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Application of Earned Value Management to Compute the Project Performance Using Analytical Network Process

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ABSTRACT

Every project confronts risk both in financial and technical dimensions. This induces a greater response on the performance of the project. A successful construction project depends on how the project participants compute the actual project performance. A commendable assessment of project performance practice determines the project productivity both quantitatively and qualitatively. Methods of project performance measurement vary among industries. As a contribution to the above, this study equips the project manager with a proficient mode of project performance measurement and the essential promising decisions that head to profit maximization. This intricate study thus facilitates the project manager to compute the project performance on the basis of the effects of Earned Value Management (EVM) indices which are broadly classified as: variance indices, performance indices and miscellaneous or forecast indices. Adopting the Analytical Network Process (ANP) structure model in Super Decision software is a reliable decision making tool. This study indicates that the cost variance (CV) index is prominent among the EVM indices that highly affect the project characteristics, the measurement of which facilitates the required control measures on respective project activities. It also indicates that cost is the major project characteristic, the variation of which immensely affects the project performance. It procures an objective reference for engineering projects by following the selection process of best EVM indices that holds an accurate measure of project performance.

KEYWORDS: Analytical network process (ANP), Project performance, Performance computation, EVM indices, Performance indices, Forecast indices, Super decision tool.

INTRODUCTION

Project development in distinctive industries is a product of powerful planning and scheduling of all the sequential activities that mold the project. In spite of efficient planning and scheduling, all projects need an extensive component to be computed known as the project performance. Performance of a project is a cumulation of all activities that employ resources which attribute to the standard outcome value of a project or property, leading to either rise or deprivation of the same. Therefore, every project requires a system that carries a project performance measurement to avert or minimize the loss in the project value. An effective project performance requires the development of various project management tools that give a sprout of new techniques each day (Alexie and Olga, 2014).

A few of the project measurement techniques include the use of Gantt Chart that provides a graphical framework of project schedule and resources. The next in the line is the Work Breakdown Structure that breaks a project into components, but does not specify the critical measures in the same. Another method is the Critical Path Analysis that is effective for lengthy

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projects but throws light only on the visual communication about the project. Following the above, an effective method of project management is the Resource Histogram that experiences a lack as it concentrates only on project materialistic resources. A further method is Project Planning Document that holds a checklist of project activities. Other techniques are project reports, buffering and PERT,… etc.

The technique of Earned Value Management (EVM), being a project management system, stands out of all these techniques in various effective ways. It accounts for all the stages of the project; namely, planning, scheduling, fund discussion, execution and maintenance (Naderpour and Mofid, 2011). It efficiently formulates all the aspects like cost, schedule and quality of every individual activity of the project. It can be effectively used as a decision making tool. It also includes risk analysis through graphical representation. Using the aspects of EVM, the objective of this paper is to provide a methodology for the computation of project performance based on the effects of Earned Value Management (EVM) indices on projects including project factors like cost, time, labor, quality and productivity for an effective explanation of the importance of project performance. This system adopts an alternative that measures the project quality. Hence, this guides to the appropriate critical path in which the project generates productive output on implementation.

Earned Value Management and Performance Assessment

Earned value management (EVM) serves as a sublime technique of project management. On employment, it renders details about the project performance and progress of the same. It is a well-known project management triangle, as it measures scope, schedule and cost all together (Chun Wei Lin, 2010). Identically, it also implies to the magnitude of project performance that originates in a project.

EVM consists of manifold indices that measure the project performance. Their primary contribution is towards the computation of performance of a project, which on measurement and control increases the project potency. Indices of this renowned project management technique are: Cost Variance (CV), Schedule Variance (SV), Cost Performance Index (CPI), Schedule Performance Index (SPI), To Complete Performance Index (TCPI) and Critical Ratio (CR) (Antony and Thirumalai, 2014). EVM indices measure the performance of a project, calling on the control of project activities at every stage of the same. Estimation of project conditions facilitates the project manager with timely decisions. This increases the productivity of the project which supports the project in all aspects like labor, material and fund constraints and unfavorable weather conditions. This set of influence on attention provides the areas of flaws in a project improving the efficiency of planning and scheduling for an effective project output.

