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Using Earned Value Management and Value Engineering tools to enhance system's productivity, A proposed Framework.

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Abstract

In today's highly competitive business landscape, enhancing productivity and optimizing resource allocation are critical for a firm's success. This paper presents a comprehensive framework that uses Earned Value Management (EVM) and Value Engineering (VE) to achieve these goals. The proposed framework consists of five key phases: Initiation and Planning, Value Engineering Analysis, Implementation of EVM, Monitoring and Control, and Continuous Improvement. By creating constructive collaboration between EVM's data-driven insights and VE's innovative approaches, the framework aims to maximize project efficiency, reduce costs, and enhance overall productivity. This comprehensive approach not only ensures that projects are completed on time and within budget but also fosters a culture of continuous improvement, positioning firms for sustained success in a dynamic market environment. The proposed framework enabled us to achieve enhancements in productivity costs ranging from 66% to 90%; moreover, we achieved total working man-hour savings ranging from 33% to 88.7% across different disciplines.

Keywords: Earned Value Management, Earned Value, Value Engineering, Value Management

1. Introduction

In the quest for excellence and competitiveness, firms continuously seek strategies to enhance productivity, optimize resource allocation, and minimize task time consumption. Two methodologies that have proven

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effective in achieving these objectives are Earned Value Management (EVM) (Quentin W. Fleming, 2016) and Value Engineering (VE) (Mukhopadhyaya, 2013). This paper presents a framework that combines Earned Value Management (EVM) and Value Engineering (VE). EVM provides a quantitative method for monitoring project performance, while VE focuses on enhancing value by analyzing functions and finding cost-effective solutions. By integrating these approaches, the framework offers a comprehensive strategy for both project management and process optimization.

Earned Value Management (EVM) is a project management technique that uses cost, schedule, and scope metrics to provide an objective measure of project performance (Quentin W. Fleming, 2016). EVM enables project managers to compare the amount of work planned with what has been accomplished to date, to determine if cost and schedule performances are on track. This technique is particularly valuable for identifying deviations from the project plan early, allowing for timely corrective actions (Institute, 2017).

Value Engineering (VE), on the other hand, focuses on maximizing the value of a project by improving its function or reducing its cost. VE involves a structured and systematic approach to analyzing the functions of project components and finding innovative ways to achieve those functions at lower costs without compromising quality (International, 2011). By emphasizing creative problem-solving and cost efficiency, VE helps in uncovering opportunities for improvement that might otherwise be overlooked. The proposed framework combines the strengths of both EVM and VE tools to create a robust system for enhancing productivity.

2. Literature Review

In the literature review, we were more interested in the applications in which the two tools were used and the intention for using them. We categorized the previous research into three distinct groups, one for application of EVM, one for application VE and the third one for application of both together.

The use of Earned Value Management (EVM) serves multiple purposes, including time and cost forecasting, Kim (2019) found that traditional EAC models for large Department of Defense contracts are often unreliable. To improve forecasting accuracy, the study recommends incorporating dynamic factors such as risk and schedule volatility, which can enhance resource allocation and budgeting. While Narbaev (2017) introduced a framework integrating risk management with EVM, which improves cost forecasting accuracy by including risk factors. This integration enhances prediction reliability and aids in better budget management. On the other hand, Franco Caron (2016) developed a Bayesian method that improves ETC forecasts by integrating historical data with real-time updates, leading to more accurate and adaptable cost management.

Batselier (2016) found that Reference Class Forecasting (RCF) provides more accurate and unbiased cost and time forecasts than Monte Carlo simulations and Earned Value Management (EVM), improving project management outcomes. while De Marco A. R. (2016) introduced a method that improves cost estimates for complex projects by incorporating risk contingencies through non-linear and probabilistic models, enhancing accuracy and decision-making.

De Koning (2016) examined how project characteristics influence the stability of EVM metrics, cost performance index (CPI) and schedule performance index (SPI). By analyzing real-world projects, the study identified factors affecting metric stability, improving forecasting and corrective actions for better project management. While Hazır (2015) found that enhancing decision support systems (DSS) to better manage uncertainty could improve project performance. The study identified gaps in current tools like Earned Value Analysis (EVA) and suggested that better DSS could increase accuracy in monitoring and control.

Jordy Batselier (2015) assessed forecasting techniques for project duration and found that while EVM extensions improved accuracy with additional factors, Earned Duration Management (EDM) was equally effective, highlighting its potential for better project control. Also, Homayoun Khamooshi (2014) developed Earned Duration Management (EDM) to improve schedule tracking, offering more precise and intuitive performance measures than EVM and Earned Schedule by focusing directly on schedule metrics.

Timur Narbaev (2014) developed a regression model combining Earned Schedule (ES) with Earned Value Management (EVM), resulting in more accurate cost forecasts and better budget management, particularly for projects with fluctuating performance. While Elshaer (2013) enhanced project duration forecasts by combining sensitivity analysis with Earned Schedule (ES). This integration improves the accuracy of completion date predictions by better accounting for performance fluctuations, particularly in projects sensitive to schedule changes.

Caron (2013) improved EAC accuracy in Earned Value Management (EVM) by using Bayesian statistics, which updates estimates based on new data and uncertainties. This method provides more accurate and adaptable predictions, especially for projects with variable performance. To address another objective, Walt Lipke (2009) used regression analysis within a statistical framework to improve the accuracy of Earned Value Management (EVM) and Earned Schedule (ES) forecasts, leading to more reliable project outcome predictions and better project management. On the other hand, Stephan Vandevoorde (2006) found that Earned Schedule (ES) provided more accurate project duration forecasts compared to traditional methods like Schedule Performance Index (SPI), particularly for projects with non-linear progress. A. Mahmoudi (2021) introduced Grey Earned Value Management (GEVM), which combines Grey System Theory with EVM to improve forecasting accuracy and reliability under uncertainty, managing incomplete data more effectively than traditional methods. On the other hand, Fernando Acebes M. P. (2015) introduced a stochastic framework that integrates Monte Carlo simulation and statistical learning with EVM, enhancing forecasting accuracy and risk management for uncertain projects.

