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Bayesian Belief Network Based Management Reviews, Using Project Performance Data from Earned Value Analysis

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Abstract:
Earned Value Analysis (EVA) is a well known technique to monitor the status of a project. Paper presents the concept of making a Bayesian Belief Network model for higher management review meetings using key outputs of EVA, as a best practice to be imbibed. It provides a quick overview of the overall state of the project from the perspective of decision making. Thus, it is employed like a Decision Support Systems, for taking project's course decisions and knowing the causes of projects' state. This practice hides the nitty-gritty of numbers and provides the desired level of abstraction, enabling easier and faster higher management level decisions for project control.

Keywords: *Project Situation Evaluation, Project Decision Support, Earned Value Analysis (EVA), Bayesian Belief Network (BBN), Project Schedule Performance, Project Cost Performance*

1. Introduction

Management reviews are important for project monitoring and control in an organization. Projects undergoing such regular reviews stand to benefit in terms of timely decisions on treatment of impediments faced by the project. Many common problems like manpower / resource unavailability, initial estimated being too low or high etc are agendas of such meetings where some informed decisions are required. Ideally these reviews should be frequent (monthly), but due to large number of projects running in an organization, time consuming review meetings and unavailability of appointments of higher management / decision making authority, poses practical constraints on regularity of such monitoring & control events. The project heath, symptoms and causes need to be visibly appreciated instead of going into too much of statistics or graphs, which are best left for project / program managers" consumption. An intuitive representation of inputs, causes / factors and decisions variables, which promotes a clear understanding, can thus enable fast decision making and increase in the number of projects getting reviewed.

2. Background and Literature Review

Many researchers have proved that application of EVM gives good results about current and forecasting status of project schedule and cost. It is [i] illustrated how project managers could use time series as an effective tool for project duration forecasting. Time series forecasting is the use of a model to forecast future events based on known past events to predict data points before they are measured. The technique [ii] is described for comparison of budgeted cost of work to actual cost through EVM. It presents scheduling, project monitoring processes and main parameters in the calculation of Earned Value Analysis (EVA) in cost management. A case study based on civil construction project is discussed based on EVM technique. There [iii] is presented technical and managerial solutions to address the practical challenges of applying EVM in the messy realm of project management. An empirical case study involving five projects at the NASA Ames Research Centre illustrates the challenges of creating a consistent performance measurement baseline under the constraints of schedule, budget, labour requirements and matching actual costs with budgeted costs on the level of granularity needed. Paper [iv] has shown how Earned Value (EV) acts as a variance and performance indicator for any deviations in

the project budget and project schedule. Special attention to [v], it demonstrates the shortcomings and suggests several improvements for EVM monitoring techniques in software development projects. It also explains EVM's metric such as Schedule Performance Index (SPI), Cost Performance Index (CPI) and forecasting Parameters like Estimation At Completion (EAC) where alone SPI does not alert the project managers early enough on late task starting date.

Bayesian Belief Networks (BBNs) belongs to the family of probabilistic graphical models. These graphical structures are used to represent knowledge about an uncertain domain [vi]. In particular, each node in the graph represents a random variable, while the edges between the nodes represent probabilistic dependencies among the corresponding random variables. Project cost is the one of the governing factor in project success.

The earned value method provides early indications of project performance to highlight the need for eventual corrective action. Earned value management was originally developed for cost management and has not widely been used for forecasting project duration. However, recent research trends show an increase of interest to use performance indicators for predicting total project duration. Paper [vii] presents method for creation of a BBN model by using domain data. There are many semi-automatic approaches available in literature but there are also many open issues in these approaches. BBN can be used risk analysis for predicting of cost and time to completion using an integrated cost-schedule Monte Car lo simulation (MCS) model as research thesis [viii]. It brings out the effect of variances in work package costs and durations on total cost and date of completion.

However to review large number of projects using EVM techniques is a cumbersome job. That's why we propose an innovative approach to review various projects under single umbrella using Decision Support System (DSS) based on EVM-BBN theory.

3. Earned Value Management

EVM is a well known technique to monitor schedule, scope and cost of project status. In another words it integrates all three words (Schedule, Scope and Cost) together. In this model, project progress is measured in monetary terms. By means of a few simple calculations, it allows the project manager to extrapolate current trends to predict their likely final effect. The basics of Earned Value can best be shown on the ubiquitous 'S-Curve'. The S-Curve in its simplest form is a graph showing how project budget is planned to be spent over time.

