line), the project is over-budget, the Actual Cost of the project at this time is higher than the 70% of the simulated projects. If the project manager decides to establish a 70% confidence level, he/she should wonder whether any important change has taken place with respect to the planned conditions.

In figure 5c, we see that the Project is delayed at AT=15 with respect to the planned value (PV around 5 in this case). But the project remains in ahead of schedule whenever we consider a 90 % confidence level. In other words, with the assumed variability of the activities, the project will remain at the left side of the red line in the 90 % of the times. However, the project is outside the confidence interval of 70 %. The project manager should decide what level of confidence to use, according to how narrow the control he/she wants to be.

Finally, we suggest a change of coordinates for those project managers who prefer to work with schedule and cost variances instead of absolute values. To this aim, we use the PV line as x-axis and we represent the deviations from PV line. We use the notation XCV P and XSV P to name the percentiles P's in terms of cost and schedule variance respectively (see figure 6). During project runtime, the traditional EVM cost variance can be directly represented in figure 6a, whereas the earned schedule variance (SV(t)) is represented in figure 6b.

Insert figure 6a around here.

Insert figure 6b around here.

3. Case Studies

In this paper, we show the results of three case studies[1]. In these cases, we have drawn two PV's: the PV we get when we use PERT as scheduling method (we call it PV_{PERT}) and PV_{MEAN}, that is, the planned value we get by computing the mean value of all the simulations for a particular project progress x. It is important to notice that the methodology is general for any PV curve considered by the project manager. We illustrate the cases using PV_{PERT} and PV_{MEAN} because they are two usual scheduling techniques, but any other PV curve considered could be used as project benchmark.

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[1] Case studies 2 and 3 have been chosen from project network literature, so that we can show and compare our results with networks previously used by other authors. We have looked for heterogeneity in the case studies in terms of probability distributions and network complexity. Both cases are inspired by Lambrechts et al. (2008) since the network topology highlights the role of parallel paths (3 paths in this case). In case study 2, we use normal distributions whereas in case study 3 we work with Beta distributions. In the first case study the use of exponential distributions is inspired by Mummolo (1997) and Pontrandolfo (2000), which underlies the effect of high uncertainty.

3.1. Case study 1. Exponential distributions.

In figure 7, we show the Activity of Node network for case study 1. Based on previous research conducted by Mummolo (1997) and Pontrandolfo (2000), in this network activity durations are modeled as exponential instead of normal distributions as the next case. The rationale behind this assumption rests on the high level of uncertainty of this type of distribution which highlights the difference in project forecasting with respect to PERT approach. Hazir & Shtub (2011) also use exponential distributions to show how format information presentation affects project control. Specific parameters used to model this case are described in Table 1. In figure 8, we represent graphically our results over 100.000 simulations. PV_{MEAN} and PV_{PERT} lines have been also represented.

Insert figure 7 around here.

Insert Table 1 around here.

According to PERT methodology, the total project expected duration should be 11 time units. However using Monte Carlo simulation, we find that the probability of the project to finish before this date is just only about 22.25%. In other words, PERT scheduling is usually too optimistic (from the statistical point of view). This result was early highlighted by Klingel (1966), MacCrimmon & Ryavec (1964) and Schonberger (1981), but in our framework, this issue becomes evident when representing the results of common project networks. This happens because PERT assumes that the expected value of the maximum of the durations of two parallel activities equals the maximum of the expected valued of the durations; and this is not true.

Insert figure 8 around here.

According to figure 8, with the 75% of the work performed, the project has a delay of almost 10 time units if PERT plan is used as reference. The project is delayed almost 5 time units with respect to the percentile P_d70 line but is ahead of schedule in relation to percentile P_d90.

The project has an over-cost of 3000 monetary units with respect to the cost baseline deducted from the PERT schedule, and an over-cost of 5000 units with respect to the percentile P_c30 in costs, but it is almost 1500 units under budget if we compare it with percentile P_c90 in costs.

3.2. Case study 2. Normal distributions.

Case study AON network is represented in figure 9. This network has been used previously by Lambrechts et al. (2008) for project scheduling research. This graph contains three parallel paths. Duration and cost of these activities are described in Table 2.

Insert figure 9 around here.

Insert Table 2 around here.

Insert figure 10 around here.

Again, it is straightforward to check that the conventional PERT schedule is very optimistic, 13 time units, while the probability of finishing before that date is just about 18.78% if we compute it using simulation. When the 75 % of the project has been performed, the project is delayed 0.62 time units with respect the PV_{PERT} curve, but it is 0.81 time units ahead of schedule when we compare with the 90 % confidence line (figure 10). The project has an over-cost of 790 monetary units when we compare with the planned costs derived from PERT scheduling, but it is 1600 monetary units under the 90 % cost confidence line.

Changing the reference coordinates, in figures 11a and 11b, we represent the X variances.

Insert figure 11a around here.

Insert figure 11b around here.

In these time and cost graphs, we represent the evolution of the project executed, compared with respect to the planned value curve. In each period of control and given a project status, we can observe the absolute delay in terms of both cost and time. In this particular example the evolution of the project seems stable between the curves corresponding to percentiles 70 and 90 of probability.

3.3. Case study 3. Beta distributions.

The AON network is the same that in case 2, the one used previously by Lambrechts et al. (2008) for project scheduling research. The activities of the network have been modeled according to a Beta distribution function, as reflected in table 3

Insert Table 3 around here.

Insert figure 12 around here.

Again, it is straightforward to check that the conventional PERT schedule is very optimistic, 13 time units, while the probability of finishing before that date is only just about 5.74% if we compute it using simulation. When approximately the 75 % of the project has been performed, the project is delayed 0.28 time units with respect the PVPERT curve, but it is 1.86 time units ahead of schedule when we compare with the 90 % confidence line (figure 12). The project has an over-cost of 2043 monetary units when we compare with the planned costs derived from PERT scheduling, but it is 2385 monetary units under the 90 % cost confidence line.

