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Application of Earned Value Management in Indian Construction Projects

Success areas and Limitations of Application of EVM

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Abstract: Earned Value Management has widely been used and considered as the best approach to Measure Performance of a Project. The reliability of EVM in measuring project's current cost performance and forecasting its final cost at completion has been well appreciated since the concept's inception which is considered as a success area of the concept which is also found to be true in case of construction projects. However, it is being discouraged in measuring current schedule performance of a construction project and forecasting Final project duration. This research work identifies the Success areas and Limitations of Application of Earned Value Management in Construction projects by applying it on real time construction projects and then relate the Earned Value Analysis results with what various authors have said in their literatures regarding the Success areas and Limitations of EVM to finally validate the Success areas and Limitations of Application of Earned Value Management in construction projects. The purpose of this research work is to help in making the Construction project management team conscious about the success areas and limitations of Application of Earned Value Management in construction projects so that they can efficiently Monitor (Measuring cost and Schedule performance of the project) and Control the same. In the end this paper derives that EVM schedule measures (SPI, SV) can only indicate whether there is a delay in a construction project or not but cannot measure schedule performance accurately or state by how many days the construction project is running behind the schedule and also recommends what are the various techniques that can cater to the limitations of Application of Earned Value Management in Construction projects.

Index Terms **- Application of Earned Value Management, Indian Construction projects, Success and Limitations of EVM.**

I. INTRODUCTION

One of the most widely used and best performing approaches to measure project cost and schedule performance and their forecasts is based on the Earned Value Management (EVM) matrices. The utility and reliability of EVM as a method for evaluating a construction project's current cost performance and forecasting its actual cost has been endorsed ever since the introduction of the technique in the 1960s for all kinds of projects, (Vanhoucke, Batselier, 2016). EVM outcome prediction for cost is reasonably reliable for large scale projects like Defense new system development, and software development etc. The result of EAC = BAC/CPI is a reasonable running estimate for the final cost as per US DoD database, (Lipke, Zwikael, Henderson, Anbari, 2009). The significance of the CPI metric in Earned Value Management system is empirically proven with over 700 DoD projects studied in USA, (Fleming, Koppelman, 2002). Earned Value Analysis (EVA) methods produce cost-based performance indicators which are not reliable in measuring Schedule performance of a construction project, (Fleming, Koppelman, 2002). The performance of EVM for the time dimension, however, only got the necessary boost from the introduction of the concept of earned schedule (ES) given by Walt Lipke in 2009 which has been successful for construction projects except for its limitations in accurately forecast Project's duration at completion, (Vanhoucke, Batselier, 2016).

II. NEED OF THE RESEARCH

The reliability of EVM in measuring and forecasting Cost and Schedule performance of various types of projects is already proven based on their robust database i.e. large scale Defense new system development projects, Software development projects, DoD projects etc. Since construction projects are also large scale projects and shows similar degree of complexity the results are likely to be relatable with the above mentioned projects. But the reliability of the concept cannot be established for Construction projects also without analyzing the results of EVM Measures applied on them. Reliability of the concept is defined as how far the concept is successful in measuring and forecasting cost and schedule performance of a construction project and what are its limitations. The concept's reliability for construction projects can only be validated by applying EVM on several construction projects (at least 6 to 8) with varying building typology, diversity in project cost and duration data and the scale of the projects instead of dragging conclusion from analysis carried out on other similar types of projects. Hence ample amount of research is required regarding Application of EVM in construction projects and to validate the concept's reliability for construction projects EVM is needed to be applied on the same and results are needed to be well analyzed.

III. AIM OF RESEARCH

The aim of this research paper is to understand the success areas and limitations of Application of Earned Value Management in construction projects.

IV. OBJECTIVES

1. To identify the success areas and limitations of Application of Earned Value Management in Construction projects.
2. To apply Earned Value Management on construction projects in order to create a database for further analysis which shall lead to validation of the concept's success and limitations. (8 Case studies).
3. To validate the Success areas and Limitations of Application of Earned Value Management in construction projects.

V. RESEARCH METHODOLOGY

To achieve the research objectives, the following research steps are followed:

Step 1 - Identify the success areas and limitations of Application of Earned Value Management in construction projects.by doing comprehensive Literature review and formulate a Hypothesis originated from the same.

Step 2 - Apply Earned Value Management on 8 Indian construction projects as Case studies using Earned Value Analysis (EVA) as a tool in order to create a database for further analysis which shall lead to validation of the Hypothesis addressing the concept's success areas and limitations.

Step 3 - Validate the Hypothesis addressing Success areas and Limitations of Application of Earned Value Management in construction projects by relating its statements to the results of Earned Value Analysis (EVA) applied on 8 live construction projects.

VI. LITERATURE REVIEW

To have a reasonable understanding on the subject matter, a comprehensive literature study has been carried out to identify success areas and limitations of Application of EVM in construction projects in the following key areas:

6.1 Cost Performance Measurement

EVM is a reliable method for evaluating a project's current cost performance (Lipke, 2009), (Lipke, Zwikael, Henderson, Anbari, 2009), (Jose, Carlos, 2006), (Fleming, Koppelman, 2002), (Vanhoucke, Batselier, 2016). CPI which is a Cost performance measure gets stabilized at the 20% completion point of a project. The final CPI does not vary by more than ±10% from the value at 20% completion. Thus, the CPI can be used to forecast the final project costs from 20% completion point of a construction project (Fleming, Koppelman, 2002), (Lipke, Zwikael, Henderson, Anbari, 2009). But for small scale construction projects (1 – 1.5 year; $1,000,000 – $3,000,000) CPI stability is seldom observed (Lipke, Zwikael, Henderson, Anbari, 2009).

6.2 Cost Performance Forecasting

EVM drags the performance of old activities which are not even relevant in forecasting future cost performance of construction projects. The concept also gives equal importance to every past activity while predicting project cost outcome (EAC$) of construction projects. EVM outcome prediction for cost (EAC$) is reasonably reliable for large scale construction projects. but not very much reliable for small scale projects (Vanhoucke, Batselier, 2016).

6.3 Schedule Performance Measurement

Schedule Performance Index (SPI) in EVM is expected to deliver similar accuracy level of Cost Performance Index (CPI) as far as measuring and forecasting schedule performance of construction projects is concerned. However, EVM does not measure schedule performance using time series data instead of that it uses cost based schedule performance indicators which makes them practically useless and often misleading. SV, SPI are not reliable indices to assess project schedule performance since it uses cost base EVM fundamentals to measure Schedule performance of a construction project (Lipke, Zwikael, Henderson, Anbari, 2009), (Vanhoucke, Batselier, 2016), (Khamooshi, Golafshani, 2013). SV = 0 or SPI = 1, could mean that a task is completed, but could also mean that the task is running according to plan. Towards the end of a construction project, SV always converges to 0 indicating a perfect performance even if the project is late. Similarly, the SPI always converges to 1 towards the end of the project, indicating a 100% schedule efficiency even in the project is late (Vanhoucke, Vandevoorde, 2005). SV and SPI works fine for construction projects which go as per planned schedule and are not subject to delay (Lipke, 2009). SPI may give reasonable results in the initial stage of a construction project (1/3) but are not reliable in the later stages of project (2/3 completion percent), (Fleming, Koppelman, 2002).

6.4 Schedule Performance Forecasting

EVM outcome prediction for schedule performance, EAC (t) is not at all reliable since it is a function of SPI which already has fundamental flaws at the concept's foundation level. (Lipke, Zwikael, Henderson, Anbari, 2009), (Khamooshi, Golafshani, 2013), (Vanhoucke, Batselier, 2016). Calculation of SPI drags along the performance of the earliest project phases as well which may not necessarily affect the future schedule performance of the project (Vanhoucke, Vandevoorde, 2005). EAC(t) calculations also do not consider the criticality of tasks that are on the Critical path since delay in these activities can result in delay to the overall project (Settlemire, 2016).

VII. FORMULATION OF HYPOTHESIS

A Hypothesis consisted of 16 statements is formulated based on the statements stated by various authors in their various literatures regarding Success areas and Limitations of Application of EVM in Construction projects. These statements are to be validated by analyzing the Earned Value Analysis results applied on 8 Indian construction projects which shall further validate the Success areas and Limitations of Application of EVM in Construction projects.