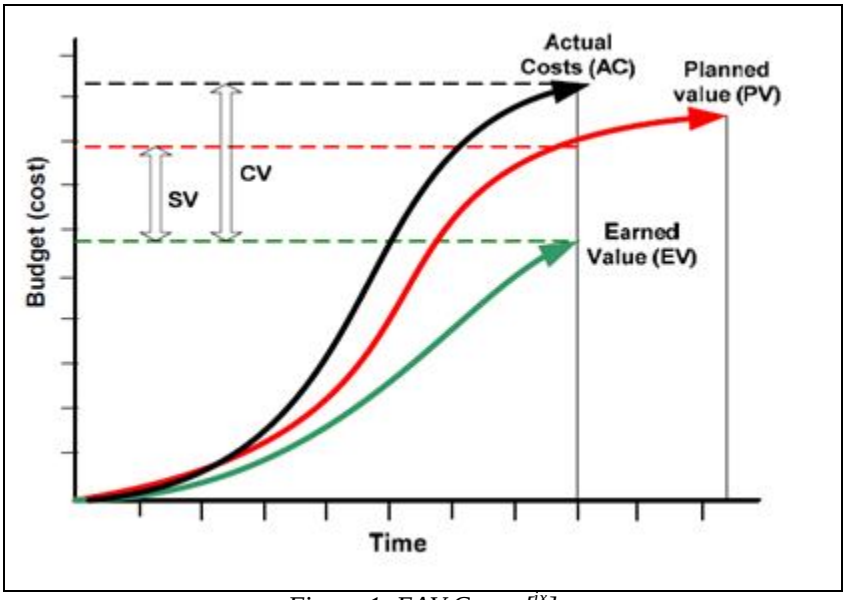

Figure 1: EAV Curve [ix]

EVM gives key parameters PV (Planned Value), AC (Actual Cost) and EV (Earned Value) on a single platform using EVA (Earned Value Analysis) graph as per Fig1. The extent to which AC and EV deviate from PV can help the project manager to understand the current status and analyze various possible reasons like cost overrun, schedule slippage, etc.

EVA graph suggests following performance and forecasting parameters to analysis project status in Fig2:

- BCWS (Budgeted Cost of Work Scheduled) – the baseline for the analysis, cumulative planned costs related to time of their incurrence. This is also known as Planned Value (PV)
- BCWP (Budgeted Cost of Work Performed) – a measure of physical progress of work expressed by cumulative planned cost of work actually done related to time. It is also called Earned Value (EV).
- ACWP (Actual Cost of Work Performed) – cumulative amount payable for work done related to time. This is also known as Actual Costs (AC)
- BAC (Budget at Completion) – total planned cost of the whole project. It equals BCWS at the planned finish
- EAC (Estimate at Completion) – expected cost to be accumulated when the project is actually completed. This is extrapolated from ACWP.

- Schedule Variance (SV) is calculated as SV = BCWP – BCWS
- Schedule Performance Index (SPI) is calculated as SPI = BCWP/ BCWS
  If SPI = 1 (Project is in the schedule)
  < 1 (Project is behind the schedule)
  > 1 (Project is ahead of Schedule)
- For an ideal scenario, SV is 0 and SPI is 1.
- Cost Variance (CV) is calculated as CV = BCWP – ACWP
- Cost Performance Index (CPI) is calculated as CPI = BCWP/ ACWP
  If CPI = 1 (PV and AC are same)
  < 1 (Project is under budget)
  > 1 (Project is over budget)
- For an ideal scenario, CV is 0 and CPI is 1.

