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Research Paper

# SEM approach for Analysis of Lean Six Sigma Barriers to Electric Vehicle Assembly

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## Abstract

This study investigates the barriers that the Lean Six Sigma implementation faces during the assembly of electric vehicles. In order to implement Lean Six Sigma methodology in electric vehicle assembly processes effectively, it is crucial to identify and analyze the barriers that hinder process improvement. To identify the obstacles and create a conceptual model, a thorough literature review was conducted. Four factors, namely, integration of assembly, inspection, and testing, lack of trained and knowledgeable human resources, external and in-plant battery transportation, and manual assembly and rigid automation, were found to have the potential to affect the lean Six Sigma implementation. Three drivers, namely assembly cost, assembly time, and assembly effort were selected for the study. The model is then tested using the structural equation modeling and the gathered data. The results show a significant relationship between the three drivers and the four barriers of Lean Six Sigma implementation to the electric vehicle assembly.

**Keywords:** Lean Six Sigma; Lean implementation; Barriers; Electric vehicle assembly; Structural Equation Modeling (SEM)

## 1. Introduction

Lean Six Sigma (LSS) is a widely recognized methodology used for process improvement in various industries, including the automotive sector. Electric vehicles (EV) are becoming popular since they are able to fulfill the consumer expectation based on several aspects such as economic, technological, social, and environmental aspects [1]. Bicycles are also following the EV trend wherein various new economical bicycle designs with two-way driving control are developed [2]. The EV operates through motor and a large battery [3], [4]. Electric vehicle (EV) assembly processes have unique challenges due to their complex components and high-tech features. To effectively implement LSS in EV assembly processes, it is crucial to identify and analyze the barriers that hinder process improvement.

In recent years, the use of structural equation modeling (SEM) has gained popularity in studying complex relationships in various fields. SEM is a powerful statistical technique that allows researchers to investigate the underlying relationships between multiple variables simultaneously. Therefore, SEM can be a valuable approach in identifying and assessing the impact of the potential barriers to LSS implementation in EV assembly processes [5]. Several studies are conducted on identifying the barriers to LSS and lean implementation to manufacturing industries [5]–[7]. However, investigation of impact of the LSS barriers on the EV assembly is not found in literature.

This paper proposes an SEM approach for analysis of LSS barriers in the EV assembly process. The proposed approach uses a set of variables such as management support, employee involvement, training, and communication, to construct a model that explains the relationship between these drivers; namely assembly cost, assembly effort, and assembly time; and the barriers to LSS implementation [8], [9]. The results of the study show that the proposed SEM approach can effectively identify the barriers to LSS implementation in the EV assembly process. The findings provide insights into the factors that hinder the successful implementation of LSS in EV assembly processes and offer practical recommendations for improving the process. Overall, the proposed SEM approach can be a valuable tool for researchers and practitioners in the automotive industry to identify and overcome barriers to LSS implementation in the EV assembly process.

## 2. Literature Review

Several papers have highlighted the different barriers affecting LSS implementation in automotive and manufacturing industries [10]. The following sections present an exhaustive survey to identify the prominent LSS barriers. The application of structural equation modeling in identifying the relationship between the drivers and the LSS barriers is discussed in the next section.

### *2.1. LSS Barriers to Implementation of Electric Vehicle Assembly*

The following barriers have been identified from the literature:

### *2.1.1. Battery Pack Transportation from Battery Manufacturer to Electric vehicle Manufacturer*

The transportation of battery packs from the battery manufacturer to the EV manufacturer can be a substantial obstacle to LSS employment in EV assembly processes [11]. To overcome this barrier, Das and Pradhan [12] suggested implementing a just-in-time delivery system and a battery pack transportation system that uses autonomous vehicles.

### *2.1.2. Battery Pack Transportation Within the Manufacturing Plant During the Final Assembly of Electric Vehicle*

In addition to transportation from the battery manufacturer, the transportation of battery packs within the manufacturing plant during the final assembly of the EV can also pose a challenge [13]. To address this issue, Tanabata et al. [14] proposed using a conveyor belt system and automated guided vehicles (AGVs) to transport the battery packs within the plant.

### *2.1.3. Manual Assembly*

Manual assembly can lead to errors and quality issues, and can be a noteworthy barrier to LSS implementation in EV assembly processes [13]. To address this issue, the use of ergonomic workstations and the implementation of standardized work procedures were proposed to reduce the potential for errors [15].

### *2.1.4. Rigid Automated Assembly*

Manual assembly and rigid automated assembly can improve efficiency and reduce errors in EV assembly processes [13], [16]. Sharma et al. [17] proposed a hybrid assembly system that combines both rigid and flexible automation to optimize the assembly process.

### *2.1.5. Integration of Assembly of Electric Vehicles with the Current Conventional IC Engine Based Vehicle Assembly Line*

Integrating the assembly of EVs with the current conventional IC engine-based vehicle assembly line can require significant changes to the existing assembly process [13], [16]. To address this issue, a modular assembly system can be effortlessly incorporated with the existing assembly line [18].