4. Conclusions.

In this paper, we suggest a new methodology for controlling projects under uncertainty. We integrate EVM methodology with all the literature concerning activity and project variability. EVM was developed under certainty assumptions, therefore project managers know whether the project is delayed or ahead of schedule, has over or under costs, depending on comparisons with planned values. But when we introduce variability within the analysis, we are more interesting in knowing how far the deviations from planned value are (from the statistical point of view). This way, project managers will know whether the deviations from planned values are or not in agreement with the deviations assumed from activities variability and, therefore, take early corrective actions.

In order to implement the methodology, we do not need more information than the data needed for using EVM, the probability distribution functions of the activities (as needed by most of the scheduling methodologies like PERT), and basic knowledge about Monte Carlo simulation.

The graphical framework underlies the optimistic schedules and cost baselines obtained when using the PERT methodologies. Do not worry if your project is delayed according to PERT scheduling. From the statistical point of view, in most of the cases the probability of achieving the PERT time is under 30 %.

Although it is a new and innovative methodology, we only go back to the fundamentals of project simulations, as we generate the “universe” of all possible projects, and we only reorganize and gather the simulated data in a language coherent with Earned Value Methodology.

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Tables

Table 1.

Duration and cost of activities of case study 1. Duration of activities is modeled as exponential distributions. Variable cost depends on duration.

Id. Activity	Duration (Mean Time) $1/\lambda_i$	Rate λ_i	Variance $(1/\lambda_i)^2$	Variable Cost	Fixed Cost
A1	5	0,20	25,00	380	50
A2	1	1,00	1,02	430	40
A3	3	0,33	9,09	370	40
A4	4	0,25	16,11	450	70
A5	2	0,50	4,03	350	50
A6	3	0,33	9,07	300	40
A7	8	0,13	64,38	280	30
A8	3	0,33	8,96	320	30

Table 2.

Case study 2. Duration activities are modeled as normal distributions. Variable cost depends on duration.

Id. Activity	Duration	Variance	Variable Cost	Fixed Cost
A1	2	0,15	555	200
A2	4	0,83	1300	450
A3	7	1,35	48	45
A4	3	0,56	880	36
A5	6	1,72	14	20
A6	4	0,28	1210	40
A7	8	2,82	725	150
A8	2	0,14	100	150

Table 3.

Case study 3. Duration activities are modeled as Beta distributions. Variable cost depends on duration.

Id. Activity	Minimum	Likeliest	Maximum	Variable Cost	Fixed Cost
A1	1,42	2	3,74	555	200
A2	2,63	4	8,12	1300	450
A3	5,25	7	12,25	48	45
A4	1,88	3	6,37	880	36
A5	4,03	6	11,92	14	20
A6	3,19	4	6,42	1210	40
A7	5,46	8	15,61	725	150
A8	1,44	2	3,68	100	150

Figures.

Figure 1.

EVM main variables and variance

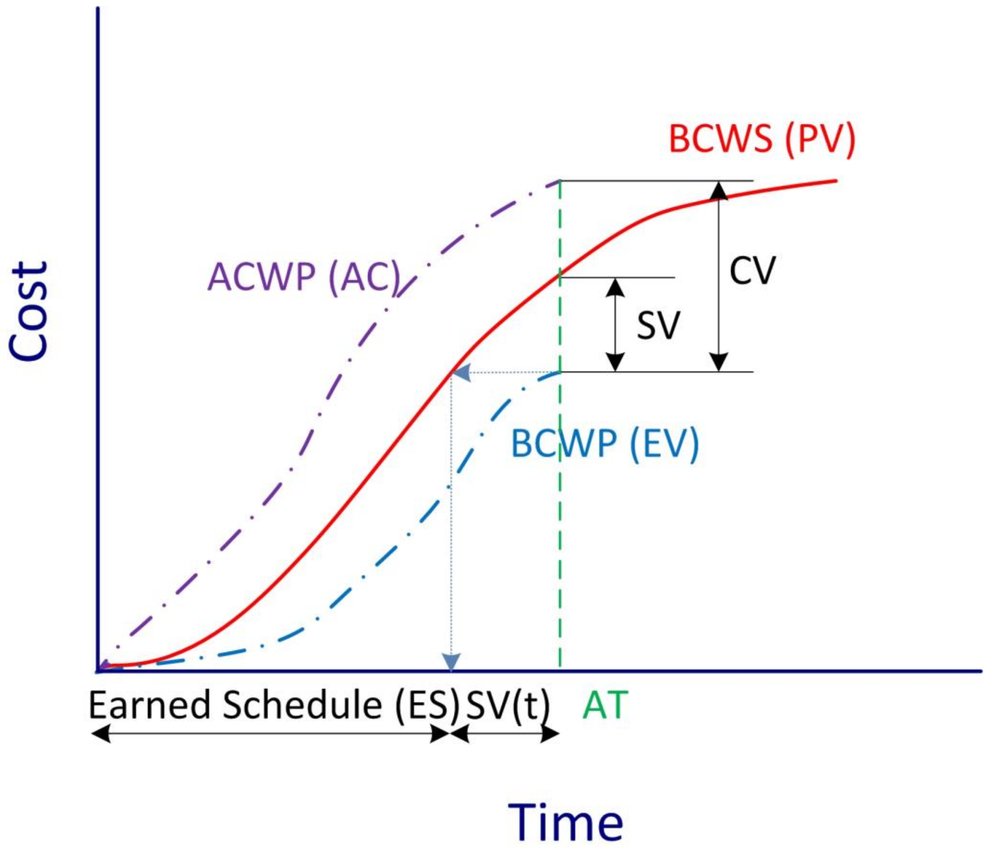


Figure 2.

Statistical features of project variability (cost and time) at the end of the project and at x percentage of compaction.