Table 7.1.1: Hypothesis addressing Success areas and Limitations of Application of EVM in Construction projects

Key areas in EVM	Hypothesis: Success areas and Limitations of Application of EVM in Construction projects
Cost Performance Measurement	1. CPI gets stabilized at the 20% completion point of a project.
	2. The final CPI of a project does not vary by more than ±10% from the value of CPI at 20% completion.
	3. CPI can be used to forecast the final project cost from 20% completion point of a project.
	4. EVM is a reliable method for evaluating a project's current cost performance.
	5. In small scale projects (1–1.5 year; $1,000,000–$3,000,000) CPI stability is seldom observed.
Cost Performance Forecasting	6. EVM drags the performance of old activities which are not even relevant in forecasting future cost performance.
	7. EVM gives equal importance to every past activity while predicting project cost outcome (EAC)
	8. EVM outcome prediction for cost (EAC$) is reasonably reliable for large scale projects. but not very much reliable for small scale projects.
Schedule Performance Measurement	9. SV, SPI are not reliable indices to assess project schedule performance since it uses cost base EVM fundamentals to measure Schedule performance of a project.
	10. SV = 0 or SPI = 1, could mean that a task is completed, but could also mean that the task is running according to plan.
	11. Towards the end of a project, SV always converges to 0 indicating a perfect performance even if the project is late. Similarly, the SPI always converges to 1 towards the end of the project, indicating a 100% schedule efficiency even in the project is late.
	12. SV and SPI works fine for projects which go as per planned schedule and not subject to delay.
	13. SPI may give reasonable results in the initial stage of a project (1/3) but are not reliable in the later stages of the project (2/3 completion percent).
Schedule Performance Forecasting	14. EVM outcome prediction for schedule performance, EAC (t) is not at all reliable since it is a function of SPI which already has fundamental flaws at the concept's foundation level.
	15. Calculation of SPI drags along the performance of the earliest project phases as well which may not necessarily affect the future schedule performance of the project.
	16. EAC(t) calculations also do not consider the criticality of tasks that are on the Critical path since delay in these activities can result in delay to the overall project.

VIII. APPLICATION OF EVM IN CONSTRUCTION PROJECTS – CASE STUDY

8.1 Case study selection

In this research paper 8 live nearly completed/completed Indian construction projects were taken as case studies. Table 8.1.1 shows Building typology, Project duration, Projects cost and Built-up area of all the case studies.

Table 8.1.1: Hypothesis addressing Success areas and Limitations of Application of EVM in Construction projects

Case study	Typology	Project Duration	Project Cost (Rs)	Built-up area (sqm)
Case study 1	Residential	869 days	22.12 cr	7290
Case study 2	Office building	807 days	63.84 cr	20469
Case study 3	Hospital	1279 days	614.35 cr	137786
Case study 4	Residential	431 days	4.35 cr	800
Case study 5	Educational	697 days	66.41 cr	13570
Case study 6	Residential	326 days	13.66 cr	4510
Case study 7	Residential	1298 days	37.07 cr	16240
Case study 8	Hospital	1280 days	578.48 cr	92448

8.2 Data collection

The raw data such as Planned and Actual Schedule data and Planned and Actual Cost data of 8 the case studies were collected to establish the Project Baseline. Table 8.2.1 partially shows Project Baseline of Case study 1. Then those construction projects were monitored throughout their project duration in regular interval and a Project Progress Report was formulated for each construction project. Table 8.2.2 and table 8.2.3 shows Project Progress Report on a specific status date and Project Progress Report throughout the Project duration respectively. Then cost and schedule performances of all the case studies are measured and forecasted and Earned Value Analysis Report (EVA Report) is formulated. Table 8.2.4 shows EVA Report of Case study 1.

Table 8.2.1 Project Baseline - Case study 1

Activity	Baseline Duration	Baseline Start	Baseline Finish	Actual Duration	Actual Start	Actual Finish	Planned Cost	Actual Cost
Genexx Valley Apartment, Kolkata	**869 days**	**Mon 04-09-17**	**Fri 12-06-20**	**913 days**	**Mon 04-09-17**	**Mon 03-08-20**	**₹ 16,46,72,804.19**	**₹ 19,44,49,740.53**
Site enabling works	15 days	Mon 04-09-17	Wed 20-09-17	15 days	Mon 04-09-17	Wed 20-09-17	₹ 1,53,379.47	₹ 1,59,083.86
Site clearance	3 days	Thu 21-09-17	Sat 23-09-17	3 days	Thu 21-09-17	Sat 23-09-17	₹ 76,689.73	₹ 79,180.52
Mobilization of materials and labours	15 days	Mon 25-09-17	Wed 11-10-17	15 days	Mon 25-09-17	Wed 11-10-17	₹ 6,13,517.88	₹ 6,30,497.38
Mobilization of machinery, tools and plants	7 days	Wed 04-10-17	Wed 11-10-17	7 days	Wed 04-10-17	Wed 11-10-17	₹ 6,90,207.61	₹ 7,07,033.42
Civil Works	**641 days**	**Thu 12-10-17**	**Tue 29-10-19**	**676 days**	**Thu 12-10-17**	**Mon 09-12-19**		
Substructure	**164 days**	**Thu 12-10-17**	**Fri 20-04-18**	**177 days**	**Thu 12-10-17**	**Sat 05-05-18**		
Excavation	32 days	Thu 12-10-17	Fri 17-11-17	45 days	Thu 12-10-17	Sat 02-12-17	₹ 16,41,391.68	₹ 23,96,826.87
Raft foundation	**29 days**	**Sat 18-11-17**	**Thu 21-12-17**	**29 days**	**Mon 04-12-17**	**Fri 05-01-18**		₹ 0.00
Reinforcement	17 days	Sat 18-11-17	Thu 07-12-17	17 days	Mon 04-12-17	Fri 22-12-17	₹ 17,46,540.01	₹ 24,57,416.76
Shuttering	3 days	Thu 07-12-17	Sat 09-12-17	3 days	Fri 22-12-17	Mon 25-12-17	₹ 22,55,947.51	₹ 32,06,080.51
Concreting	10 days	Mon 11-12-17	Thu 21-12-17	10 days	Tue 26-12-17	Fri 05-01-18	₹ 32,74,762.51	₹ 46,13,300.89
Basement	**97 days**	**Fri 29-12-17**	**Fri 20-04-18**	**97 days**	**Sat 13-01-18**	**Sat 05-05-18**		
-2B Basement lvl	**15 days**	**Fri 29-12-17**	**Mon 15-01-18**	**15 days**	**Sat 13-01-18**	**Tue 30-01-18**		
Shuttering	10 days	Fri 29-12-17	Tue 09-01-18	10 days	Sat 13-01-18	Wed 24-01-18	₹ 20,46,715.33	₹ 27,99,543.92
Reinforcement	6 days	Fri 05-01-18	Thu 11-01-18	6 days	Sat 20-01-18	Fri 26-01-18	₹ 15,84,553.80	₹ 21,87,031.58
Concreting	3 days	Fri 12-01-18	Mon 15-01-18	3 days	Sat 27-01-18	Tue 30-01-18	₹ 29,71,038.38	₹ 41,04,126.63
Columnl upto -1B Basement lvl	**10 days**	**Tue 23-01-18**	**Fri 02-02-18**	**10 days**	**Wed 07-02-18**	**Sat 17-02-18**		
Reinforcement	5 days	Tue 23-01-18	Sat 27-01-18	5 days	Wed 07-02-18	Mon 12-02-18	₹ 10,56,369.20	₹ 14,77,208.15
Shuttering	4 days	Fri 26-01-18	Tue 30-01-18	4 days	Sat 10-02-18	Wed 14-02-18	₹ 13,64,476.89	₹ 19,16,147.03
Concreting	3 days	Wed 31-01-18	Fri 02-02-18	3 days	Thu 15-02-18	Sat 17-02-18	₹ 19,80,692.25	₹ 27,66,863.52
-1B basement lvl	**19 days**	**Sat 10-02-18**	**Sat 03-03-18**	**19 days**	**Mon 26-02-18**	**Mon 19-03-18**		
Shuttering	10 days	Sat 10-02-18	Wed 21-02-18	10 days	Mon 26-02-18	Thu 08-03-18	₹ 20,46,715.33	₹ 27,77,786.57

