OPEN ACCESS
Saudi Journal of Engineering and Technology
Abbreviated Key Title: Saudi J Eng Technol
ISSN 2415-6272 (Print) | ISSN 2415-6264 (Online)
Scholars Middle East Publishers, Dubai, United Arab Emirates
Journal homepage: https://saudijournals.com

Original Research Article

Earned Value Management in Intralogistics: A Case Study in Mexican Manufacturing

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DOI: 10.36348/sjet.2024.v09i07.003 | **Received:** 22.05.2024 | **Accepted:** 30.06.2024 | **Published:** 08.07.2024

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Abstract

Earned Value Management (EVM) is a project management tool primarily used in engineering and project management to assess performance in terms of cost and schedule. Earned Value Management/Scheduling systems (EVM/ES) have been fundamental in project control, providing key metrics that measure deviations between planned and actual performance in terms of time and cost. However, its application as a project control technique is not very common in Mexico. In this article, EVM was applied to the intralogistics improvement of a manufacturing process in the automotive sector located in Aguascalientes, Mexico. The case study concluded in February 2024 and includes the project scope, scheduling charts, physical progress reports, and budgeted versus actual cost reports. The aim of this article is to provide practical evidence on how to apply EVM in manufacturing projects in Mexico. This will enable project professionals to more effectively utilize EVM for schedule and cost control in their manufacturing projects, with a specific emphasis on intralogistics.
Keywords: Earned Value Management, Framework, Performance Measurement, Risk Management, Intralogistics, Case study.

1. INTRODUCTION

The performance of an intralogistics improvement project in manufacturing processes can be evaluated using various traditional approaches such as progress against the activity schedule, daily or monthly reports, project meetings, among others. However, these types of controls applied to new projects in the automotive manufacturing industry located in Aguascalientes, Mexico, have proven to be inadequate for properly managing new projects. This is because in the company where the case study was applied, there have been recorded delays in project startups of up to 9% (considering the fiscal years from 2019 to 2023). The importance and necessity of launching projects on time without delays against the established plan must be imperative for any manufacturing or service company because this implies a competitive advantage to lead the market where the products compete with other brands.

Project control is a crucial phase within project management aimed at ensuring in an integrated manner that the project objectives are met according to plan (Santos *et al.*, 2023). The Earned Value Management (EVM) method is an effective tool for evaluating and controlling project performance through the measurement of project performance. It allows for the measurement of project progress in terms of time and cost by comparing planned work with completed work and incurred costs. Additionally, it helps in the following areas:

- Identification of deviations. Deviations between the plan and the actual execution of the project can be identified, both in terms of time (schedule) and cost. This helps to detect potential problems early on.
- Informed decision-making. Project managers can make informed decisions to correct deviations, reallocate resources, and adjust strategies to ensure the project gets back on track.
- Resource optimization. It helps optimize resource utilization, ensuring they are used efficiently and effectively to meet project objectives.

- Continuous improvement. Continuous analysis of project performance through EVM fosters a culture of continuous improvement, where lessons can be learned from past projects and best practices applied to future projects.

The application of EVM in projects focused on intralogistics improvement is uncommon in the manufacturing industry in Mexico. Earned value management/earned schedule (EVM/ES) systems have played a central role in project control and provide straightforward key performance metrics that measure the deviations between planned and actual performance in terms of time and cost (Colin *et al.*, 2014).

The case study presented in this article aims to offer an alternative to current methods used in a manufacturing company in the automotive sector, strengthened by the implementation of EVM in the management of new projects. It focuses on intralogistics improvement that will benefit the company by adopting and standardizing new project management methods, aiming to reduce delays in the project lifecycle.

2. BACKGROUND

This case study was funded by the same private equity company, with a value of 1.5 million pesos, allocated in August 2022 under the modality of reengineering and implementation based on a framework shown in Fig 6. To this end, an interdisciplinary team was established with the scope of redesigning the layout and implementing the intralogistics improvement between the vehicle engine manufacturing lines and the storage of engines before shipment to customers. The objective is for this project to be executed in February 2024, considering the involvement of Project scheduling, risk analysis and project tracking are key parameters to a project's success or failure (Vanhoucke, 2011).

The case study focuses on two engine assembly lines that produce 24 different engine specifications, of which some engines (10%) go through hot testing while others (90%) go directly to the warehouse for storage. The process of moving engines is done using a metal rack with a capacity of six engines each. The operator at the end of the engine assembly line uses a hoist to take each engine and place it in each slot of the rack until it is filled with six engines. Once the rack is filled, it is moved with a forklift assigned to these engine assembly lines. There are a total of two forklifts assigned to service lines E1 and E2 respectively. The distance between the assembly lines and the engine warehouse is 120 linear meters (see Fig 1).