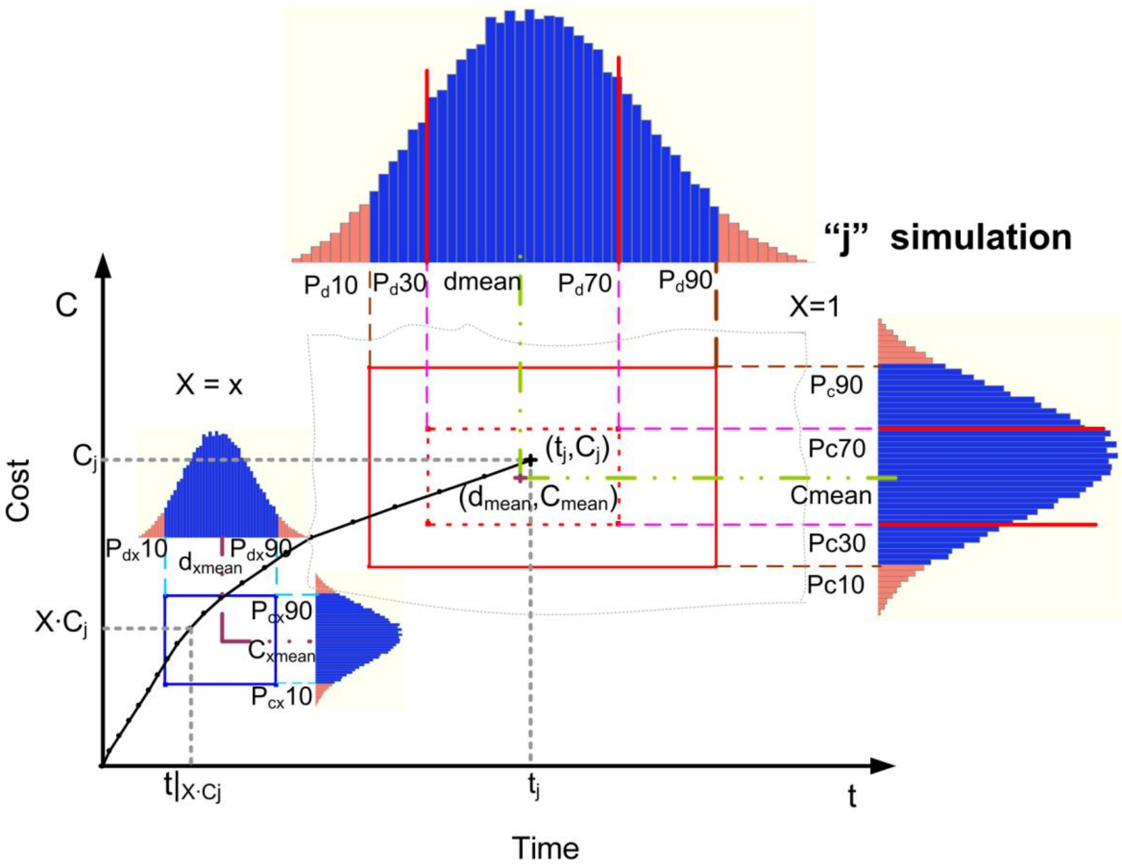


Figure 3.

Graphical representation: triad and projections (time and cost)

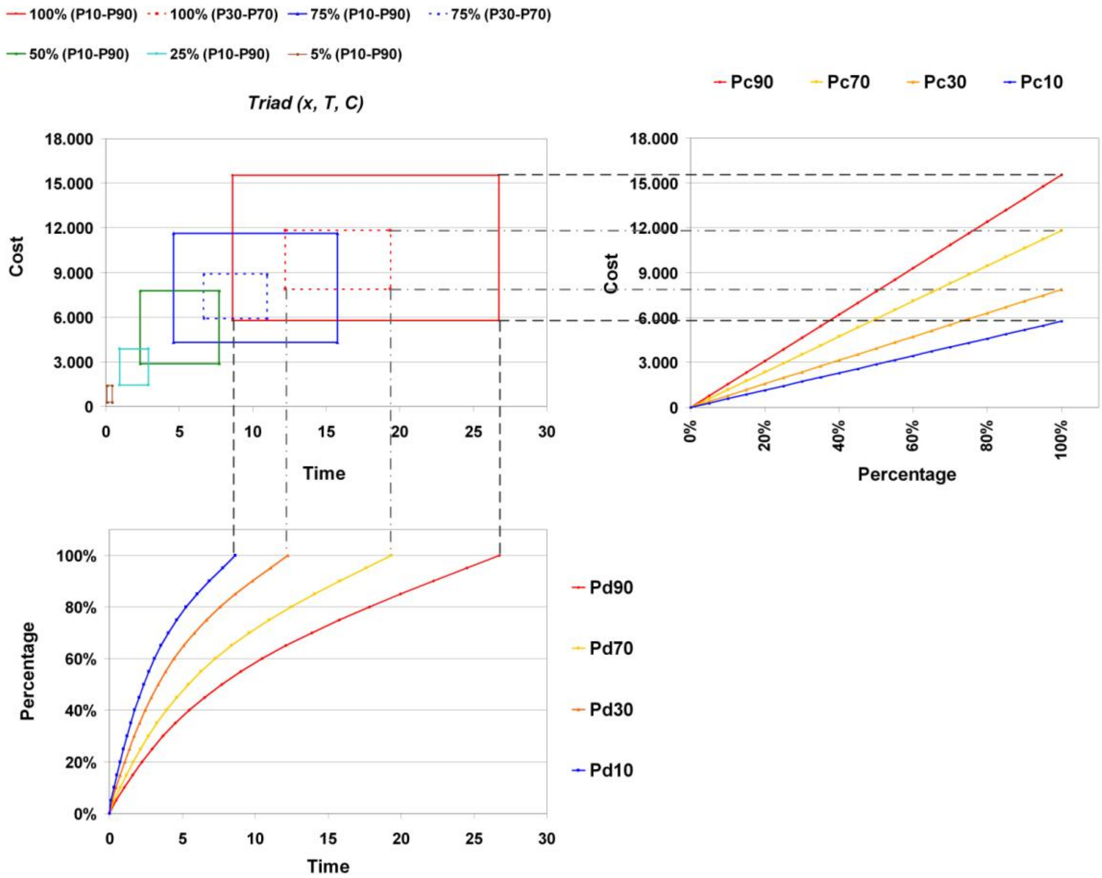


Figure 4.

Flow-chart of the methodology.