Table 8.2.2 Project Progress Report as on 05-01-2018 - Case study 1

Activity	% Completed (Planned)	% Completed (Actual)	Baseline Duration	Actual Duration	Planned Cost/BCWS	Earned Cost/BCWP	Actual Cost/ACWP
Genexx Valley Apartment, Kolkata	**13%**	**13%**	**869 days**	**913 days**	**₹ 1,70,54,743.92**	**₹ 1,10,94,747.74**	**₹ 1,48,09,328.98**
Site enabling works	100%	100%	15 days	15 days	₹ 1,53,379.47	₹ 1,53,379.47	₹ 1,59,083.86
Site clearing	100%	100%	3 days	3 days	₹ 76,689.73	₹ 76,689.73	₹ 79,180.52
Mobilization of materials and labours	100%	100%	15 days	15 days	₹ 6,13,517.88	₹ 6,13,517.88	₹ 6,30,497.38
Mobilization of machinery, tools and plants	100%	100%	7 days	7 days	₹ 6,90,207.61	₹ 6,90,207.61	₹ 7,07,033.42
Civil Works	**13%**	**12%**	**641 days**	**676 days**			
Substructure	**50%**	**46%**	**164 days**	**177 days**			
Excavation	**100%**	100%	32 days	45 days	₹ 16,41,391.68	₹ 16,41,391.68	₹ 23,96,826.87
Raft foundation	**100%**	**100%**	**29 days**	**29 days**			
Reinforcement	100%	100%	17 days	17 days	₹ 29,21,028.83	₹ 29,21,028.83	₹ 24,57,416.76
Shuttering	100%	100%	3 days	3 days	₹ 38,558.00	₹ 38,558.00	₹ 32,06,080.51
Concreting	100%	100%	10 days	10 days	₹ 43,17,663.20	₹ 43,17,663.20	₹ 46,13,300.89
Basement	**15%**	**2%**	**97 days**	**97 days**			
-2B Basement lvl	**100%**	**13%**	**15 days**	**15 days**			
Reinforcement	100%	20%	10 days	10 days	₹ 32,11,556.67	₹ 6,42,311.33	₹ 5,59,908.78
Shuttering	100%	0%	6 days	6 days	₹ 6,20,790.24	₹ 0.00	₹ 0.00
Concreting	**100%**	**0%**	**3 days**	**3 days**	**₹ 27,69,960.60**	**₹ 0.00**	**₹ 0.00**
Columnl upto -1B Basement lvl	**0%**	**0%**	**10 days**	**10 days**			
Reinforcement	0%	0%	5 days	5 days	₹ 21,41,037.78	₹ 0.00	₹ 0.00
Shuttering	0%	0%	4 days	4 days	₹ 4,13,860.16	₹ 0.00	₹ 0.00
Concreting	0%	0%	3 days	3 days	₹ 18,46,640.40	₹ 0.00	₹ 0.00

Table 8.2.3 Project Progress Report - Case study 1

Date	% Completed (Planned)	% Completed (Actual)	Planned Cost/BCWS	Earned Cost/BCWP	Actual Cost/ACWP
17-11-2017	7%	7%	₹ 31,75,186.38	₹ 26,99,182.79	₹ 32,16,635.53
15-01-2018	13%	13%	₹ 1,70,54,743.92	₹ 1,10,94,747.74	₹ 1,42,35,305.56
20-04-2018	23%	22%	₹ 3,90,62,435.62	₹ 3,43,87,062.11	₹ 4,64,76,016.55
25-07-2018	32%	31%	₹ 4,35,53,502.38	₹ 4,24,40,984.12	₹ 5,73,07,484.05
29-10-2018	42%	40%	₹ 4,80,44,569.14	₹ 4,65,47,546.88	₹ 6,27,84,458.67
01-02-2019	51%	49%	₹ 5,38,44,506.07	₹ 5,04,50,312.52	₹ 6,80,22,779.00
08-05-2019	60%	58%	₹ 6,04,58,015.77	₹ 5,48,03,633.28	₹ 7,38,75,065.30
12-08-2019	70%	66%	₹ 8,88,06,215.05	₹ 7,40,36,503.80	₹ 9,60,38,825.80
29-10-2019	78%	74%	₹ 11,78,21,733.30	₹ 9,95,90,003.55	₹ 12,33,29,575.21
15-02-2020	88%	84%	₹ 15,79,10,673.47	₹ 14,00,13,743.25	₹ 16,51,48,013.85
03-08-2020	100%	100%	₹ 16,47,27,744.19	₹ 16,47,27,744.19	₹ 19,06,39,203.42

Table 8.2.4 Earned Value Analysis (EVA) Report - Case study 1

Date	BCWS	BCWP	ACWP	CV	SV	BAC	EAC ($)	% Deviation	CPI	SPI	CR
17-11-2017	₹ 31,75,186.38	₹ 26,99,182.79	₹ 32,16,635.53	-₹ 5,17,452.74	-₹ 4,76,003.59	₹ 31,75,186.38	₹ 2,03,24,260.90	42.77%	0.839132	0.850086	0.713335
15-01-2018	₹ 1,70,54,743.92	₹ 1,10,94,747.74	₹ 1,42,35,305.56	-₹ 31,40,557.81	-₹ 59,59,996.18	₹ 1,70,54,743.92	₹ 5,01,19,725.09	7.84%	0.779382	0.650537	0.507017
20-04-2018	₹ 3,90,62,435.62	₹ 3,43,87,062.11	₹ 4,64,76,016.55	-₹ 1,20,88,954.44	-₹ 46,75,373.51	₹ 3,90,62,435.62	₹ 5,88,64,967.61	2.72%	0.739888	0.88031	0.651331
25-07-2018	₹ 4,35,53,502.38	₹ 4,24,40,984.12	₹ 5,73,07,484.05	-₹ 1,48,66,499.93	-₹ 11,12,518.26	₹ 4,35,53,502.38	₹ 6,48,73,928.74	3.33%	0.740584	0.974456	0.721666
29-10-2018	₹ 4,80,44,569.14	₹ 4,65,47,546.88	₹ 6,27,84,458.67	-₹ 1,62,36,911.79	-₹ 14,97,022.26	₹ 4,80,44,569.14	₹ 7,26,26,773.98	6.77%	0.741386	0.968841	0.718286
01-02-2019	₹ 5,38,44,506.07	₹ 5,04,50,312.52	₹ 6,80,22,779.00	-₹ 1,75,72,466.48	-₹ 33,94,193.55	₹ 5,25,46,217.90	₹ 8,15,16,288.81	10.34%	0.741668	0.936963	0.694915
08-05-2019	₹ 6,04,58,015.77	₹ 5,48,03,633.28	₹ 7,38,75,065.30	-₹ 1,90,71,432.03	-₹ 56,54,382.49	₹ 5,70,61,048.66	₹ 11,97,10,401.37	24.65%	0.741842	0.906474	0.672461
12-08-2019	₹ 8,88,06,215.05	₹ 7,40,36,503.80	₹ 9,60,38,825.80	-₹ 2,20,02,322.00	-₹ 1,47,69,711.25	₹ 8,88,06,215.05	₹ 15,28,36,240.76	23.93%	0.770902	0.833686	0.64269
29-10-2019	₹ 11,78,21,733.30	₹ 9,95,90,003.55	₹ 12,33,29,575.21	-₹ 2,37,39,571.66	-₹ 1,82,31,729.75	₹ 11,78,21,733.30	₹ 19,55,52,320.36	18.41%	0.807511	0.84526	0.682557
15-02-2020	₹ 15,79,10,673.47	₹ 14,00,13,743.25	₹ 16,51,48,013.85	-₹ 2,51,34,270.60	-₹ 1,78,96,930.22	₹ 15,79,10,673.47	₹ 19,42,98,496.33	1.92%	0.847808	0.886664	0.751721
03-08-2020	₹ 16,47,27,744.19	₹ 16,47,27,744.19	₹ 19,06,39,203.42	-₹ 2,59,11,459.23	₹ 0.00	₹ 16,47,27,744.19	NA	NA	0.864081	1	0.864081
							₹ 22,26,38,658.11				

8.3 Database formulation

Project Baseline data, Project Progress Report and Earned Value Analysis Report of all the 8 case studies shall act as key inputs to Post Earned Value Analysis I.e. Comparative analysis of EVA measures of case studies, CPI/SPI Trend analysis, %Deviation analysis etc. which shall lead to Validation of the Hypothesis addressing Success areas and Limitations of Application of EVM in Construction projects.

IX. VALIDATION OF HYPOTHESIS

Comparative analysis EVA measures of case studies, CPI/SPI Trend analysis, %Deviation analysis etc. are tools used in this paper to validate the 16 Statements of the Hypothesis addressing Success areas and Limitations of Application of EVM in Construction projects. The validation of the 16 statements are as followed:

9.1 Statement 1

CPI gets stabilized at the 20% completion point of a project. (Fleming, Koppelman, 2002), (Lipke, Zwikael, Henderson, Anbari, 2009)