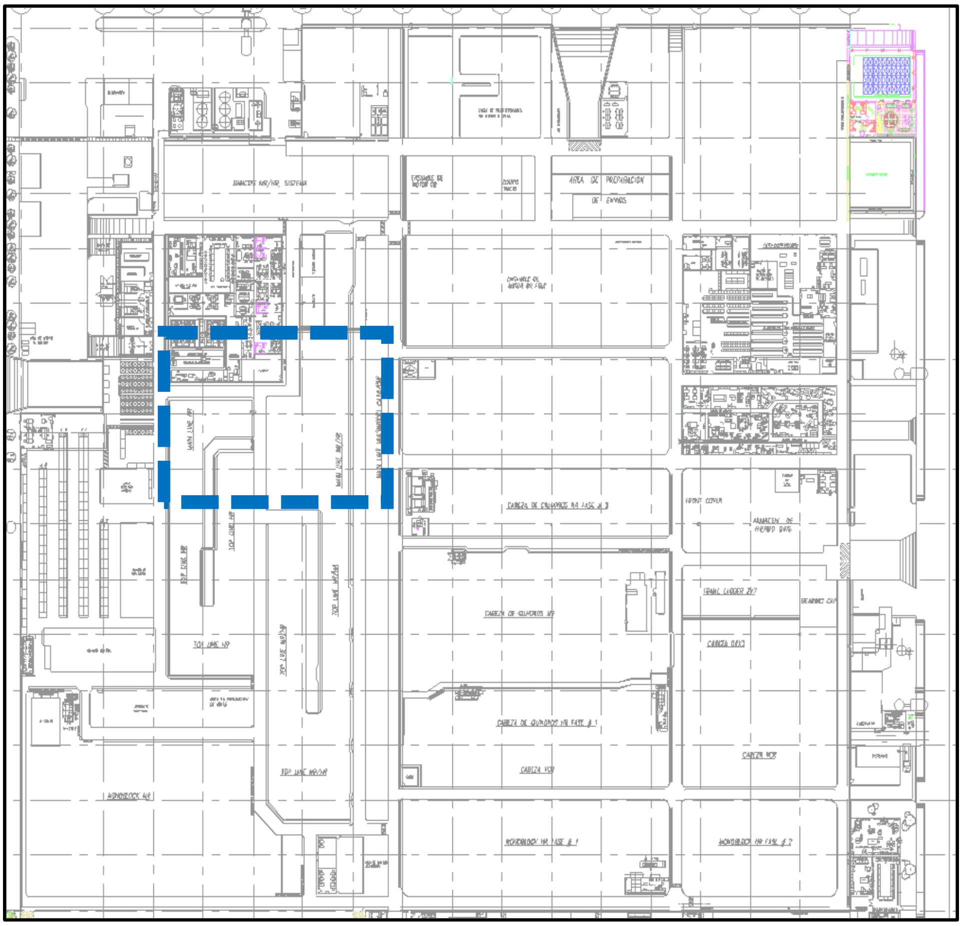

Fig 1: Opportunity area identified to improve intralogistics

Records within the company show that projects executed from fiscal year 2019 to 2023 have started with delays. Consequently, the production ramp-up has also been affected, leading to issues due to non-compliance with established dates, program timelines, and allocation of additional resources. Disruption risks may arise in a project-based supply chain due to the involvement of various actors, e.g. suppliers and transport service providers, along the chain besides its decentralized structure (Ashraf *et al*., 2023).

The Fig 2 mentions that at least 4 projects managed from 2019 to 2023 using commonly employed methods for the Start of Production (SOP) for new projects have experienced delays in both the startup and ramp-up phases.

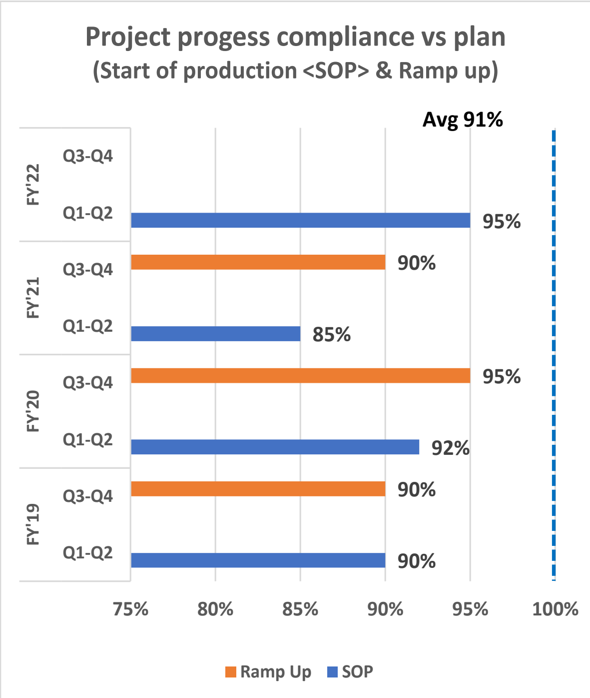

Fig 2: SPO compliance tracking

This means that considering effectiveness against defined program timelines, only an average of 91% compliance with committed dates is achieved.