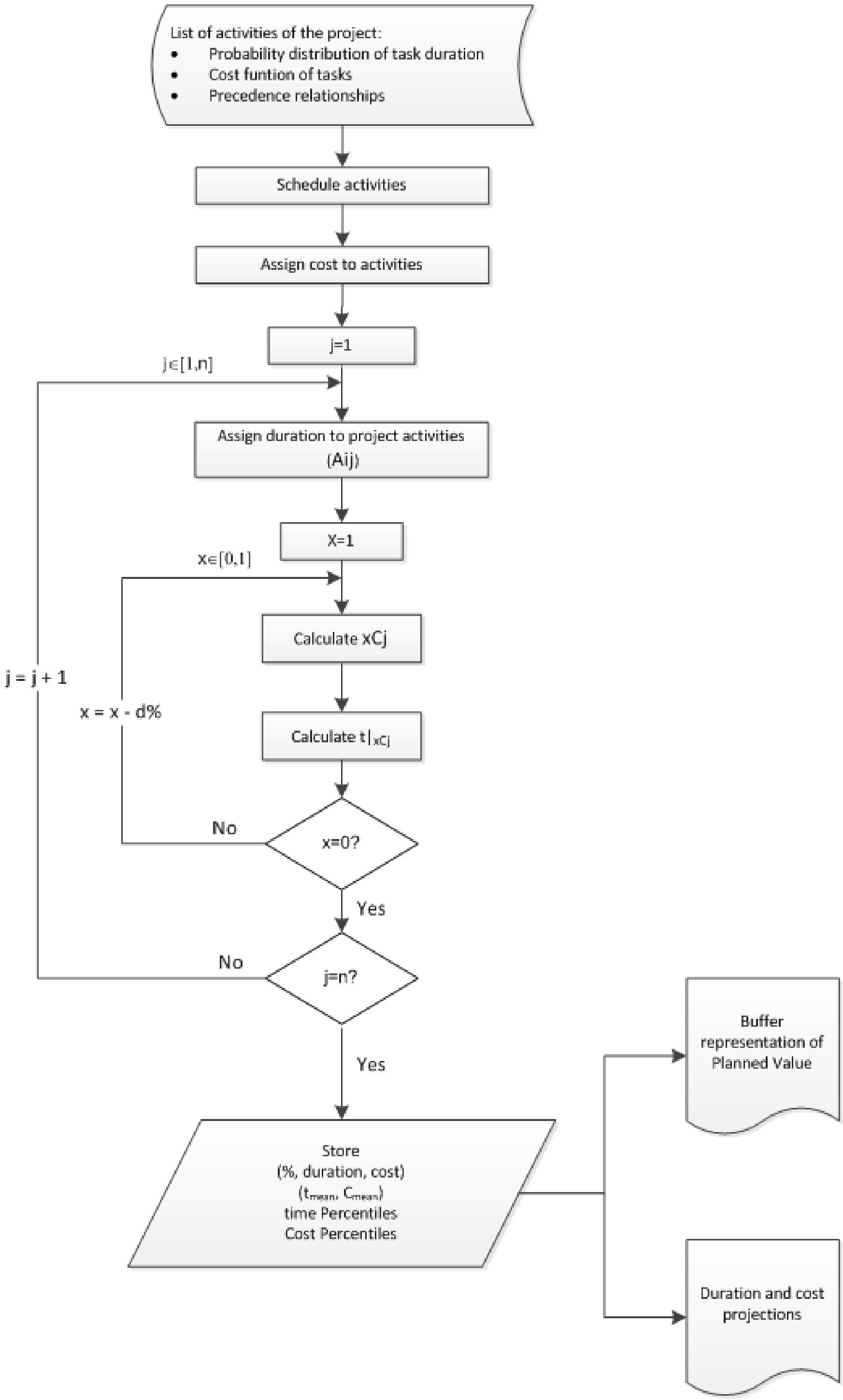


Figure 5.

Graphical Framework during run time.