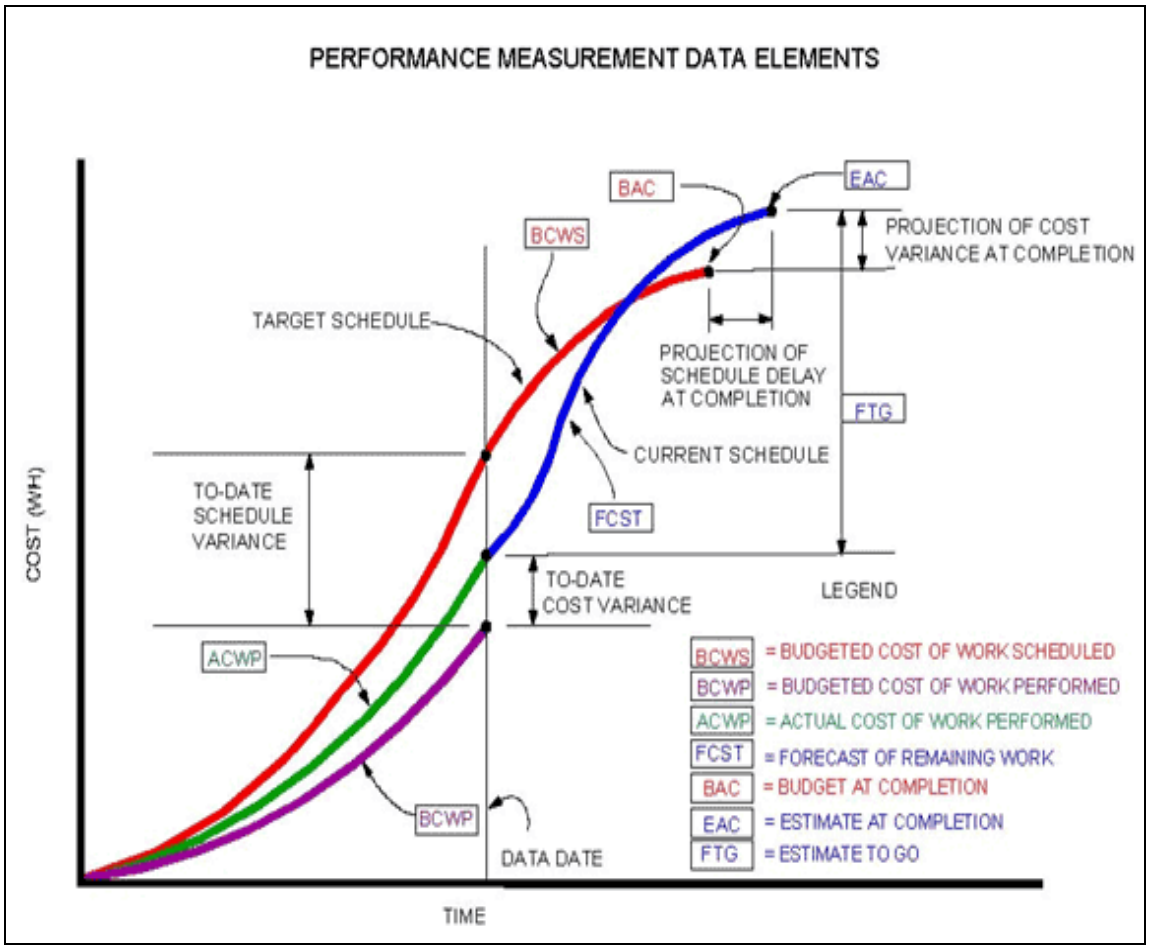

Figure 2: EAV Terminology [9]

4. Bayesian Belief Network

BBN is a powerful intuitive graphical representation to represent the relationship between cause and effect. It provides a flexible framework to express and assess uncertain relation. BBNs scores over traditional expert systems as they try to model the expert through the knowledge elicited from them in the form of a rule base and are poor in dealing with uncertainties. Whereas BBNs try to model the domain and have provisions of using knowledge elicited from an expert or learned from (existing) data or a combination of both. The qualitative domain knowledge is captured in a Directed Acyclic Graph (DAG) and quantitative information is stored in (joint/conditional) probability Table1. Thus BBNs handle uncertainties via probability distributions.

	Less	**Normal**	**High**
Less	Less	Less	Normal
Normal	-	Normal	Normal
High	-	-	High

Table 1: Quantitative Information Table [x]

A Bayesian Network models a problem by mapping cause-and-effect relationships among key variables and assigning them probabilities that represent the extent to which one variable is likely to affect another [iii]. The underlying theory is as provided by Bayes‟ Theorem (from Reverend Thomas Bayes), which is the backbone of BBN. It is based on the concept of conditional probability, where one event is regarded as being conditional on another, i.e. the probability of even B occurring given that event A has already occurred represents a conditional probability relationship and is expressed as: **P (B | A) = P (B ∩ A) / P(A)**
Stated formally, Bayes‟ Theorem provides the probability of the truth of a hypothesis, H, given some evidence, E, and is expressed mathematically as:

$$P(H \mid E) = P(H) * P(E \mid H) / P(E)$$

Where:

- P (H | E) – posterior probability that H is true given E
- P (H) – prior probability that H is true
- P (E | H) – probability of observing E when H is true
- P (E) – probability of E occurring

A chance node (or simple a node) in a BBN takes up multiple discrete states and refers to a variable in the problem domain. The conditional probability table defines the probability of the node taking a particular state given its parent node(s) state. When we enter evidence in form of observations on other nodes in the system, the BBN efficiently propagates this evidence to whichever other nodes in the network are affected by it and updates probability distributions at those nodes given the new evidence. Having introduced the building blocks following section would describe the best practice evolved using these concepts.

