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ANALYSIS OF FORECASTING METHODS FROM THE POINT OF VIEW OF EARLY WARNING CONCEPT IN PROJECT MANAGEMENT

Review Article

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Abstract

Early warning system (EWS) based on a reliable forecasting process has become a critical component of the management of large complex industrial projects in the globalized transnational environment. The purpose of this research is to critically analyze the forecasting methods from the point of view of early warning, choosing those useful for the construction of EWS. This research addresses complementary techniques, using Bayesian Networks, which addresses both uncertainties and causality in project planning and execution, with the goal of generating early warning signals for project managers. Even though Bayesian networks have been widely used in a range of decision-support applications, their application as early warning systems for project management is still new.

INTRODUCTION

In the today's volatile economic environment, risk management retains its important position on the agenda of each organization or project. Today's big organizations and projects are still struggling with the changes to the post-recession economy, where investors are looking for a thorough risk assessment before investing. Risk management in projects has been and is still being debated vigorously, project managers realizing the importance of predictability of external factors correlated with the internal process. In this context, risk and uncertainty management is again a trend, many risk identification/evaluation tools being developed to allow management teams to identify and assess the risks that their organizations face before produce negative effects. Planning and execution of complex industrial projects inevitably involve uncertainties, vulnerabilities and risks both internally and externally. Basic inputs (time, costs, and resources planned for each activity) are not deterministic and are affected by various sources of uncertainties. Moreover, there is a causal relationship between these sources of uncertainties and the project parameters which is not modeled by the traditional project planning techniques. Early warning of risks and uncertainties should be seen as an essential component of the management of any complex large-scale project to incorporate uncertainties from the early project planning stage, despite the different approaches, methods and tools available. Most current techniques for addressing risk and uncertainty in project planning and execution (simulation techniques) are often event-oriented and attempt to model the impact of possible threats to project performance. They ignore the causal relationship between sources of uncertainty and project parameter and, consequently, advanced techniques are needed to capture different aspects of uncertainties in projects. EWS new approach that makes it possible to include risk, uncertainties and causality in the planning and execution of projects by:

- identification of different sources of uncertainty and their use for informing the project staff from the planning stage;
- exposing the uncertainties about the completion time for each activity and for the whole project with full probability distributions;
- using the analysis "What if?" to identify the level of resources needed, taking into account constraints such as, for example, a certain completion time;
- awareness of the veracity of data so that forecasts become more relevant and accurate.

UNCERTAINTIES AND RISKS IN PROJECT MANAGEMENT

When a decision is taken under risk conditions, it involves knowing the assumed risk, ie knowledge of the likelihood of occurrence of the risk. In the case of a decision taken under uncertainty, risks are not known, although they are assumed. For example, an individual who goes to work on the morning is looking out the window and sees it is cloudy but not raining, which makes him take his umbrella considering it may be raining during the day. This is a decision under uncertain conditions. If he watched the weather, he could see that there was an 80% chance of it raining that day, which would have made him surely take his umbrella, in which case he would have taken a risk-taking decision. In the example above, it can be noticed that the decision under uncertainty conditions is based more on intuition than on substantiated information, so we can say that if the probability of occurrence of an event is known it is possible to make more correct judgments under risk conditions than under conditions of uncertainty.

The possibility of something undesirable happens is referred to as "risk" (Rowe, 1977). Typically, critical words in a sentence describing the nature of the risks are "possibility" and "unwanted". In the literature, several parallel definitions of risk coexist. Rescher, (1983) defined risk as an uncertain situation with possible negative outcomes. Williams et al., 1998, said that risk can generally be defined as a collection of pairs between probabilities (L) and results (O):

Risk = {(L1O1), (L2O2), (L3O3),.... (LnOn)}

The pattern of pairs distribution formed by probabilities and outcomes is called a risk profile (Avyub, 2003). Risk definitions must also have a time dimension or a certain time horizon, as well as a specific perspective or view that defines the unit of analysis (eg limits, etc.). International Organization for Standardization (ISO 2002) defines two of the essential components of risk: the losses and the uncertainty of their occurrence (the probability of a risky event).

PMBOK 2004 sees risk management as a key area: "... as those processes involved in identifying, analyzing and responding to project riskS, including maximizing positive event outcomes and minimizing the consequences of adverse events." Ward and Chapman (2003) argue that the central element of risks management has a narrow focus on managing uncertainties in projects, which they believe is due to the fact that the term "risk" has become associated with "events", rather than general sources of significant uncertainties. The most obvious area of uncertainty is in estimating the duration for a particular activity. The difficulty in this estimate comes from a lack of knowledge of

what is involved, rather than the uncertain consequences of potential threats or opportunities.
From, both, specialized literature and management practice on risk management, this research synthesizes "roots" of uncertainties as well as the most important internal or external factors that could have a major impact on the performance of large complex industrial projects:
"Roots" of uncertainty could be represented by the one or more of the following:

- the level of resources needed and available;
- compromise between resources and time;
- possible occurrence of uncertain events;
- causality factors and interdependencies, including common occasional factors affecting multiple activities (such as organizational problems);
- lack of experience and use of subjective data than objective ones;
- incomplete or inaccurate data, or total data loss.

External risk factors and internal factors could affect the results of large complex industrial projects:

- External risks
  - Interruption/lack of critical infrastructures (physical and virtual) - the backbone of any complex project;
  - High competition/complementary projects;
  - Exchange rate risk;
  - The sudden change in the price of raw materials;
  - Interruptions of the supply chains;
  - Regulatory risks (national and/or regional);
  - Local and/or regional economic instability;
  - Access to credit.
- Internal factors
  - Complexity and size of the project;
  - Time pressure in project execution;
  - Volume of workload;
  - Productivity variation;
  - The level of dependence on key people;
  - Lack of key technologies;
  - Degree of maturity of technological development;
  - Level of communication in the project team;
  - Level of change control;
  - Rate of defects.

As Ward and Chapman (2003) have argued, management of project uncertainties should not only be reduced to managing perceived threats, but also to their opportunities and implications. Appropriate management of uncertainties should include: identifying different sources of uncertainty, understanding its origins and then managing it with desired or unwanted implications. To capture uncertainties in projects, it needs to go beyond the variability and availability of data. It has to address ambiguities and incorporate structures and knowledge "(Chapman and Wards, 2000). In order to properly measure and analyze uncertainties, relationships between the trigger (source), risks and their impact (consequences) must be shaped.