EVM stands exceptional to all the other project assessment methods like Gantt Chart that provides a graphical framework, critical path analysis, work breakdown structure and histogram representation. Supporting the above, the following lines enumerate the merits of EVM in comparison to the other project measurement tools. The Earned Value Management (EVM) method is a powerful tool that supports the management of scope, time and cost of the project (Anbari, 2003). It allows the calculation of cost and schedule variances, as well as performance indices and forecast of project cost and schedule at completion. It provides early indications of expected project results based on project performance. It highlights the possible need for corrective measures. It allows the project management team to alter or adjust the project strategy and to make interchange based on project performance, objective, trend and the environment in which the project is being executed. The method includes various indices like cost variance (CV), schedule variance (SV), cost performance index (CPI), schedule performance index (SPI), to complete performance index (TCPI), critical ratio (CR),… etc. These indices on calculation indicate the level of stringency or

leniency that is to be maintained over the resources. It employs the current project performance to estimate the future project condition based on cost, time, labor, quality and productivity. This facilitates the project manager to tabulate the factors that affect the project and reduce its quality and productivity. These are then analyzed in accordance to the existing condition of the project to obtain the required corrective measures. It also allows the measurement of cost and value in dollars, hours, worker days or any other parameters similar to the above. EVM can be used for progress payments based on the earned value of contracted or outsourced work. As such, contractual arrangements create legal and financial obligations. It is important to consider the method specified for evaluating the project progress. For long-term projects, it may be appropriate to consider a system that employs EVM, as it also measures time value of money and time discounted cash flow. An organization elects to apply EVM uniformly to all of its projects, or only to projects that exceed their own limits of cost and schedule with their respective report and control. It measures the impact of all the factors that reduce the project duration and increase the project cost. This also affects the quality and client satisfaction. EVM facilitates the identification and impact measurement of the respective factors. This on discussion by the project management team leads to corrective measures that head the project into a track of expected outcome. The industry applies EVM to projects of various types and sizes in the public and private sectors. It also applies to various levels of project WBS and to various cost components such as labor, material and sub-contractors.

Super Decision and Analytical Network Process (ANP)

Analytical Network Process (ANP) structures a decision problem in the design of a network (Laura and Adrien, 2002). It allocates the rank for alternative decisions. Its capability increases as it uses a system of pairwise comparison to measure the weights of the constituents in a structure. ANP also allows to study the interdependence of the components in a structure. It assists as a framework that facilitates the selection of appropriate factors that significantly contribute to a project's success.

Super decision software tool implements Analytical Network Process (ANP) for decision making (Hui and Mao Mei, 2011; Eddie et al., 2004). It allows to decompose a problem systematically and fix judgements on all factors of the same. It derives priorities through pairwise comparison on components that influence the project performance. It configures an ANP network using a set of clusters and nodes. The need of an appropriate decision and the alternative requirement lead to the formation of connection among the above clusters and nodes. This further generates priorities and assigns ranks according to the priority that leads to the rise of supreme alternatives which facilitate decision making in accordance to the effects of the components on each other. Super decision tool categorizes the task into clusters inclusive of nodes. The super decision software illustrates the ANP network and its respective goals, criteria and alternatives. The process of the same includes prioritization of indices and their influences on the project performance as a parameter. It denotes a sequential network of decision making and selection process. Hence, a combination of ANP and Super decision software tool serves as an efficient analyzing and decision making sequence.

METHODOLOGY

Project performance measurement is based on methods like calculation of performance of various activities constituting the projects, application of project management concept, computation of performance deviations… and so on. This paper divulges the aspect of performance computation based on factors like cost, time, labor, quality and productivity with the effects of EVM indices *viz.* Cost Variance (CV), Schedule Variance (SV), Cost

Performance Index (CPI), Schedule Performance Index (SPI), To Complete Performance Index (TCPI) and Critical Ratio (CR) on a project. For a valuable interpretation of idea sanity check and EVM indices priority computation is carried out.