### *2.1.6. Integrate Inline Inspection and Testing Necessary IN Case of Electric Vehicles into Existing IC Engine Based Conventional Assembly Line*

Integrating inline inspection and testing necessary in the case of EVs into the existing IC engine-based conventional assembly line is a significant barrier [13], [16]. It can require careful planning and coordination; and proposed the use of a hybrid inspection system that combines both human and automated inspection to improve the quality of the assembly process [19].

### *2.1.7. Qualified Human Resource Working in the EV industry*

The lack of qualified human resources working in the EV industry can be a significant barrier to the successful implementation of LSS in EV assembly processes [20]–[22]. To address this issue, Li et al. [23] proposed a talent training program that focuses on developing the skills and knowledge necessary for the EV industry.

### *2.1.8. Qualified Human Resource Working in the Lean Six Sigma and Statistics Applied in Automotive Industries*

The lack of qualified human resources working in LSS and statistics applied in automotive industries can also be a significant barrier to the successful implementation of LSS in EV assembly processes [20]–[22]. To address this issue, Elboq et al. [24] proposed the use of a training program that includes both theoretical and practical training to develop the necessary skills and knowledge. **Figure 1** depicts the four constructs for barriers on the first level while their eight indicators are classified on next level.

In summary, the successful implementation of LSS in EV assembly processes requires overcoming various barriers related to transportation, assembly processes, integration with existing assembly lines, and the availability of qualified human resources. SEM can be a valuable approach for identifying and analyzing these barriers and developing strategies to overcome them.

## *2.2. Analysis by SEM*

Structural Equation Modeling (SEM) is a statistical technique used to analyze the complex relationships between variables in a given dataset. SEM has been applied to various fields, including the manufacturing industry, to study the relationships between different variables that affect manufacturing processes and outcomes. This literature review explores some of the studies that have utilized SEM in manufacturing industries.

One of the earliest studies to use SEM in the manufacturing industry was conducted by Anderson and Gerbing [25], who used SEM to examine the relationships between various factors, including quality, customer satisfaction, and profitability, in the context of a manufacturing firm. The study showed that there was a direct and positive relationship between quality and customer satisfaction, which in turn led to higher profitability.

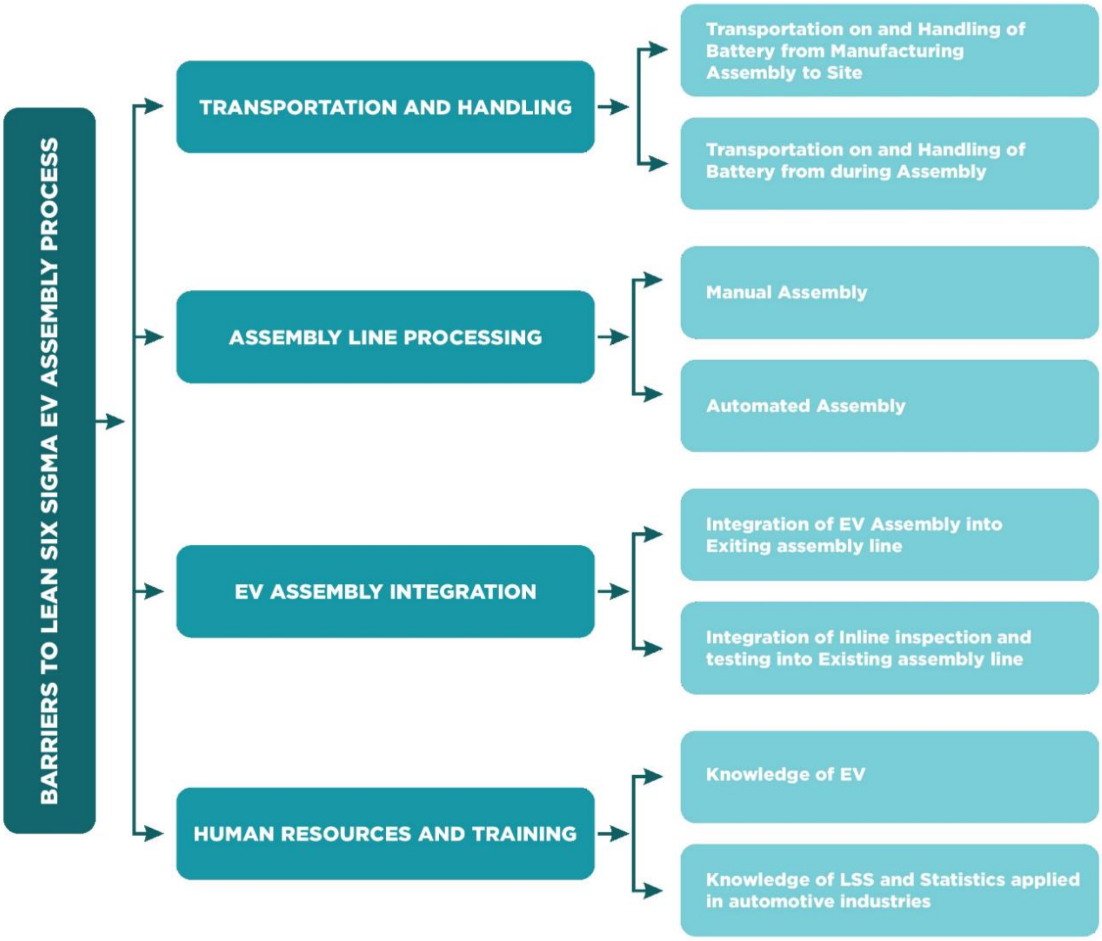

**Figure 1.** Lean Six Sigma barriers to implementation of electric vehicle assembly [10]

Another study that used SEM to explore the relationships between different variables in the manufacturing industry was conducted [26]. They examined the relationships between quality management practices, organizational culture, and performance in manufacturing firms. The study showed that quality management practices had a direct and positive impact on organizational culture, which in turn had a direct and positive impact on performance.