EVALUATION CRITERIA FOR FORECASTING METHODS IN PROJECT MANAGEMENT FROM THE POINT OF VIEW OF GENERATING EARLY WARNING SIGNALS

In project management, various forecasting methods are used to provide confidence estimates of success in achieving the final goals. Each project is unique in its objectives, in its plan to achieve its objectives and in the actual progress guided by the established plan. By default, the performance of the forecasting methods varies from one project to another depending on the project's specific situations. Even with the same information available, some projects may be more difficult to predict for some methods than others because of the individual features of each project. Therefore, it was the challenge of this research, namely to evaluate the performance of the different methods and compare them objectively.
Therefore, setting evaluation criteria is a crucial first step in evaluating and comparing forecasting methods. Correct understanding of the criteria is essential for the correct interpretation of the results. In a traditional project control system, the forecasts are evaluated and compared to whether the deviation from the planned performance is significant or not. In the view of this research, the performance of predictive methods through early warning has to be measured in terms of:

- accuracy;
- timeliness;
- reliability.

An ideal case would be one in which the three above criteria are maximized simultaneously. However, in most situations, compromises between these factors are required to be in line with the management strategy or project priorities. The main purpose of the assessment framework is to analyze different forecasting methods with regard to prediction accuracy, alertness, and the reliability of the warnings they generate. The novelty, confidence and reliability of a method should be evaluated on the basis of early warning warnings instead of the average of precision over a period of time.
In the predictive literature, precision is known as the most commonly used criterion, both among practitioners and researchers (Carbone and Armstrong 1982). Vanhoucke and Vandevoorde (2006) state that "the accuracy of forecasts based on statistical error measures should not be confused

with the early warning capability of forecasting methods."

The current alert signals have also been recognized as a desirable feature of project performance forecasts (Teicholz 1993) and serve as an important criterion for assessing their performance (Vanhoucke and Vandevoorde 2006). Confidence in warnings is also an important factor, especially for practitioners, which needs to be considered in the evaluation of forecasting methods. The ultimate goal of analyzing forecasting methods is to select them for different phases of the project as inputs for SHAT construction. Therefore, an early warning system based on predictive predictions becomes an essential part of pro-active project management. With an early trusted warning system, project teams may be able to decide when further attention is needed to detect some early symptoms or indicators of future problems.

EVALUATING THE PERFORMANCE OF FORECASTING METHODS BASED ON EVALUATION CRITERIA THROUGH THE "EARLY WARNING" APPROACH

The project performance forecast is a complex task depending on the project manager's interest and abilities, the type of project, the size and complexity of the project, as well as the strategy adopted and an essential part of the decision-making process in the industrial project management process carried out in an environment characterized by volatility, uncertainties and risks.

A lot of forecasting methods are available in the literature, but they are often avoided because they do not contain appropriate tools and reliable data, but also a high difficulty in addressing uncertainties and risks in the external environment of projects. The limitations of deterministic forecasting approaches have been repeatedly addressed over the last decades (Ang and Tang 1975, Barraza et al., 2004, Hertz 1979, Spooner 1974) and will be set out in the final section of this research.

Criteria for classifying forecasting methods: In the literature there are many classifications, according to different criteria, as follows: For example, Makridakis et. al. have classified the forecasting methods into four broad groups:

- Subjective approaches;
- Causality or explanatory methods;
- Extrapolated methods (time series);
- Any combination of the three.

On the other hand, Al - Tabtabai and Diekmann, 1992, classified prognostic methods in:

- Econometric models;
- Time series models;
- Judicial models.

Having so many models encountered in the literature, the ones listed above not being the only ones, the choice of the right method was itself a challenge for this research.

Some authors, such as Georgoff and Murdick (1986), evaluated over 20 forecasting techniques and models based on 16 criteria to provide a guide to project managers for choosing the best techniques or a combination of them.

In the view of this research, the evaluation of prognosis methods and techniques, whether deterministic, statistical or probabilistic, has been a challenge. In the industrial project management community, the most commonly used practices for project performance prediction are the Earned Value Method, Critical Path Method and Monte Carlo simulation. They will be analyzed from a prism Early warning signals that they can generate for managers and project teams.

Earned Value Method

Earned Value concept has been used since the 1890s when early industrial age engineers wanted to measure the performances of US factories. They analyzed the "cost variation" correlated with "earned standards" relative to "actual spending" to determine the industrial performance of that time. In 1962 that earned value concept was formally introduced into US Navy projects as part of the PERT/Costing methodology. In 1967, EVM was promoted and adopted in the Department of Defense of the United States of America, wishing to be a valuable project management and control system that interconnects the cost, schedule and physical progress achieved by the project team. The following sections provide an overview of the basics of EVM, based on several books and articles, among which the most cited are Anbari (2003), Fleming & Koppelman (2006) and Vanhoucke (2006).

In addition to the traditional EVM methods, this section also integrates the concept of Earned Schedule (ES), because this relatively recently developed concept goes beyond certain traps and limitations of EVM, especially on the duration of the forecast. But first of all, it is considered necessary to clarify the terminology associated with the "earned value" because it is often misused and abusive.

- Earned value (EV0 analysis is a quantitative technique for evaluating project performance and predicting the project's final results based on comparing progress with planned budget and current costs;
- Earned Value Management (EVM) - integrated cost and value management is a methodology used to control a project that is based on work performance measurement with a WBS (Work Breakdown Structure) and includes an integrated program and budget on the WBS project;

- Earned Value Management System (EVMS) - represent the processes, procedures, tools and models used by an organization to apply value-added management.

One of the most important issues for a project management team is to accurately estimate the time and cost of completion. Was the primary aim of this research to analyze at the same time whether EVM can be used as an early warning tool for the performance of the internal process that might be useful for project managers to identify and manage problems before they become a risk for their execution.