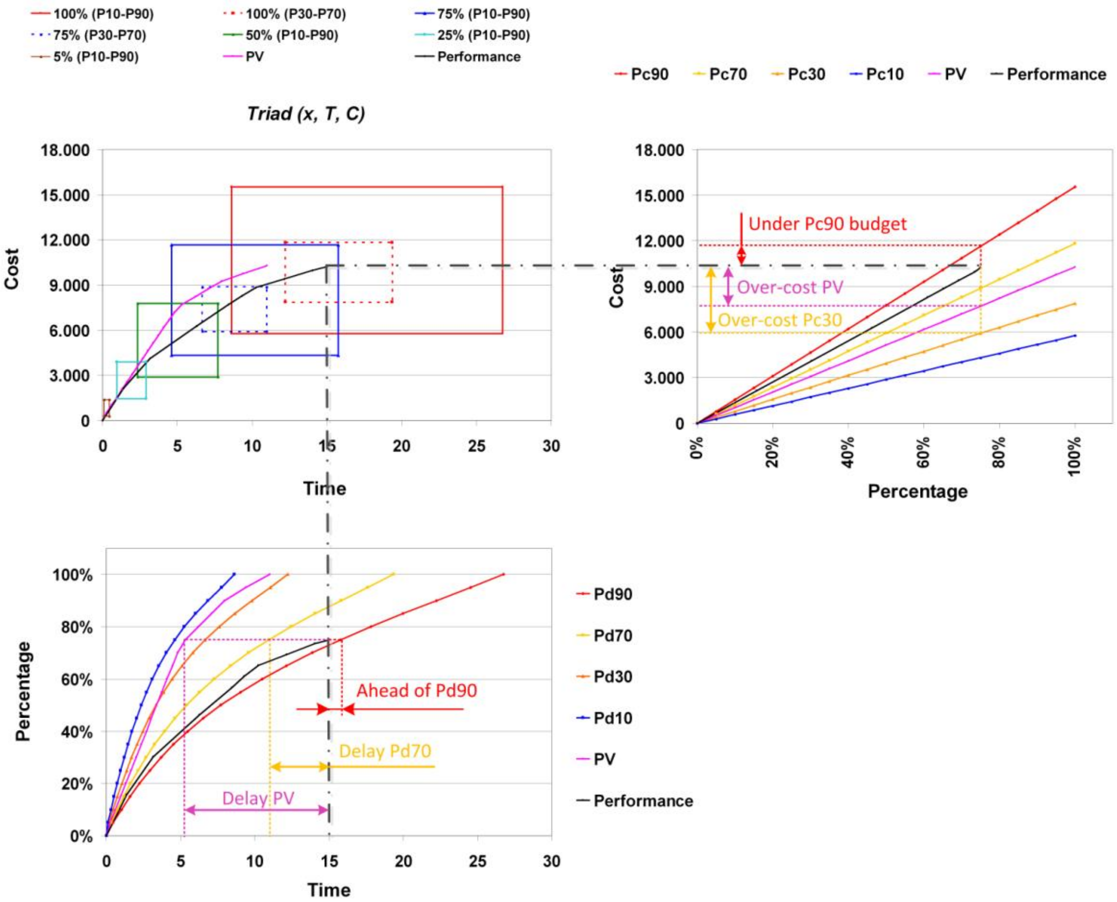


Figure 6a

XC V P. Conficence intervals for cost variance.

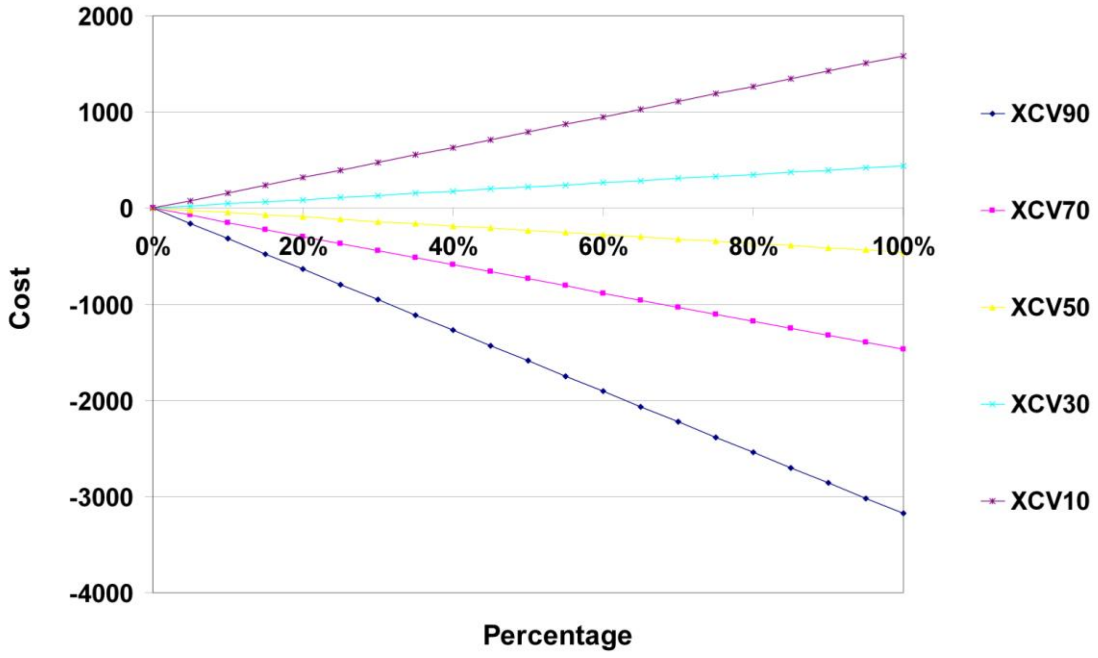


Figure 6b

XSV P. Confidence percentiles for earned schedule variance.

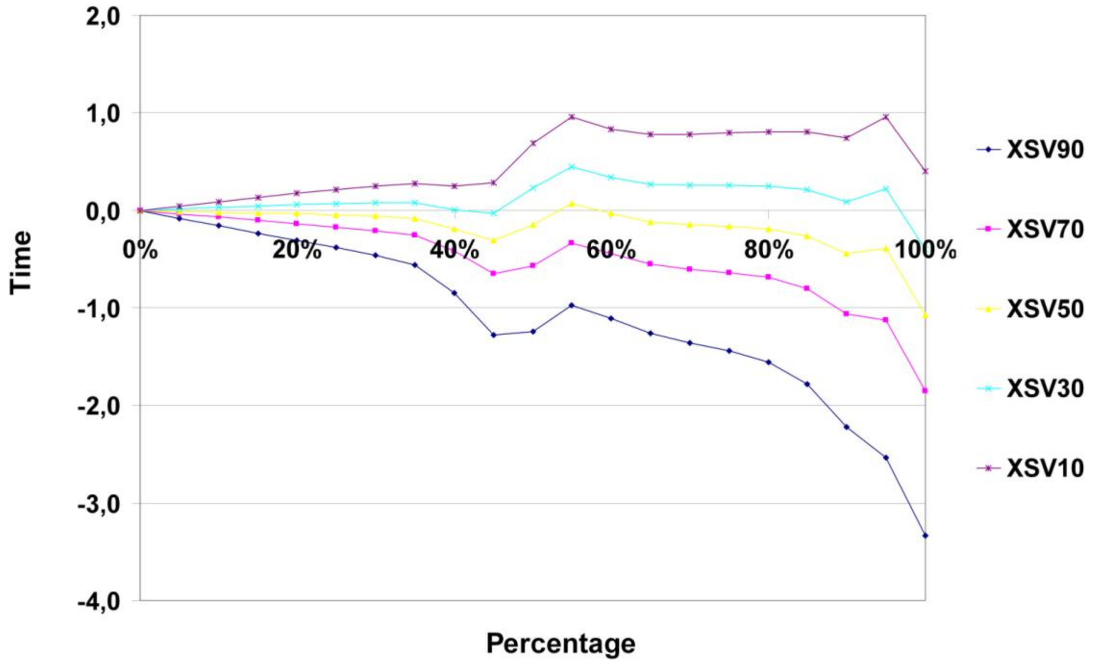


Figure 7.

