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EARNED VALUE IN A PROJECT MANUFACTURING ENVIRONMENT

A CASE STUDY ASSESSING THE EFFECTIVENESS OF EVM

Anisulrahman Nizam, PhD Student
Department of Industrial Engineering and Management Systems
University of Central Florida

Hani M. Aburas, Ph.D. Professor
Faculty of Engineering, Department of Industrial Engineering,
King Abdulaziz University

Ahmad K. Elshennawy, Ph.D. Professor
Executive Director UCF Quality Institute in the Department of Industrial Engineering and Management Systems
University of Central Florida

Abstract: Project manufacturing is an operation designed to provide unique yet similar products, where every product is the result of a project (Yang 2012). The primary purpose of this study is to assess the effectiveness of traditional project management techniques, specifically Earned Value Management (EVM), in a manufacturing environment. This assessment was done by utilizing the case study method on 31 different projects at a large aerospace manufacturing firm. The analysis suggests that EVM may not be a useful tool in a project manufacturing environment. Furthermore, the findings indicate there is a gap between what the project team is baselining in terms of effort and what is actually getting executed to on the manufacturing floor by the manufacturing team. The extremely conservative approach to baselining by project team members results in EVM indicators that may not truly reflect the true health of the project on the manufacturing floor.

Keywords: Earned Value Management, Operations Management, Project Management, Project Manufacturing, Variance at Completion, Actual Cost

1. INTRODUCTION

Project Manufacturing is associated with the production of non-standardized products in a highly complex environment where each product is the result of a project (Yang 2013). Project Manufacturing occurs in an Engineering to Order (ETO) environment where fully customized products are developed a single time based on customer specifications. This environment experiences a high level of customization, small batches, abnormal work processes, and complex products (Rahim and Baksh, 2003). The design, engineering, and production phases are not kicked off in the project until after the customer has confirmed the order (Rudberg and Wikner, 2004). Compared to a repetitive Make to Stock operation, it is rather difficult and costly for any organization to operate in this environment with irregular demand. In order to be successful in this type of ETO environment, many organizations have started to supplement their Operations Management principles with that of Project Management. This intersection of projects and operations is at the core of Project Manufacturing. Operations Management is the set of all activities that creates value in the form of goods and services by transforming inputs into outputs (Heizer and Render, 2008). Project Management, as defined by the Project Management Institute (PMI), is the application of knowledge, skills, tools, and techniques to project activities to meet the project requirements. It is a set of activities that is temporary with a defined start and end time, and it is something that must be considered unique. Over the last 40 years, Project Management has increasingly become the preferred form of management for organizations (Kloppenborg & Opfer, 2000). One of the most highly regarded tools of Project Management is Earned Value Management (EVM). Earned Value Analysis (EVA) is a method that allows the project manager to measure the amount of work actually performed on a project beyond basic reports of cost and schedule (Reichel, 2006). EVM is based on the assumption that past performance is an indicator of future conditions. Theoretically, it is an objective indicator to allow a comparison of where a project is headed compared to where it should be. However, projects have a long list of uncertainties that can limit the ability of EVM to be as powerful as advertised in an operations environment. Customer requirements can change, technical problems can be found, additional work can be discovered, vendors may not deliver on time, the work may materialize slower than expected, approvals may not come in on time, and priorities may change.

Considering this context, the objective of this work is to provide an assessment on the effectiveness of Earned Value Management in a Project Manufacturing Environment. Specifically, the objectives are as follows:

1. To identify if early EVM metrics are a true indicator of the final project cost in an ETO environment
2. To identify any statistical relationships between EVM metrics and traditional OM metrics in an ETO environment.
3. To identify the right combination of indicators of the final project cost in an ETO environment.

This article is structured as follows: The introduction is followed by a review of Operations Management, Project Management, and Earned Value Management in order to introduce the basic concepts of each. The research methods are then described followed by a presentation of data and subsequent data analysis of the results. The final section will summarize the findings of the data analysis and will draw appropriate conclusions.