For this reason a brief introduction to key parameters used by EVM, as sketched in Fig.1 :

For the implementation of EVM and ES, a clear project goal is needed, along with a budget and a project runtime. Two project performance metrics (cost and time) can be obtained during project execution so that a comparison can be made between reality and plan. Integrated cost and value management uses three key parameters:

• Planned cost (PV), previously known as the planned cost of work, is the amount that was planned to be spent in accordance with the initial plan.

• The actual cost (AC), formerly known as Actual Cost for Work Performed (ACWP), is the actual cost for all work that is executed at a given point in time.

• Cost of Work Performed (BCWP) – the value of an activity performed within a project is the cost that the estimator associated with that activity when the project budget was defined. The value obtained is equal to the BAC (Budget at completion) multiplied by the completed percentage (PC) at a given point in time (EV = PC * BAC).

Measuring project performances:

If the three key parameters are properly recorded over the life of the project, project managers may be able to calculate two types of project performance measurements. The first type of performance measurement is the difference between the current state of the project and the basic one in monetary terms, called cost variation (CV), which is used to track the project budget. A negative/positive value shows that more/less money was spent on the executed activities than what was initially planned. The Time or Schedule Variance is an indicator that gives project managers a value showing whether the project is within graphic or not. Positive or negative values mean that the project is behind (before) the set schedule. Another type of performance measurement of a project is also calculated based on the three key parameters described above. The indices are used to show how well the project is performed.

Two types of indices can be distinguished:

- the first type of index is the cost performance index (CPI), which expresses the cost-effectiveness of the executed works. An CPI of less or bigger than to 1 (one) means that the project is under or over the budget.
- the second index is the Schedule Performance Index (SPI) that shows whether the project is in the program set or not.

It is clear that clues and deviations are interdependent. Variations can give a picture of where the project is currently, while clues are used to represent the performance of a project. To sum up, deviations and clues can be calculated as follows:

- Cost Variance is a value to be constantly updated throughout the project = EV-AC;
- Cost Performance Index CPI - (Cost Performance Index) = EV/AC;
- Deviation from program-SV- (Schedule Variance) = EV –PV;
- Program performance-SPI(Schedule Performance Index) = EV/PV.

Predictions on the evolution of a project using the EVM method.

All performance metrics are designed to help project managers to monitor project progress, both, in terms of cost and schedule.

Cost forecast:

- Before the mathematical formulas are displayed, some terms must be defined: ETC - (Estimate To Complete) - estimated cost for project completion;
- EAC - (Estimated At Completion) - the total expected cost of project completion based on performance up to the current date;
- BAC (Budget At Completion) - estimated total budget estimate (including project unforeseen).

In the case of the cost forecast, the emphasis is on the estimate of the final cost of the project. EAC consists of the actual cost (AC), the cost that has been spent so far and an estimate of the cost of the remaining works (ETC). In some specialized works, the ETC is mentioned as find the Planned Labor Cost of Work Remaining (PCWR). ETC can be calculated using the following formula:

ETC = (BAC - EV)/performance factor.

There are several different formulas to calculate EAC, depending on the performance factor that is used to calculate the ETC (equation above). Generally, eight forecast formulas are commonly used and are accepted in managerial practice which are synthetized within Table 1.

EAC1 assumes an update factor that is equal to one. This means that in order to estimate the rest of the project cost, no performance measurement of the project is taken into account. The remaining cost is assumed to be equal to the planned cost for the remaining works. The most commonly used formula for predicting the costs of an ongoing project is EAC2. In this formula, the CPI is used as an update factor for estimating the remaining cost. EAC3 and EAC4, on the other hand, are used in cases where the duration has a great impact on the final cost of the project.

In the last four EAC formulas, both cost performance and planning indicators are assumed to have a significant impact on the remaining labor costs. The update factor in EAC 5 is called the Critical Report (Anbari, 2001, Lewis, 2001) of the Cost - Program Index (SPI) (Barr, 1996, Meredith and Mantel, 2000) (Christensen, 1993; Vanhoucke, 2010). It attempts to combine cost and program indicators into a single global health indicator of the project. A CR equal to 1 (one) indicates that the overall performance of the project is on the proposed target, while a value less than one indicates a lower performance than the proposed target.

CR can be calculated as follows: $CR = CPI * SPI$

A performance factor equal to CR (t) substitutes SPI with SPI (t). The last two equations EAC7 and EAC8 are derived formulas that give weight for both CPI (WT1) and SPI/SPI(t)(wt1). In this way a personalized formula can be obtained for a particular project.

Project duration forecast:

EVM has also been used for a long time to predict the final duration of projects, the oldest method being the Independent Estimation At Completion (t) - IEAC(t). This method estimates the time that has already passed (Actual Time) and the estimated duration of the work to be executed (ETC (t)). ETC (t) is referred to as the remaining runtime of Remaining Work (PDWR) and can be calculated as follows:

$$ETC(t) = (BAC - EV)/Work\ Rate$$

$$IEAC(t) = AT + ETC(t)$$

Although this traditional method has been applied for forty years, it faces certain mathematical deficiencies (Lipke, 2009). This observation induces the idea that the method does not give reliable estimates for all projects and therefore adjusted methods have been developed. Recently, three expansions of the EVM: Planned Value Method (Anbari, 2003), Earned Duration method (Jacob, 2003) and the Earned Schedule method (Lipke, 2003). Table 2 provides an overview of the formulas used in the prognosis of these three methods.

The Planning Value Method (PV) is based on the projected total time (PD), expressed in units of time, to predict the future. This factor is then adjusted to project performance. In EAC (t) PV1 the adjustment factor is the time variation (TV), which can be calculated by dividing the program variance to the planned rate (PV rate).

$$TV = SV/PVrate = SV * PD/BAC = EV - PV * PD/BAC$$

For the other two forecasting equations $CR = SPI * CPI$ are applied as a reduction factor to adjust the expected duration. The Earned Dates (ED) method introduces a new variable called Earned Time (ET), this variable being calculated by multiplying Actual Duty (AD) by the SPI index.

$$ET = AD * SPI$$

Earned Schedule (ES) - the winning program method can be seen as an EVM extension because the ES performance measures are similar to EVM. ES was introduced for the first time by LIPKE (2003) introducing performance in time units instead of costs, which is done in EVM. The method is based on two parameters: current time (AT) and earned program (ES). The ES concept is similar to EV in EVM. In practice, this is done by cumulatively designing the EV at a time point (AT) on the PV curve. By doing so, a point in time (ES) is obtained at which the current EV would actually have been achieved. This may be before or after a current point in time, depending on whether the project is behind or before the deadline. With these two parameters, the program variance (Schedule Variance - SV (t)) and the plan - performance index (SPI (t)) can be calculated at time t. These values need not be converted from units of currency into units of time. But similar to EVM, ES performance measures can be applied to make predictions about the final duration of the project.