3. OBJECTIVE AND BENEFITS

The combination of existing and yet to be applied methods within a company can enhance management performance for new projects, for which the framework of the Fig 6 with the aim of having a model adapted to the needs of the company through the application of EVM. This will allow ensuring the SOP on the committed date for new projects.

With this enriched framework of tools, techniques, and models, it is projected to increase the effectiveness of managing future projects, thereby reducing cost overruns and minimizing risks of greater impact on subsequent processes for the company. It can be easily adaptable once its execution effectiveness is confirmed and guaranteed with the results obtained of this case study, the intention is to stimulate knowledge and define new procedures within the company to manage the start of larger-scale projects.

With a good project management structure, it will be easier to implement technological tools such as simulation to evaluate the scope of new projects, where the systematic impacts of the parameters can be visualized (Lopes *et al*., 2020).

4. APPLICATION OF THE EVM SYSTEM

Project management through the EVM System in intralogistics improvement at an automotive manufacturing plant is carried out in the following steps:

4.1. Project progress control software or Tool

In this case study, Microsoft Project Standard was used to input all activities, their start and end dates, required resources, and allocated budgets for controlling and monitoring activities.

4.2. Development of the work breakdown structure

The Work Breakdown Structure (WBS) is a critical process in an EVM System. The WBS is a hierarchical decomposition of project tasks into smaller, manageable components. By creating a detailed WBS, it becomes easier to measure project performance using techniques such as EVM, which helps compare planned work with actual work completed and work in progress. This comparison is essential for assessing project progress and making informed decisions.

Schedule compliance is one of the main logistic objectives of production systems. To achieve high schedule compliance, different control variables of a job shop production system can be adopted (Schmidt *et al.*, 2014).

A WBS provides a solid foundation for establishing a project schedule to be executed. It consists of a detailed listing of activities within the work package with planned start and end dates, (see Fig 4). In the automotive manufacturing industry, the project scheduler is typically responsible for creating schedules approved by the project manager.

4.3. Organizational breakdown structure

The Organizational Breakdown Structure (OBS) displays job descriptions of project team members. It is also used to establish relationships within the team and assign roles and responsibilities. Unlike a task-based perspective, the OBS provides a hierarchical chart of the project.

This hierarchical structure allows for consolidating project information at higher levels such as the proposal of Fig 3 in this project to define roles and responsibilities, the OBS and WBS are integrated to create a Human Resources Plan (HRP). Operational Risk (OR) is usually caused by losses due to human errors, inadequate or defective internal processes, system failures or external events that affect an organization (Pena *et al*., 2021).

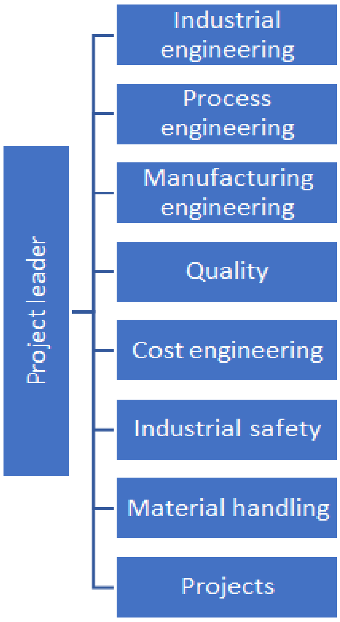

Fig 3: Organizational structure for the project

The combination of the WBS and OBS ensures that all project elements are assigned to team members according to the Responsibility Assignment Matrix (RAM).

The organizational structure will help identify the project leader who will act as a facilitator and coordinate tasks with each of the assigned participants from different departments. This is to assess and monitor the fulfillment of activities defined in the project.

The RAM in Table 1 establishes relationships for each participating department's responsibilities such as reporting, decision-making, consultation, and progress reporting. In general, this matrix helps avoid ambiguities in actions.

Below there are the meanings of each type of assignment available:

- R (responsible). Responsible for task execution.
- A (accountable). Ultimately responsible and makes decisions.
- C (consulted). Consulted and contributed knowledge.
- I (informed). Informed about progress and outcomes.

4.4. Budget allocation

The intralogistics improvement in the manufacturing process within the automotive sector was designated as a necessary project to enhance productivity and minimize internal logistics costs, based on cost-benefit analyses previously presented to the plant management. A budget of 1.5 million Mexican pesos was allocated.