Table 9.1.1: CPI Comparison and %Deviation

Status Date	CPI - CS 1	CPI - CS 2	CPI - CS 3	CPI - CS 4	CPI - CS 5	CPI - CS 6	CPI - CS 7	CPI - CS 8
Status Date 1	0.823539	0.865589	1		0.8656	0.945933	0.943209	1
Status Date 2	0.749173	0.904352	0.989958	0.910825	0.871213	0.912743	0.947333	0.890944
Status Date 3	0.741559	0.935466	0.95189	0.915067	0.877567	0.918239	0.939055	0.893185
Status Date 4	0.728802	0.966699	0.872511	0.92785	0.874078	0.913384	0.926433	0.914531
Status Date 5	0.727208	0.973415	0.812252	0.933616	0.885003	0.909972	0.925609	0.924298
Status Date 6	0.728348	0.965943	0.812111	0.934594	0.897004	0.912384	0.92814	0.930211
Status Date 7	0.727667	0.959158	0.821709	0.937975	0.899811	0.908004	0.92926	0.936942
Status Date 8	0.756311	0.95399	0.817061	0.9401	0.941153	0.891725	0.929853	0.940031
Status Date 9	0.791877	0.930017	0.800729	0.937308	0.928244	0.892852	0.929483	0.944588
Status Date 10	0.831317	0.927508	0.820208	0.929258	0.92735	0.892551	0.92814	0.948388
Status Date 11	0.846866	0.938291	0.837238	0.922201	0.919477		0.932076	0.950395
Status Date 12			0.864177	0.91505			0.931088	0.952379
Status Date 13			0.877572	0.916903			0.926318	0.947482
Status Date 14			0.883485				0.924744	0.940026
Status Date 15			0.888992				0.923733	0.932662
Status Date 16			0.889451				0.923131	0.931782
Status Date 17							0.928691	0.931691
Status Date 18							0.927519	0.932076
Status Date 19							0.926867	0.932589
Status Date 20								
CPI @20%	0.741559	0.935466	0.872511	0.92785	0.874078	0.918239	0.925609	0.914531
CPI @100%	0.846866	0.938291	0.889451	0.916903	0.919477	0.892551	0.926867	0.932589
%Deviation	14.20%	0.30%	1.94%	-1.18%	5.19%	-2.80%	0.14%	1.97%

CPI comparison in table 9.1.1 shows that in 7 cases the minimum to maximum %Deviation ranges from 0.14% to 2.80%. One exceptional case which is showing 14.20% of deviation from 20% completion to 100% completion state of a construction project. If this value is considered as an outlier there is 87.5% probability that the CPI gets stabilized at 20% completion state of a construction project. It is observed that in most the cases at 20% completion state the activities like Site Preparation, Excavation, Foundation etc. gets completed and Structural work of Substructure i.e. RCC works of Basements etc. remains under progress. Figure 38 shows irrespective of how worse the CPI gets during the execution of construction project the Trend remains stable. Hence "Statement 1" is validated as True by using %Deviation analysis and CPI Trend analysis as tools.

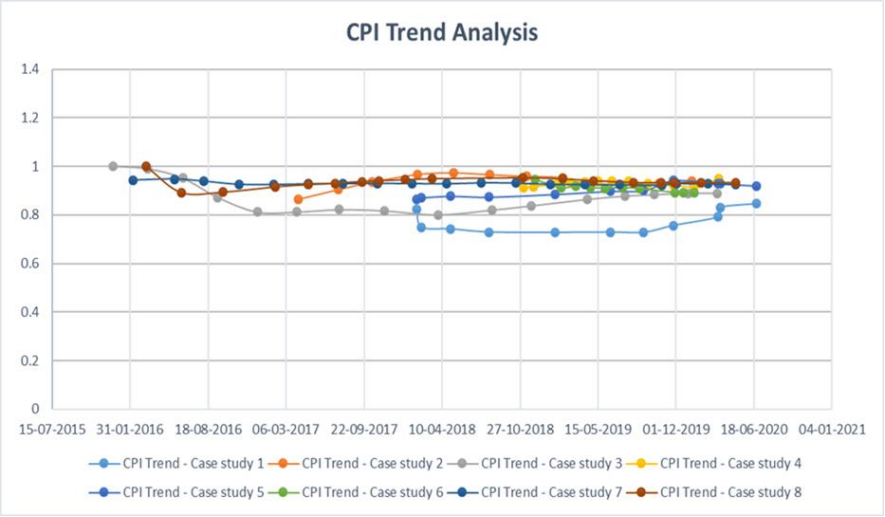

Figure 9.1.1: CPI Trend Analysis

9.2 Statement 2

The final CPI does not vary by more than ±10% from the value at 20% completion of a project. (Fleming, Koppelman, 2002), (Lipke, Zwikael, Henderson, Anbari, 2009)

Table 9.1.1 clearly defines that in most of the cases (7 in 8 cases) the %Deviation from CPI at 20% completion state to CPI at100% completion state vary within the range of ±10% if we consider Case 1 as an exception. Figure 9.2.1 bellow shows a graphical representation of the %Deviation from CPI at 20% completion state to CPI at 100% completion state of 8 construction projects. Therefore "Statement – 2" is Validated as True using %Deviation analysis as a tool.

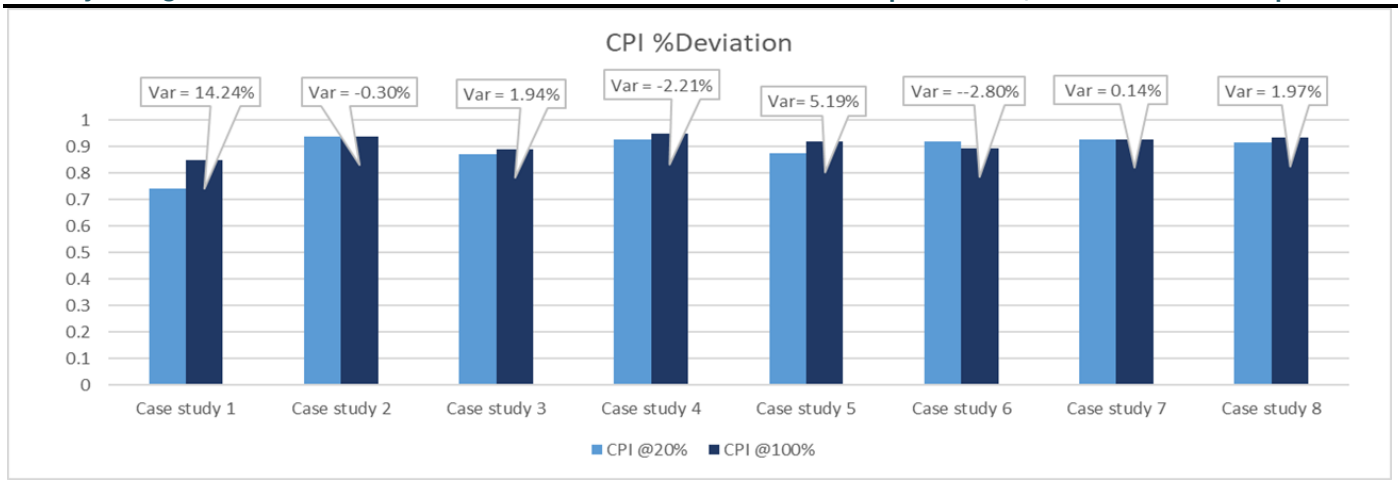

Figure 9.2.1: CPI %Deviation

9.3 Statement 3

CPI can be used to forecast the final project costs (EAC$) from 20% completion point. (Fleming, Koppelman, 2002), (Lipke, Zwikael, Henderson, Anbari, 2009)

Table 9.1.1, Figure 9.1.1 and 9.2.1 supports the fact that CPI of Construction project gets stabilized at 20% completion state. More stable the value of CPI more accurately EAC ($) can predict the Final cost at completion Now EAC ($) or Estimated cost at Completion which is use to Forecast Cost performance of a construction projects is a linear function of CPI i.e. [EACCOST = AC + (BAC-EV) / CPI]. Table 32 shows a comparison among Actual cost at completion and Estimated cost at completion of 8 construction projects. %Deviation analysis says, every 7 out of 8 cases show a range of ±0.14% to ±5.19% deviation between Actual cost at completion and Estimated cost at completion. Therefore "Statement – 3" is Validated as True.