AON network. Case study 1

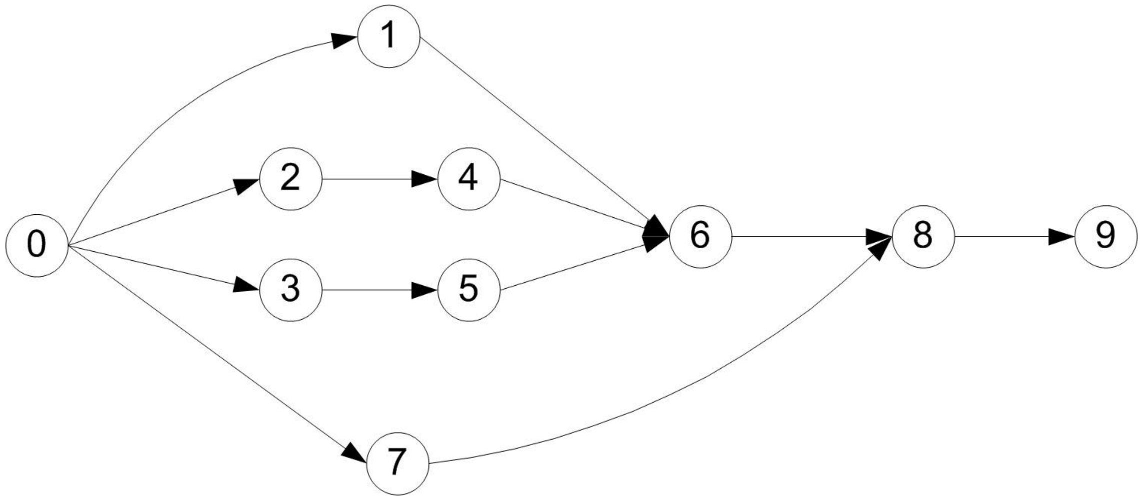


Figure 8.

Control framework for case study 1.

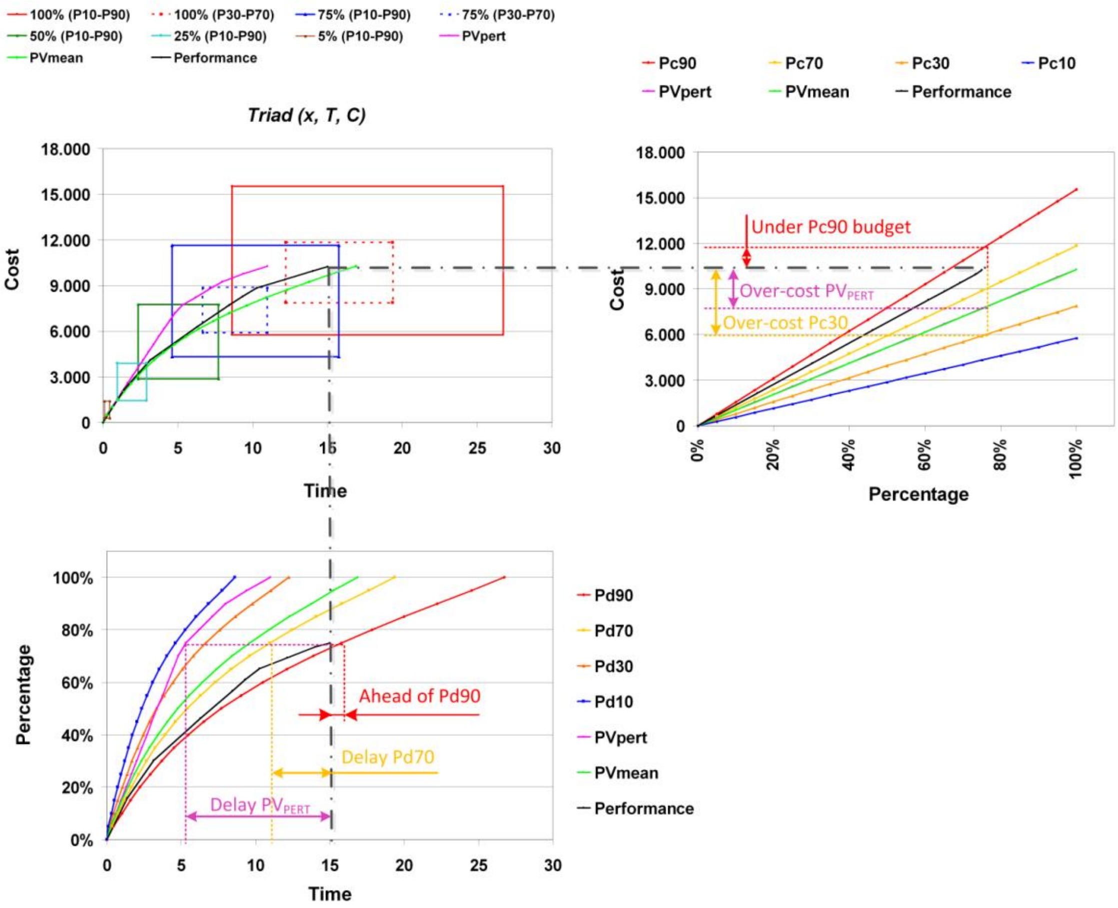


Figure 9. AON network for case study 2.

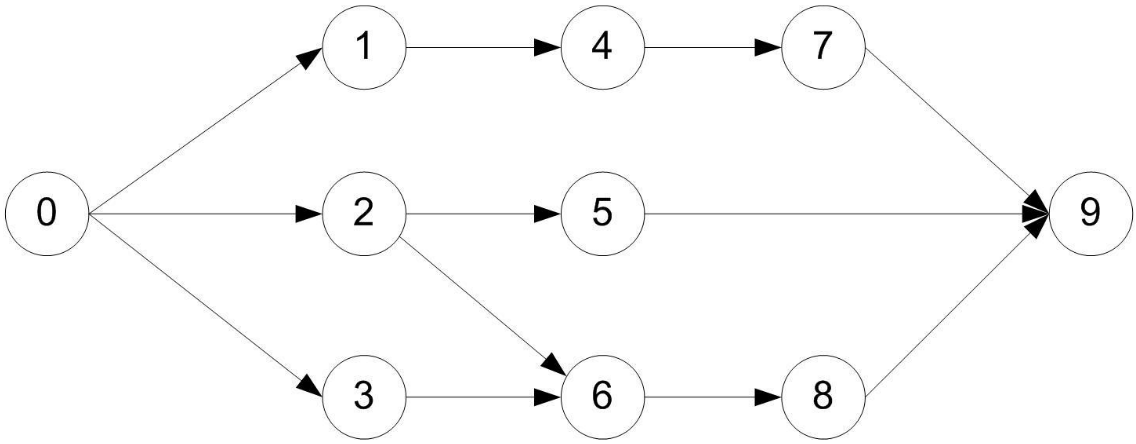


Figure 10.