In a more recent study, Liu and Li [27] used SEM to explore the relationships between lean manufacturing practices, supply chain integration, and performance in Chinese manufacturing firms. The study found that lean manufacturing practices had a direct and positive impact on supply chain integration, which in turn had a direct and positive impact on performance.

Another study that explored the use of SEM in the manufacturing industry was conducted by Putri et al. [28]. They used SEM to examine the relationships between organizational culture, quality management practices, and employee satisfaction in the context of a Pakistani manufacturing firm. The study showed that there was a direct and positive relationship between organizational culture and quality management practices, which in turn led to higher employee satisfaction.

Finally, a study by Sadikoglu and Zehir [29] used SEM to examine the relationships between quality management practices, innovation, and performance in Taiwanese manufacturing firms. The study found that quality management practices had a direct and positive impact on innovation, which in turn had a direct and positive impact on performance. In conclusion, the studies reviewed in this literature review demonstrate the usefulness of SEM in exploring the complex relationships between different variables in the manufacturing industry. SEM has been used to study various factors that affect manufacturing processes and outcomes, including quality, customer satisfaction, organizational culture, lean manufacturing practices, supply chain integration, employee satisfaction, innovation, and performance. These studies have provided valuable insights that can help manufacturing firms improve their processes and outcomes.

## 3. Methods

Practitioners and experts from industry and academia participated in the survey. The sample size of completed and usable responses was 240 [30], [31]. The minimum sample size calculated for a statistical power of 0.8 and a significance level of 0.05 by inverse square root method and gamma exponential method was 160 and 146 respectively. In Structural equation modeling, Partial least squares (PLS-SEM) and co-variance based (CB-SEM) approaches exist, out of which the present study adopted the former as the WarpPLS software takes into account non-linear regression.

The three parameters for successful implementation were cost, effort, and time. The combined loadings and cross-loadings verified the theoretical classification to be appropriate, as shown in **Table 1**. The respective indicators give the highest score under their respective construct.

**Table 1.** Combined loadings and cross-loadings

| | Trans | Auto | Int | HR | Drv_Cost | Drv_Time | Drv_Effort | Type (as defined) | SSE | P value |
|---|---|---|---|---|---|---|---|---|---|---|
| **TPBE** | -0.728 | 0.051 | -0.009 | 0.221 | -0.129 | -0.145 | -0.22 | Reflective | 0.076 | <0.001 |
| **TPASY** | -0.728 | -0.051 | 0.009 | -0.221 | 0.129 | 0.145 | 0.22 | Reflective | 0.076 | <0.001 |
| **MAUT** | 0.082 | -0.74 | -0.003 | 0.05 | 0.082 | 0.086 | -0.07 | Reflective | 0.075 | <0.001 |
| **DesRA** | -0.082 | -0.74 | 0.003 | -0.05 | -0.082 | -0.086 | 0.07 | Reflective | 0.075 | <0.001 |
| **IntCon** | -0.212 | 0.075 | -0.747 | -0.096 | 0.042 | -0.092 | -0.012 | Reflective | 0.075 | <0.001 |
| **IntinsTes** | 0.212 | -0.075 | -0.747 | 0.096 | -0.042 | 0.092 | 0.012 | Reflective | 0.075 | <0.001 |
| **HRKNT** | -0.004 | 0.038 | -0.102 | -0.676 | 0.131 | -0.058 | 0.122 | Reflective | 0.077 | <0.001 |
| **HRKNLSE** | 0.004 | -0.038 | 0.102 | -0.676 | -0.131 | 0.058 | -0.122 | Reflective | 0.077 | <0.001 |
| **COST** | 0 | 0 | 0 | 0 | -1 | 0 | 0 | Reflective | 0.071 | <0.001 |
| **TIME** | 0 | 0 | 0 | 0 | 0 | -1 | 0 | Reflective | 0.071 | <0.001 |
| **EFFORT** | 0 | 0 | 0 | 0 | 0 | 0 | -1 | Reflective | 0.071 | <0.001 |

The objective is formulated with following four latent independent variables (each as a combination of indicators):

- Manual assembly and rigid automation;
- Lack of trained and knowledgeable human resource;
- Integration of assembly, inspection and testing; and
- External and in-plant battery transportation while the three dependent variables are assembly cost, assembly effort and assembly time.

