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OVERCOMING LEAN SIX SIGMA BARRIERS IN ELECTRIC VEHICLE ASSEMBLY: POTENTIAL SOLUTIONS

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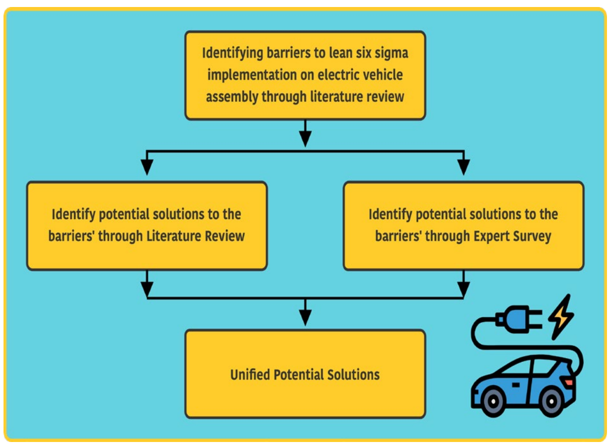
Graphical abstract



Abstract

The purpose of this paper is to identify the various types of lean six sigma (LSS) barriers involved in the assembly process of electric vehicles (EV). An exhaustive literature survey was conducted to identify the critical barriers in LSS implementation. Four main barriers affecting the assembly process are transportation and handling, assembly line processing, EV assembly integration, and human resources and training. The main barriers were further separated into several sub-barriers. The potential solutions to address the sub-barriers are investigated through literature survey and an expert survey. The implementation of these solutions will help automotive industries to achieve an optimized and economical high-volume production, make operations easy, improve process flexibility, and develop human resources essential for the EV assembly process.

Keywords: Lean six sigma, LSS barrier, electric vehicle, assembly, EV assembly automotive, potential solutions.

1.0 INTRODUCTION

The electric vehicle (EV) industry is growing rapidly, with an increasing number of consumers switching to electric cars due to their environmental benefits and cost savings over time [1]. A similar trend can be observed in the bicycle industry, where innovative and cost-effective bicycle designs with two-way driving control are emerging, aligning with the EV trend [2]. However, the manufacturing of EVs presents several unique challenges that must be overcome to ensure high-quality production and efficient operations. One approach to address these challenges is to implement Lean Six Sigma methodology, which focuses on reducing waste and variability in manufacturing processes while improving product quality and customer satisfaction [3]–[6].

Despite the potential benefits of Lean Six Sigma, there are several barriers to its successful implementation in the EV assembly process. This technical article presents potential solutions to overcome these barriers and successfully implement Lean Six Sigma methodology in the EV assembly process. The proposed solutions are based on industry best practices, academic research, and case studies from successful implementations of Lean Six Sigma in other manufacturing industries.

2.0 LITERATURE REVIEW

The electric vehicle (EV) industry is experiencing rapid growth and is expected to continue to do so in the coming years. However, the manufacturing process of EVs poses several unique challenges that must be addressed to ensure high-quality production and efficient operations. One approach to address these challenges is to implement the Lean Six Sigma methodology, which is designed to reduce waste and variability in manufacturing processes while improving product quality and customer satisfaction. Multiple research papers have focused on elucidating the various barriers that impact the adoption of Lean Six Sigma (LSS) in the automotive and manufacturing sectors [7]. In this literature review, we will discuss the barriers to the successful implementation of Lean

Six Sigma in EV assembly and explore potential solutions to overcome these barriers, as shown in Figure 1.

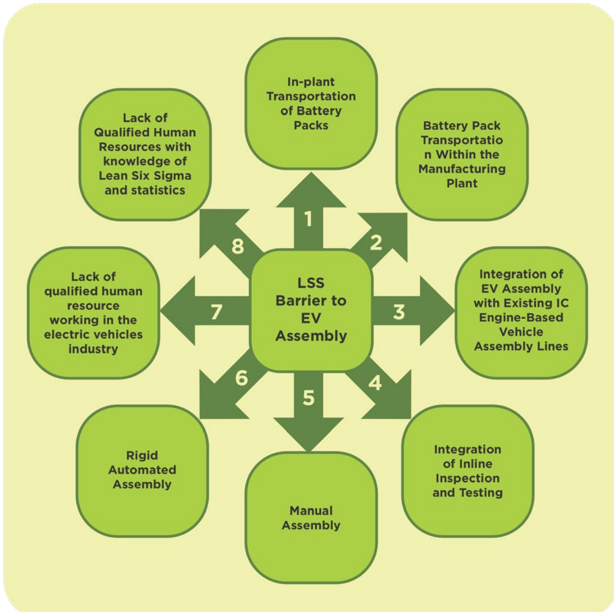


Figure 1. Barriers to the implementation of Lean Six Sigma in EV assembly

2.1. In-Plant Transportation Of Battery Packs

The transportation of battery packs from the battery manufacturer to the EV manufacturer is another barrier to the successful implementation of Lean Six Sigma in EV assembly. Battery packs are large and heavy, making transportation challenging and costly [8]. Additionally, the transportation process can result in damage to the battery packs, reducing their lifespan and performance [9].