Control framework for case study 2.

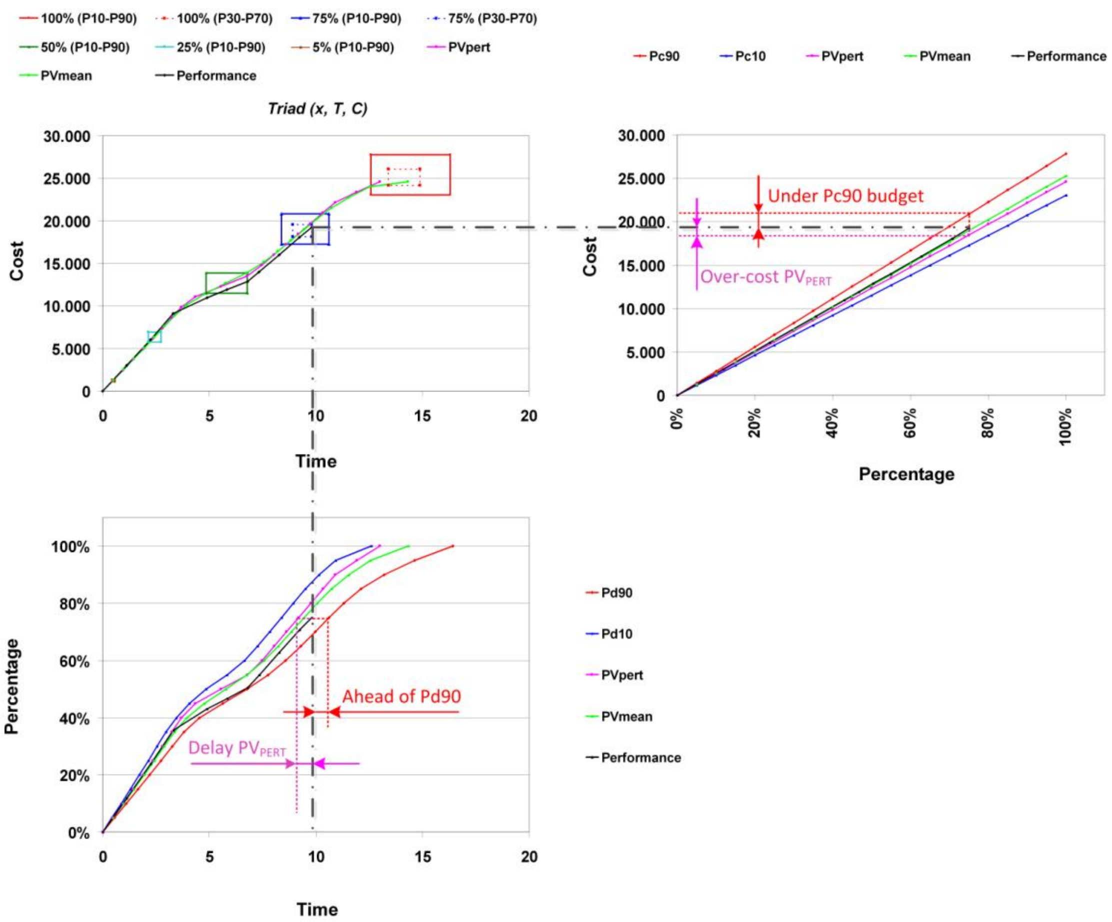


Figure 11a.

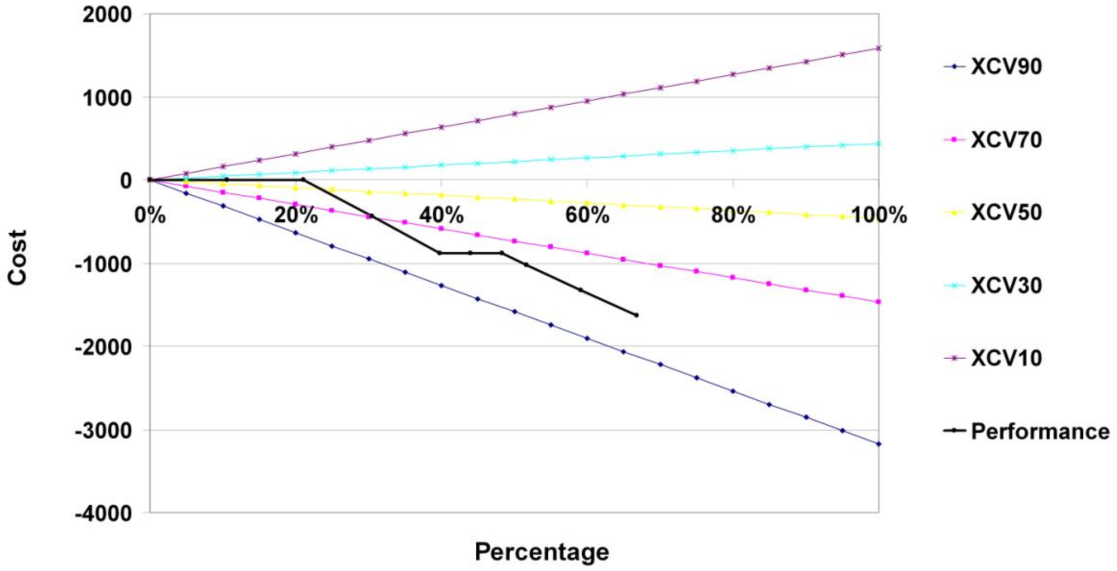


Figure 11b.