2. EARNED VALUE MANAGEMENT

Earned Value Management (EVM) is a comprehensive performance measurement system (PMS) that integrates cost and schedule parameters into a single methodology to provide joint situational awareness for project managers and customers to assess project cost, schedule, and technical performance. EVM is an increasingly popular tool that organizations are utilizing to report and control project performance in an objective manner. EVM is mostly prevalent in the defense industry as it has been mandated by the United States Government for DoD contracts valued at or greater than $20M in accordance with ANSI/EIA-748. Utilized as a PMS, EVM helps drive organizational success (Upadhaya, 2014). Without an effective PMS, an organization lacks the ability to track, monitor, or take corrective actions as necessary. Prior to EVM, traditional PMS's had two separate and independent systems with one focusing on cost and the other focusing on schedule. Lacking integration of these two systems, a project manager could not truly understand the health of the project. This glaring weakness could not identify the reason a project was over or under spending since it did not cross-reference time-based data. EVM brings together cost and schedule data by integrating them into one metric. By integrating cost and schedule data together, project managers and the contracting agency can monitor project health while providing a mechanism to forecast the final cost at completion of the project as well as when the project will be completed. This easily aligns the organization at both the strategic and operational levels (McAdam, 2014) by providing detailed day to day information while also providing the performance of the project overall. EVM does this by using a common monetized value of work for both cost and schedule. This is where the true power of EVM lies, allowing EVM to produce variance and performance indices to predict final project cost and schedule at completion.

There are three fundamental metrics of EV that are used to generate the performance indices for cost performance and schedule. They are Planned Value (PV), Earned Value (EV), and Actual Costs (AC). PV is defined as the budgeted cost of work scheduled at the measuring point (MP). EV is defined as the budgeted cost of work performed at MP. Finally, AC is defined as the actual cost of work performed at the MP. Once these three fundamental measures are obtained, several key metrics and ratios can be derived which indicate the health, performance, and outlook of the project. The Cost Variance (CV) is equal to the difference between EV and AC. This number indicates the extent of over or under run in terms of cost. The Schedule Variance (SV) is equal to the difference between EV and PV. This number indicates whether a project is running behind or ahead of schedule. Negative values of CV and SV indicate a lack of progress against the baseline plan. The Cost Performance Index (CPI) is equal to the EV divided by AC. This is a powerful index that indicates how much it costs to earn one dollar of budget (Wake, 2008). The Schedule Performance Index (SPI) is equal to EV divided by PV. This index indicates the extent to which the project is running ahead or behind schedule. If both SPI and CPI are equal to 1, the project is running exactly on schedule and budget. The To Complete Performance Index (TCPI) is a useful index that indicates how well a project must perform in terms of cost on the remaining work in order to complete on budget. The TCPI is equal to the difference in Budget at Completion and EV divided by the difference in Budget at Completion and AC. As a general rule of thumb, once a TCPI exceeds a value of 1.1, such a dramatic shift in performance is difficult to achieve in reality.

3. DATA SOURCE

The EVM data is being collected from multiple manufacturing projects for a large aerospace company. The duration of the project, initial, mid, and final CPI, Actual Cost of Work Performed (ACWP), Budget at Completion (BAC), and Variance at Completion (VAC), Baselined number of units, baselined unit hours, baselined total hours, actual number of units, actual unit hours, actual total hours, budgeted hours per unit, and actual hours per unit of 31 individual projects within the programs is being collected from system generated monthly EVM data reports from January 2017 to July 2019.

4. PROJECT MANAGEMENT ENVIRONMENT:

Projects are formally kicked off with the project team with the release of the Program Direction (PD) by the Project Manager. This PD provides direction to each of the functional teams to begin the execution of their work. For the project operations team, this involves creating demand for the project in the Enterprise Resource Planning (ERP) system. The ERP system is in a group environment, which backward schedules project start dates based on the required end date of the project. It looks at all material lead times as well as the assembly lead times to schedule when the project must start on the manufacturing floor and when material needs to be ordered. The basic project launch process in SAP is as follows (depicted in Figure 1.1 below). First, end item demand is loaded with start dates calculated automatically based on given lead times. Then, Purchase Requisitions (PR's) are launched which notify the Procurement team that material is needed to be placed on order. Then the procurement team sends out Request for Proposals (RFP) to the supply chain and places Purchase Orders with the appropriate supplier. Material is then received in a house after the lead time passes and once all the material for the project is available in stock, the material will then be released to the manufacturing floor for assembly.