Pro and cons - EVM

EVM has a number of advantages, but it has, of course, limitations on the possibility of generating early warning signals for project managers and their staff. Since its introduction into project management, EVM has proven to be valuable as a control tool, due to its various functions. EVM has the advantage of being universally applicable across a wide range of project types and sizes, because each project, no matter how large or complex, is represented by the three functions: the planned value (PV), earned value (EV), and actual actual cost (AC). EVM has enabled quantitative project performance indicators and future performance predictions that project managers can use to objectively manage their projects and take proactive measures. Using EVM, project managers also have the ability to analyze, understand and report the cost, schedule, and technical performance of the project in an integrated way, including members of the executive management team and other project stakeholders. The interaction of the three project management elements (goal, cost and time) that is done through EVM can provide project managers with important information about project performance and progress during their lifecycle, which can help project managers identify what to do to bring the project back to the track.

EVM provides an overview of the current status of the project and also provides insight into the future of the project. As mentioned above, EVM focuses mainly on project costs, which is why all parameters and measures are expressed in monetary units. On the one hand this has enabled EVM to be very useful in presenting and analyzing project cost performance, and on the other hand this has led to some performance-plan performance abnormalities. As Lipke mentioned, expressing plan-performance measurements in monetary units instead of time units makes it counterintuitive and difficult to compare with other program indicators over time.

From a practical point of view, project managers should be more concerned about the timeliness and reliability of the early warning signals generated by this method than the accuracy in terms of statistical errors. The ultimate goal of the forecast should be to provide project managers with early warning signals about success in achieving the project goals (goal, budget, and completion date). Therefore, alert signals should be accurate and, more importantly, should be transmitted in due time.

One problem with the program pointers is that for a project behind the program, at the completion of the SV it returns back to zero, and the SPI equals one unit. This may lead to biased conclusions regarding the final duration of the project.

The EVM method for a program's prognosis can only be used to get trusted warnings after project performance is stable. In practice, EVC EAC, EAC = BAC/CPI, are recommended to be used only for projects that are at least 20 percent achieved due to instability inherent to CPI cumulative measurements (Fleming and Koppelman 2006). On the other hand, the predictive potential of EVM's various prognosis formulas is still a controversial problem among professionals. Some EVM experts argue that ES data is not sufficient and should not be invoked to predict the final completion date for a project (Fleming and Koppelman 2006), while others are struggling to find the appropriate homologous formulas for cost forecasting in projects (Lipke 2006, Vanhoucke and Vandevoorde 2006). Therefore, it can be concluded that the winning method, which is known as the most popular project management forecasting method, provides reliable early warnings only after project performance has stabilized, but it is very difficult to know when this is achieved.

Critical Path Method (CPM)

In 1957, DuPont developed a new method for project management to meet the need to shut down a chemical plant for maintenance and then restart it under operational conditions. Since the project was extremely complex, a clear methodology had to be set up and so DuPont creates Critical Path Method. CPM is a deterministic technique that, by using a dependency network between loads and deterministic values for the given working time, calculates the longest path in the network called the "critical path." Activities are presented as nodes in the network, and events that represent the beginning or end of an activity are presented as arcs or lines between these nodes. Such a graph represents a meeting of arches and nodes in certain relationships. Process activities are represented by the arcs, while its events, meaning the significant moments of time corresponding to the transition from one activity to another, are represented by nodes.

Generally speaking a graph is mathematically defined as follows:

- Sets of X;
- Aplication $\Gamma{:}X \rightarrow P(X)$.

The relationship between the set and the application, ie the torque (X, D), is a graph and can be represented by an analogical physical model consisting of arcs and nodes, where the nodes represent the elements of the set, and the arcs the functional dependencies (Figure 2).

$$X = \{x_1,x_2,x_3,x_4\} \qquad \begin{aligned} \Gamma(x_1) &= \{ x_2, x_4\} \\ \Gamma(x_2) &= \{ x_1,x_3,x_4\} \\ \Gamma(x_3) &= \{ x_1 \} \\ \Gamma(x_4) &= \{ x_2 \} \end{aligned}$$

The following conventions are considered in the network diagram representation:

- each activity is associated with an orientated segment called the arc, defined by its ends, each activity being identified by a spring;
- each arc is associated with a value equal to the duration of the activity it represents;
- the conditioning of two activities is represented by the succession of two adjacent arcs.

By means of such graphs, it is possible to model operational or decisional managerial processes, such as transport networks. The structure of such a process can be represented by a graph as in the Figure 3.

Every graph has a start and end time between which there are many roads and the one with the longest length is called a critical road. By the way is meant a sequence of arcs, ie activities so that the termination of one coincides with the beginning of another. A road is considered complete when it leaves the initial node and reaches the final node. The length of a road is the sum of the activities that make up that road. The critical road is the full length path or the succession of activities that gives the minimum total duration of the process. The activities on this road are called critical activities. The critical path method aims to determine critical activities as well as their path, as they can disrupt the process. Failure to observe critical moments leads to the entire process being dismantled and, therefore, to failure to observe the planned final term.

The main stages in CPM project planning:

- establishing individual activities;
- establish succession of these activities;
- diagram drawing;
- estimating the completion period for each activity;
- identifying the critical path (the longest path through the drawn network);
- updating the chart as the project progresses.

Subsequent developments of the method have allowed, in addition to determining the logical links between the elements of the project and taking into account the resources needed to carry out the activities (Critical Project Chain - CCPM). Therefore, the utility of CPM in project management is that it allows prioritization and reorganization of activities to shorten the critical path originally set either by performing parallel activities in parallel or by reducing the time to perform the activities identified as essential for completion project, allocating new resources ("crashing the critical path").