The objectives of the investigation are stated below:

- Objective 1: To investigate the impact of manual assembly and rigid automation on assembly cost.
- Objective 2: To investigate the impact of manual assembly and rigid automation on assembly effort.
- Objective 3: To investigate the impact of manual assembly and rigid automation on assembly time.
- Objective 4: To investigate the impact of lack of trained and knowledgeable human resource on assembly cost.
- Objective 5: To investigate the impact of lack of trained and knowledgeable human resources on Assembly effort.
- Objective 6: To investigate the impact of lack of trained and knowledgeable human resources on assembly time.
- Objective 7: To investigate the impact of integration of assembly, inspection, and testing on assembly cost.
- Objective 8: To investigate the impact of integration of assembly, inspection, and testing on Impact on assembly effort.
- Objective 9: To investigate the impact of integration of assembly, inspection, and testing on assembly time.
- Objective 10: To investigate the impact of external and in-plant battery transportation on assembly cost.
- Objective 11: To investigate impact of external and in-plant battery transportation on Impact on assembly effort.
- Objective 12: To investigate the impact of external and in-plant battery transportation on assembly time.

## 4. Results and Discussion

The model was tested by different quality indices. The average block variation inflation factor (VIF) is 1.012 and average full co linearity VIF is 1.067, both within acceptable limits. The goodness of fit of model and data was found to be large. The three ratios measuring errors - Simpson's paradox ration, R-squared contribution ratio and statistical suppression ratio turned out to be the ideal value 1, indicating minimum errors in causality. The graphs of significant objectives were generated to gain insight into relationships. The final structural equation model obtained is shown in **Figure 2**. (where Drv_Cost refers to 'Cost driver', Drv_Time refers 'Time driver', Drv_Eff refers to 'Effort driver', Trans refers to 'External and in-plant battery transportation', HR refers to 'Lack of trained and knowledgeable human resource', Auto refers to 'Manual assembly and rigid automation', Int refers to 'Integration of assembly, inspection and testing'.)

Objective 1: Manual assembly and rigid automation have significant impact on assembly cost whereas objective 2: Manual assembly and rigid automation do not have significant impact on assembly effort and Objective 3: Manual assembly and rigid automation do not have significant impact on assembly time. The graph of 'manual assembly and rigid automation vs. assembly cost, assembly effort, and assembly time, respectively' is shown in **Figure 3**.

**Figure 3** shows a high mean assembly cost, low mean assembly efforts, and, low mean assembly time, with respect to manual and rigid automation assembly. Manual assembly can be slower and may have a higher risk of errors, which can increase assembly cost, time, and effort. However, the manual assembly can be flexible and allows for quick changes and adjustments to the assembly process modifications, thereby reducing the time required for assembly process modifications, which can be beneficial for batch production. On the other hand, rigid automation involves the use of robotic arms and other automated equipment to assemble the vehicle. Rigid automation can be faster and more precise, reducing assembly effort and time and improving overall quality. However, rigid automation can be expensive to implement and maintain, and can be less flexible than manual assembly. This lack of flexibility can increase the time, cost and effort required for assembly if extensive rigid automation is done. In 2019, Sharma et al. [17] suggested a hybrid assembly system that utilizes a combination of rigid and flexible automation techniques in order to improve the efficiency and effectiveness of the assembly process.