5. EVM-BBN Concept for Project Management Review

This paper presents a Decision Support System (DSS) that is based on EVM and BBN concepts. EVM has various key parameters for monitoring of project status. From among all key parameters of EVM, there have been chosen three nodes SPI, CPI and their monthly trend data that acts like key driver input for proposed EVM-BBN model as Fig3.

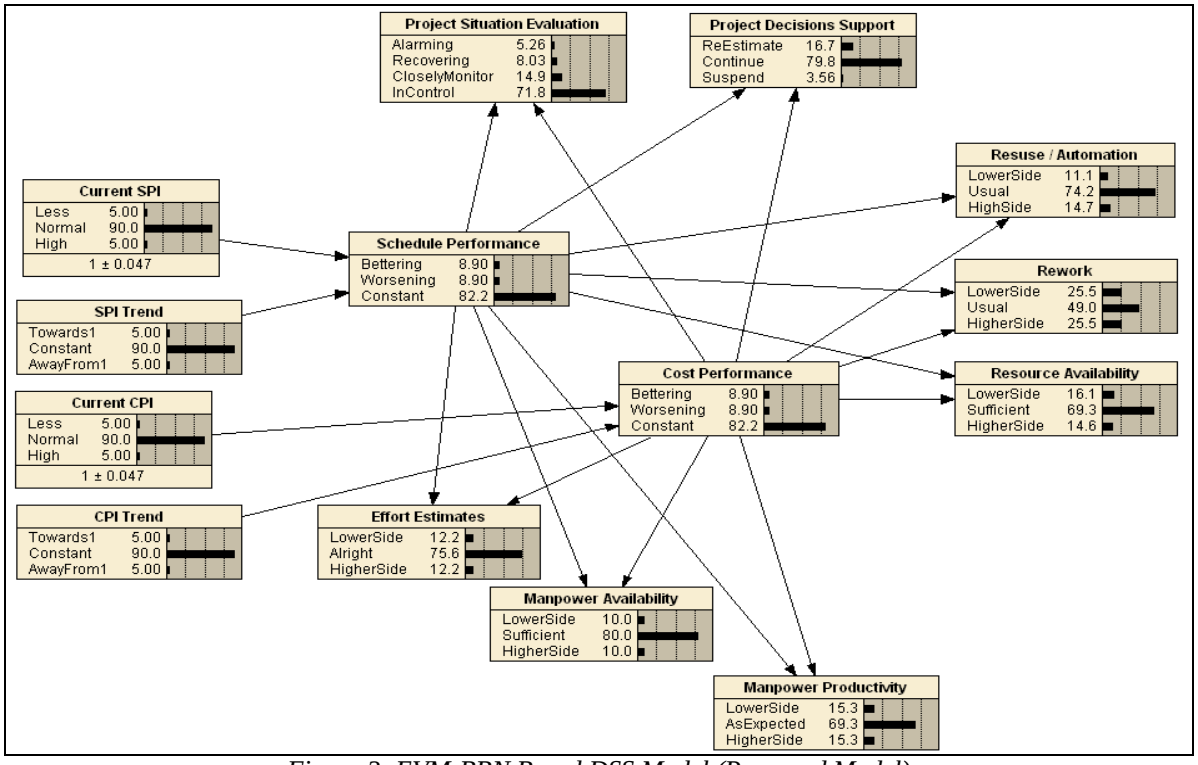

Figure 3: EVM-BBN Based DSS Model (Proposed Model)

5.1. Current SPI Node

This node is for observing the belief in the current Schedule Performance Index (SPI). Evidence of 'Less' can be provided if project's current SPI value is at lower control limit of 0.85 or below. Evidence of 'High' can be provided if project's current SPI value is at higher control limit of 1.15 or above. Within limits, would lead to a 'Normal' state.