EVM was used as a tool for performance monitoring and reporting, helping to track and assess project progress, Monty Sutrisna (2020) revealed that while EVM improves project control and performance in Spain's construction industry, its use is limited by low awareness, lack of training, and concerns about complexity and cost. Greater adoption could enhance sector competitiveness. While Mahabir (2022) demonstrated that combining Earned Value Management (EVM) with KPI-based performance management boosts PMO operations by improving visibility, decision-making, and efficiency, despite challenges like resistance to change and the need for ongoing KPI adjustments.

David Bryde (2018) found that effective Earned Value Analysis (EVA) depends on organizational backing, thorough training, and a focus on data. EVA works best in large, complex projects with clear objectives and formal tracking, and benefits from engaged stakeholders. On the other hand, Petter (2015) found that early performance indicators like EAC, CPI, and SPI stabilize after 20-30% of a project's completion, making them reliable for forecasting final costs and schedules, which supports better budgeting and resource allocation.

Fernando Acebes M. P. (2015) introduced a stochastic EVM framework that uses Monte Carlo simulations and statistical learning to improve project forecasting. This method provides better accuracy in predictions and risk management for uncertain projects. While Laura L. Willems (2015) reviewed EVM literature, identifying key themes and gaps. The study found that EVM research is growing but lacks empirical studies in emerging economies and industries like IT. It suggested expanding EVM's application and integrating it with modern project management methods.

Fernando Acebes J. P.-P. (2014) argued for a simplified project control approach, emphasizing basic principles like clear goals and effective communication over complex tools like EVM. The study found that focusing on these fundamentals improves project control and adaptability in uncertain environments. While Browning (2014) developed a framework integrating value, risk, and opportunity management with Earned Value Management (EVM). This approach improves decision-making and project outcomes by using EVM data to balance value, manage risks, and seize opportunities.

Reza Aliverdi (2013) demonstrated that integrating Statistical Quality Control (SQC) charts with Earned Value Management (EVM) improves project monitoring by detecting deviations earlier and allowing for timely corrective actions, resulting in better control of project cost and schedule. On the other hand, De Marco A. (2013) showed that Earned Value Management (EVM) effectively tracks cost, schedule, and scope in facility construction projects. It enhances performance monitoring and early deviation detection, supporting timely corrective actions, though its success depends on accurate data.

Kwak (2012) assessed EVM's role in NASA's government projects, finding it significantly improves project control and performance. The study highlights the importance of data quality and consistent application and suggests integrating EVM with modern project management tools for future challenges. While Vanhoucke (2012) compared project control methods, including EVM, using simulations and real-world data. The study highlighted that practical challenges often arise beyond theoretical models, emphasizing the need for real-world testing to ensure control methods' effectiveness and adaptability.
Leila Moslemi Naeni (2011) developed a fuzzy logic-based EVM method to manage data uncertainties, offering a more flexible and accurate assessment of project performance than traditional EVM. The approach, assessed with various data, improved project control and decision-making by addressing imprecision in cost and schedule data. On the other hand, Javier Pajares (2011) introduced the Cost Control Index (CCI) and Schedule Control Index

(SCI) to improve EVM. These indices enhance cost and schedule monitoring, leading to more precise performance evaluations and better project management.

Burns (2011) enhanced EVM with path-sensitive heuristics, improving forecasting by considering various project scenarios. The study found that these heuristics lead to more accurate and reliable performance estimates, benefiting decision-making and project control in complex environments. While Diamantas (2011) integrated risk management into EVM, enhancing its ability to manage uncertainties and improve project assessments.

Warburton (2011) developed a time-dependent EVM model for software projects, enhancing accuracy by incorporating fluctuating work rates and project phases. This model improves performance assessments and forecasting for the dynamic nature of software development. However, Shokri-Ghasabeh (2009) developed an improved EVM schedule control method that enhances schedule monitoring and deviation detection, proving more effective than traditional EVM, particularly in Iran. On the other hand, Marshall (2008) improved Earned Value Management (EVM) by combining it with inferential statistics, which enhanced its predictive power and reliability, leading to better project insights and decision-making.

Jigeesh (2006) advanced Earned Value Analysis (EVA) with dynamic modeling and simulation, offering a clearer understanding of project performance and interactions among factors, which improves management and decision-making for complex projects. While Alvarado (2004) showed that Earned Value Management (EVM) enhances construction project performance at the General Services Administration (GSA) by improving cost and schedule visibility, which leads to better forecasting and resource management. On the other hand, Alberto De Marco (2023) shows that effective cost contingency management improves project estimate accuracy and reduces budget deviations.

EVM was integrated with risk management to improve EAC forecasting performance; Moselhi (2022) finds that combining Earned Duration Management (EDM) with risk management improves project duration forecasts. The integration of risk analysis into EDM enhances prediction accuracy by addressing uncertainties, which leads to better planning and control in complex projects. While Dashkov (2022) showed that integrating Earned Value Management (EVM) at Sakhalin Energy improves efficiency, coordination, and risk management in large-scale oil and gas projects, enhancing overall project monitoring and control. On the other hand, De Andrade (2017) developed a framework that integrates Earned Duration Management (EDM) with Earned Value Management (EVM), which enhances accuracy and simplifies project time and cost management, making performance monitoring more efficient for project managers.

EVM was used as a monitoring tool for greenhouse gas (GHG) emissions during construction projects; Abdollah Abdi (2018) integrated EVM with GHG emissions metrics to better manage environmental impacts in construction. This model improved both project performance monitoring and environmental control, leading to greater project sustainability.

Value Engineering tool was used for a different purpose, it was used as a cost optimization tool; Paulo Henrique Palma Setti (2021) combined Value Engineering (VE) with Design for Assembly (DFA) to optimize product development. This method improved cost-effectiveness, assembly efficiency, and product performance, showing greater benefits than using VE or DFA alone. On the other hand, Uddin (2013) shows that applying Value Engineering (VE) to intermodal transportation infrastructure improves cost efficiency, performance, and sustainability. The study's framework for VE enhances lifecycle costs and aligns economic and environmental goals, leading to more effective and sustainable infrastructure solutions.