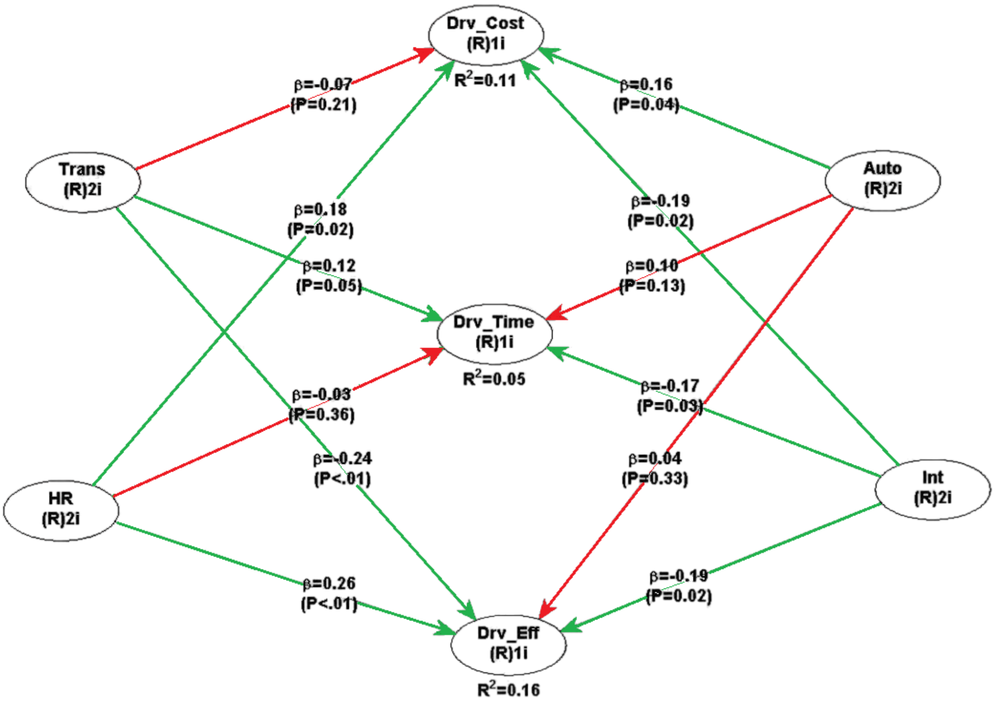

**Figure 2.** Final Structural equation model

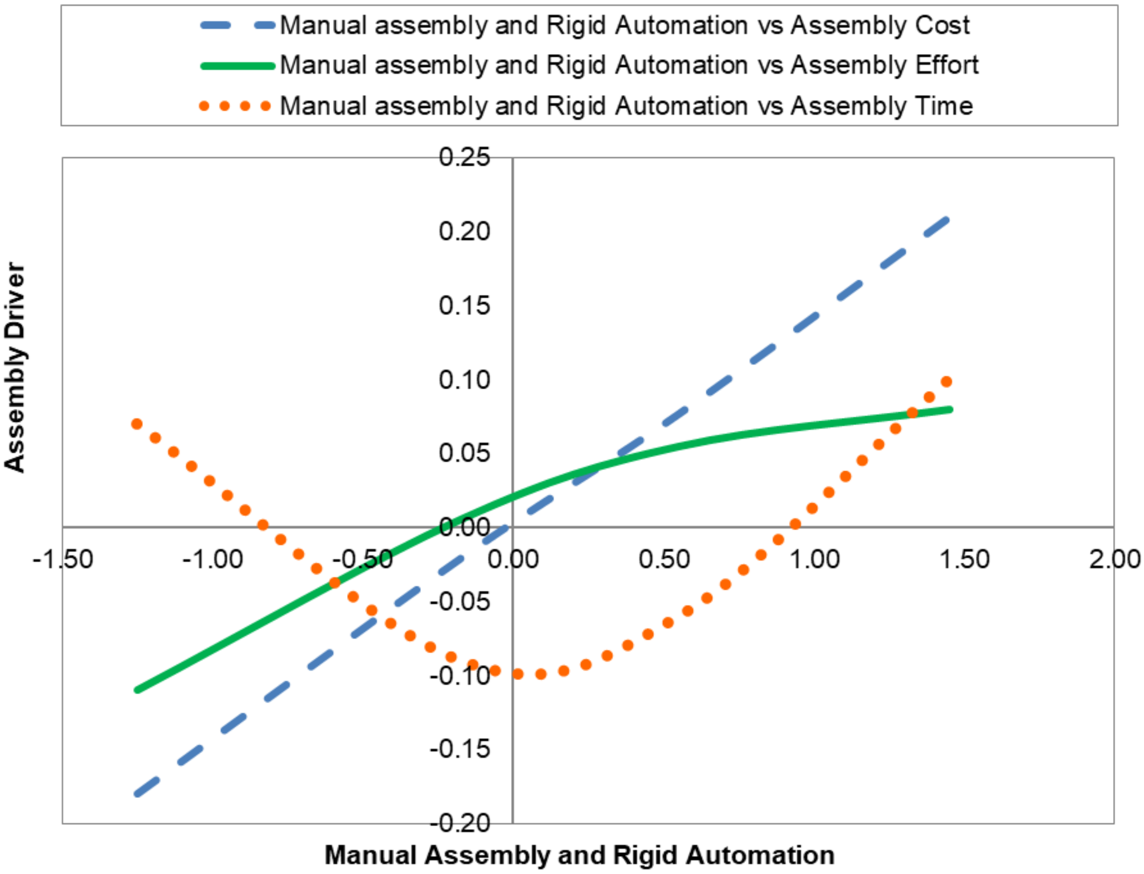

**Figure 3.** Manual assembly and rigid automation vs. assembly cost, assembly effort, and assembly time respectively

In some cases, a hybrid approach that combines both manual assembly and automation may be used to optimize the assembly process. This approach can help to balance assembly time, effort, and cost, by using manual assembly for tasks that require more flexibility and automation for tasks that require higher precision and speed. Overall, the choice between manual assembly and rigid automation will depend on various factors, such as the size of the assembly line, the complexity of the assembly process, and the availability of skilled labor. The cost, assembly effort, and assembly time will also be affected by the specific approach used in electric vehicle assembly.

Objective 4: Lack of trained and knowledgeable human resource has a significant impact on assembly cost and objective 5: Lack of trained and knowledgeable human resource has a significant impact on assembly effort, whereas objective 6: Lack of trained and knowledgeable human resource does not have significant impact on assembly time. The graph of 'lack of trained and knowledgeable human resource vs. assembly cost, assembly effort, and assembly time, respectively' is shown in **Figure 4**.

These findings are in line with literature findings where lack of specialized LSS training is identified as a barrier in several studies [32]–[37]. This is in turn attributed to the lack of understanding of the importance of LSS in various operations [20], [38]–[42]. The lack of trained and knowledgeable human resources can have a significant impact on the electric vehicle assembly cost, assembly effort, and assembly time. Figure 4. shows high mean assembly cost, high mean assembly effort, and, low mean assembly time with respect to lack of trained and knowledgeable human resources.