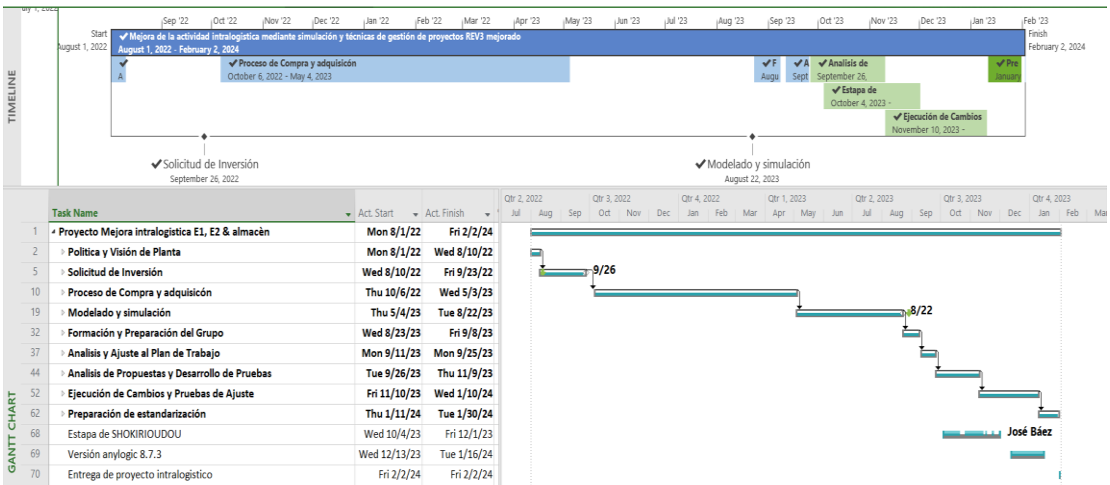

Fig 4: Work schedule summary

The Budgeted Cost of Work Scheduled (BCWS), also known as Planned Value (PV), is a key metric in project management, especially in EVM. The BCWS represents the monetary value of the work that was planned to be completed by a specific date in the project (see Fig 5). Its use in controlling the Budget at Completion (BAC) is essential for monitoring progress and ensuring that the project stays within the Budget.

The prediction of the odds of achieving higher or lower productivity as compared to some baseline productivity is one of the important steps to consider while analyzing labor productivity in construction projects (Gurmu *et al*., 2020).

4.5. EVM.

In EVM, the indicators BAC, EAC, SV, CV, SPI, and BCWS are crucial for evaluating the performance of the intralogistics improvement project in terms of cost and schedule to establish actions that mitigate any delays. Each indicator is detailed below:

- BAC (Budget at Completion). This is the total budget of the project approved at the baseline cost.
- EAC (Estimate at Completion). This is an estimate of the total project cost at completion, based on current performance and projections for the future. Common methods for calculating EAC include Performance-based EAC (EAC = AC + (BAC – (Earned value (EV))) and Trend-based EAC (EAC = BAC / CPI).
- SV (Schedule Variance). Indicates whether the project is ahead of or behind schedule at a given point in time. It is calculated as SV = EV - PV. A positive value indicates the project is ahead, while a negative value indicates delay.

Table 1: Responsibility Assignment Matrix (RAM)

Tasks/Departments	Project Leader	Industrial Engineering	Process Engineering	Manufacturing Engineering	Quality	Cost Engineering	Industrial Safety	Materials Handling	Projects
1. Current situation analysis	A	R	C	C	C	I	I	I	A
2. Definition of QCTS objectives	A	R	C	C	I	C	I	I	R
3. Cost-Benefit Study (NPV)	R	C	C	C	I	R	I	I	C
4. Requirements elaboration	R	R	R	C	C	R	I	I	C
5. Solution design	A	R	R	R	I	C	C	R	C
6. Evaluation and validation	A	R	R	C	R	C	C	R	I
7. Implementation planning	A	R	C	R	I	C	R	R	A
8. Risk management	A	C	C	C	I	I	R	C	C
9. Project execution	R	R	R	R	I	C	R	R	A
10. Monitoring and control	A	R	R	R	R	C	R	R	A
11. Quality verification	R	C	C	C	R	I	C	R	C
12. Project closure	A	R	C	R	R	I	C	R	A