This creed of selection of EVM indices that extremely contributes to project performance measurement, employs the Super decision software. The study focuses on selecting the appropriate EVM indices that audibly focus on project factors like cost, time, labor, quality and productivity, indicating the status of the project performance using an ANP model as illustrated in Figure 1. This also employs the study of influences of EVM indices along with their priorities on each project factor like planning, schedule, labor management and project closure. All together, these yield a sequel over the performance analysis for a project and its promising decisions.

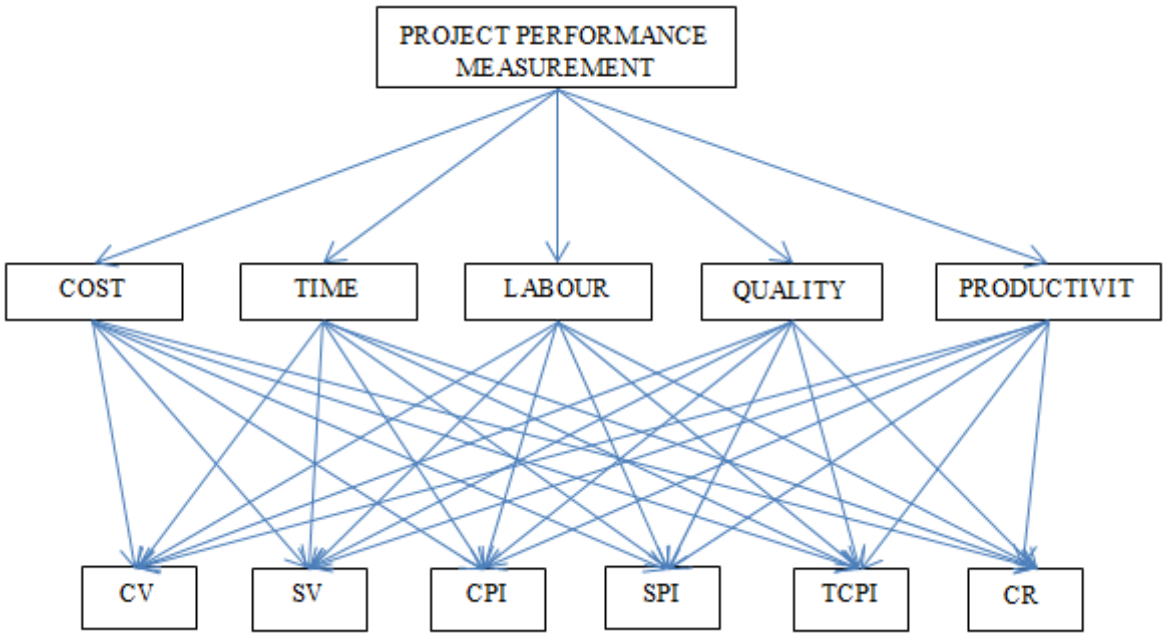


Figure (1): The ANP network model

Operation of Super Decision in Project Performance Computation

Super decision serves as an efficient tool for decision making based on the weights of the involved parameters. It exerts the usage of clusters and nodes to inter-relate the EVM indices along with the factors that contribute to project success. In this decision making process, this tool involves the creation of three prominent clusters *viz.* goals, criteria and alternatives (Eddie and Heng, 2004). Each cluster includes one or more nodes that tag:

- PROJECT PERFORMANCE as node in the GOAL cluster;
- COST, TIME, LABOR, QUALITY and PRODUCTIVITY as nodes in the CRITERIA cluster;
- CV, SV, SPI, CPI, TCPI and CR as nodes in the ALTERNATIVES cluster.