Once assembly begins on the production floor, the project operations team utilizes Earned Value Management to measure performance and to predict estimated completion cost. The foundation of Earned Value Analysis begins with a list of deliverables that need to be met, which is captured in a product-oriented Work Breakdown Structure or WBS. The WBS is a very important project planning document as it serves as the foundation document for the project. The WBS is what is used to develop an accurate schedule, cost, and staffing plan. For each deliverable listed on the WBS an estimate is made of how long it will take to complete the task and the number of resources that will be required to complete each task. Following the establishment of durations, a dependency network is created in order to understand how long the entire project will take. This will eventually form into the project baseline plan. Project performance will be measured against this established baseline plan on a monthly basis. After the baseline has been established and frozen, a second plan is created that reflects the actual status of the project. At each monthly monitoring point, critical information will be gathered for each deliverable being tracked. The first piece of information to gather is the time spent working on a deliverable and the second piece of critical information is the remaining time needed to complete the task. These values are used to calculate the BCWP, CPI, SPI, and EAC. Any performance indices below 0.95 trigger a "red status" which requires management intervention and a corrective action plan to get the project back to a level at or above 1.0.

5. MANUFACTURING ENVIRONMENT:

The manufacturing center operates entirely independently of the project teams. In fact, the manufacturing center is a purely functional center with its leadership team reporting up thru the Vice President of Operations. The manufacturing center supports well over one hundred projects a year and does not prioritize one over the other. It is designed to be a completely flexible manufacturing center that can adjust its output based on the demand that is needed to support projects as they come along. The manufacturing center does not utilize Project Management nor Earned Value Management on the floor. Rather, it focuses on traditional Operations Management metrics such as Hours Per Unit (HPU), efficiency, on-time completions, etc.

Figure 1.1: Operations launch process

The manufacturing center utilizes the basic principles of Lean Six Sigma and product flow. Teams are organized based on functional specialization within the manufacturing center as opposed to by the project. The manufacturing team is constantly shifting work schedules and priorities as a result of multiple changes set forth by the project management team (engineering changes, project priorities, customer demands, etc.).

6. PRELIMINARY DATA ANALYSIS

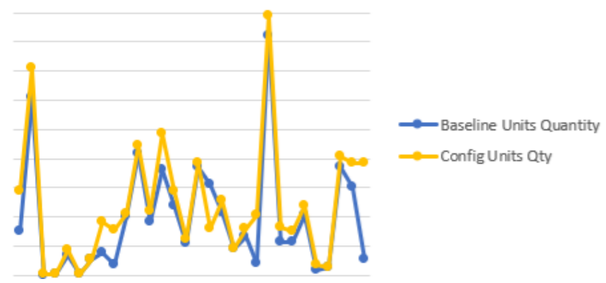


Figure 1.2

In almost every project, manufacturing ended up with a higher quantity of units that were built than what was projected in the baseline plan by the project team.

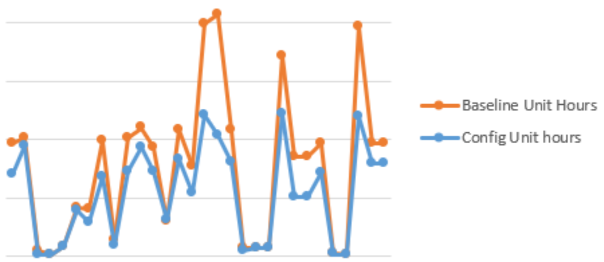


Figure 1.3

In almost every project, the manufacturing team was able to build each piece faster than what the project team had baselined.

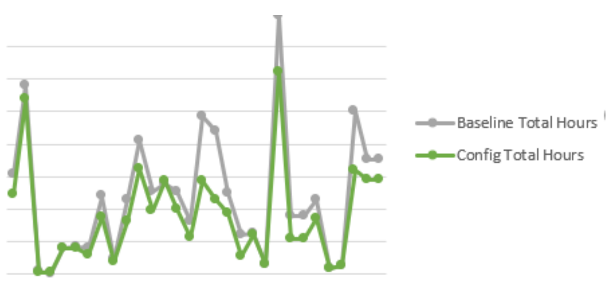


Figure 1.4

In almost every project, the manufacturing team was able to spend less time on the entire project than what the project team had baselined.