Problems associated with using CPM in managerial practice

Although the CPM has proven to be effective for managing many types of projects, the process has its own issues, some of which can lead to erroneous estimates, inefficient programming, and cost overruns. The inherent shortcomings of classical CPM have been criticized since the early 1960s (Cottrell 1999, Lu and AbouRizk, 2000), because CPM has proven to be too simplistic to use in complex real projects because it fails to incorporate vulnerabilities and inevitable uncertainties. There are several issues associated with using CPM in managerial practice, among which I would highlight:

- the most important limitation of the critical path method results from the fact that CPM is an analysis process in which the only parameter analyzed is time duration;
- another significant limitation of CPM is that it is trying to develop "optimal" programs without taking into account the availability of resources. The resources are intended for the estimated duration of each task, but before developing a program, no one knows exactly when these resources are needed. Once the program is developed, some of the resources needed may not be available at the necessary times. Thus, the program of the critical road proves to be too optimistic;
- the graph is difficult to achieve, so it is difficult to represent exactly all the conditions in the project, as they are very complicated, and the drawing must be simple and clear enough to be intelligible and therefore useful;
- even if all the rules for building the chart are met, there are still plenty of drawing options so that two representations of the same project made by two individuals in the project stack may not resemble almost anything;
- from the above it can be seen that the representation is cumbersome even if all conditionings are of the "top-end" type with direct precedence, the attempt to form the graph in the conditions of existence and the other types of interdependencies leading very quickly to an extreme drawing loadable and hard to use.

The CPM method is not capable of providing early warnings. CPM can not be used to predict the program's end date before it actually happens. Everything CPM predicts for the end of the project is how much the project is currently behind the set schedule. In the CPM, there are no suitable algorithms acceptable for systematically updating the initial estimates of future tasks based on historical performance data. This has the goal of a poor early warning capability to detect overcoming project boundaries before the project is actually behind the set schedule.

Monte Carlo simulation

Monte Carlo simulation is probably the most common simulation technique in engineering and management. The Monte Carlo simulation was brought to the fore by Stanislaw Ulam in 1940, a scientist in the nuclear-atomic field, and was named Monte Carlo after the city of Monaco, which is renowned for its casinos. This is at the same time a mathematical and statistical technique by which a quantity is calculated repeatedly using the "what - if" scenario, randomly selected for each calculation. Using this technique, you can determine the impact of identified risks by running simulations several times, and identify a number of possible outcomes in different scenarios. Although the simulation process is internally complex, commercial computer programs perform calculations as a single operation, showing results in simple graphs and tables. When the Monte Carlo simulation is applied to the risk assessment, it appears as a similarly distributed distribution graph known as the bell curve. This method has many interpretations and has received various definitions, so we can say that this method has gone through a long and controversial process of training and development. What recommends using this method to solve a variety of problems is that, in order to get the best result, a small computing effort is required compared to the difficulty of the problem. The

simulation of economic decisions can be applied to all classes of issues that include operating rules, policies and procedures such as those on adapting and controlling decisions. Solving problems with simulation techniques involves the use of iterative algorithms and the existence of well-defined steps to achieve the supposed objective. Input data are usually random variables obtained by generating them by a random number generator. Monte Carlo method is based on the use of such random variables, because for models involving a large number of decision variables, the method necessarily uses computing techniques, and the algorithm of the method is presented in the sequence of its interactive steps.
In approaching large-scale industrial projects as complex nonlinear systems, Monte Carlo method studies the uncertainties associated with some variables in the random number system of the probability distributions estimated for these variables. Monte Carlo simulation begins with sketching a set of random numbers for the variables considered, then a deterministic analysis is performed to obtain a result based on the set of random variable values. Monte Carlo simulation repeats these two steps until significant statistical results can be obtained.

The main steps of Monte Carlo method are as follows:

- Identify the most significant variables or components of the model;
- Determine a measure of the efficacy of the variables of the studied model;
- Shows the cumulative probability distributions of the model;
- Set random number rows that are in direct correspondence with the cumulative probability distributions of each variable;
- Set random number rows that are in direct correspondence with the cumulative probability distributions of each variable;
- Based on the examination of the obtained results the possible solutions of the problem are determined;
- A set of random numbers is generated using random number tables;
- Using each random number and probability distribution, the values of each variable are determined;
- Calculate the variable functional value of the performance;
- Repeat the tests in steps 6 and 8 for each possible solution;
- Based on the results obtained, a decision on the optimal solution is made.

Limitations of the Monte Carlo simulation

Because of the complexity of calculating the total duration of a project resulting from probabilistic estimates of the component work packages, the Monte Carlo simulation has been extensively investigated by several researchers (Finley and Fisher 1994; Hulett 1996, Lee 2005, Lu and AbouRizk 2000). For example, Barraza et al. (2004) conducted a probability forecasting of project duration and cost using Monte Carlo simulation. In the study, the correlation between the past and the future of performance is simplified by adjusting the probability distribution parameters of future activities with performance indices (eg CPI as defined in the earned value method) of the completed work, resulting in a series of limitations as follows:

- In order to run the Monte Carlo simulation, it is necessary to enter three estimates for an activity, so the results depend on the quality of the introduced estimates;
- Monte Carlo simulation shows the likelihood of completing the tasks, it is not the time actually considered to complete the task;
- Monte Carlo simulation technique can not be applied to a single task or activity. Project management requires all activities, as well as the risk assessment completed for each activity;
- Running Monte Carlo simulation requires the purchase of a software program.

Although Monte Carlo Simulation presents a number of limitations, it remains, however, an instrument and at the same time a technique used in the process of quantitative analysis of internal risks arising in the implementation of projects and which can provide their managers with a starting point in the process project planning and execution, but it should be noted that this technique does not provide any warning signals to managers about uncertainties, risks and changes in the external environment.

USING COMPLEMENTARY TECHNIQUES TO GENERATE WARNING SIGNALS ABOUT THE CAUSAL RELATIONSHIP BETWEEN SOURCES OF UNCERTAINTIES, RISKS AND PROJECT PARAMETERS - BAYESIAN NETWORKS.