An authentic connection between the clusters along with the pairwise comparison matrix provide the weights of the EVM indices and their influences on the measurement of project performance. An inter-node connection in the ALTERNATIVES cluster provides the weights of all indices that correlate to the effect of

indices on each other as shown in Figure 2 that represents the super decision model using ANP network. The appropriate network between the various clusters renders the matrix incorporation on check. Verification of entries is necessary and is performed through a sanity check which follows the above steps.

The sanity check that indicates zero error or warning allows the computation of various weights. These are essentially used for the measurement of project performance and influence on the aspects of the project.

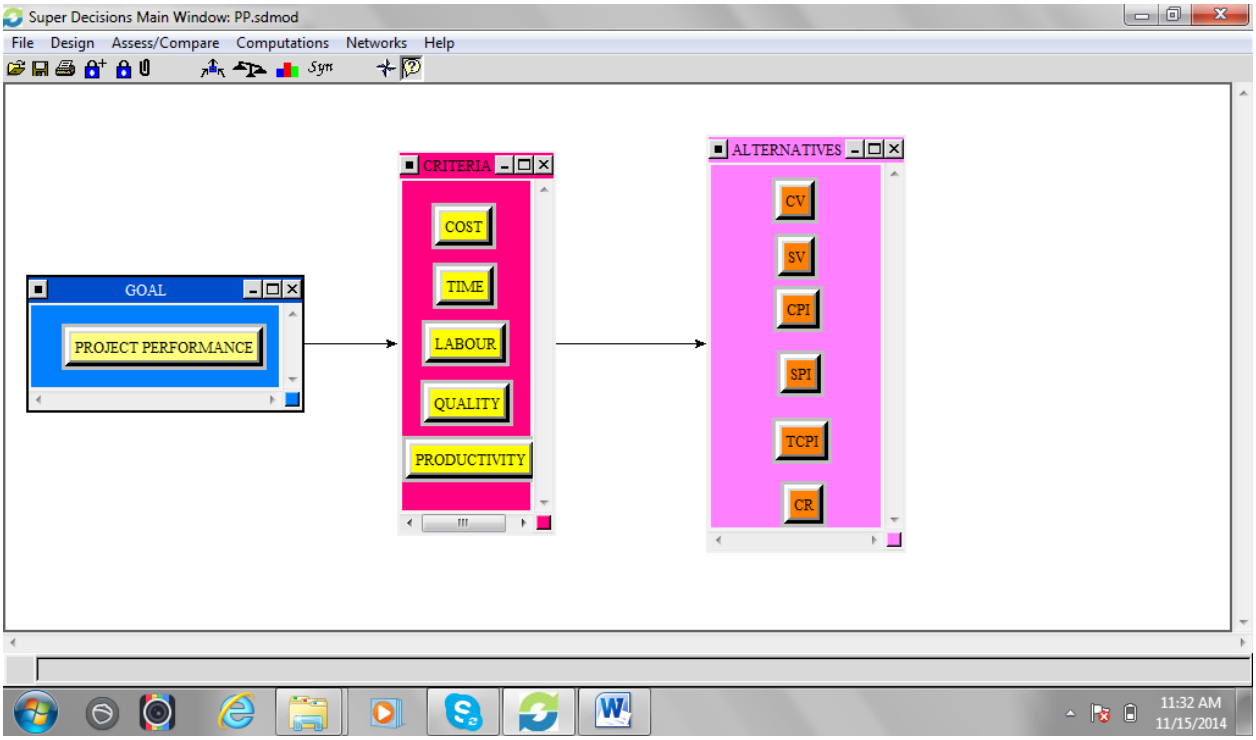


Figure (2): Super decision tool representing ANP network model

Table 1. Matrix of project performance

Top Goal	Cost	Time	Labor	Quality	Productivity	Weights
COST	1	2	3	2	4	0.37473
TIME	1/2	1	2	1/2	2	0.17475
LABOUR	1/3	1/2	1	1/2	2	0.12140
QUALITY	1/2	2	2	1	3	0.24975
PRODUCTIVITY.	1/4	1/2	1/2	1/3	1	0.07936
					INCONSISTANCY = 0.01890	