D. Janz (2005) integrates Value Engineering (VE) with life cycle costing to improve product redesign. This combined approach enhances cost-effectiveness and product value throughout its lifecycle, leading to better decision-making, cost savings, and improved product value. For other aim (VE) and Building Information Modeling (BIM) were integrated to save 2,208,600$; Xiaojuan Li (2021) shows that combining Building Information Modeling (BIM) with Value Engineering (VE) improves cost control and project efficiency in construction by enhancing cost estimates and identifying savings opportunities. While Ahmed Mahmoud Elsayed (2024) presents a framework that combines Value Engineering (VE) and Building Information Modeling (BIM) to improve construction project efficiency. It enhances design quality, cost-effectiveness, and decision-making, resulting in better overall project performance.

VE was implemented to achieve sustainability and reduce the ecological impact; Kineber (2022) introduces a Value Engineering (VE) model for sewer projects, improving cost management and sustainability, which enhances project outcomes. Moreover, VE is highly effective approach for transferring knowledge among the working team; Marco Formentini (2011) demonstrates that Value Analysis (VA) improves knowledge transfer in multi-project settings by systematically assessing and sharing critical knowledge. The study finds that VA enhances efficiency and effectiveness in knowledge management, leading to better project outcomes. For another aim, VE was used as A Problem-Solving tool; Tang (2014) shows that Value Engineering (VE) improves design solutions in marine construction by fostering innovation and cost-effectiveness. The study finds that VE enhances design functionality, identifies cost-saving opportunities, and resolves project challenges, leading to better project outcomes and increased efficiency.

The intention of using combining EVM and VE tools was for improving construction project management performance in Iran; Nejatyan (2023) finds that combining Earned Value Management (EVM) with Value Engineering (VE) improves construction project management. The integration enhances cost control, performance measurement, and efficiency, leading to better management practices and more successful project outcomes. And for Investigating cost overrun in most public construction projects in Iraq; Husam Al-Jawhar (2016) highlights that integrating Earned Value Management (EVM) with Value Engineering (VE) helps manage cost overruns in construction projects. This combined method improves cost control and project performance, leading to better financial results and overall project success.

Reviewing existing literature reveals key research gaps. One major area is understanding how stakeholders including project managers, engineers, and clients perceive and experience the integration of EVM and VE, and how these perspectives affect project outcomes and stakeholder satisfaction. Additionally, with the increasing use of advanced technologies like BIM in EVM and VE practices, further research is needed to explore how these technologies can improve the accuracy and efficiency of these methodologies.

Further research should focus on the environmental and social impacts of integrating EVM and VE, as current studies primarily address cost and performance. Additionally, exploring best practices for training project teams on these integrated approaches is crucial, including strategies to overcome resistance and ensure successful implementation.

Existing research often examines the short-term effects of combining EVM and VE. However, further study is needed on their long-term impacts, particularly regarding sustainability and lifecycle costs. This research also shifts focus from product components to the production process itself, proposing a framework that uses both EVM and VE to boost productivity, reduce task times, lower costs, and optimize resource use, aiming to improve overall production efficiency.

3. The Proposed Framework:

The proposed framework combines Earned Value Management (EVM) and Value Engineering (VE) to enhance project efficiency and cost-effectiveness. By utilizing EVM’s detailed performance metrics, such as Earned Value and Cost Performance Index, it provides accurate progress tracking and informed decision-making.

At the same time, VE's methodical analysis of functions and development of cost-effective alternatives improves production processes and maintains product quality, leading to optimized resource use and reduced task times.

The framework consists of five key phases. The Initiation and Planning phase involves defining the project scope, objectives, and key performance indicators (KPIs) to align with strategic goals. During the Value Engineering Analysis phase, current processes are examined, and creative alternatives are developed to enhance efficiency. In the Implementation of EVM phase, performance is monitored using Earned Value Management (EVM) metrics. The Monitoring and Control phase focuses on analyzing variances from the plan and applying corrective actions to keep the project on track. Finally, the Continuous Improvement phase incorporates feedback and lessons learned to update practices and recommend strategies for future projects.

The framework steps as shown in **figure 1**, are designed to be adaptable and scalable, making it applicable to a wide range of projects across various industries. By using both EVM and VE, the framework not only enhances productivity and optimizes resource use but also fosters a culture of continuous improvement and innovation, leading to superior project outcomes.