Bayesian Networks (BN) are recognized as a mature formalism for managing causality and uncertainty (Heckerman et al, 1995). Known as belief networks, causal probabilistic networks, probability charts, probability-cause models..., Bayesian Networks provide decision support in project management for a wide range of issues involving uncertainty and probabilistic reasoning, being often used to analyze causal relationships between different entities. In the field of project management, Bayesian Networks are a useful tool for multivariate and integrated risk analysis, for monitoring and evaluating intervention strategies (through a graphical decision) as well as for their mitigation (Jensen, 2001, Alexander, 2003). According to Bayesian approach, project risk can be defined as the possibility that something is happening with an impact on objectives and is measured in terms of probability combinations of an event (frequency) and its consequences (impact). To estimate the frequency and impact distributions, both, historical data and expertise are used (Cruz, 2004). In this context, Bayesian networks can be a useful tool to integrate historical data with those from experts, which can be qualitative or quantitative (Fanoni, Giudici, and Muratori, 2005).

The main advantages of Bayesian networks that can make them suitable for project planning and execution are:

• the explicit quantification of uncertainties and the modeling of the causal relationship between variables;
• Provides reason-to-cause and cause-to-effect reasoning (propagation is both "forward" and "backward")
• Ensures the possibility of overturning previous beliefs in the light of new data;
• Can make predictions with incomplete data;
• Combines subjective and objective data;
• Allows users to make judgments based on reasoned audits.

Bayesian networks are defined as a graph pattern that effectively encodes the common probability distribution for a large set of variables. (Pai et al., 2003). In a Bayesian network, nodes represent random variables, and edges represent conditional dependencies. Nodes that are not connected represent variables that are conditionally independent of each other (Heckerman, 1996). Each node is associated with a probability function that has as input a set of values for the parent node variables and gives the probability of the variable represented by the node (Jensen, 2001; Heckerman, 1996).

The Bayesian Networks are a graphical method of knowledge representation that uses mathematical probability theory to model uncertainty over information and various aspects of interest. Bayesian networks are defined by graphs, which have associated probability tables and which are used to model and reason with uncertainties. The main purpose of the Bayesian reasoning is to recalculate the probabilities associated with the variables taking into account the new observed events and to exploit the assumptions of interdependence between the variables to make the calculations more efficient. Causal or inferential networks are used in a number of domains to represent patterns of influence between variables. In general, causality can be regarded as any relationship of natural order in which the knowledge of an event influences the opinion on another event. This influence can be logical, physical, in time, or simply conceptual. A Bayesian network is a network of nodes connected by links oriented to a probability function attached to each node. The network (or graph) of a BN is a directed aciclic graph (DAG), where there is no targeted start-up path ending in the same node. If a node has no parent (for example, there is no link to it), the node will contain a marginal probability table. If a node has parents (for example, one or more links to it), the node contains a conditional probability table (CPT). Formally, a Bayesian network can be defined as follows: Bayesian network is a pair (G, P) where G = (V, E) is an acyclic oriented graph (DAG) over a finite set of nodes vertices, V, interconnected by directed links (or margins), E, P and is a set of probability distributions (conditional). Each node represents a variable A with a parent nodes representing variables B1, B2, ..., Bn is assigned a conditional probability table (CPT) representing P (A | B1, B2, ..., Bn). Nodes are random variables and links are probabilistic dependencies between variables. These dependencies are quantified by a set of conditional probability tables (CPTs); each variable is assigned a CPT. For parentless variables, this is an unconditional distribution (also called marginal). In line with the definitions and data above definition, the network of external and internal risk factors is presented in the Figure nr. 4. Once we have built the BN analysis model, we can predict the probability of risk, which can help us to take precautionary measures to reduce the risks in large-scale industrial projects. The most popular software used to perform the above-mentioned process in building BN is Hugin Expert. While running projects, we usually encounter all sorts of issues, such as finding the origin of the problem. Because BN can calculate posterior probability, BN can help find the root of the problem. As an effective mathematical model of probability deduction, Bayesian networks have many advantages in risk control in projects. In project implementation process, real-time risk analysis is essential to estimate the impact on project deadlines and quality. At the same time, we can assess the effect of optional measures to determine the best decision-making strategy. Using the advantages of the Bayesian backsight capability, combined with implementation situations, we can quickly identify and analyze the risk factors that lead to project delay, downsizing or cost overruns, so action can be taken quickly. In addition, Bayesian network structures are suited to the changing features of risk factors in projects due to their light expansiveness and strong self-learning ability. So, applying Bayesian networks for risk factor analysis in projects is more appropriate and more viable than other methods, as the results from this method are appropriate for real situations. Figure 5 shows a Bayesian network model built to model sources of uncertainty as well as how they affect the duration of a particular activity in a large-scale complex industrial project. The model contains variables that capture the uncertain nature of the duration of an activity or activity. The "Early Estimation of Duration" of an activity is based on historical data, past experiences, or expert judgment. "Resources" include any factor that may increase or decrease the duration of the activity. Each node is ranked, which for simplicity is limited to three levels: low, medium and high. The resource level can be deduced from the so-called "indicator" nodes. Therefore, the causal link is from "resources" to the values of the indicators, such as the "cost", the available "people" experience and the level of "technology" available. An important and new aspect of this approach is to allow the model to be adapted to use any indicators that are available. The advantage of this model (BN) is a better understanding by presenting the results in different scenarios. It is possible to introduce observations anywhere in the model to perform not just predictions, but also several types of compromise and explanatory analysis. So, for example, we can introduce observations for the 'Early Estimate of Duration' and 'Resources' and let the model show the 'duration' distributions.

CONCLUSIONS

Bayesian networks can be used to predict internal progress correlated with external volatile factors to obtain early confidence testimonies. There are at least three reasons why Bayesian Networks are to be applied in large complex industrial projects. First, Bayesian Networks provide useful predictions, while CPM and EVM can not do so. Predictive limits indicate the range of possible results at a given confidence level. Secondly, Bayesian Networks not only share EVM merits, but they can provide stable forecasts from the outset of the project and do not require a stabilization period. This feature can be attributed to the adaptive nature of Bayesian networks. EVM forecasts show significant variability in a project, as predictions are made only on the basis of small real data samples. On the contrary, the Bayesian Networks predict both real data and performance information in project plans, historical data, and subjective judgments. The more the project progresses, the influence of the prior information decreases and the forecasts become more influenced by the actual performance data. Like EVM, Bayesian Networks are universally applicable to a wide range of projects Thirdly, Bayesian Networks allow users to adjust the sensitivity of forecasts to actual performance data based on their confidence in the accuracy of performance metrics. Measurement errors are almost inherent in project management due to human errors, insufficient norms for determining the value gained, and variations in reporting ranges. As a result, the level of accuracy of actual performance data may vary from project to project. Therefore, Bayesian network flexibility in relation to measurement errors will be useful in real projects under various circumstances.