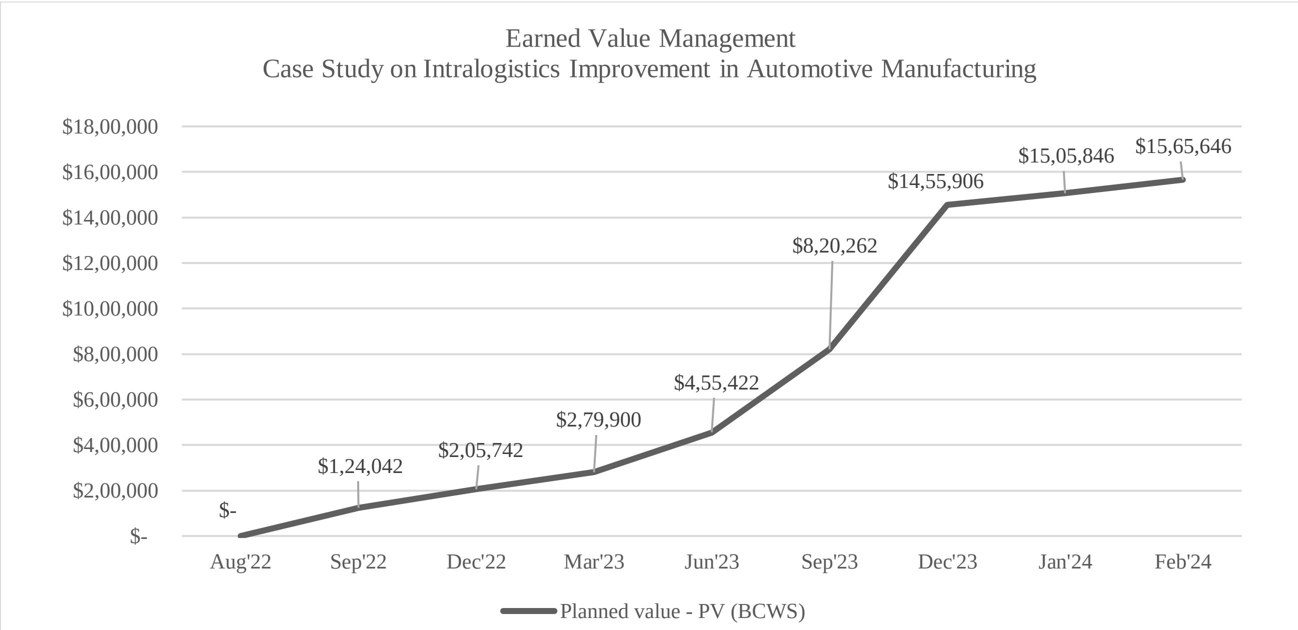

Fig 5: S Curve for cumulative cash flows

- CV (Cost Variance). Indicates whether the project is under or over budget at a given point in time. It is calculated as CV = EV - AC. A positive value indicates the project is under budget, while a negative value indicates it is over budget.
- SPI (Schedule Performance Index). Measures the schedule efficiency of the project compared to the planned schedule. It is calculated as SPI = EV / PV. A value greater than 1 indicates better than planned performance, while a value less than 1 indicates poorer performance.
- BCWS (Budgeted Cost of Work Scheduled). The authorized budget allocated for the work planned up to the current date of the project, based on the cost baseline.

All the above-mentioned indicators are tracked over the course of the project in the Table 2. These indicators relate to each other as follows within the context of earned value analysis:

- SV and CV relate to the difference between actual performance (AC and EV) and planned performance (PV and BAC), respectively.
- SPI is a ratio between EV and planned value (PV).
- EAC is used to project the final cost of the project based on current performance.
- BAC is the total budget of the project set at the cost baseline.
- BCWS represents the budget allocated for planned activities up to the current date.
- Collectively, these indicators provide a comprehensive view of the project's performance in terms of cost and schedule, allowing the project manager to identify early deviations and take corrective actions as needed to meet established objectives.

Table 2: Master data table for measuring project performance over time

	Aug'22	Sep'22	Dec'22	Mar'23	Jun'23	Sep'23	Dec'23	Jan'24	Feb'24
Planned value - PV (BCWS)	$ -	$ 124,042	$ 205,742	$ 279,900	$ 455,422	$ 820,262	$ 1,455,906	$ 1,505,846	$ 1,565,646
SV	$ -	$ (14,454)	$ (11,967)	$ (9,014)	$ (6,372)	$ (3,730)	$ 63,244	$ 63,711	$ 64,332
Project planned progress		**$ 0.08**	**$ 0.13**	**$ 0.18**	**$ 0.29**	**$ 0.52**	**$ 0.93**	**$ 0.96**	**$ 1.00**
Project planned real		**$ 0.07**	**$ 0.12**	**$ 0.17**	**$ 0.29**	**$ 0.52**	**$ 0.97**	**$ 1.00**	**$ 1.04**
Earned Value - EV (BCWP)	$ -	$ 109,588	$ 193,775	$ 270,885	$ 449,050	$ 816,532	$ 1,519,150	$ 1,569,557	$ 1,629,978
CV	$ -	$ (12,712)	$ (8,310)	$ (3,941)	$ 5,954	$ 34,088	$ 163,864	$ 172,155	$ 180,054
CV%	0.00%	-11.60%	-4.29%	-1.45%	1.33%	4.17%	10.79%	10.97%	11.05%
CPI	0.00	0.90	0.96	0.99	1.01	1.04	1.12	1.12	1.12
BAC	$ 1,565,646	$ 1,565,646	$ 1,565,646	$ 1,565,646	$ 1,565,646	$ 1,565,646	$ 1,565,646	$ 1,565,646	$ 1,565,646
EAC	$ 1,449,924	$ 1,747,259	$ 1,632,784	$ 1,588,425	$ 1,544,887	$ 1,500,285	$ 1,396,767	$ 1,393,920	$ 1,392,698
VAC	$ 115,722	$ (181,613)	$ (67,138)	$ (22,779)	$ 20,759	$ 65,361	$ 168,879	$ 171,726	$ 172,948
TCPI	1.00	1.01	1.01	1.00	0.99	0.96	0.22	-0.02	-0.56
SPI	0.00	0.88	0.94	0.97	0.99	1.00	1.04	1.04	1.04
Actual Cost ACWP	$ -	$ 122,300	$ 202,084	$ 274,827	$ 443,096	$ 782,444	$ 1,355,286	$ 1,397,402	$ 1,449,924