5.2. Current CPI Node

This node is for observing the belief in the current Cost Performance Index (CPI). Evidence of 'Less' can be provided if project's current CPI value is at lower control limit of 0.85 or below. Evidence of High can be provided if project's current CPI value is at higher control limit of 1.15 or above. Within limits, would lead to a 'Normal' state.

5.3. SPI & CPI Trend Nodes

These nodes are for observing the belief in the trend followed by SPI & CPI respectively. Evidence of 'Constant' can be provided, if last time it was going away from value 1, but stabilized within limits (within LCL & UCL) or If there no significant change from previous value. 'Higher Side' means that more that 15% positive deviation and 'Lower Side' means 15% negative deviation.

5.4. Root Causes Nodes

Effort Estimate, Manpower Availability, Manpower Productivity, Resource Availability, Reworks and Reuse Nodes can be observed for belief. If 'Higher Side' indications are there then it means effort was over estimated, more than required manpower resources were available and more rework or more than usual reuse was done. Similar logic is for 'Lower Side'. If a shown more belief in alright / usual / sufficient then the middle option will be prominent.

5.5. Schedule & Cost Performance Observation Nodes

These nodes are intermediary central nodes, this show if the project is worsening or bettering or maintaining constant state

5.6. Project Situation Evaluation

This node is a decision support node which provides belief about project being 'In Control' or requires close monitoring or the status is improving / recovering or the project has reached alarming state. Reviewer takes a note of beliefs if they are not indicating 'In Control' clearly

5.7. Project Decision Support

This node provide decision support and comes handy as a scientific rational behind decision to let the project continue or suspend or let project manager re-estimate. Node Project Situation Evaluation and Project Decision Support are the final outcome of the BBN model.

5.8. Sample Decision Tables

The following are some sample tables which describe the captured subject matter expert (SME) knowledge [xi] about the relationship of nodes in the BBN model. This data can be collected either from history of organization project data or experience based. This are conditional probabilities which are combined with evidences and propagated to and fro the BBN model to gets beliefs. There are following listed tables which are used in DSS model for project monitoring:

- Effort Estimation Decision table (Table2)
- Project Situation Evaluation Decision Table (Table3)
- Schedule Performance Decision Table (Table4)
- Project Decision Support Decision Table (Table5)

Schedule Performance	Cost Performance	LowerSide	Alright	HigherSide
Bettering	Bettering	0	10	90
Bettering	Worsening	50	0	50
Bettering	Constant	0	50	50
Worsening	Bettering	50	0	50
Worsening	Worsening	90	10	0
Worsening	Constant	50	50	0
Constant	Bettering	0	50	50
Constant	Worsening	50	50	0
Constant	Constant	5	90	5

Table 2: Conditional Probability of Effort Estimation [xi]

Schedule ...	Cost Perfo...	Alarming	Recover...	Closely...	InControl
Bettering	Bettering	0	90	0	10
Bettering	Worsening	10	0	50	40
Bettering	Constant	0	50	10	40
Worsening	Bettering	10	0	50	40
Worsening	Worsening	90	0	10	0
Worsening	Constant	30	0	40	30
Constant	Bettering	0	50	10	40
Constant	Worsening	30	0	40	30
Constant	Constant	0	0	10	90

Table 3: Conditional Probability of Project Situation [xi]

Current SPI	SPI Trend	Bettering	Worsen...	Constant
Less	Towards1	70	0	30
Less	Constant	25	25	50
Less	AwayFrom1	0	70	30
Normal	Towards1	50	0	50
Normal	Constant	5	5	90
Normal	AwayFrom1	0	50	50
High	Towards1	70	0	30
High	Constant	25	25	50
High	AwayFrom1	0	70	30

Table 4: Conditional Probability of Schedule Performance [xi]

Schedule Performance	Cost Performance	ReEstimate	Continue	Suspend
Bettering	Bettering	20	80	0
Bettering	Worsening	80	20	0
Bettering	Constant	10	90	0
Worsening	Bettering	80	20	0
Worsening	Worsening	20	0	80
Worsening	Constant	70	10	20
Constant	Bettering	10	90	0
Constant	Worsening	70	10	20
Constant	Constant	5	95	0

Table 5: Conditional Probability of Project Status [xi]

6. Case Study

6.1. For Project Reviews

A case study is shown in Figure3 that is EVM-BBN based model for analysis of project status. Every project maintains a monthly project review document which has many details about project including the Earned value management related measures. Current CPI an SPI values and their trend from past month(s) are taken and evidence is provided on respected node in the given BBN model. Beliefs on all nodes are observed and inferred. The decision support nodes are seen first so as to check if there is a real necessity for some action or the projects is doing fine. If these nodes are showing strong beliefs in 'In control' and 'Continue' then the review discussion moves to other important current and future issues/risk related to the project. In any other state of these decision support nodes, root cause nodes are examined for most probable cause and discussion moves into resolving the situation. In worst case if project reaches alarming state then suitable decisions as to re-estimate or suspend are taken, to salvage the project. The following Table6 shows four scenarios and results on which higher management deliberates upon. Rest scenarios are combinatorial of these basic fours.