Firstly, the lack of skilled workers can lead to delays in the assembly process and increase assembly time. Workers who are not adequately trained may make mistakes, which can lead to rework and increased assembly effort, ultimately increasing the assembly time and cost. However most companies involved in manufacturing new products tend to over hire human resource to compensate for the lower time efficiencies in order to ensure timely delivery of the products.

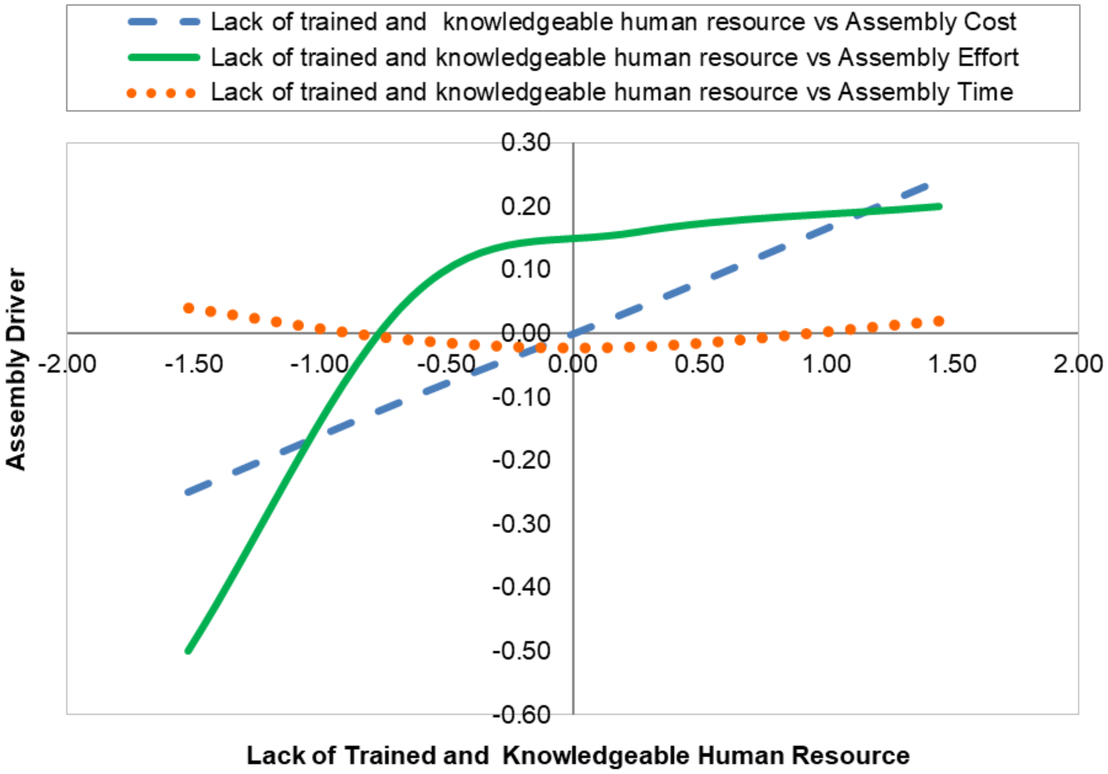

**Figure 4.** The lack of trained and knowledgeable human resources vs. assembly cost, assembly effort, and assembly time respectively

Secondly, the lack of skilled workers may result in decreased efficiency, as workers may not be familiar with the latest assembly techniques and technologies. This may lead to inefficiencies in the assembly process, including a decrease in productivity, increased assembly time, and increased assembly effort.

Thirdly, the lack of skilled workers may lead to higher labor costs, as companies may need to pay higher wages to attract and retain skilled workers. This can increase the overall cost of the assembly process. To address these issues, companies may need to invest in training programs to ensure that workers are adequately trained and knowledgeable in the latest assembly techniques and technologies. This investment can help to reduce assembly time and effort, improve the quality of the assembly process, and ultimately reduce the overall cost of assembly. Overall, the lack of trained and knowledgeable human resources can have significant implications for the cost, assembly effort, and assembly time in electric vehicle assembly. Companies need to prioritize the training and development of their workers to ensure the efficient and effective assembly of electric vehicles.

Objective 7: Integration of assembly, inspection and testing has a significant impact on assembly cost, objective 8: Integration of assembly, inspection and testing has a significant impact on assembly effort, and objective 9: Integration of assembly, inspection and testing has a significant impact on assembly time. The graph of 'integration of assembly, inspection, and testing vs. assembly cost, assembly effort, and assembly time, respectively' is shown in Figure 5.

Figure 5 shows a high mean assembly cost, high mean assembly efforts, and high mean assembly time, with respect to the integration of assembly, inspection and testing. Integrating the assembly, inspection, and testing of electric vehicles with conventional internal combustion engine vehicle production and assembly systems can have both positive and negative impacts on electric vehicle assembly cost, assembly effort, and assembly time.

On the positive side, integration can result in cost savings by leveraging existing infrastructure, equipment, and resources. This can help to reduce the capital costs associated with establishing a separate assembly line for electric vehicles, ultimately reducing the overall cost of assembly.