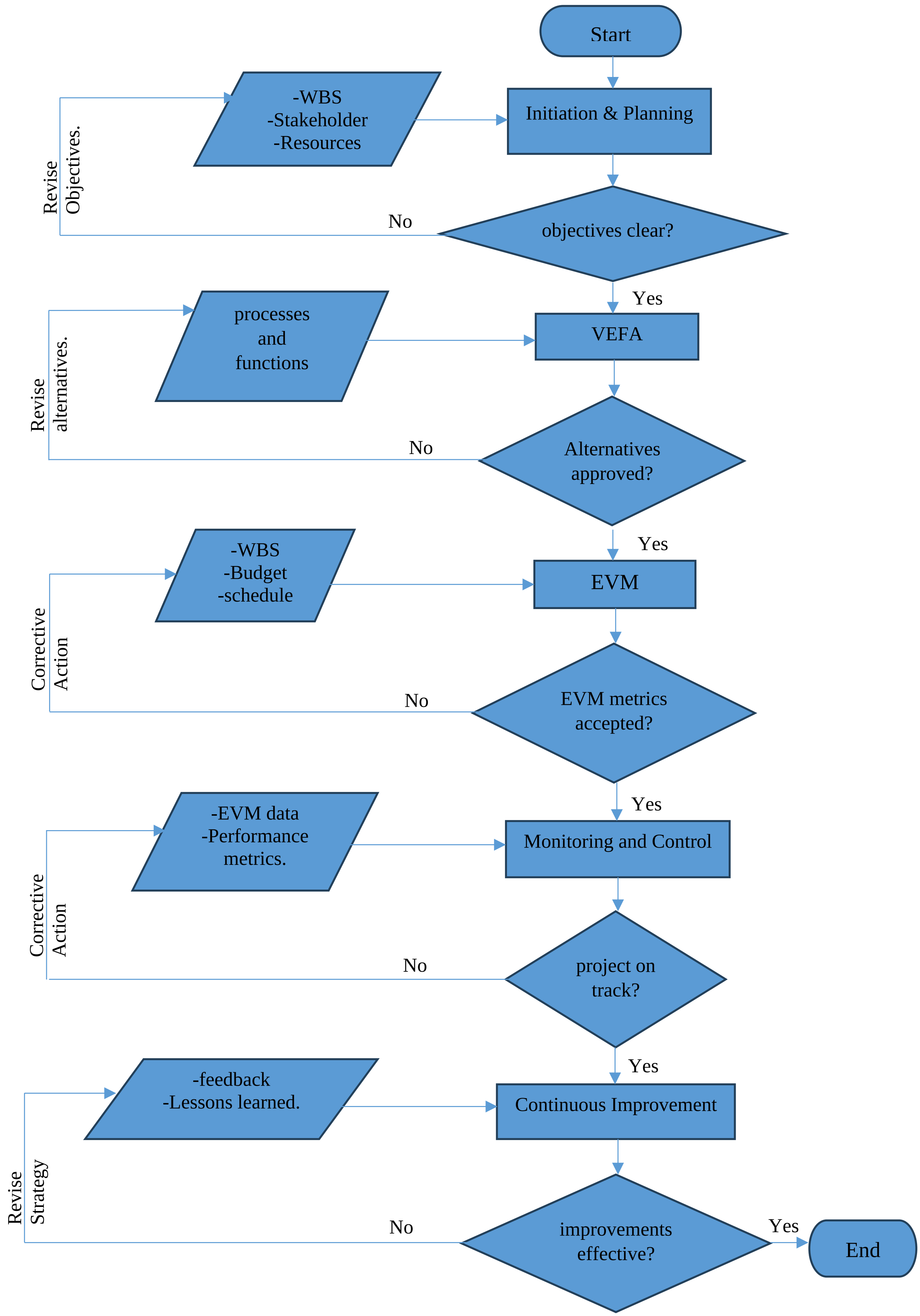

Figure 1. Proposed framework steps

Steps for Implementation

In this section, the steps for implementing the proposed framework are outlined as follows, the process begins with initiation and planning, where the primary objectives are identified and clarified to ensure they align with the overall strategic goals. A detailed action plan is then developed, which includes assembling a cross-functional team and establishing clear key performance indicators (KPIs) to guide the process.

Following this, the Value Engineering Analysis phase involves conducting a thorough functional analysis and exploring various creative alternatives. Based on the outcomes of this analysis, alternatives are either approved or revised to meet the project's needs more effectively.

The next step is the implementation of Earned Value Management (EVM). This includes reviewing the baseline schedules and budget allocations established at the project's outset. Project performance is then monitored using EVM metrics, such as Earned Value (EV), Actual Cost (AC), and Cost Performance Index (CPI), to track and assess progress against the initial plans. Specifically, PV is calculated as the Planned Percentage of Completion multiplied by the Total Budget, EV is the Actual Percentage of Completion multiplied by the Total Budget, CV is the difference between EV and AC, CPI is the ratio of EV to AC, and productivity increase is determined by comparing the time before and after implementation.

In the Monitoring and Control phase, project performance is continuously tracked, and variance analysis is performed. If deviations are identified, corrective actions are taken to address them promptly.

Finally, the Continuous Improvement step involves reviewing project feedback and lessons learned to refine practices. This includes updating procedures and recommending strategies for future projects to ensure ongoing enhancement and success.

This framework helps optimize resource allocation and task time consumption, leveraging the combined strengths of EVM and VE. By following the decision points and iterative processes, the model ensures continuous improvement and effective project management.

4. Phase Descriptions

Phase 1: Initiation and Planning**,** the first phase focuses on setting up the foundation for integrating Earned Value Management (EVM) and Value Engineering (VE) tools. This involves defining the project scope, objectives, and key performance indicators (KPIs). A detailed plan outlining timelines, resources, and budget is developed, and a cross-functional team with expertise in project management, engineering, and finance is assembled. The phase concludes with a kick-off meeting to align stakeholders and clarify expectations.

Phase 2: Value Engineering Analysis**,** in this phase, the aim is to identify opportunities for enhancing value by optimizing cost, quality, and performance. Activities include conducting a functional analysis to understand the essential functions of the task, generating creative alternatives that achieve the same functions at a lower cost, and evaluating these alternatives. The best alternatives are then selected for implementation.

Phase 3: Implementation of Earned Value Management, this phase establishes a system for measuring project performance and progress. It involves reviewing the Work Breakdown Structure (WBS) to ensure that budgets and resources are appropriately allocated and developing performance measurement techniques such as Planned Value (PV), Earned Value (EV), and Actual Cost (AC).

Phase 4: Monitoring and Control, the focus here is on tracking performance, identifying variances, and implementing corrective actions. Data on PV, EV, and AC are collected at regular intervals, and performance metrics like Cost Performance Index (CPI) and Schedule Performance Index (SPI) are calculated as needed. Variances are analyzed to determine their root causes, corrective actions are taken, and stakeholders are updated through regular reports.

Phase 5: Continuous Improvement, the final phase ensures ongoing enhancement of processes and outcomes. Post-project reviews are conducted to identify lessons learned, feedback mechanisms are implemented to capture insights from the project team, and project management and VE practices are updated based on these lessons. A culture of continuous improvement is fostered within the organization.

5. Application

i. Earned Value Management

To implement the EVM we need to define the following:

Determine the planned value PV? Planned Value represents the budgeted cost of the work scheduled to be done by a specific point in time. To calculate PV for the task, multiply the planned percentage of completion (based on the project schedule) by the total budget allocated to the task.

$$PV = \text{Planned Percentage of Completion} \times \text{Total Budget}$$

Determine the actual cost (AC)? Actual Cost represents the actual amount spent or resources consumed to complete the task up to the current point in time. This can include labor costs, material costs, and other direct expenses associated with the task. However, in our proposed framework we are concerned with the working hours as a cost.