	Earned Value Analyses Scenarios	EVA 4 Significant Scenarios			
	Inputs	1	2	3	4
1	SPI	Less/High	Less/High	Less/High	Less/High
2	SPI Trend	Towards1	Towards1	AwayFrom1	AwayFrom1
3	CPI	Less/High	Less/High	Less/High	Less/High
4	CPI Trend	Towards1	AwayFrom1	Towards1	AwayFrom1
	Insights				
1	Schedule Performance	Battering	Bettering	Worsening	Worsening
2	Cost Performance	Bettering	Worsening	Bettering	Worsening
	Outputs				
1	Project Status	Recovering	CloselyMonitor	CloselyMonitor	Alarming
2	Project Decision Support	Continue	ReEstimate	ReEstimate	Suspend
	Probable Causes				
1	Effort Estimate	HigherSide	CantSay	CantSay	LowerSide
2	Manpower Availability	Sufficient-LowerSide	Sufficient-HigherSide	Sufficient-LowerSide	Sufficient-HigherSide
3	Resource Availability	Higher	HigherSide	LowerSide	LowerSide
4	Manpower Productivity	HigerSide	LowerSide	HigherSide	LowerSide
5	Resuse / Automation	HighSide	HigherSide	LowerSide	LowerSide
6	Rework	LowerSide	HigherSide	LowerSide	HigherSide

Table 6: EVA for Significant Scenarios [x]

Essentially, by a single look at the beliefs present at BBN model nodes, reviewer comes to know the status of the project and decision demands immediately.

6.2. For Other Usage Modes

The BBN model can also be used in two other modes, apart from reviews. In these modes project manager can himself get an insight into what all can be analyzed in his projects. These type of modes are more about study/training purposes (What if analysis) and not for management reviews. For e.g.:

- Providing evidence that project is in 'Alarming' situation and decision support as 'Suspended', one can play with the model to observe the cause and expected CPI and SPI to gain insight as to tell-tale signs when such project state is about to occur.
- Providing evidences on a combination of causes nodes, one play with model to observe the effect on decision variables and expected CPI and SPI to gain insight as to tell-tale signs when such project state is about to occur.
- Providing evidences for schedule only and leaving cost as uncertain and vice versa to see BBN model behaviour.

7. Performance Analysis

There are many advantages in using such an approach for management review of projects, as mentioned point-wise:

- Very clear understanding of the relationships between EVA, root causes and the decisions support
- Visual representation is much more preferable than numbers
- Instead of binary yes or no, the model leaves full scope for overlaps and its fuzziness leaves room for discussions.
- Higher management is more apt for 'overall feeling' like on 'higher side' or 'sufficient' or 'worsening' etc. It makes decision making more 'human like' and natural.
- The agreements/disagreements/arguments are for the right reasons and not for accuracy of numbers.
- Decoding of graphs (PV-EV-AC graphs) produced by EVA becomes an easy and non-time consuming task.
- Gives a way to do what if, in a given situation, and the effect of decisions can be visualized.

8. Relevance and Importance to Industry

When seen from the wider perspective of applicability to similar and other industries following points come as summary:

- It is as general purpose as EVA itself.
- The model can be fine-tuned as per organizations‟ subject matter expert knowledge
- It promotes automation in decision making.
- It recognizes fuzziness as essential element of decision making.
- Industries get encouraged to think of similar events in a different way of presentation for decision support to higher management.

9. Conclusion & Future Scope

Proposed project status review model promotes automation in decision making and recognizes fuzziness as essential element of decision making. It is a DSS tool for innovative project management in monitoring and control area and provides a different way of presentation, for decision support to higher management. The model can be fine-tuned as per organization's SMEs. Validation of the

proposed model is an important part of our future work. It is a generic model to review each category of projects like software, finance, civil and hardware.

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