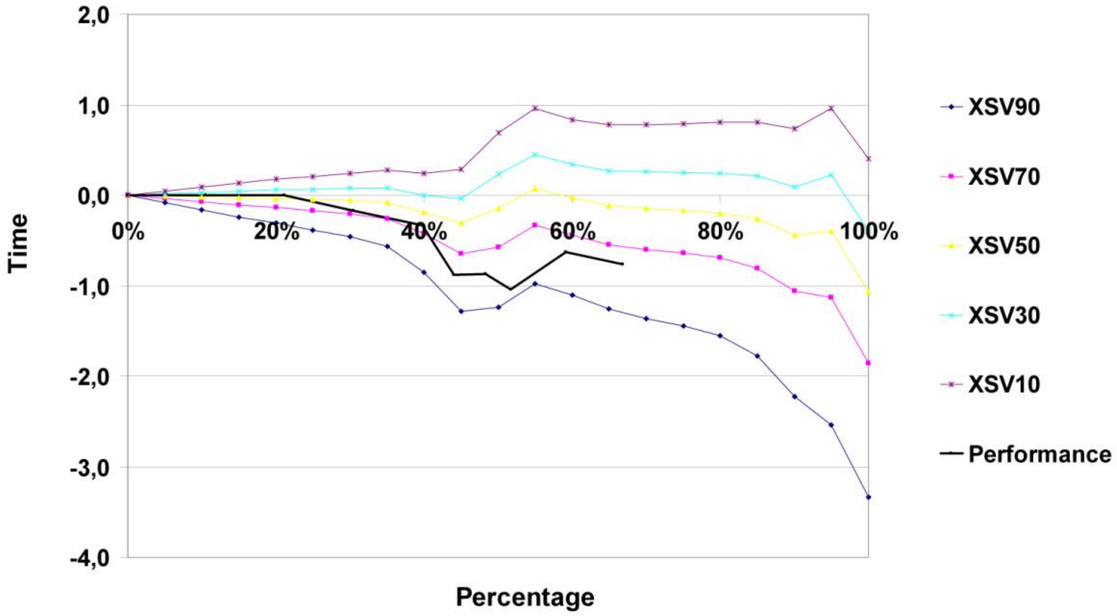
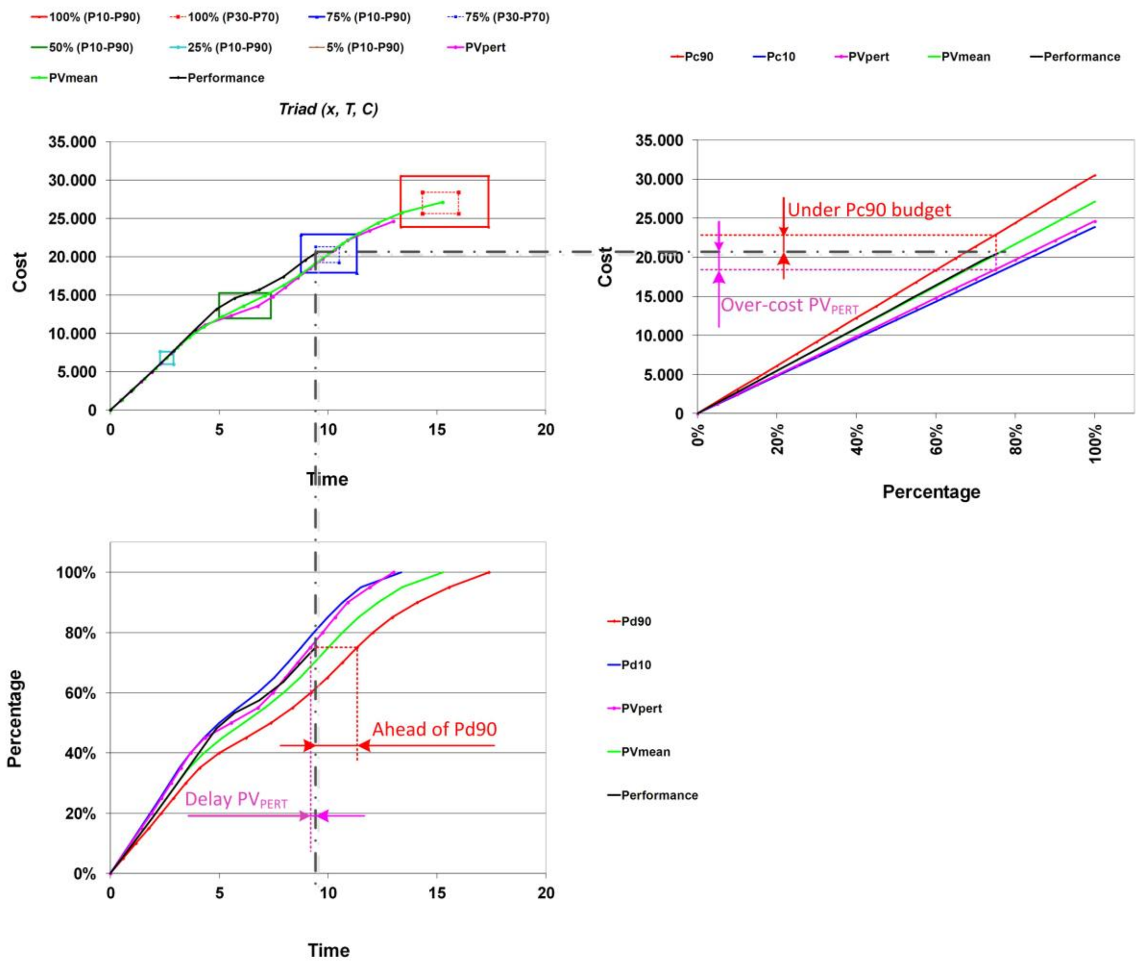


Figure 12.

Control framework for case study 3.



Highlights

- We propose a new methodology for project control under uncertainty, integrating Earned Value Management (EVM) methodology and Risk Analysis.
- The methodology helps project managers to know whether the project deviations from planned values are within the “expected” deviations derived from activity planned variability.
- We use Monte Carlo simulation to generate the “universe” of possible projects and then, we organize the information to make the data coherent with EVM.
- We show two case studies.
- The methodology makes explicit that the schedule and budget resulting from traditional methods like PERT is statistically very optimistic.