Table 9.3.1: %Deviation between EAC ($) and Actual cost at completion

Case study	Actual cost at 20% completion	Actual cost at 100% completion	Estimate at 100% completion - EAC($)	%Deviation	CPI at 20% completion
Case study 1	₹ 4,63,71,289.86	₹ 19,44,49,740.53	₹ 22,20,62,888.37	14.20%	0.74156
Case study 2	₹ 4,86,36,757.72	₹ 68,03,95,208.12	₹ 68,24,49,802.34	0.30%	0.93547
Case study 3	₹ 90,37,65,962.11	₹ 6,90,71,66,027.26	₹ 7,04,12,71,225.30	1.94%	0.87251
Case study 4	₹ 1,05,61,185.60	₹ 4,75,25,033.07	₹ 4,69,64,315.14	-1.18%	0.92785
Case study 5	₹ 8,42,14,587.28	₹ 72,23,29,130.60	₹ 75,98,45,965.78	5.19%	0.87408
Case study 6	₹ 2,89,99,347.43	₹ 15,31,30,177.67	₹ 14,88,46,348.93	-2.80%	0.91824
Case study 7	₹ 10,31,82,071.44	₹ 40,00,44,025.31	₹ 40,05,87,988.72	0.14%	0.92561
Case study 8	₹ 65,48,34,568.18	₹ 6,20,29,85,414.95	₹ 6,32,04,01,717.96	1.89%	0.91453

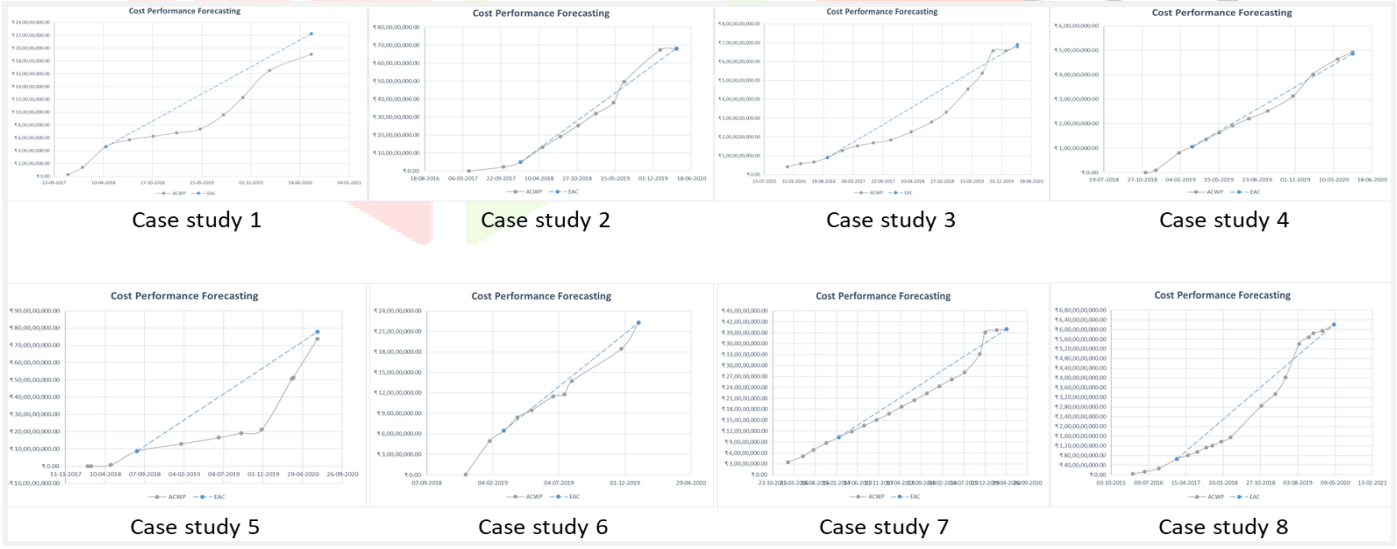

Figure 9.3.1: Comparative EAC ($) analysis of case studies

9.4 Statement 4

EVM is a reliable method for evaluating a project's current cost performance. (Lipke, 2009), (Lipke, Zwikael, Henderson, Anbari, 2009), (Jose, Carlos, 2006), (Fleming, Koppelman, 2002), (Vanhoucke, Batselier, 2016)

Cost performance evaluation = Cost Performance Measurement + Cost Performance Forecasting

CPI is a reliable Cost performance index since it's a ratio of Earned cost to Actual cost incurred to the construction project i.e. CPI = Earned Value (EV) / Actual Cost (AC). Table 9.4.1 gives a comparative idea of CPI and %Cost overrun of Case study 4. CPI and %Cost overrun are very much relatable which defines CPI is a reliable indicator in measuring cost performance of a construction project. Similar type of relation is observed in the other 7 case studies also. Cost Performance Forecasting: Statement 1, 2 and 3 are already in support of the fact that CPI is a reliable EVM indices which plays a fundamental role in calculating EAC($). Therefore "Statement – 4" is Validated as True.

Table 9.4.1: Reliability of CPI

Date	Planned Cost/BCWS	Earned Cost/BCWP	Actual Cost/ACWP	% Cost Overrun	CPI
05-11-2018	₹ 23,305.64	₹ 0.00	₹ 0.00		0
01-12-2018	₹ 13,25,798.88	₹ 8,57,396.84	₹ 9,41,340.79	9.79%	0.910825
31-01-2019	₹ 89,84,126.71	₹ 73,57,842.59	₹ 80,40,765.31	9.28%	0.915067
07-03-2019	₹ 1,16,83,968.37	₹ 97,99,192.43	₹ 1,05,61,185.60	7.78%	0.92785
11-04-2019	₹ 1,44,13,046.30	₹ 1,25,79,386.17	₹ 1,34,73,837.49	7.11%	0.933616
16-05-2019	₹ 1,70,82,233.22	₹ 1,52,88,353.47	₹ 1,63,58,276.77	7.00%	0.934594
20-06-2019	₹ 1,97,88,274.40	₹ 1,79,64,468.27	₹ 1,91,52,397.62	6.61%	0.937975
02-08-2019	₹ 2,10,66,324.83	₹ 2,07,81,875.34	₹ 2,21,06,026.52	6.37%	0.9401
20-09-2019	₹ 2,58,38,279.31	₹ 2,20,63,789.14	₹ 2,35,39,520.63	6.69%	0.937308
25-11-2019	₹ 3,27,79,247.49	₹ 2,75,56,937.07	₹ 2,96,54,761.65	7.61%	0.929258
16-01-2020	₹ 3,85,09,306.44	₹ 3,55,75,690.80	₹ 3,85,76,942.13	8.44%	0.922201
20-03-2020	₹ 4,35,75,823.63	₹ 4,09,53,083.77	₹ 4,47,55,028.28	9.28%	0.91505
29-04-2020	₹ 4,35,75,823.63	₹ 4,50,70,123.63	₹ 4,75,25,033.07	5.45%	0.948345

9.5 Statement 5

For small scale projects (1 – 1.5 year; $1,000,000 – $3,000,000 or ₹7,00,00,000 - ₹21,00,00,000) CPI stability is seldom observed. (Lipke, Zwikael, Henderson, Anbari, 2009)

Table 8.1.1 shows that, Case study 4 and Case study 6 meets the criteria of being small scaled construction project as mentioned by the authors Lipke, Zwikael, Henderson and Anbari (2009). Table 9.1.1 shows similar kind of CPI stability in Case study 4 and 6 showing a %Deviation ranging from ±0.18 to ±2.80 which falls under ±10% range of deviation. Therefore "Statement – 5" is Validated as Not True.

9.6 Statement 6

EVM drags the performance of old activities which are not even relevant in forecasting future cost performance. (Vanhoucke, Batselier, 2016)

Table 9.6.1 shows Planned cost, Earned cost and Actual cost data of Earned Value Analysis Report of Case study 4 on 13 consecutive status dates. The costs appearing on table 9.6.1 are nothing but cumulative costs of construction activities of Case study 4 on 13 consecutive status dates starting from 05-11-2018. Therefore, on 07-03-2019 if the construction work witnesses its 20% completion completing activities like Site Preparation, Excavation, Foundation, RCC works of Substructure etc. on subsequent status dates irrespective of whether or not these activities faced any delay or cost overrun the effect of the same is likely to get carried over. Since CPI is a function of Earned cost/BCWP and Actual cost/ACWP, the carry over effect affects CPI of subsequent status dates.in the similar manner. The similar observations can be made in other 7 case studies. Therefore "Statement – 6" is Validated as True.

Table 9.6.1: CPI – Carry over

Date	BCWS	BCWP	ACWP	CPI
05-11-2018	₹ 23,305.64	₹ 0.00	₹ 0.00	
01-12-2018	₹ 13,25,798.88	₹ 8,57,396.84	₹ 9,41,340.79	0.910825
31-01-2019	₹ 89,84,126.71	₹ 73,57,842.59	₹ 80,40,765.31	0.915067
07-03-2019	₹ 1,16,83,968.37	₹ 97,99,192.43	₹ 1,05,61,185.60	0.92785
11-04-2019	₹ 1,44,13,046.30	₹ 1,25,79,386.17	₹ 1,34,73,837.49	0.933616
16-05-2019	₹ 1,70,82,233.22	₹ 1,52,88,353.47	₹ 1,63,58,276.77	0.934594
20-06-2019	₹ 1,97,88,274.40	₹ 1,79,64,468.27	₹ 1,91,52,397.62	0.937975
02-08-2019	₹ 2,10,66,324.83	₹ 2,07,81,875.34	₹ 2,21,06,026.52	0.9401
20-09-2019	₹ 2,58,38,279.31	₹ 2,20,63,789.14	₹ 2,35,39,520.63	0.937308
25-11-2019	₹ 3,27,79,247.49	₹ 2,75,56,937.07	₹ 2,96,54,761.65	0.929258
16-01-2020	₹ 3,85,09,306.44	₹ 3,55,75,690.80	₹ 3,85,76,942.13	0.922201
20-03-2020	₹ 4,35,75,823.63	₹ 4,09,53,083.77	₹ 4,47,55,028.28	0.91505
29-04-2020	₹ 4,35,75,823.63	₹ 4,35,75,823.63	₹ 4,75,25,033.07	0.916903

9.7 Statement 7

EVM gives equal importance to every past activity while predicting project cost outcome (EAC$). (Vanhoucke, Batselier, 2016)

EVM drags the performance of old construction activities in current construction activities because of the Carry over effect. But this phenomenon does not affect the Final cost outcome prediction (refer table 9.7.1) because in the end every construction activity will have equal contribution to Final actual cost of the construction project. But if we consider the Expected Cost outcome of an intermediate near future status date (07-03-2019) using CPI of current status date (31-01-2019, CPI = 0.91507), it's unlikely that all past construction activities too will have equal contribution in forecasting the same. A comparative analysis of 8 case studies shows a wide range of %Deviation (±0.05% to ±54.8%) while calculating EAC ($) of intermediate status dates. Therefore "Statement – 7" is Validated as True.