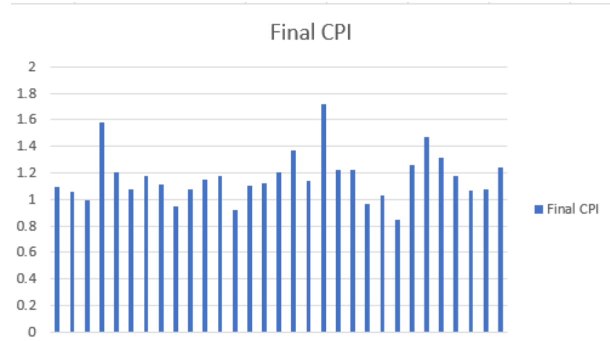


Figure 1.5

From the charts above, it seems that the project team was extremely conservative when establishing the project baseline. This may be a large factor in why the projects CPI ratios performed exceptionally well, with over 84% of projects having a CPI greater than or equal to 1.0. This occurred even though the project team consistently underestimated the amount of engineering changes that will take place during manufacturing which added to the quantity of parts actually being built by manufacturing.

7. METHODOLOGY

Multiple Regression analysis was utilized on the data collected to predict both the final project cost (ACWP) as well as the Variance at Completion (VAC). The variables utilized in the model are represented below.

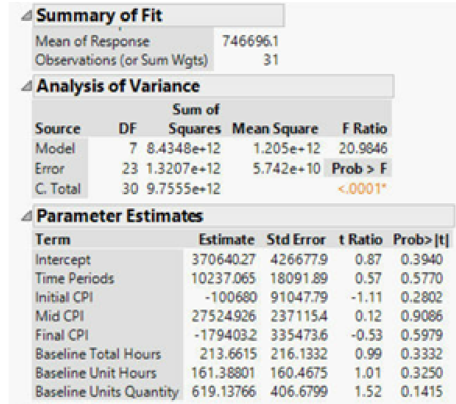
Scenario # 1:
Dependent variable: Final project cost (ACWP)
Independent variables: Time Periods, Initial CPI, Mid CPI, Final CPI, Baseline Total Hours, Baseline Unit Hours, and Baseline Unit Quantity

Scenario # 2:
Dependent variable: Variance at Completion (VAC)
Independent variables: Time Periods, Initial CPI, Mid CPI, Final CPI, Baseline Total Hours, Baseline Unit Hours, and Baseline Unit Quantity

8. RESULTS

Scenario # 1: *Dependent Variable: Actual Cost of Work Performed (ACWP)*

Multiple regression analysis did not yield any statistically significant factors in explaining the Actual Cost of Work Performed (ACWP) for these projects as can be seen in the data output in Figure 1.6:



Summary of Fit

Mean of Response	746696.1
Observations (or Sum Wgts)	31

Analysis of Variance

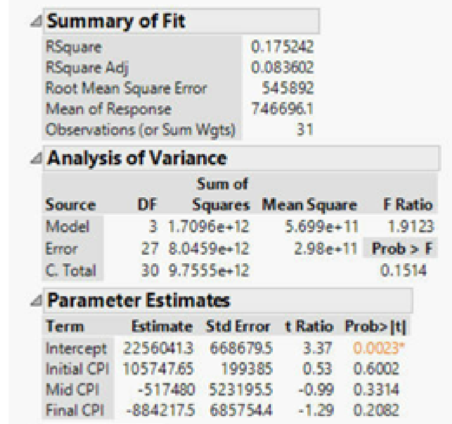
Source	DF	Sum of Squares	Mean Square	F Ratio
Model	7	8.4348e+12	1.205e+12	20.9846
Error	23	1.3207e+12	5.742e+10	Prob > F
C. Total	30	9.7555e+12		<.0001*

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	37064027	4266779	0.87	0.3940
Time Periods	10237.065	18091.89	0.57	0.5770
Initial CPI	-100680	91047.79	-1.11	0.2802
Mid CPI	27524.926	2371154	0.12	0.9086
Final CPI	-1794032	3354736	-0.53	0.5979
Baseline Total Hours	213.6615	216.1332	0.99	0.3332
Baseline Unit Hours	161.38801	160.4675	1.01	0.3250
Baseline Units Quantity	619.13766	406.6799	1.52	0.1415

Figure 1.6

Exclusion of non-EVM factors similarly yielded in a model that did not identify any statistically significant factors for predicting the ACWP for the projects as can be seen in the data output n Figure 1.7:



Summary of Fit

RSquare	0.175242
RSquare Adj	0.083602
Root Mean Square Error	545892
Mean of Response	746696.1
Observations (or Sum Wgts)	31

Analysis of Variance

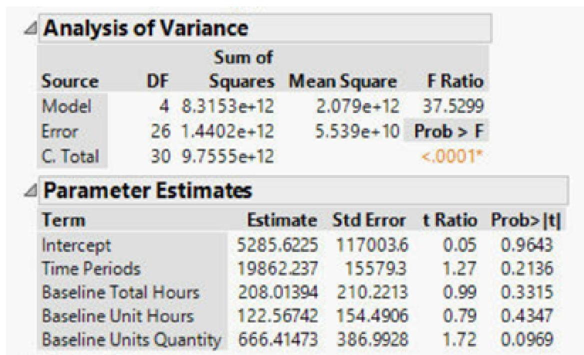
Source	DF	Sum of Squares	Mean Square	F Ratio
Model	3	1.7096e+12	5.699e+11	1.9123
Error	27	8.0459e+12	2.98e+11	Prob > F
C. Total	30	9.7555e+12		0.1514

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	2256041.3	668679.5	3.37	0.0023*
Initial CPI	105747.65	199385	0.53	0.6002
Mid CPI	-517480	523195.5	-0.99	0.3314
Final CPI	-884217.5	685754.4	-1.29	0.2082

Figure 1.7

Exclusion of EVM factors also yielded in a model that did not identify any significant factors for predicting the ACWP for the projects as can be seen in the data output in Figure 1.8:



Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	4	8.3153e+12	2.079e+12	37.5299
Error	26	1.4402e+12	5.539e+10	Prob > F
C. Total	30	9.7555e+12		<.0001*

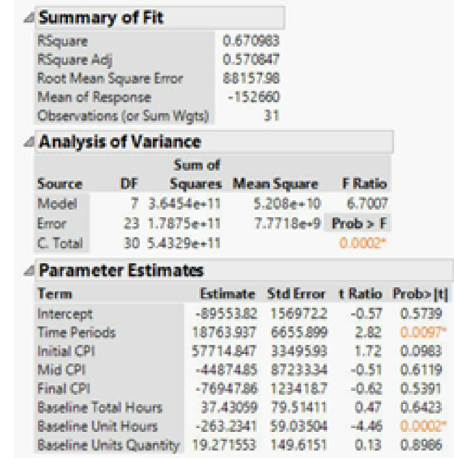
Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	5285.6225	117003.6	0.05	0.9643
Time Periods	19862.237	15579.3	1.27	0.2136
Baseline Total Hours	208.01394	210.2213	0.99	0.3315
Baseline Unit Hours	122.56742	154.4906	0.79	0.4347
Baseline Units Quantity	666.41473	386.9928	1.72	0.0969

Figure 1.8

Scenario # 2: *Variance at Completion (VAC)*

Multiple regression analysis yielded in the identification of two statistically significant factors in explaining the Variance at Completion (VAC) for these projects as can be seen in the data output in Figure 1.9:



Summary of Fit

RSquare	0.670983
RSquare Adj	0.570847
Root Mean Square Error	88157.98
Mean of Response	-152660
Observations (or Sum Wgts)	31

Analysis of Variance

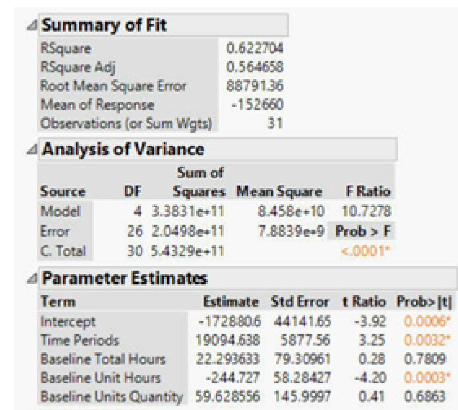
Source	DF	Sum of Squares	Mean Square	F Ratio
Model	7	3.6454e+11	5.208e+10	6.7007
Error	23	1.7875e+11	7.7718e+9	Prob > F
C. Total	30	5.4329e+11		0.0002*