Determine the earned value for this task? Earned Value represents the value of the work completed on the task up to the current point in time. To calculate EV, multiply the actual percentage of completion (based on the progress of the task) by the total budget allocated to the task.

$$EV = \text{Actual Percentage of Completion} \times \text{Total Budget}$$

Then we need to calculate Earned Value metrics. In our framework we are more interested in cost: monitoring:

Cost Variance (CV) indicates whether the task is under or over budget. $CV = EV - AC$

Cost Performance Index (CPI): CPI measures cost efficiency CPI = EV / AC

Finally, we need to interpret the Results: Analyze the CV and CPI values to understand the performance of the task. Positive CV value indicates favorable performance, while CPI value greater than one indicates efficient performance.

ii. Value Engineering Function analysis

Function Analysis is a technique used to identify and understand the needs of the project, product, or service, (what does it do, what must it do). Function Analysis is an essential component of the Value Engineering process, **figure 2** shows the function analysis system technique diagram FAST.

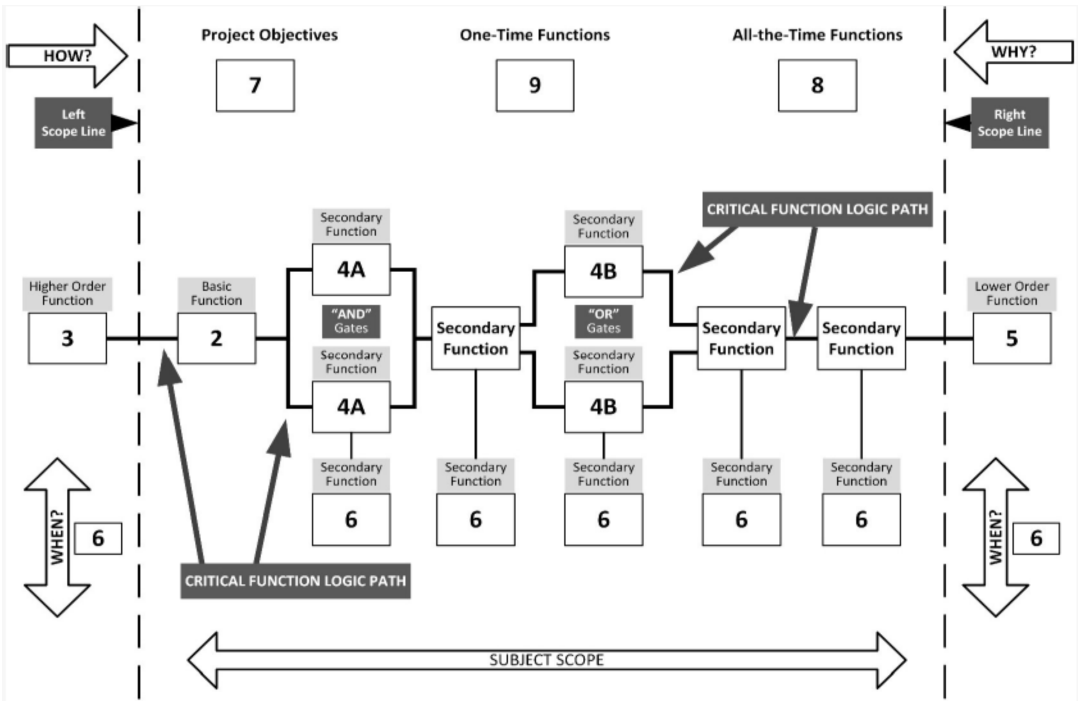

Figure 2. Function Analysis System Technique (FAST) diagram,

Function Analysis Guide, SAVE international.

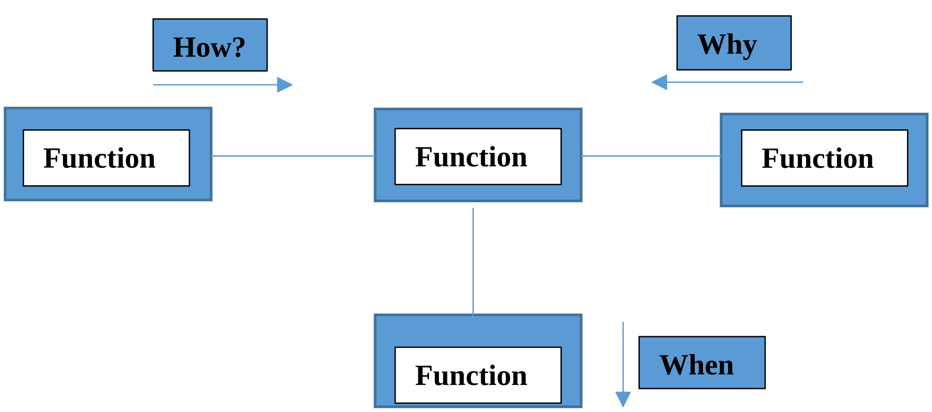

Figure 3. Simple VEFA diagram

Figure 3 shows a simplified FAST diagram, using value engineering function analysis (VEFA) to identify why (what for) the task is done for and how the task can be accomplished by analyzing the task and breaking it down into adjective verb and function noun.

iii. Implementation

We applied the proposed framework on production tasks in an engineering design firm. Tasks were categorized into two groups: Repetitive Tasks that must be done in every project and One-time task which is not repetitive for all the projects. We were more interested in the repetitive tasks.

To initiate the planning phase, we organized a meeting with various teams, requesting them to identify repetitive tasks that were time-consuming and needed a more efficient approach. We reviewed the working hours allocated for each task and compared them to the budgeted hours for the work packages they were part of. Each discipline provided a list of tasks, and we prioritized those that consumed the most time (up to 9 working hours) for applying the framework.