2.2. Battery Pack Transportation within the Manufacturing Plant

The transportation of battery packs within the manufacturing plant during the final assembly of EVs is another barrier to the successful implementation of Lean Six Sigma in EV assembly. Battery packs are heavy and bulky, making transportation within the plant challenging [8].

2.3. Integration of EV Assembly with Existing IC Engine-Based Vehicle Assembly Lines

The integration of EV assembly with existing internal combustion (IC) engine-based vehicle assembly lines is a significant barrier to the successful implementation of Lean Six Sigma in EV manufacturing. The assembly of EVs involves several unique steps, such as the installation of battery packs and electric motors, which are not present in IC engine-based vehicles [10]-[12]. This can lead to disruptions in the assembly line, resulting in increased lead times, decreased productivity, and increased costs.

2.4. Integration of Inline Inspection and Testing

The integration of inline inspection and testing is essential for ensuring high-quality production in EV assembly [13]-[14]. However, the unique characteristics of EVs, such as the high-voltage electrical systems and complex software, make inline inspection and testing challenging.

2.5. Manual assembly

It has been identified as a potential barrier to implementing Lean Six Sigma methodology in electric vehicle (EV) assembly. Manual assembly is often associated with a high degree of variability, which can increase the risk of defects and reduce overall production efficiency [15]. However, manual assembly is still prevalent in many stages of EV assembly, such as final assembly and battery pack installation. Therefore, it is crucial to find potential solutions to overcome the challenges associated with manual assembly. The manual assembly process is shown in Figure. 2.

Figure 2. Manual assembly of electric vehicle [16]

2.6. Rigid Automated Assembly

The use of rigid automated assembly is a significant barrier to the successful implementation of Lean Six Sigma in EV assembly. Rigid automated assembly systems are inflexible and can be challenging to adapt to changes in the manufacturing process, resulting in increased lead times, decreased productivity, and increased costs [17]–[19]. The process of installation of EV power trains using automated systems is shown in Figure. 3.

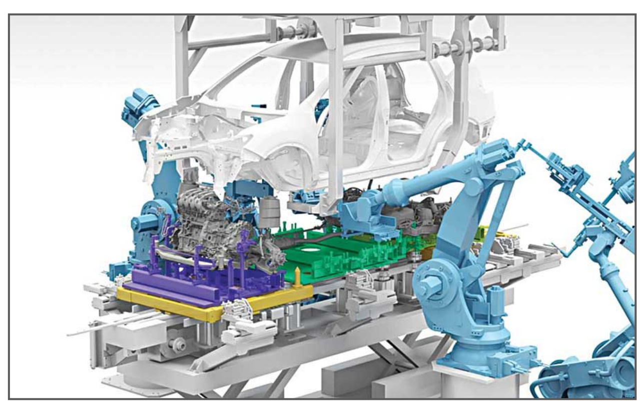


Figure 3. Installation of EV power trains using automated systems [16]

2.7. Lack Of Qualified Human Resource Working In The Electric Vehicles Industry

The EV industry is relatively new, and there is a shortage of skilled workers with the necessary knowledge and experience [21], [22].

2.8. Lack of Qualified Human Resources with knowledge of Lean Six Sigma and statistics:

The lack of qualified human resources with knowledge of Lean Six Sigma and statistics is another barrier to the successful implementation of Lean Six Sigma in EV assembly [23] – [25].

3.0 METHODOLOGY

A survey is a research method employed to collect data from a representative group of individuals or organizations. This is achieved through the use of standardized questionnaires or interviews. Surveys are extensively utilized in a wide range of fields, including engineering, management, social sciences, health, and education, among others. They offer valuable insights into complex matters and prove particularly useful in studying the attitudes, beliefs, and behaviors of large and diverse populations [26].

The survey research process typically involves several key steps. These include identifying the research question, defining the target population, selecting a sample, developing the survey instrument, administering the survey, and analyzing the data. Surveys can be conducted through various modes such as face-to-face interviews, telephone interviews, mail surveys, or online surveys. Online surveys, in particular, have gained significant popularity in recent years due to their cost-effectiveness, accessibility, and convenience [27].

The collected survey data can be analyzed using different statistical methods, such as descriptive statistics, inferential statistics, or regression analysis. These analyses enable researchers to draw conclusions and make generalizations about the larger population. Surveys also provide a means to compare results across different time periods, locations, or groups [28].

To gather information on the “potential solutions to overcome the lean six sigma barriers to electric vehicle assembly”, a two-fold approach was adopted. Firstly, an exhaustive literature survey was conducted to gather existing knowledge and insights. Secondly, a survey involving 240 participants from various fields, including engineers, technicians, and other professionals working in the electric vehicle domain, was carried out. The survey employed a Likert scale of 1 to 5, where respondents specified their level of agreement to statements, ranging from very low impact to very strong impact. A Google Forms based questionnaire was used for the survey.

The literature review implies a need to study the potential solutions to the eight identified barriers to lean six sigma implementation. Addressing these research gaps could contribute to a more comprehensive understanding of the challenges and potential solutions in the evolving landscape of electric vehicle assembly process. Literature review and expert survey techniques are popular methods to identify prospective solutions.