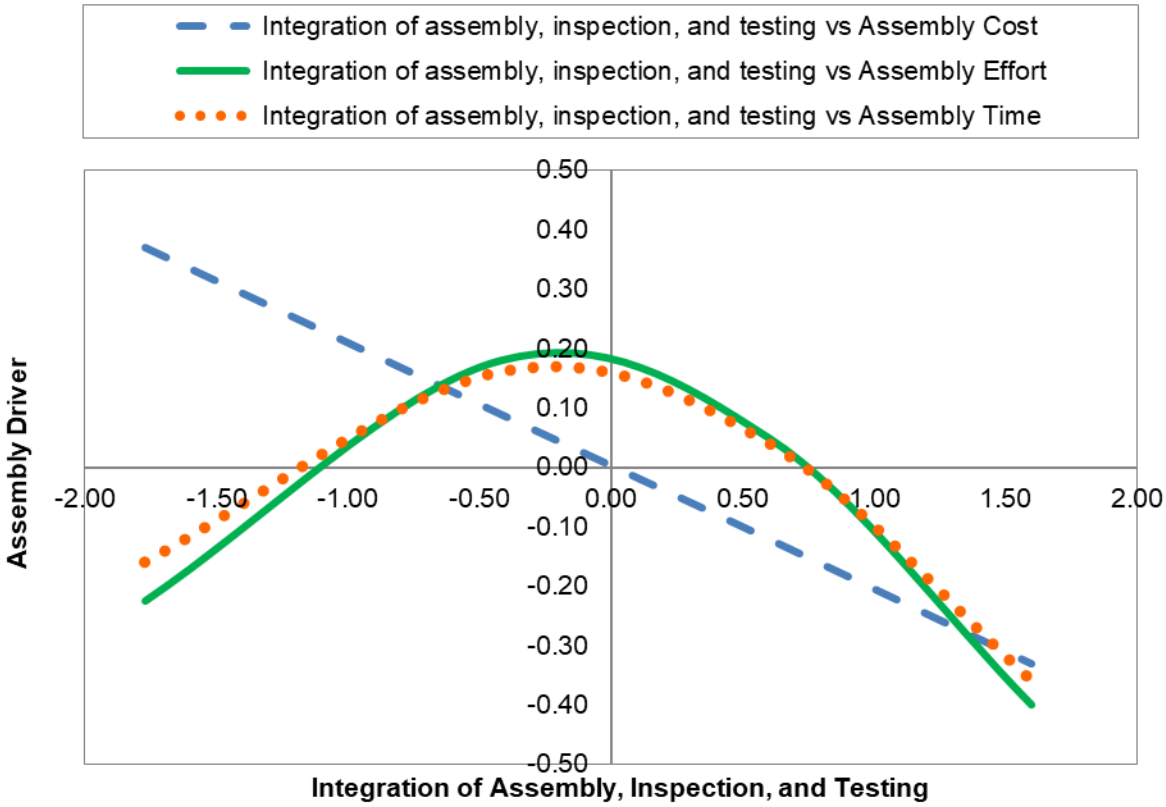

**Figure 5.** Integration of assembly, inspection and testing vs. assembly cost, assembly effort, and assembly time respectively

Integration can also lead to efficiency gains by streamlining the assembly process, reducing assembly time, and improving the quality of the assembly process. This can be achieved by leveraging the expertise and experience gained from the production of conventional internal combustion engine vehicles.

However, there are also potential negative impacts of integration. The complexity of integrating electric vehicle assembly with conventional internal combustion engine vehicle production and assembly systems can increase assembly effort and time. This complexity can result in increased downtime, rework, and increased assembly effort.

Moreover, integrating electric vehicle assembly with conventional internal combustion engine vehicle production and assembly systems may require retooling and modification of the existing assembly line, which can result in additional costs.

Overall, the impact of integrating electric vehicle assembly with conventional internal combustion engine vehicle production and assembly systems on electric vehicle assembly cost, assembly effort, and assembly time will depend on the specific circumstances of the integration. However, if planned and executed properly, integration can result in cost savings, efficiency gains, and improved quality in the assembly process. Further research is needed to better understand the implications of integration on electric vehicle assembly cost, assembly effort, and assembly time.

Objective10: External and in-plant battery transportation does not have significant impact on assembly cost, whereas objective 11: External and in-plant battery transportation have significant impact on assembly effort and objective 12: External and in-plant battery transportation have significant impact on assembly time. Kumar et al. identified that 'ineffective material handling and transportation' is a barrier to LSS in Indian medium and small scale enterprises [42]. The graph of 'external and in-plant battery transportation vs. assembly cost, assembly effort, and assembly time, respectively' is shown in **Figure 6**.