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	-89553.82	156972.2	-0.57	0.5739
Time Periods	18763.937	6655.899	2.82	0.0097*
Initial CPI	57714.847	33495.93	1.72	0.0983
Mid CPI	-44874.85	87233.34	-0.51	0.6119
Final CPI	-76947.86	123418.7	-0.62	0.5391
Baseline Total Hours	37.43059	79.51411	0.47	0.6423
Baseline Unit Hours	-263.2341	59.03504	-4.46	0.0002*
Baseline Units Quantity	19.271553	149.6151	0.13	0.8986

Figure 1.9

Exclusion of non EVM factors resulted in a model that identified the two same statistically significant factors for predicting the VAC for these projects as can be seen in the data output in Figure 1.10:



Summary of Fit

RSquare	0.622704
RSquare Adj	0.564658
Root Mean Square Error	88791.36
Mean of Response	-152660
Observations (or Sum Wgts)	31

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	4	3.3831e+11	8.458e+10	10.7278
Error	26	2.0498e+11	7.8839e+9	Prob > F
C. Total	30	5.4329e+11		<.0001*

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	-172880.6	44141.65	-3.92	0.0006*
Time Periods	19094.638	5877.56	3.25	0.0032*
Baseline Total Hours	22.293633	79.30961	0.28	0.7809
Baseline Unit Hours	-244.727	58.28427	-4.20	0.0003*
Baseline Units Quantity	59.628556	145.9997	0.41	0.6863

Figure 1.10

Including only two statistically significant models identified in the analysis above resulted in an even stronger statistically significant model as the p values for each independent variable were reduced even further as can be seen in the data output in Figure 1.11:

Summary of Fit

RSquare	0.581821
RSquare Adj	0.551951
Root Mean Square Error	90077.91
Mean of Response	-152660
Observations (or Sum Wgts)	31

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	2	3.161e+11	1.58e+11	19.4785
Error	28	2.2719e+11	8.114e+9	Prob > F
C. Total	30	5.4329e+11		<.0001*

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	-157549.8	43089.89	-3.66	0.0010*
Time Periods	17774.75	5441.971	3.27	0.0029*
Baseline Unit Hours	-187.3923	30.11637	-6.22	<.0001*

Figure 1.11

Exclusion of EVM factors resulted in model that failed to identify any statistically significant factors for predicting the VAC for these projects as can be seen in the data output in Figure 1.12:

Summary of Fit

RSquare	0.019602
RSquare Adj	-0.08933
Root Mean Square Error	140454.5
Mean of Response	-152660
Observations (or Sum Wgts)	31

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	3	1.065e+10	3.5499e+9	0.1799
Error	27	5.3264e+11	1.973e+10	Prob > F
C. Total	30	5.4329e+11		0.9091

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	-84953.36	172046.9	-0.49	0.6255
Initial CPI	-512.5259	51300.47	-0.01	0.9921
Mid CPI	64263.126	134614.8	0.48	0.6369
Final CPI	-122968.4	176440.2	-0.70	0.4918

Figure 1.12

9. CONCLUSIONS FROM DATA

From the regression analysis and scenarios identified above, it is clear that the right statistically significant factors for predicting ACWP have not been identified. Neither EVM metrics (CPI) nor the non EVM metrics identified in this study have proven to be a useful indicator in predicting the ACWP on these projects. However, a subset of statistically significant factors has been identified for predicting the VAC for these projects. Interestingly, the two factors found to be statistically significant are non EVM metrics. EVM metrics (CPI) were not identified as statistically significant in this scenario as well. The two statistically significant factors identified were the number of time periods of the project (in months) as well as the baseline unit hours for those projects. Interestingly, both of these factors have to do with the element of time, even though the majority of costs on these projects had to do with material costs.
Another interesting conclusion can be drawn from the preliminary data analysis on the baselined vs. configuration graphs. It is clear that project managers in this environment are overestimating the time it will take to complete manufacturing as well as underestimating the number of units that will be needed to complete manufacturing. Unfortunately, the baseline estimates are utilized as key factors in developing the Performance Measurement Baseline (PMB), which is the basis for Earned Value Analysis. It is against this baseline plan that Earned Value is measured and compared against BCWS and ACWP to come up with the CPI and SPI metrics.