5. RESULTS AND DISCUSSION

The analysis of data provided for the project from August 2022 to February 2024 shows a clear evolution in terms of cost and schedule. Using EVM indicators, the project has demonstrated varied, yet overall positive, performance.

5.1. Project evolution over time and decision making.

- Schedule (SPI and SV):

Project start (August 2022 to March 2023): Initially, the project experienced some delays. SPI values were consistently below 1 (with a minimum of 0.88 in September 2022), and SV was negative, indicating that the work performed was behind schedule.

Gradual improvements (June 2023 to September 2023): SPI began to improve and reached values close to 1 (0.99 in June 2023 and 1.00 in September 2023), indicating that the project was meeting the planned schedule (see Table 2).

Advancement (December 2023 to February 2024): Towards the end of the analyzed period, the SPI exceeded 1, reaching 1.04, and SV turned positive, indicating that the project not only met but exceeded the planned schedule (see Fig 7).

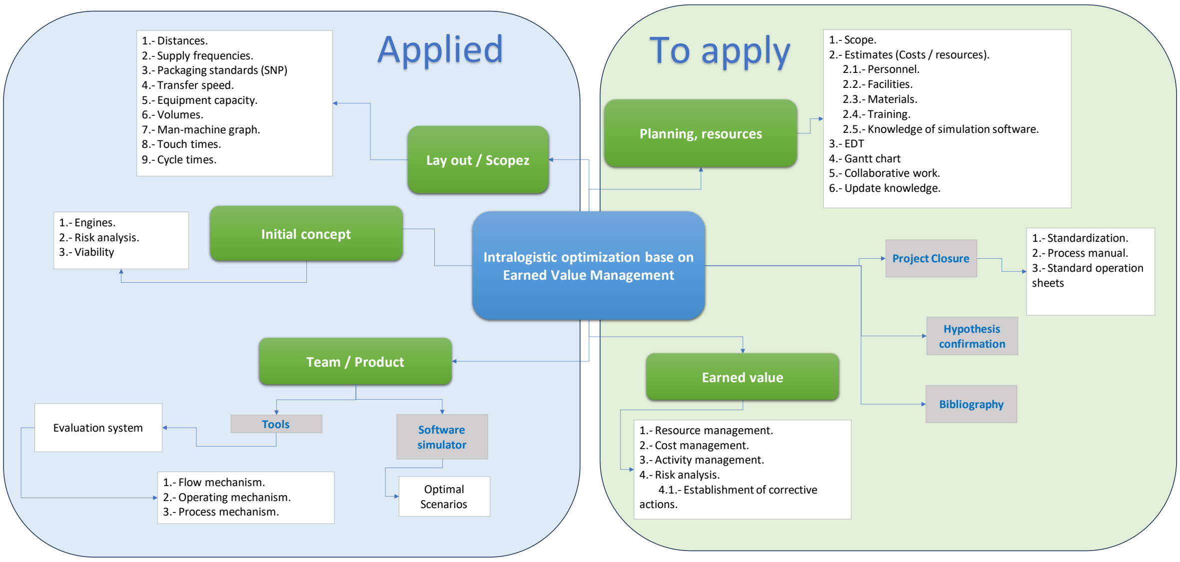