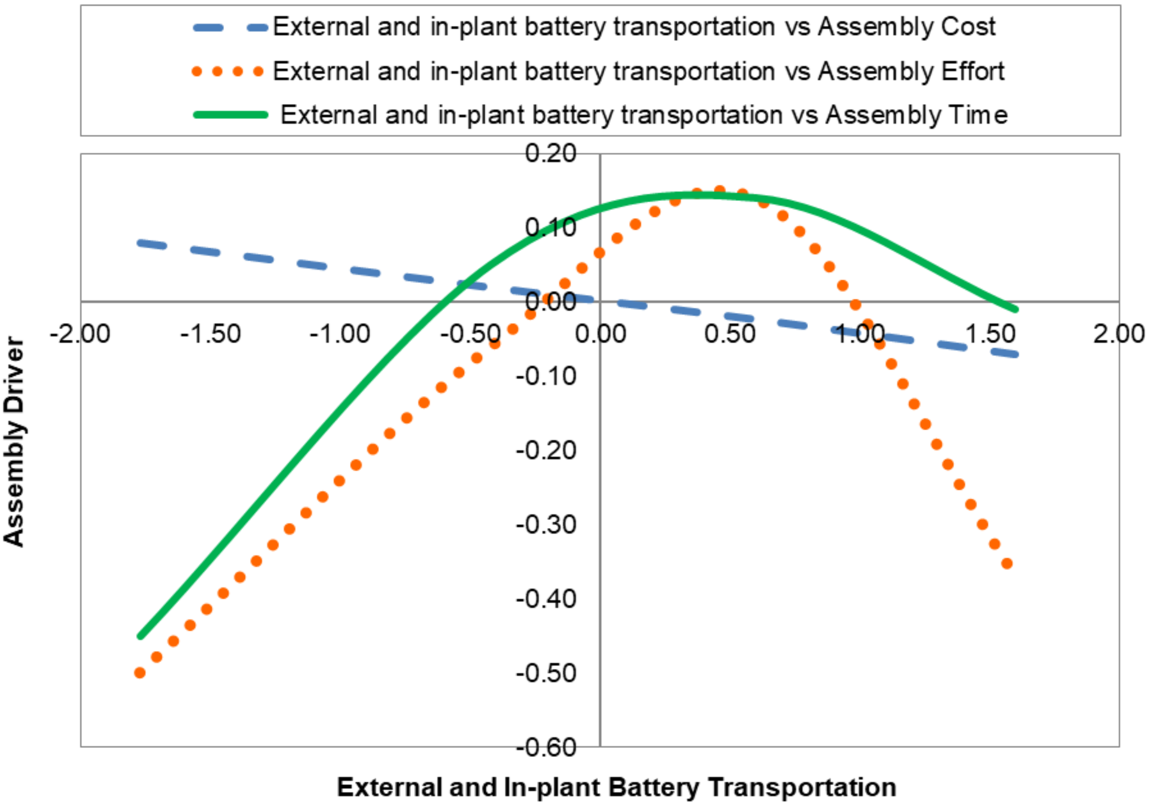

**Figure 6.** External and in-plant battery transportation vs. assembly cost, assembly effort, and assembly time respectively

Figure 6 shows low mean assembly cost, high mean assembly efforts, and, high mean assembly time, with respect to the external and in-plant battery transportation. The transportation of batteries from an external vendor site to the in-plant assembly line, as well as within the assembly line, can affect electric vehicle assembly cost, assembly effort, and assembly time. Transporting batteries from external vendors to the in-plant assembly line can increase costs associated with transportation, handling, and storage. Moreover, delays in battery delivery can affect assembly schedules and lead to increased assembly effort and time. In addition, the need to handle and store large batteries can also increase assembly effort and time.

On the other hand, in-plant transportation of batteries can help to reduce transportation costs and delivery delays, although the effort involved is still significant. It can also provide greater control over the storage and handling of batteries, improving safety and reducing the risk of damage during transportation. Additionally, in-plant transportation can reduce assembly time and effort by providing just-in-time delivery of batteries to the assembly line, avoiding the need for storage and handling at the assembly line.

Overall, the impact of battery transportation on electric vehicle assembly cost, assembly effort, and assembly time will depend on various factors such as the distance between the vendor and the assembly line, the size and weight of the batteries, and the efficiency of the transportation and handling processes. Further research is needed to better understand the implications of battery transportation on electric vehicle assembly cost, assembly effort, and assembly time, and to identify strategies for optimizing battery transportation to minimize costs and improve efficiency.

## 5. Conclusion

Four factors, namely, integration of assembly, inspection and testing, lack of trained and knowledgeable human resource, external and in-plant battery transportation, and manual assembly and rigid automation; were found to have a potential to affect the lean six sigma implementation. Structural equation modeling was used to obtain the relationship between the three drivers and four barriers of LSS implementation to electric vehicle assembly. Integration of assembly, inspection and testing is the first most important barrier as it influences all the three parameters: namely, assembly cost, assembly effort, and assembly time. Lack of trained and knowledgeable human resources follows next which strongly influences assembly effort and assembly cost. External and in-plant battery transportation affects assembly time and assembly effort. Manual assembly and rigid automation only affect assembly cost.

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## Author's Declaration

### Authors' contributions and responsibilities

The authors made substantial contributions to the conception and design of the study. The authors took responsibility for data analysis, interpretation and discussion of results. The authors read and approved the final manuscript.

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### Availability of data and materials

All data are available from the authors.

### Competing interests

The authors declare no competing interest.

### Additional information

No additional information from the authors.

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