Summary conclusions:
Although the analysis of each forecasting method has been finalized with its findings from early warning point of view, the major findings of this study are:

- EVM predictions can be used to obtain reliable warnings after project performance is stabilized;
- The CPM is not capable of providing early warnings due to its retrospective nature;
- Bayesian networks can be used to forecast progress and obtain early confidence testimonies for all types of projects, regardless of size and complexity;
- Early warning capability of predictive methods should be evaluated and compared to the timeliness and reliability of the warning in the context of early warning systems.
- A full comparative analysis of prognosis methods regarding prediction characteristics is done within Table 3.

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ANNEXES

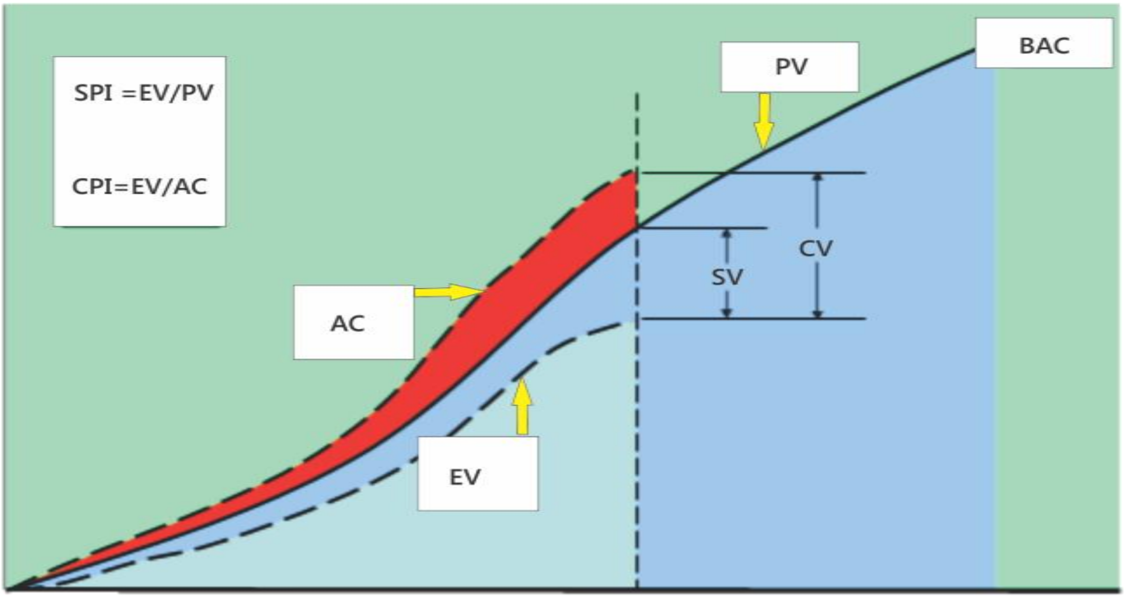

Fig. 1. EVM elements, adapted from Lipke W., 2003, page 2.

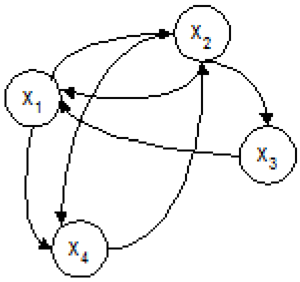

Fig. 2. Math graph representation model for CPM

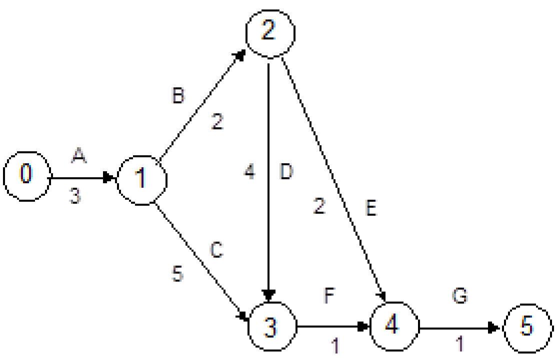

Fig. 3. Graph model for managerial processes.