Fig 6: Framework proposed of knowledge to apply

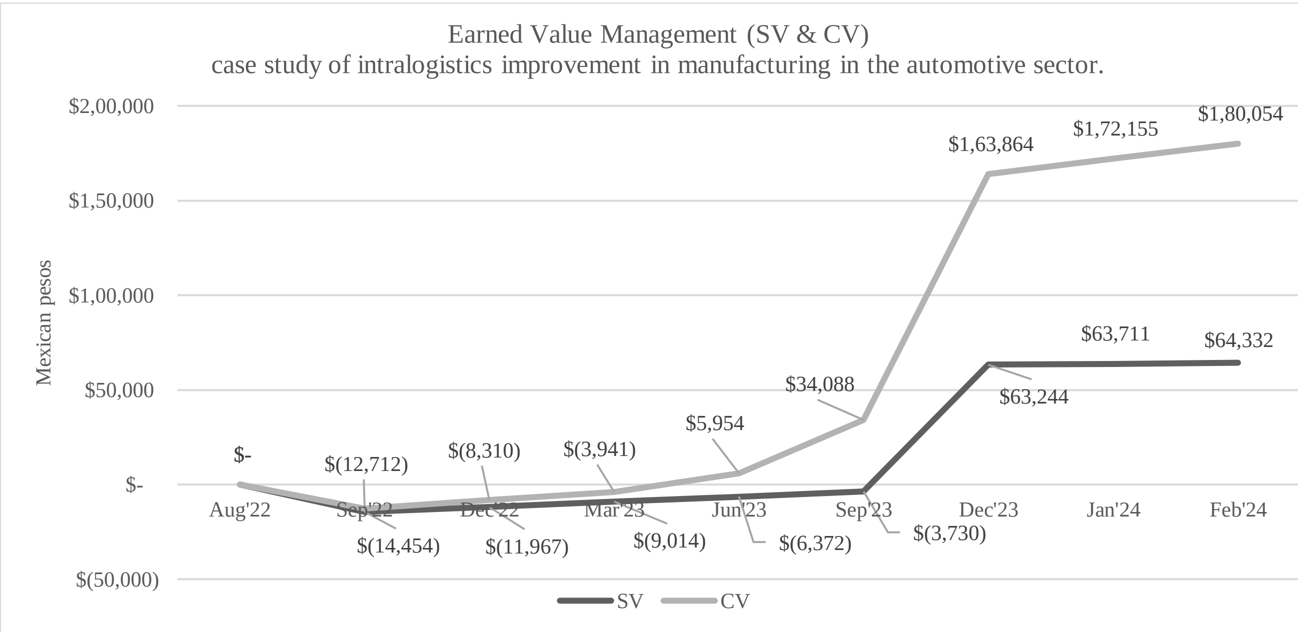

Fig 7: Performance of SV and CV over time

- Cost (CPI and CV):

Initial Performance (August 2022 to March 2023). Initially, the project struggled to stay within budget. CPI was less than 1 (with a minimum of 0.90 in September 2022), and CV was negative, indicating actual costs were exceeding earned values.

Adjustment and Control (June 2023 to September 2023). CPI began to improve, exceeding 1 from June 2023 onwards, indicating efficient cost management. CV also turned positive, indicating the project was spending less than budgeted (see Table 2).

Cost Optimization (December 2023 to February 2024). Towards the end of the period, CPI reached a value of 1.12, showing high efficiency in resource utilization (see Fig 8), and CV was very positive, indicating significant savings compared to the budget.

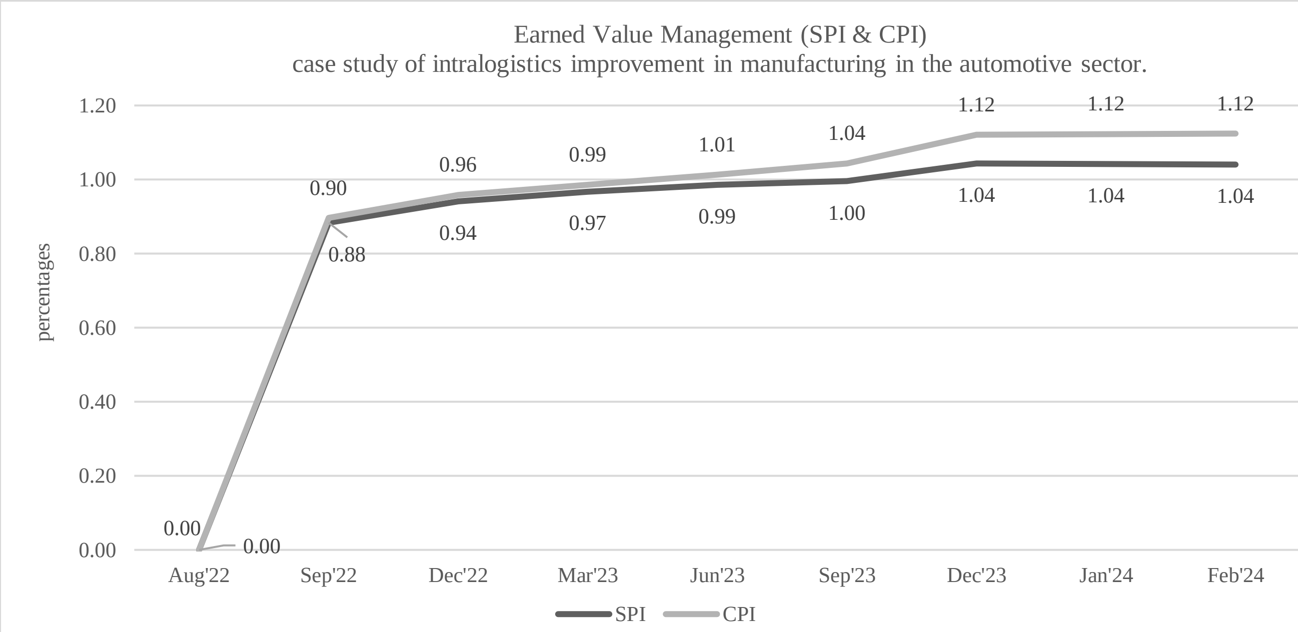

Fig 8: Performance of SPI and CPI over time

- Total Budget and Estimates (BAC and EAC):

Baseline Budget. The BAC remained constant at $1,565,646 throughout the period.