We assembled a cross-functional team from the relevant departments, defined our goals, and developed a clear action plan. We gathered all data related to each task to establish clear KPIs and obtained the allocated working-hours for each task according to the Work Breakdown Structure (WBS). One task that required considerable working hours was the quantity surveying of HVAC ducts in the mechanical section. This involved manually extracting duct dimensions from drawings and entering them into Excel sheets to calculate the weights or areas of the ducts. These calculations were then used to prepare the bill of quantities (BOQ), which helps the client determine the HVAC ductwork budget within the overall project budget.

The second phase of the framework involved implementing Value Engineering Function Analysis. **Figure 4** shows the simplified FAST diagram for Duct weight calculation task.

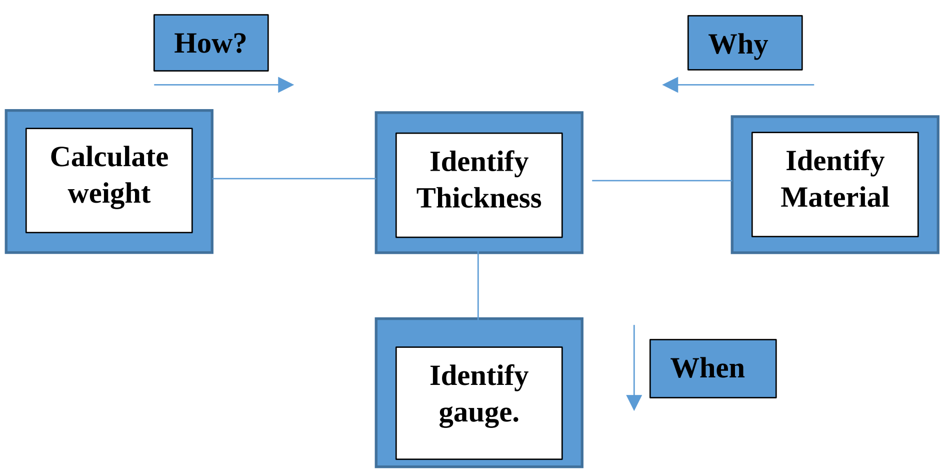

Figure 4. Simplified FAST diagram for Duct weight calculation task.

Then after setting the basic steps for accomplishing the task, there is a need to develop an alternative way to do the task and for that the researcher used the building information modeling (BIM) visual programing tool [Dynamo] along with the scheduling feature in the BIM software [Revit] to develop an automatic tool that pick the dimension of the ducts from the drawing then do the mathematics needed to calculate the weight or the area of the ducts based on the thickness of ducts.

Revit Schedule feature is used to collect all ducts of different systems in one table, then the Dynamo script with the help of Python code classifies the ducts according its manufacturing material based on the duct system, then back to Revit schedule, look up tables were settled as per standard so that all mathematical calculations of thickness according to duct size are done while at same time classification of Gauges based on thickness is also done.

The users get weight, area, thickness, gauge, and duct material for each single piece of duct used in the project along with the grand total weight and area of each gauge of every material. Settling the system components on model and running the script consumed around an average of five minutes while it took an average of four working hours to do it manually.

Validation for the tools has been done, it was used many times on the same project and the output was the same each time, also it was assessed over different projects to find the limitations or issues if any.

The third phase involved the implementation of EVM, both Earned Value and Planned Value metrics were calculated in this phase for this task. The Planned hours for the task were 4 hrs. (240min) to be done manually by an engineer whose working hour is estimated by 12$/hr. while its actual consumed time was only 5 minutes using the developed alternative tool and costed around 1$ (based on the user working hour rate). These 5 minutes represents only 2% of the total planned hours while the task is 100% accomplished, given the details:

Planned Time: 4 hours (240 minutes)

Actual Time Consumed: 5 minutes.

Planned Cost: $48

Actual Cost: $1

Percentage of Planned Time Consumed: 2%

Task Completion: 100%

Planned Value (PV), Actual Cost (AC), and Earned Value (EV) are as shown in table 1:

Table 1. Determined PV, AC and EV for Duct QS task.

Task	PV	AC	EV
Duct QS	48$	1$	48$

The monitor and control phase involved tracking performance, identifying variances, and implementing corrective actions. In this phase the cost variance and cost performance index were calculated.

Cost Variance (CV) indicates whether the task is under or over budget.

CV = EV – AC   CV = 48 – 1

CV = 47$ which is a remarkably high positive cost variance

Cost Performance Index (CPI): CPI measures cost efficiency

CPI = EV / AC   CPI = 48 / 1

CPI = 48, which indicates exceptional cost efficiency, as the cost incurred is significantly lower than the value of the work performed.

In Continuous Improvement, phase, regular feedback is collected from users to refine the proposed tools and enhance workflow. This ongoing feedback helps identify areas for improvement and address any additional needs that arise, ensuring the tools evolve to better meet user requirements and project demands.

The above implementation of VEFA shortened the time of duct QS from many working hours to few minutes. On the other hand, it also improves quality by avoiding human error in calculations or classifications of different duct materials. At the same time, it helped in another task which the duct insulation area calculation which is based on calculation the duct areas in the first place.

With the application of the Earned value management, we managed to calculate the cost variance and the cost performance index which gave us insights into the productivity improvement we accomplished.

For the Landscape team, the annotation task, which is repetitive, the planned hours of manual work by an engineer at a rate of $12 per hour to complete 300 annotations are 9 hours. Using value engineering function analysis, this task was broken down into several logical steps and a Dynamo script was developed to perform the task by detecting the geometry faces and lines of objects in the model. This script uses these references to set dimensions accurately and measures the inclination of these lines from true north to ensure proper alignment of the dimension lines. It was determined that the developed script can complete this task in just 3 minutes. In contrast, the planned hours for this task were 9 hours (540 minutes) to be performed by a modeler at rate of $10 per hour, incurs costs of $108. The automated approach, however, reduced the time to 3 minutes and the cost to only $0.60 (based on the user's working hour rate), achieving full completion of the task. Given the details:

Planned Time: 9 hours (540 minutes)

Actual Time Consumed: 3 minutes.