Table 9.7.1: EAC ($) calculations on intermediate status dates

Case study	Date	BAC	Earned Cost	Actual Cost	EAC ($)	% Deviation	CPI
Case study 4	05-11-2018	₹ 23,305.64	₹ 0.00	₹ 0.00	₹ 0.00	0.00%	0.00000
	01-12-2018	₹ 13,25,798.88	₹ 8,57,396.84	₹ 9,41,340.79	₹ 98,63,722.99	22.67%	0.91083
	31-01-2019	₹ 89,84,126.71	₹ 73,57,842.59	₹ 80,40,765.31	₹ 1,27,68,423.13	20.90%	0.91507
	07-03-2019	₹ 1,16,83,968.37	₹ 97,99,192.43	₹ 1,05,61,185.60	₹ 1,55,33,816.51	15.29%	0.92785
	11-04-2019	₹ 1,44,13,046.30	₹ 1,25,79,386.17	₹ 1,34,73,837.49	₹ 1,82,96,857.35	11.85%	0.93362
	16-05-2019	₹ 1,70,82,233.22	₹ 1,52,88,353.47	₹ 1,63,58,276.77	₹ 2,11,73,115.20	10.55%	0.93459
	20-06-2019	₹ 1,97,88,274.40	₹ 1,79,64,468.27	₹ 1,91,52,397.62	₹ 2,24,59,369.44	1.60%	0.93797
	02-08-2019	₹ 2,10,66,324.83	₹ 2,07,81,875.34	₹ 2,21,06,026.52	₹ 2,74,84,607.54	16.76%	0.94010
	20-09-2019	₹ 2,58,38,279.31	₹ 2,20,63,789.14	₹ 2,35,39,520.63	₹ 3,49,71,679.96	17.93%	0.93731
	25-11-2019	₹ 3,27,79,247.49	₹ 2,75,56,937.07	₹ 2,96,54,761.65	₹ 4,14,40,901.10	7.42%	0.92926
	16-01-2020	₹ 3,85,09,306.44	₹ 3,55,75,690.80	₹ 3,85,76,942.13	₹ 4,72,51,985.53	5.58%	0.92220
	20-03-2020	₹ 4,35,75,823.63	₹ 4,09,53,083.77	₹ 4,47,55,028.28	₹ 4,76,21,254.36	0.20%	0.91505
	29-04-2020	₹ 4,35,75,823.63	₹ 4,35,75,823.63	₹ 4,75,25,033.07	NA	NA	0.91690
					₹ 4,69,64,315.14	-1.18%	

9.8 Statement 8

EVM outcome prediction for cost (EAC$) is reasonably reliable for large scale projects. but not very much reliable for small scale project (1 – 1.5 year; $1,000,000 – $3,000,000 or ₹7,00,00,000 - ₹21,00,00,000). (Vanhoucke, Batselier, 2016)

Table 8.1.1 shows that, Case study 4 and Case study 6 meets the criteria of being small scaled construction project as mentioned by the authors Lipke, Zwikael, Henderson and Anbari (2009). From table 9.3.1, a range of ±0.18% to ±2.80% deviation between Actual cost at completion and Estimated cost at completion is observed in Case study 4 and 6. Therefore along with large scale construction projects EVM outcome prediction for cost or EAC ($) is reasonably reliable in small scale construction projects. Therefore "Statement – 8" is Validated as Not True.

9.9 Statement 9

SPI is not a reliable index to assess project schedule performance since it uses cost base EVM fundamentals to measure Schedule performance of a project. (Lipke, Zwikael, Henderson, Anbari, 2009), (Vanhoucke, Batselier, 2016), (Khamooshi, Golafshani, 2013)

Table 9.9.1 shows a comparative analysis of SPI and %Delay om 13 status dates of Case study 4. However both of them are not interpreting the same information since SPI uses cost base EVM fundamentals (SPI = Earned cost/ Planned cost) to measure Schedule performance of a construction project. Therefore "Statement – 9" is Validated as True using %Deviation analysis as a tool.

Table 9.9.1: Reliability of SPI

Date	Elapsed days	Delay (days)	% Delay	Planned Cost/BCWS	Earned Cost/BCWP	SPI	%Deviation
05-11-2018	0	0	0.00%	₹ 23,305.64	₹ 0.00	0	0.00%
01-12-2018	24	6	25.00%	₹ 13,25,798.88	₹ 8,57,396.84	0.646702	10.33%
31-01-2019	76	10	13.16%	₹ 89,84,126.71	₹ 73,57,842.59	0.818983	4.94%
07-03-2019	106	11	10.38%	₹ 1,16,83,968.37	₹ 97,99,192.43	0.838687	5.75%
11-04-2019	136	11	8.09%	₹ 1,44,13,046.30	₹ 1,25,79,386.17	0.872778	4.63%
16-05-2019	166	11	6.63%	₹ 1,70,82,233.22	₹ 1,52,88,353.47	0.894986	3.87%
20-06-2019	196	11	5.61%	₹ 1,97,88,274.40	₹ 1,79,64,468.27	0.907834	3.60%
02-08-2019	233	14	6.01%	₹ 2,10,66,324.83	₹ 2,07,81,875.34	0.986497	-4.66%
20-09-2019	275	14	5.09%	₹ 2,58,38,279.31	₹ 2,20,63,789.14	0.853919	9.52%
25-11-2019	331	22	6.65%	₹ 3,27,79,247.49	₹ 2,75,56,937.07	0.840682	9.29%
16-01-2020	376	25	6.65%	₹ 3,85,09,306.44	₹ 3,55,75,690.80	0.923821	0.97%
20-03-2020	431	25	5.80%	₹ 4,35,75,823.63	₹ 4,09,53,083.77	0.939812	0.22%
29-04-2020	465	34	7.31%	₹ 4,35,75,823.63	₹ 4,50,70,123.63	1.034292	-10.74%

9.10 Statement 10

SV = 0 or SPI = 1, could mean that a task is completed, but could also mean that the task is running according to plan. (Vanhoucke, Vandevoorde, 2005)

SV or SPI cannot clearly interpret whether a construction activity is running as per plan or already finished because in both the cases they show an output value of "0" and "1" respectively. If we refer EVA report of Case study 7 (table 9.10.1) it can be clearly seen that at 100% completion SV and SPI shows output value "0" and "1" respectively, and if construction activities are running as per schedule (from 24-05-2016 to 26-10-2017) both the indices behave in the same manner. If EVA report can be combined with Project Progress report the same confusion can be mitigated. Therefore "Statement – 8" is Validated as True.