Estimate at Completion. Estimates initially fluctuated, with an increase in September 2022 ($1,747,259) due to initial delays and overruns. However, risk analysis safeguards implemented gradually improved the EAC projection, reducing it to $1,392,698 by February 2024 (see Fig 9), indicating that the project is expected to finish with a cost lower than the original budget (see Table 2).

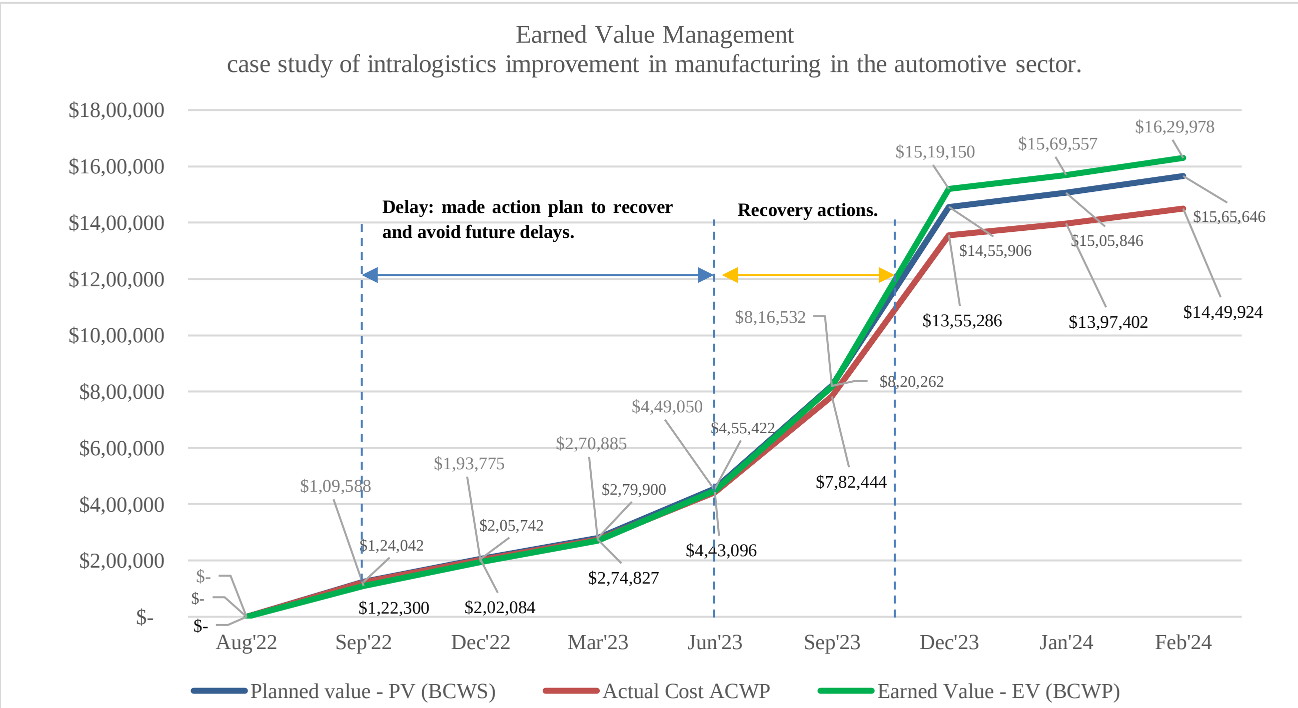

Fig 9: Result of earned value analysis in intralogistics improvement

6. CONCLUSIONS

The project began with significant challenges in both schedule and costs, showing initial delays and overruns. However, corrective measures were implemented that substantially improved project performance thanks to the implementation of the proposed framework. By June 2023, the project was meeting its time and cost objectives. From

December 2023 onwards, the project exceeded the established objectives, finishing ahead of schedule and with significant cost savings.

Based on the above, the proposed framework is considered beneficial for the company and efforts will be made to extend it to other process areas. Considering the dissemination regarding the effective use of project management tools and techniques given the presented results and their contribution to decision-making.

The use of current project control methods strengthened by EVM greatly aids timely decision-making and addresses conditions that could jeopardize the committed project start date.

Additionally, this research may help clarify potential solution alternatives in Mexico for those responsible for a project, tailoring the proposal to the needs of the context, the expected objectives, and the systems or techniques already implemented.

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