Table 2. Matrix indicating the influence of EVM indices on cost

COST							
TOP GOAL	**CV**	**SV**	**CPI**	**SPI**	**TCPI**	**CR**	**WEIGHTS**
CV	1	3	2	4	2	5	0.34430
SV	1/3	1	1/2	2	1/2	2	0.11569
CPI	1/2	2	1	2	1/2	3	0.16680
SPI	1/4	1/2	1/2	1	1/3	2	0.08155
TCPI	1/2	2	2	3	1	4	0.23635
CR	1/5	1/2	1/3	1/2	1/4	1	0.05532
					INCONSISTANCY=0.01610		

Table 3. Matrix indicating the influence of EVM indices on time

TIME							
TOP GOAL	**CV**	**SV**	**CPI**	**SPI**	**TCPI**	**CR**	**WEIGHTS**
CV	1	1/2	2	1/2	2	3	0.16703
SV	2	1	4	2	3	5	0.34425
CPI	1/2	1/4	1	1/3	1/2	2	0.08152
SPI	2	1/2	3	1	2	4	0.23633
TCPI	1/2	1/3	2	1/2	1	2	0.11565
CR	1/3	1/5	1/2	1/4	1/2	1	0.05522
					INCONSISTANCY=0.01610		

Weights of EVM Indices and Their Consistencies

Matrix formation for the super decision tool provides the consistency of all EVM matrices. Check of consistency being less than 0.1 proves that the formed matrices are relatively undistorted. Table 1 represents the matrix of project performance relying on the factors determining the performance of the project based on the effects of cost, time, labor, quality and productivity. Table 2 represents the influence of EVM indices on cost. The weightage is provided such that CV has greater influence on cost. Fluctuation of the same alters the cost to be incurred. Table 3 represents the effect of EVM indices on time on the basis of greater SV influence on work schedule. Table 4 and Table 5 represent the effect of indices on labor and quality on the basis of highest influence of EVM cost indices CV and TCPI as they are under the category of necessary resources for a project. These are highly under the influence of project progression method. All these factors together determine the project productivity. Table 6 represents the influence of EVM indices on productivity measurement that includes project resources. The attribution of weights of the EVM indices is according to their individual influence on the factors of the project. All the table values (weights and consistency ratios) are obtained after the pairwise matrices are developed, a vector of priorities (weights) of each matrix is calculated and then normalized to sum to 1.0 or 100 percent. This is done by dividing the elements in each column of the matrix by the sum of the column (i.e., normalizing the column); then obtaining the weights by adding the

elements in each resulting row. Dividing this sum by the number of elements in the row allows to obtain the priorities (Cheng and Li, 2002). This inconsistency limit must be below 0.1 (Cheng and Li, 2002) to authorize the consistency of relative weights and priorities. A sanity check run authenticates all the connections among various clusters and their entries in the respective tool. Computation of values like super weighted super matrix follows the above. The influence line is set to smart p0 that acts as a benchmark for the computation of weighted super matrix and priorities, as well as to synthesize the full report.

Table 4. Matrix indicating the influence of EVM indices on labor

LABOR							
TOP GOAL	**CV**	**SV**	**CPI**	**SPI**	**TCPI**	**CR**	**WEIGHTS**
CV	1	1/2	2	1/2	1/3	2	0.11543
SV	2	1	3	2	1/2	4	0.23622
CPI	1/2	1/3	1	1/2	1/4	2	0.08150
SPI	2	1/2	2	1	1/2	3	0.16696
TCPI	3	2	4	2	1	5	0.34469
CR	1/2	1/4	1/2	1/3	1/5	1	0.05520
					INCONSISTANCY=0.01610		