Table 9.10.1: Case study 7 – Earned Value Analysis report

Date	BCWS	BCWP	ACWP	CV	SV	BAC	EAC ($)	% Deviation	CPI	SPI	CR
08-02-2016	₹ 3,20,49,000.00	₹ 3,23,39,642.50	₹ 3,42,86,809.45	-₹ 19,47,166.95	₹ 2,90,642.50	₹ 3,20,49,000.00	₹ 5,13,23,977.00	6.02%	0.943209	1.009069	0.951763
24-05-2016	₹ 4,84,09,259.85	₹ 4,84,09,259.85	₹ 5,11,00,593.93	-₹ 26,91,334.08	₹ 0.00	₹ 4,84,09,259.85	₹ 6,78,86,985.16	5.56%	0.947333	1	0.947333
06-08-2016	₹ 6,43,11,555.95	₹ 6,43,11,555.95	₹ 6,84,85,385.59	-₹ 41,73,829.64	₹ 0.00	₹ 6,43,11,555.95	₹ 8,59,05,863.12	6.49%	0.939055	1	0.939055
05-11-2016	₹ 8,06,70,345.57	₹ 8,06,70,345.57	₹ 8,70,76,243.19	-₹ 64,05,897.62	₹ 0.00	₹ 8,06,70,345.57	₹ 10,30,90,231.63	7.94%	0.926433	1	0.926433
02-02-2017	₹ 9,55,06,240.35	₹ 9,55,06,240.35	₹ 10,31,82,071.44	-₹ 76,75,831.09	₹ 0.00	₹ 9,55,06,240.35	₹ 11,92,10,326.24	8.04%	0.925609	1	0.925609
02-05-2017	₹ 11,03,42,135.13	₹ 11,03,42,135.13	₹ 11,88,85,264.70	-₹ 85,43,129.57	₹ 0.00	₹ 11,03,42,135.13	₹ 13,48,69,813.80	7.74%	0.92814	1	0.92814
29-07-2017	₹ 12,51,78,029.90	₹ 12,51,78,029.90	₹ 13,47,07,220.20	-₹ 95,29,190.30	₹ 0.00	₹ 12,51,78,029.90	₹ 15,06,72,498.98	7.61%	0.92926	1	0.92926
26-10-2017	₹ 14,00,13,924.68	₹ 14,00,13,924.68	₹ 15,05,76,359.75	-₹ 1,05,62,435.07	₹ 0.00	₹ 14,00,13,924.68	₹ 16,79,08,923.46	7.54%	0.929853	1	0.929853
23-01-2018	₹ 15,61,30,666.21	₹ 15,60,84,221.62	₹ 16,79,25,905.38	-₹ 1,18,41,683.76	-₹ 46,444.59	₹ 15,61,30,666.21	₹ 18,68,10,499.74	7.59%	0.929483	0.999703	0.929206
21-04-2018	₹ 17,36,37,125.11	₹ 17,33,73,939.08	₹ 18,67,97,142.94	-₹ 1,34,23,203.86	-₹ 2,63,186.03	₹ 17,36,37,125.11	₹ 20,59,50,914.69	7.74%	0.92814	0.998484	0.926733
19-07-2018	₹ 19,11,51,324.77	₹ 19,06,63,656.54	₹ 20,45,58,167.46	-₹ 1,38,94,510.93	-₹ 4,87,668.23	₹ 19,11,51,324.77	₹ 22,38,63,606.88	7.29%	0.932076	0.997449	0.929698
16-10-2018	₹ 20,86,57,783.67	₹ 20,79,45,633.23	₹ 22,33,36,125.32	-₹ 1,53,90,492.08	-₹ 7,12,150.43	₹ 20,86,57,783.67	₹ 24,29,03,132.10	7.40%	0.931088	0.996587	0.92791
12-01-2019	₹ 22,61,64,242.56	₹ 22,52,35,350.69	₹ 24,31,51,150.66	-₹ 1,79,15,799.96	-₹ 9,28,891.87	₹ 22,61,64,242.56	₹ 26,30,61,253.19	7.95%	0.926318	0.995893	0.922514
11-04-2019	₹ 24,36,78,442.22	₹ 24,25,25,068.15	₹ 26,22,61,740.87	-₹ 1,97,36,672.72	-₹ 11,53,374.07	₹ 24,36,78,442.22	₹ 28,39,39,144.03	8.14%	0.924744	0.995267	0.920367
09-07-2019	₹ 26,25,71,124.67	₹ 25,99,52,831.42	₹ 28,14,15,638.04	-₹ 2,14,62,806.62	-₹ 26,18,293.25	₹ 26,25,71,124.67	₹ 39,42,84,347.41	8.26%	0.923733	0.990028	0.914521
25-10-2019	₹ 36,42,13,350.78	₹ 30,62,10,513.20	₹ 33,17,08,521.67	-₹ 2,54,98,008.47	-₹ 5,80,02,837.57	₹ 36,42,13,350.78	₹ 39,80,59,234.37	8.33%	0.923131	0.840745	0.776118
02-12-2019	₹ 36,74,60,931.74	₹ 36,32,25,643.60	₹ 39,11,15,725.93	-₹ 2,78,90,082.33	-₹ 42,35,288.15	₹ 36,74,60,931.74	₹ 39,92,58,532.77	7.68%	0.928691	0.988474	0.917987
21-02-2020	₹ 37,07,87,794.80	₹ 36,82,80,593.66	₹ 39,70,59,944.02	-₹ 2,87,79,350.37	-₹ 25,07,201.14	₹ 37,07,87,794.80	₹ 39,97,63,070.83	7.81%	0.927519	0.993238	0.921247
02-05-2020	₹ 37,07,87,794.80	₹ 37,07,87,794.80	₹ 40,00,44,025.31	-₹ 2,92,56,230.51	₹ 0.00	₹ 37,07,87,794.80	NA	NA	0.926867	1	0.926867
							₹ 40,05,87,988.72				

9.11 Statement 11

Towards the end of a construction project, SV always converges to 0 indicating a perfect performance even if the project is late. Similarly, the SPI always converges to 1 towards the end of the project, indicating a 100% schedule efficiency even in the project is late. (Vanhoucke, Vandevoorde, 2005)

SV and SPI show output value "0" and "1" respectively at the end of a construction projects irrespective of the fact that whether the project is running as per schedule or delayed. But if the project is running behind schedule certainly the status date changes on which SV and SPI were supposed to show output value "0" and "1" respectively. If the EVA report (table 9.11.1) of a delayed construction project (Case study 6) is closely observed the confusion can easily be mitigated. Therefore "Statement – 11" is Validated as True.

Table 9.11.1: Case study 6 – Earned Value Analysis report

Date	BCWS	BCWP	ACWP	CV	SV	BAC	EAC ($)	% Deviation	CPI	SPI	CR
04-12-2018	₹ 4,03,303.39	₹ 4,03,303.39	₹ 5,16,675.28	-₹ 1,13,371.90	₹ 0.00	₹ 4,03,303.39	₹ 6,08,77,507.63	22.19%	0.780574	1	0.780574
28-01-2019	₹ 4,75,19,410.72	₹ 4,28,77,979.77	₹ 4,98,23,721.12	-₹ 69,45,741.35	-₹ 46,41,430.94	₹ 4,75,19,410.72	₹ 7,75,37,129.35	20.03%	0.860594	0.902326	0.776536
01-03-2019	₹ 6,67,27,963.89	₹ 5,71,82,085.87	₹ 6,46,00,511.80	-₹ 74,18,425.93	-₹ 95,45,878.02	₹ 6,67,27,963.89	₹ 9,11,38,890.89	7.82%	0.885165	0.856943	0.758536
01-04-2019	₹ 8,06,72,919.45	₹ 7,63,09,008.79	₹ 8,45,25,979.02	-₹ 82,16,970.23	-₹ 43,63,910.66	₹ 8,06,72,919.45	₹ 10,50,19,429.40	11.02%	0.902788	0.945906	0.853952
03-05-2019	₹ 9,48,10,242.42	₹ 8,57,87,613.29	₹ 9,45,96,755.45	-₹ 88,09,142.16	-₹ 90,22,629.13	₹ 9,48,10,242.42	₹ 11,86,90,913.61	3.37%	0.906877	0.904835	0.820574
21-06-2019	₹ 10,76,38,049.00	₹ 10,50,56,763.31	₹ 11,48,25,307.48	-₹ 97,68,544.17	-₹ 25,81,285.69	₹ 10,76,38,049.00	₹ 14,20,48,976.46	20.52%	0.914927	0.976019	0.892986
17-07-2019	₹ 12,99,64,430.55	₹ 10,77,06,862.95	₹ 11,78,67,989.45	-₹ 1,01,61,126.50	-₹ 2,22,57,567.59	₹ 12,99,64,430.55	₹ 15,78,77,259.24	14.84%	0.913792	0.828741	0.757297
03-08-2019	₹ 14,42,67,026.22	₹ 12,42,72,996.09	₹ 13,74,70,371.79	-₹ 1,31,97,375.70	-₹ 1,99,94,030.13	₹ 14,42,67,026.22	₹ 21,79,62,195.45	18.02%	0.903998	0.86141	0.778713
23-11-2019	₹ 19,70,37,475.85	₹ 16,40,07,800.96	₹ 18,46,83,792.86	-₹ 2,06,75,991.90	-₹ 3,30,29,674.90	₹ 19,70,37,475.85	₹ 22,18,77,423.90	-0.52%	0.888047	0.832369	0.739182
01-01-2020	₹ 19,70,37,475.85	₹ 19,70,37,475.85	₹ 22,30,28,404.73	-₹ 2,59,90,928.88	₹ 0.00	₹ 19,70,37,475.85	NA	NA	0.883464	1	0.883464
							₹ 22,25,99,815.84				

9.12 Statement 12

SV and SPI works fine for projects which go as per planned schedule and are not subjected to delay. (Lipke, 2009)

If we observe table 9.12.1, on first status date up to 8th status date of case study 7, %Deviation between %Delay and SPI shows 0%. It implies that the construction activities on those mentioned status dates are running as per schedule. Except for these dates no other status dates show similar interpretation of %Delay and SPI. Therefore "Statement – 12" is Validated as True.