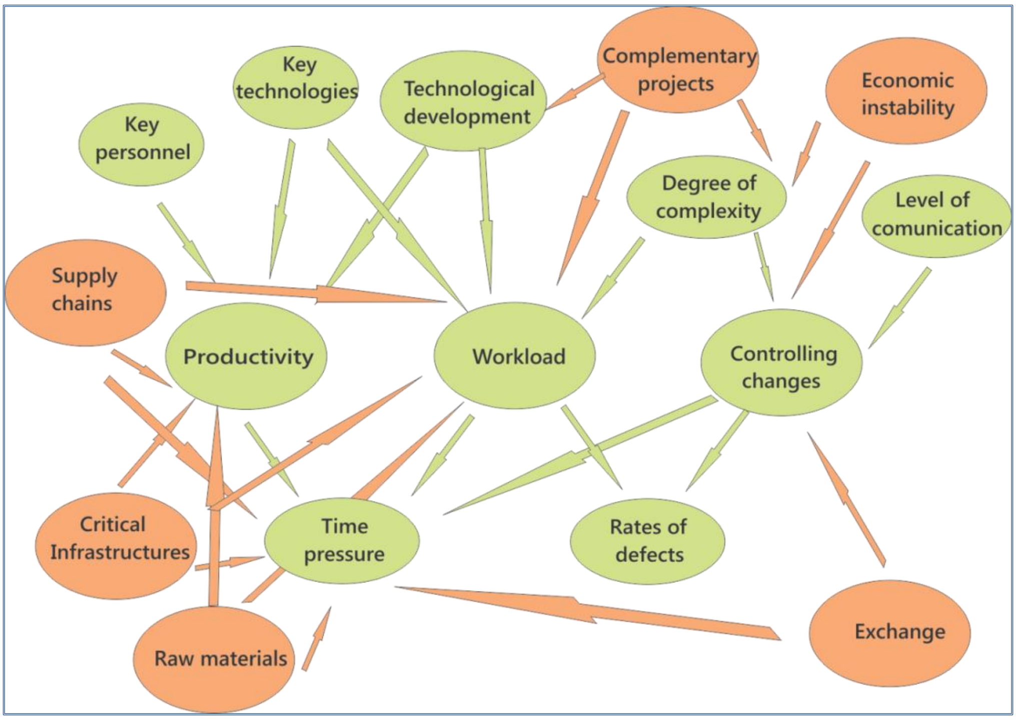

Fig. 4. Model of Bayesian representation of risk factors in project management

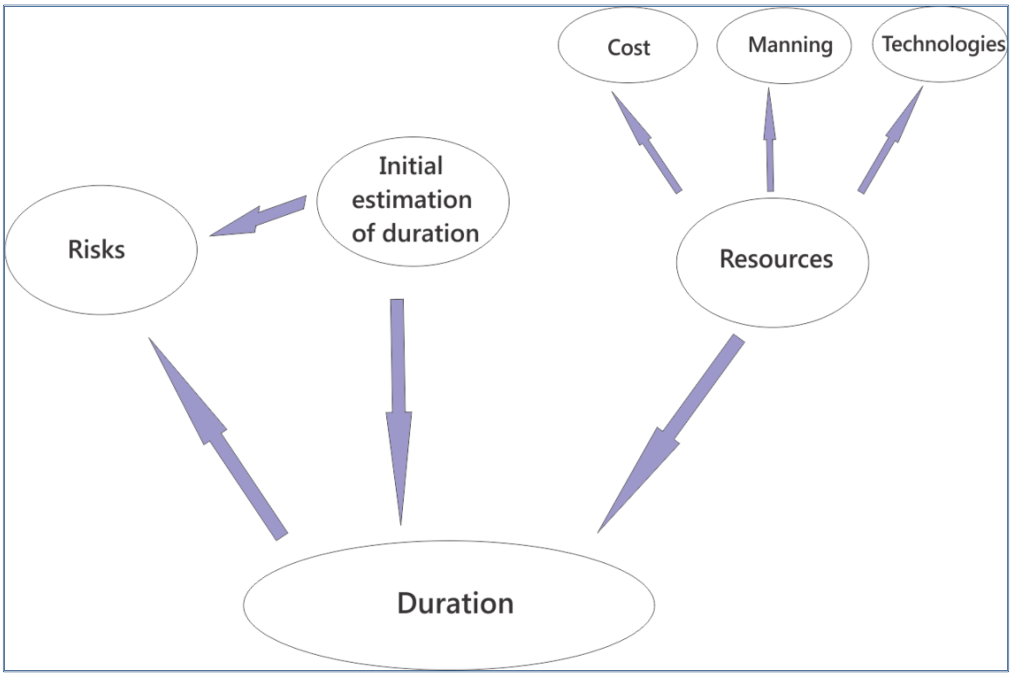

Fig. 5. Model of Bayesian representation for the duration of a project activity

Table 1. Formulas used in the cost forecast in project management

EAC 1 = AC + (BAC − EV)	EAC5 =AC+(BAC − EV)/CR
EAC2 =AC+(BAC − EV)/CPI	EAC6 =AC+(BAC − EV)/CR(t)
EAC3 =AC+(BAC − EV)/SPI	EAC7 = AC +BAC – EV /(wt1 ∗ SPI + wt2 ∗ CPI)
EAC4=AC+(BAC − EV)/SPI(t)	EAC8 = AC +BAC – EV /(wt1 ∗ SPI(t) + wt2 ∗ CPI)

Table 2. Calculation formulas for EAC

Planned Value Method **(Anbari)**	Earned Duration Method **(Jacob)**	Earned Schedule Method **(Lipke)**
EACt PV 1 = PD − TV	EACt ED 1 = AD + (PD − ED)	EACt ES 1 = AD + (PD − ES)
EACt PV 2 =PD/SPI	EACt ED 2 = AD +(PD − ED)/SPI	EACt ES 2 = AD +(PD − ES)/SPI(t)
EAC t PV 3 =PD/CR	EACt ED 3 = AD + (PD − ED)/CR	EACt ES 3 = AD +(PD − ES)/CR

Table 3. Comparative analysis of prognosis methods regarding prediction characteristics

Methods / Criteria	EVM	CPM	Bayesian Networks
Major properties	- Project-level control. - Linear extrapolation.	-Control on the level of achievement of the activity; - Retrospective method.	-Control at project level; -Probabilistic predictions; -Use of prior information.
Entry requirements	-Planned value; -Value earned; -The real cost.	-Network of activities; -Estimates of activities.	-Pre-probability; -Project distribution; -Duration of the project; -Basic curve; -The real progress.
Applications	-For the program and the cost of the project.	-Only for the project schedule.	-For program and project cost.
Practicability	-Universal applicable to all projects of all types, sizes, and complexity.	-Only for projects with a network available.	-Universal applicable to all projects of all types, sizes, and complexity.
Ease of implementation	-Upgrading at project level; -Simple formulas based on three variables.	-Knowing at each activity level is necessary; -Activity level updates. -Commercial software.	-Upgrading at project level; -Simple formulas based on three variables; -Basic knowledge of probabilistic prognosis.
Ease of communication	-The understanding of the three basic variables is mandatory.	-The difficulty increases with the number of activities.	-The understanding of EVM and probability forecast is mandatory.
Precision	-EVM makes accurate predictions only after project performance is	-CPM updates predictions based on observation performance only.	-BN offers accurate forecasts from the early stages of the projects.

	stabilized.		
The opportunity to warning	-EVM offers early warnings, but EVM can only be applied after project performance stabilizes.	-CPM almost does not offer any warnings	-BN generates early warnings from the planning stage.
Flexibility	-Predictions can be adjusted with various performance factors that can be chosen by the user.	The results are deterministic.	-Sensitivity of real data predictions can be modified by the likelihood of variation of terms.