Table 5. Matrix indicating the influence of EVM indices on quality

QUALITY							
TOP GOAL	CV	SV	CPI	SPI	TCPI	CR	WEIGHTS
CV	1	2	3	4	2	5	0.34469
SV	1/2	1	2	3	2	4	0.23622
CPI	1/3	1/2	1	2	1/2	2	0.11543
SPI	1/4	1/3	½	1	1/2	2	0.08150
TCPI	1/2	1/2	2	2	1	3	0.16696
CR	1/5	1/4	½	1/2	1/3	1	0.05520
					INCONSISTANCY=0.01610		

Table 6. Matrix indicating the influence of EVM indices on productivity

PRODUCTIVITY							
TOP GOAL	CV	SV	CPI	SPI	TCPI	CR	WEIGHTS
CV	1	2	2	3	1/2	4	0.23589
SV	1/2	1	2	2	1/2	3	0.16702
CPI	1/2	1/2	1	2	1/3	2	0.11547
SPI	1/2	1/2	½	1	1/4	2	0.08166
TCPI	2	2	3	4	1	5	0.34475
CR	1/4	1/3	½	1/2	1/5	1	0.05521
					INCONSISTANCY=0.016108		

Table 7. Super matrix of ANP model

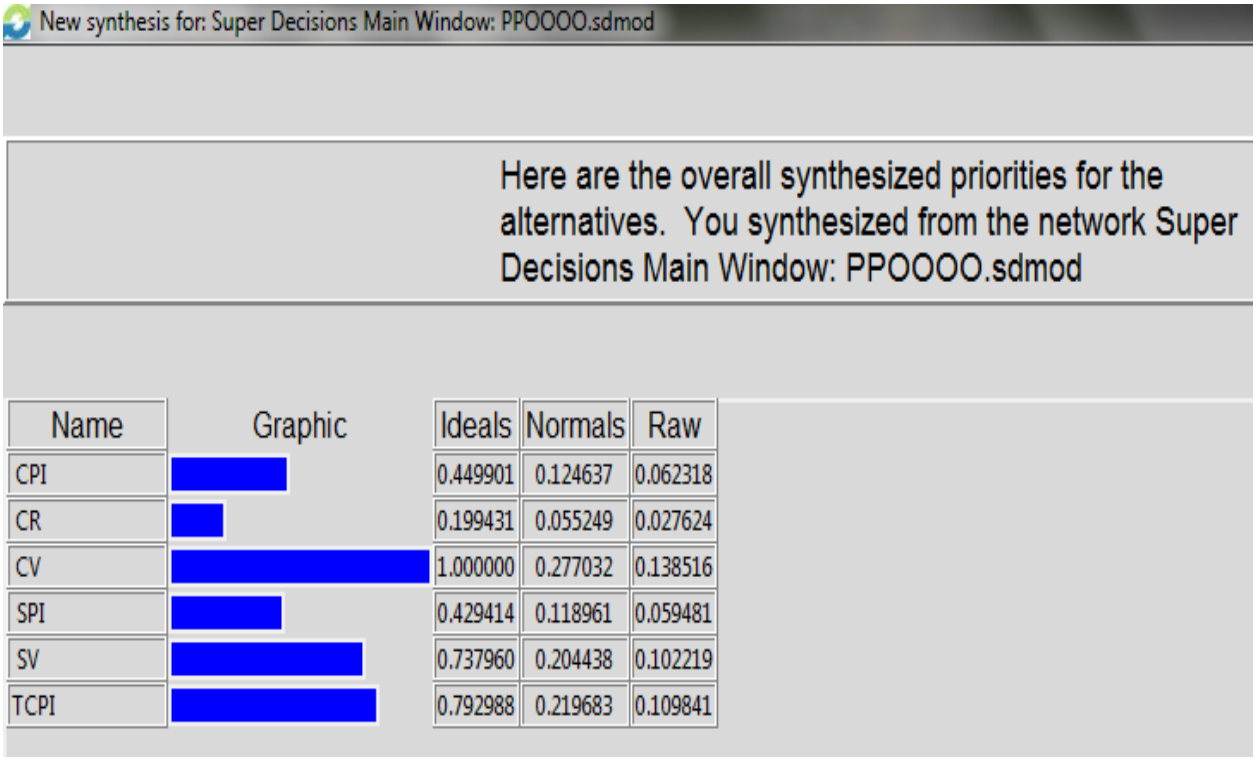
	CPI	CR	CV	SPI	SV	TCPI	COST	LABOR	PRODUCTIVITY	QUALITY	TIME	PP
CPI	0.00	0.00	0.00	0.00	0.00	0.00	0.16680	0.08150	0.11547	0.11543	0.08153	0.00
CR	0.00	0.00	0.00	0.00	0.00	0.00	0.05532	0.05520	0.05521	0.05520	0.05522	0.00
CV	0.00	0.00	0.00	0.00	0.00	0.00	0.34430	0.11543	0.23589	0.34469	0.16703	0.00
SPI	0.00	0.00	0.00	0.00	0.00	0.00	0.08155	0.16696	0.08166	0.08150	0.23633	0.00
SV	0.00	0.00	0.00	0.00	0.00	0.00	0.11569	0.23622	0.16702	0.23622	0.34425	0.00
TCPI	0.00	0.00	0.00	0.00	0.00	0.00	0.23635	0.34469	0.34475	0.16696	0.11565	0.00
COST	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.37473
LABOR	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.12140
TIME	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.07936
PRODUCTIVITY	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.24975
QUALITY	0.00	0.00	0.00	P0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.17475
PP	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Table 8. Final limit matrix