Table 9.12.1: %Deviation between %Delay and SPI of Case study 7

Date	% Completed	Elapsed days	Delay (days)	% Delay	Planned Cost/BCWS	Earned Cost/BCWP	SPI	%Deviation
08-02-2016	2%	30	0	0.00%	₹ 3,20,49,000.00	₹ 3,23,39,642.50	1	0.00%
24-05-2016	9%	121	0	0.00%	₹ 4,84,09,259.85	₹ 4,84,09,259.85	1	0.00%
06-08-2016	14%	185	0	0.00%	₹ 6,43,11,555.95	₹ 6,43,11,555.95	1	0.00%
05-11-2016	19%	263	0	0.00%	₹ 8,06,70,345.57	₹ 8,06,70,345.57	1	0.00%
02-02-2017	25%	339	0	0.00%	₹ 9,55,06,240.35	₹ 9,55,06,240.35	1	0.00%
02-05-2017	31%	415	0	0.00%	₹ 11,03,42,135.13	₹ 11,03,42,135.13	1	0.00%
29-07-2017	36%	491	0	0.00%	₹ 12,51,78,029.90	₹ 12,51,78,029.90	1	0.00%
26-10-2017	42%	567	0	0.00%	₹ 14,00,13,924.68	₹ 14,00,13,924.68	1	0.00%
23-01-2018	47%	643	4	0.62%	₹ 15,61,30,666.21	₹ 15,60,84,221.62	0.999703	-0.59%

9.13 Statement 13

SPI may give reasonable results in the initial stage of a project (1/3) but are not reliable in the later stages of the project (2/3 completion percent) (Fleming, Koppelman, 2002).

All SPI curves of 8 case studies are superimposed in figure 9.13.1 to carry out a SPI Trend analysis. Despite of being an unreliable interpreter of Project schedule performance, SPI does not show any trend in the first 1/3 of the construction project neither does it show the same in the later 2/3 of the construction project. Therefore "Statement – 13" is Validated as Not True.

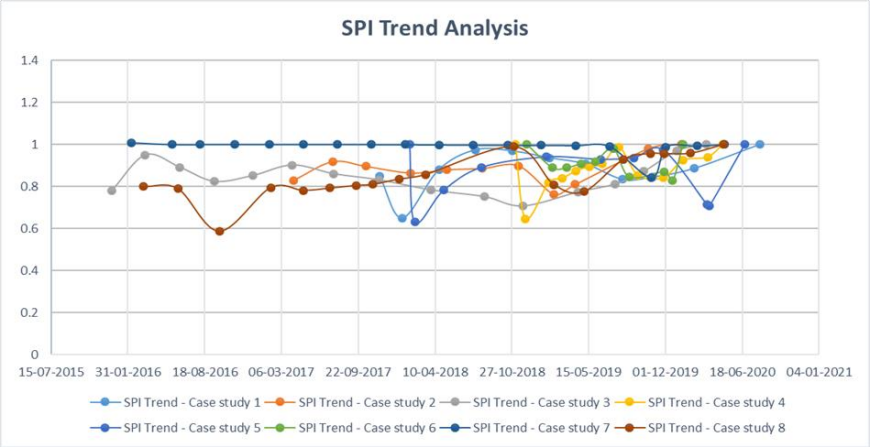

Figure 9.13.1: SPI Trend Analysis

9.14 Statement 14

EVM outcome prediction for schedule performance, EAC (t) is not at all reliable since it is a function of SPI which already has fundamental flaws at the concept's foundation level. (Henderson, 2003), (Lipke, Zwikael, Henderson, Anbari, 2009), (Khamooshi, Golafshani, 2013), (Vanhoucke, Batselier, 2016)

EAC(t) = PD/SPI. Table 9.14.1 shows %Deviation between EAC(t) and Actual project duration ranging from ±4.21% to 18.91% which is far more than what we have seen in %Deviation analysis of CPI. At the same time SPI Trend analysis (figure 9.13.1) shows there is an absence of Stability or any visible Trend that could help in increasing the accuracy of predicting Final project duration. Therefore, EAC(t) which is a function of SPI is appeared as an unreliable EVM measure as far as forecasting Final project duration is concerned. Therefore "Statement – 14" is Validated as True.

Table 9.14.1: %Deviation between EAC(t) and Actual project duration

Case study	Planned Duration (days)	SPI @20% completion	EAC(t)	Actual Duration (days)	%Deviation
Case study 1	869	0.88031	987	913	8.12%
Case study 2	807	0.86437	934	870	7.31%
Case study 3	1279	0.82401	1552	1418	9.46%
Case study 4	431	0.83869	514	465	10.52%
Case study 5	697	0.89154	782	747	4.66%
Case study 6	326	0.88993	366	349	4.96%
Case study 7	1298	1.00000	1298	1355	-4.21%
Case study 8	1280	0.79441	1611	1355	18.91%

9.15 Statement 15

Calculation of SPI drags the performance of the earliest project phases which may not necessarily affect the future schedule performance of the project. (Vanhoucke, Vandevoorde, 2005)

SPI is a function of Planned and Earned cost incurred on a specific date. This process of calculation considers carryover of Cost of previous construction activities to subsequent construction activities. Therefore, it cannot be accurately stated that whether the delay indicated by SPI on current status date is the delay caused by the running construction activities of current date or the majority of delay on current date is a contribution of delay caused by activities of past status dates. Therefore "Statement – 15" is True.

9.16 Statement 16

EAC(t) calculations also do not consider the criticality of tasks that are on the Critical path since delay in these activities can result in delay to the overall project. (Settlemire, 2016)

This process of calculating SPI considers carryover of Cost of previous construction activities to subsequent construction activities.
This process considers every construction activity in measuring Schedule performance of a status date irrespective of whether they are on Critical path or not. Because only delay in Critical activities can cause overall delay in project duration however if other Non-critical activities are subjected to delay they are likely to consume schedule buffer. But calculation process of SPI overlooks this fact completely and since EAC(t) is a function of SPI it too does not consider criticality of construction activities.

X. Conclusion

Among the 16 Statements of the Hypothesis 13 statements were found to be "True" and "Statement 5", "Statement 8" and "Statement 13" were found to be "Not True" which goes in favor of Applicability of EVM in Measuring and Forecasting Cost performance in construction projects and it discourages the use of EVM in Measuring and Forecasting Schedule performance in construction projects.

However, it can also be concluded that even if EVM schedule measures (SPI, SV) are used they can only indicate whether there is a delay in a construction project or not but cannot measure schedule performance accurately or state how much the construction project is running behind the schedule. Schedule performance measures of EVM works fine with the construction projects which are not subjected to delay. It is highly recommended that the Construction project management team should not use EVM without integrating any suitable extension while forecasting final project completion time if the project is already delayed.

XI. RECOMMENDATIONS

Earned Schedule Method (ESM) (Lipke, 2009) and Earned Duration Method (EDM) (Khamooshi, Golafshani, 2013) are great extensions of EVM which can cater to the limitation of EVM to some extent. They both use time series data to measure Schedule performance of construction projects SPI(t) unlike Cost based schedule performance indicators of EVM. It gives similar degree of accuracy in schedule forecasting, the way EAC ($) does in EVM. But both of them has got certain limitations too. They assign equal importance (or weightage) to all past time series data while calculating EAC(t) (Vanhoucke, Batselier, 2016). ESM and EDM both do not consider the occurrence of natural performance improvement during the course of the project such as efficient use of resources (e.g. workers) the effect of corrective measures that were recently taken with the aim of improving future performance etc. Another limitation of SPI(t) in ESM or EDM is it will always drag along the performance of the earliest project phases as well which may not necessarily affect the future schedule performance of the project. (Vanhoucke, Andrade, Salvaterra, Batselier, 2015)

Exponential Smoothing or XSM uses Weighted averages of time series data (Status dates) of past observations to forecast schedule performance of a project. Such consideration can potentially create room to incorporate natural performance improvement and corrective measures taken during the course of the project. (Vanhoucke, Batselier, 2016), (Khamooshi, Abdi, 2017) The accuracy of XSM is further refined using Reference Class Forecasting (RCF) where a relevant reference class of similar historical construction projects are used as a basis for making forecasts. (Batselier, Vanhoucke, 2016)

XII. LIMITATIONS

In this research paper EVM was applied on 8 Indian construction projects. All of them were having conditions which are generally observed in India. Therefore, special cases i.e. Financially distressed construction projects or projects executed under different conditions i.e. in other countries etc. are not considered in this research work. Therefore, real time scenario for such projects can differ from what we have seen while applying EVM on typical Indian construction projects.

XIII. ACKNOWLEDGMENT

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