Planned Cost: $108

Actual Cost: $0.6

Percentage of Planned Time Consumed: 0.5%

Task Completion: 100%

Planned Value (PV), Actual Cost (AC), and Earned Value (EV) are as shown in table 2:

Table 2. Determined PV, AC and EV for LS annotations task.

Task	PV	AC	EV
LS annotations	108$	0.6$	108$

Cost Variance (CV) indicates whether the task is under or over budget.

CV = EV – AC   CV = 108 – 0.6

CV = 107.4$ which indicates a significant cost underrun

Cost Performance Index (CPI): CPI measures cost efficiency

CPI = EV / AC   CPI = 108 / 0.6

CPI = 180, which represents exceptional cost efficiency achieved through automation.

Another repetitive task required for every project by all teams across different disciplines is the creation and renaming of PDF sheets to match the model sheets. These PDFs are submitted to the client for review at each stage of the project.

In the initiation and planning phase, we assembled a cross-functional team and gathered all relevant information related to the task. This task previously required 4 minutes to manually create and rename just two sheets. The manual process involved selecting "Print PDF," choosing the two sheets from the model, exporting them as PDFs, and then renaming each file to match the title block of each sheet. In large-scale projects, different disciplines can submit between 400 to 800 sheets per discipline at each stage, totaling approximately 3,000 sheets across all disciplines in the building sector. The planned working hours for this task were one hundred hours to be performed by a modeler at rate of $10 per hour, incurs costs of $1,000 for each stage.

In the second phase, we utilized VEFA to decompose the task into logical steps, creating a sequence of sub-tasks. After establishing the basic steps for the task, an alternative approach was developed using a Dynamo script combined with Python code. This method automates the selection of predefined sheets, applies printing settings, and uses the sheet name from the title block as the PDF name. The development team successfully created a tool that generates and renames two sheets in just 1.36 minutes. Consequently, processing three thousand sheets now takes only thirty-four working hours, reducing the time by 66%.

The third phase involved calculating the earned value metrics for this single task, given the details:

Planned Time: 100 hours (6000 minutes)

Actual Time Consumed: 34 hours.

Planned Cost: $1000 per stage

Actual Cost: $340

Percentage of Planned Time Consumed: 0.5%

Task Completion: 100%

Planned Value (PV), Actual Cost (AC), and Earned Value (EV) are as shown in table 3:

Table 3. Determined PV, AC and EV for PDF sheets task.

Task	PV	AC	EV
PDF sheets	1000$	340$	1000$

The fourth phase involved calculating the cost variance and cost performance index:

CV = EV – AC   CV = 1000 – 340

CV = 660 which is a remarkably high positive cost variance

CPI = EV / AC   CPI = 1000 / 340

CPI = 2.95, which indicates a favorable cost performance.

6. Preliminary results and discussion

Similar steps were followed for other repetitive tasks across various disciplines, and the Earned Value Management (EVM) metrics were calculated and summarized as demonstrated in table 4.

Table 4. Cost Before /Cost after in $ – EVM metrics

Task	Discipline	Cost Before ($)	Cost After ($)	CV	CPI
A	HVAC	48$	1$	47$	48$
B	Landscape	108$	0.6$	107.4$	180$
C	Landscape	360$	2$	25$	180$
D	Landscape	2880$	4$	2876$	720$
E	All disciplines	1000$	340$	660$	2.95$
F	infrastructure	48$	0.2$	47.8$	240$

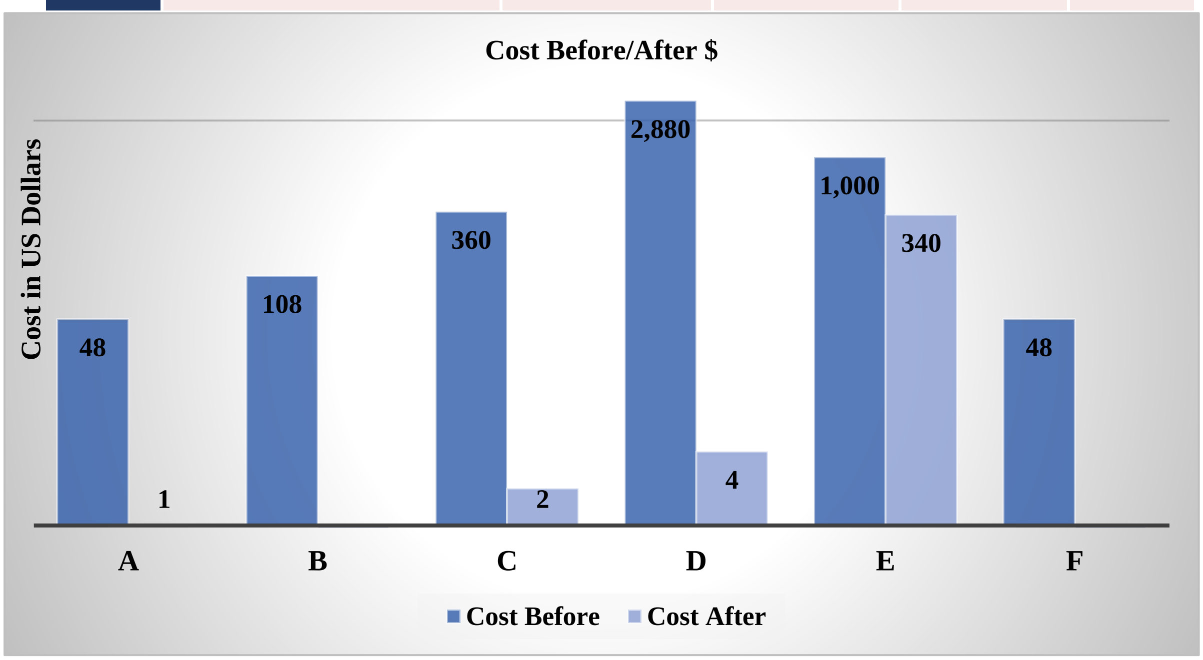

Figure 5. Cost enhancement after implementation

The results show strong cost performance index and variance values, indicating successful framework implementation. These savings allow the firm to optimize resource allocation, enhancing productivity and increasing profit margins. The enhancement in cost was impressive as some tasks cost was decreased to less than one dollar as presented in **figure 5**. While the cost savings were impressive the time consumed for each task was also decreased and even reached one minute for some tasks which also reflects the resource allocation optimization as demonstrated in table 5:

Table 5. Time Before /Time after in minutes

Task	Discipline	Time Before (min)	Time After (min)
A	HVAC	240 min	5 min
B	Landscape	540 min	3 min
C	Landscape	1800 min	10 min
D	Landscape	14400 min	20 min
E	All disciplines	6000 min	2040 min
F	infrastructure	240 min	1 min

The enhancement in time consumed for each task was as presented in **figure 6**:

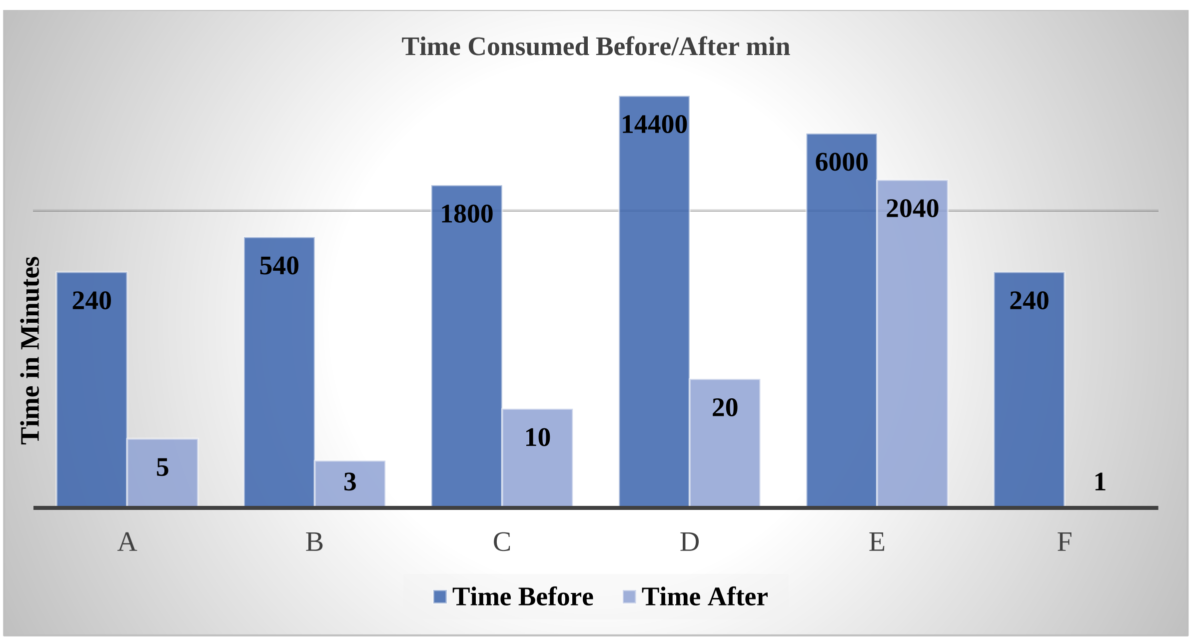

Figure 6. Time enhancement after implementation

The findings support the success of the proposed framework in saving cost and optimizing resource allocations which directly lead to system's productivity enhancement ranged from 66% to 99.9 as shown in table 6:

Table 6. Productivity increase %

Task	Discipline	Productivity Increase (%)
A	HVAC	97.92
B	Landscape	99.44
C	Landscape	99.44
D	Landscape	99.86
E	All disciplines	66.00
F	infrastructure	99.58

7. Challenges and Solutions

Implementing the proposed framework integrating Earned Value Management (EVM) and Value Engineering (VE) may face challenges, particularly resistance to change. Employees and managers accustomed to existing processes might be skeptical or fearful of new methodologies. To address this, it is crucial to clearly communicate the framework's benefits, involve stakeholders early, and provide thorough training and support. Employees may worry that efficiency improvements through VE and EVM could lead to job cuts or reassignment. To alleviate these concerns, communicate clearly that the goal is to enhance productivity and support job stability. Show how roles can positively evolve with new processes. Address fears of personal blame by promoting a culture of collective growth and continuous improvement and present the framework as a tool for overall efficiency. Provide a clear analysis of long-term benefits and share examples of past successes to demonstrate the value of VE activities. Carefully plan VE activities to minimize disruptions and use resources effectively. By proactively addressing these challenges, the firm can smooth the transition to the new framework and ensure its successful implementation, leading to enhanced productivity and optimized resource allocation.

8. Conclusion

Integrating Earned Value Management (EVM) and Value Engineering (VE) can face resistance and job loss concerns. Address these by clearly communicating benefits, engaging stakeholders early, and providing training. Promote collective growth, recognize achievements, and use cost-benefit analyses and case studies to show VE’s long-term value. Proactive issue resolution ensures successful implementation, enhancing productivity and resource management.

Both EVM and VE tools and the proposed framework contributed to enhancing the system’s productivity. For some disciplines, the consumed time for getting tasks done decreased to one minute while the cost was reduced from some tasks to one dollar, which is impressive compared to the original time and cost needed for getting tasks done.

Allover Enhancement in productivity cost ranged from 66% to 90%. Total working hours savings ranged from 33% to 88.7%. The quality enhancement of the resulting product ranged from 40% to 64%. This success in optimizing resource allocation and increasing cost savings directly leads to enhanced total productivity.

The findings encourage firms to invest more in enhancing their own productivity systems, and open new windows for researchers to use the EVM and VE tools for new intentions in different application and to look at the possibility of the application of these tools from different perspectives.

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Conceptualization, Dr. Arafa S. Sobh; collecting data, Shaimaa Darwish; Analysis tools, Dr. Mohamed Etman; Performed analysis, Dr. Abdullah Elfar; authoring paper, Shaimaa Darwish.

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