	CPI	CR	CV	SPI	SV	TCPI	COST	LABOR	PRODUCTIVITY	QUALITY	TIME	PP
CPI	0.00	0.00	0.00	0.00	0.00	0.00	0.16680	0.08150	0.11547	0.11543	0.08153	0.06232
CR	0.00	0.00	0.00	0.00	0.00	0.00	0.05532	0.05520	0.05521	0.05520	0.05522	0.02762
CV	0.00	0.00	0.00	0.00	0.00	0.00	0.34430	0.11543	0.23589	0.34469	0.16703	0.13852
SPI	0.00	0.00	0.00	0.00	0.00	0.00	0.08155	0.16696	0.08166	0.08150	0.23633	0.05948
SV	0.00	0.00	0.00	0.00	0.00	0.00	0.11569	0.23622	0.16702	0.23622	0.34425	0.10222
TCPI	0.00	0.00	0.00	0.00	0.00	0.00	0.23635	0.34469	0.34475	0.16696	0.11565	0.10984
COST	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.18737
LABOR	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.06070
TIME	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.03968
PRODUCTIVITY	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.12488
QUALITY	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.08737
PP	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

RESULTS AND DISCUSSION

Project performance measurement includes the project factors. The EVM indices exhibit a superlative contribution towards computation of project performance by measuring the project factors *viz.* cost, time, labor, quality and productivity. With interdependent influences, the system that consists of clusters and criteria matrices must translate to a super matrix. This can be achieved by entering the local priority vectors in the super matrix, which on run allows to obtain global priorities. Table 7 shows the super matrix for the ANP decision model of EVM indices on project factors. It contains the priorities for the judgement matrix. In the process, the super matrix with sub-matrices is then raised to sufficient large power until convergence occurs (Saaty, 1996). Table 8 represents the final limit matrix. Each column is the same and provides the local relative weight of each element. Computation of the matrices occurs in the ANP model.