The major findings from this study are identified below:

1. EVM metrics like CPI were not found to be statistically significant factors in explaining ACWP nor VAC
2. Non-EVM factors like the length of the project as well as the baselined unit hours of the project were found to be statistically significant factors in predicting the VAC
3. Extremely conservative estimates are made during the baseline process, which prevents EVM from being utilized to its full potential in this project manufacturing environment

10. FUTURE RESEARCH

This case study has clearly demonstrated that there is a gap in the successful use of EVM methodology in a project manufacturing environment. While, critical success factors (CSFs) for achieving manufacturing (Yang 2013), project management (Yang, 2013), project manufacturing (Pacagnella, Silva, et all, 2019), and earned value management objectives (Duffey, Kim, and Wells, 2003) have been studied, critical success factors for the effective implementation of earned value management in a project manufacturing environment have yet to be identified. It is suggested that in-depth studies be carried out thru action surveys or case studies to identify the CSFs for the successful use of EVM in a project manufacturing environment.

AUTHORS

Anisulrahman Nizam is a current PhD Student at the University of Central Florida in the Department of Industrial Engineering and Management Systems. He obtained both his Master of Science in Industrial Engineering and Bachelor of Science in Finance from the University of Central Florida. He also has a Graduate Certificate in Supply Chain Management from Penn State University. He holds an APICS certification in Production and Inventory Management as well as certification as a Lean Six Sigma Black Belt. He has held increasingly responsible leadership roles in Global Supply Chain, Production Operations, and Project Management at a large Fortune 100 Aerospace firm.

Hani M. Aburas, King Abdulaziz University, Faculty of Engineering, Department of Industrial Engineering, Saudi Arabia. Email: haburas@kau.edu.sa
His Excellency Prof. Hani Mohammad Aburas, a KAU Professor in the Department of Industrial Engineering, has the honor to serve as the Mayor of Jeddah for two consecutive terms from 2010 to 2018. During his tenure, Jeddah Historic city was listed among the UNESCO World Heritage sites. He initiated and completed numerous mega-development projects for the future expansion of Jeddah. In recognition of his contributions for the people and city of Jeddah, he was shortlisted among the best twenty-five Mayors of the World in 2014 by the Philanthropic City Mayors Foundation. On account of his meritorious services, The Arab League has awarded him the Golden Order of Merit in the field of Leadership.
He holds a Bachelor's Degree from the Department of Industrial Engineering, King Abdulaziz University. He completed his Master's and Ph.D. degrees in Simulation Modeling and Analysis from the University of Central Florida, USA.
Prof. Hani Aburas is the first Arab graduate to receive the UCF Outstanding Alumni Award in 2016. Furthermore, he holds the Graduate Faculty Scholar position from UCF since 2013.

Ahmad K. Elshennawy, Ph.D. is Professor and Executive Director of The UCF Quality Institute in the Department of Industrial Engineering and Management Systems at the University of Central Florida (UCF). Prior to joining UCF, he served as a Guest Researcher with the Precision Engineering Division of the National Institute of Standards and Technology (NIST) in Gaithersburg, Maryland for two years.
Dr. Elshennawy combines over 30 years of international experience with exemplary academic record in the areas of quality management and strategic improvement, as a researcher, academician and a consultant in the United States and different parts of the world. He is the co-author of the Certified Quality Engineer Handbook (1st and 2nd Editions), the Certified Quality Technician Handbook, and the Certified Quality Inspector Handbook (ASQ publications) and Manufacturing Processes and Materials (SME publication).
Elshennawy received a BS and MS degrees in Production Engineering from Alexandria University and M.Eng. & Ph.D. degrees in Industrial Engineering from Penn State University. His teaching and research areas of expertise include Quality and Reliability Engineering, Quality Systems and Management, Six Sigma Quality/Lean Six Sigma, Statistical Process Control, Lean Service, and Business and process Performance Improvement and Management. Elshennawy is a Fellow of the American Society for Quality (ASQ), Senior Member of the Institute of Industrial Engineers (IIE), and the Society of Manufacturing Engineers (SME). He is an ASQ Certified Quality Engineer (CQE) and a Certified Reliability Engineer (CRE) and is a Certified Lean Six Sigma Master Black Belt. Dr. Elshennawy has served on the Editorial Review Board of Quality Press of the American Society for Quality and currently serves on the Editorial Board of Quality Progress and is a Senior Editor for the Journal of management and Engineering Integration. He is also the Director of Development and Quality Control of the Association for Industry, Engineering, and Management Systems (AIEMS)

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