Name	Graphic	Ideals	Normals	Raw
CPI		0.449901	0.124637	0.062318
CR		0.199431	0.055249	0.027624
CV		1.000000	0.277032	0.138516
SPI		0.429414	0.118961	0.059481
SV		0.737960	0.204438	0.102219
TCPI		0.792988	0.219683	0.109841

Figure (3): Priorities of influence of EVM indices on the computation of project performance

The cost, being the most significant component that serves for the estimation of project performance, can be effectively measured using the EVM index, CV. The index CV measures the project performance that indicates the financial status of the project in comparison to the other cost variance index, CPI. It shows that whether a project is over-budgeted or under-budgeted. Labor employment is another prominent factor that follows the above. TCPI index of EVM delivers the statistics on the usage of labor resource in the project among all the other indices. This indicates whether the labor resource is effectively used in a project and its usage must be lenient or stringent in the progress of the project. Time also adds to the

triangle of the major factors influencing a project. This component is adequately measured using the influence of EVM index known as SV. SV serves more effectively than the other schedule index SPI. It implies whether the project is ahead or behind the schedule. This also gives rise to the estimation of proper utilization of time as a resource. A project which is ahead schedule is minimal of risk. The above three project indices, comprise the factor known as quality. Every project needs to be rendered with the highest quality for customer satisfaction. Hence, measurement of project quality is facilitated by the EVM index, CV. As the terms investments and returns measure the client and contractor satisfaction, this reveals whether the project is profitable to both the contractor and the client. All these factors together mark the productivity of a project. Every contactor aims to achieve a positive project productivity. This is efficiently measured using the EVM index, TCPI. The project that completes on or before planned cost, time and resources specifies a positive project productivity. This efficiently provides the measurement of project characteristics on which the corrective measures are based and applied on the project to improve its performance. This includes the fitting use of available resources. Serving the above, TCPI indicates whether the resources must be used leniently or stringently for activities in the ahead areas of the project. This minimizes the wastage of resources.

The priorities synthesized in the ANP analysis as in Figure 3 show ranking (priorities) of EVM indices for their best selection for project performance measurement. Supporting the above lines, cost variance index CV with a weight of 0.277 on its selection provides the complete status of the project performance. The cost that alters any work or schedule can be effectively measured using CV, thus preventing the project form cost overrun. TCPI index receives the rank next to CV with a weight of 0.219 among the other indices. Every project experiences variations in cost, schedule and labor resources in its progression. The cost-effective project increases the project quality. Supporting the above, TCPI can be effectively used to estimate the required resources to complete a project. This forecasting method of computation leads to an effective usage of resources in the project for its pre-schedule completion. The schedule variance SV stands the next to serve the performance computation with a weight of 0.204. This provides a report over the extended schedule of the project that provides a measure of cost to be incurred due to the project delay that affects the project productivity. EVM indices CPI and SPI show minimal variations on their contribution to the project control with weights of 0.124 and 0.118, respectively. CPI and SPI act as substitutes to CV and SV that show a marginal computation of cost and schedule of the project. The least index among all that adds to the assessment of project performance is CR with a weight of 0.055 which is the minimal of all other weights. This indicates the effective critical path that increases the productivity of the project. Productivity is further influenced by cost, time and labor.

CONCLUSIONS

The data and results of the study reveal that:

- Cost Variance (CV) index is the best selected among all other EVM indices that affect the project characteristics like cost, time, labor, quality and productivity.
- The distribution of priorities in project performance indicates that CV stands as the best project performance measurement index in accordance to which the control measures are formulated in order to improve the project characteristics.
- CV can be effectively used to enumerate and measure the factors that highly affect the project performance. These factors can be tabulated and effective control can be achieved by the project management team. This improves the project performance.
- It is also indicated that the Critical Ratio (CR) is the least among the other EVM indices that shows

minimal effect on the project performance which makes it less fit to be used as a measurement index. On computation, CR does not facilitate the project manager with the factors that affect the project characteristics and their respective control measures.

- Hence, CV is nominated as the best and CR as the least fit EVM indices in accordance to which the project performance is computed and the respective corrective measures are obtained in order to increase the project outcome. It is also indicated that cost is the major project characteristic which on variation highly affects the project performance.
- Cost is the major project characteristic that influences project performance measurement and productivity stands to be the minor characteristic that is dependent on other measures and affects the project performance to minimal.

These head to an effective planning and timely alternative selection by the project manager. This maximizes the profit of a project that satisfies the interests of both the contractor and the client.

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