4.0 RESULTS AND DISCUSSION

The potential solutions to the LSS barriers in EV assembly, based on literature review and expert survey, are discussed below.

4.1. Potential Solutions through Literature Review:

4.1.1. In-plant Transportation of Battery Packs:

One potential solution is the on-site battery manufacturing and assembly or a site very near to the EV manufacturer [17].

4.1.2. Battery Pack Transportation within the Manufacturing Plant:

One potential solution is the on-site battery assembly near the assembly lines, is becoming popular [17].

4.1.3. Integration of EV Assembly with Existing IC Engine-Based Vehicle Assembly Lines:

The integration of EV assembly in the existing conventional assembly lines can be achieved by involving dedicated and specialized human resource for assembly of EV wherein the EV assembly involves unique components and parts, which in turn will reduce the fluctuation and inefficiency in the assembly process [29].

4.1.4. Integration of Inline Inspection and Testing

Inline inspection and tests increase the complexity of the assembly process, therefore optimizing is essential for efficient and scaled-up production [30].

4.1.5. Manual Assembly

One solution could be to implement ergonomic workstations and tools that reduce physical strain and fatigue on assembly line workers. This could involve the use of adjustable work surfaces, anti-fatigue mats, and ergonomic hand tools. Additionally, the electric vehicle manufacturer could provide training and education to workers on proper lifting techniques, stretching exercises, and other measures to reduce the risk of injury, and increase overall productivity [31] – [34].

4.1.6. Rigid Automated Assembly:

Due to changing battery designs due to technological disruptions, rigid automation cannot be done and the automation system has to be made adaptable in view of the EV advancements [17] – [19]. High performance computerization costs required for automation will also further reduce due to mass production [35]. Flexible assembly lines offer advantage in terms of low-capital investment for low-volume production with deferred cost up to 25 percent, wherein the additional costs may be deployed during high-volume production further, flexible assembly lines allow the conventional IC engine-based vehicle manufacturers to integrate with the existing conventional assembly lines. The efficiency of the system can be further improved by multiple decking, in which about 5 to 10 % capital saving is possible [36].

4.1.7. Lack Of Qualified Human Resource Working In The Electric Vehicles Industry

Another solution is to collaborate with educational institutions to develop training programs for students interested in the EV industry [37].

4.1.8. Lack of Qualified Human Resources with knowledge of Lean Six Sigma and statistics

One potential solution to this problem is to provide training to existing employees, allowing them to develop the skills necessary to implement Lean Six Sigma methodology [38].

4.2. Potential solutions through Expert Review

4.2.1. In-plant Transportation of Battery Packs

One potential solution to this barrier is to develop specialized transportation equipment designed to handle the transportation of battery packs safely and efficiently. Another solution is to locate the battery manufacturer near the EV assembly plant, reducing transportation costs and minimizing the risk of damage to the battery packs.

4.2.2. Battery Pack Transportation within the Manufacturing Plant

One potential solution to this barrier is to develop specialized equipment, such as overhead cranes or automated guided vehicles, designed specifically for the transportation of battery packs within the manufacturing plant, as shown in Figure 3. Another solution is to locate the battery pack assembly line near the final assembly line, reducing transportation distance and minimizing the risk of damage to the battery packs.

Figure 3. Automated guided vehicles in Porsche's new flexible EV assembly line [39]

4.2.3. Integration of EV Assembly with Existing IC Engine-Based Vehicle Assembly Lines

Another solution is to develop a flexible or modular assembly line that can accommodate both IC engine-based vehicles and EVs. This approach has been used by several major automakers, including Ford and General Motors.

4.2.4. Integration of Inline Inspection and Testing

One potential solution to this barrier is to develop specialized inspection and testing equipment designed specifically for EVs. Another solution is to provide training to inspectors and testers to ensure they have the knowledge and skills necessary to perform their jobs effectively.

4.2.5. Manual Assembly

One solution is to implement standardized work instructions to minimize the variation in the assembly process. Standardized work instructions can help ensure that all workers perform the same tasks in the same way, reducing the likelihood of defects and improving the consistency of the final product. Additionally, visual management techniques, such as color-coding or shadow boards, can be used to improve the efficiency of manual assembly tasks and reduce the risk of errors. Another solution is to develop specialized tools and equipment that can help automate certain manual assembly tasks. For example, automated torque wrenches can be used to tighten bolts and nuts to a specific torque value, reducing the risk of over-tightening or under-tightening. Additionally, the use of robotic arms or other automated equipment can improve the consistency and efficiency of manual assembly tasks, reducing the risk of defects and increasing production speed. Finally, training and development programs can be implemented to improve the skills and knowledge of workers involved in manual assembly tasks. These programs can help workers develop a deeper understanding of the assembly process and identify potential areas for improvement.

4.2.6. Rigid Automated Assembly

One potential solution to this barrier is to develop flexible automated assembly systems that can adapt to changes in the manufacturing process quickly. Another solution is to use a combination of manual and automated assembly, allowing for greater flexibility in the manufacturing process.

4.2.7. Lack of Qualified Human Resource Working In The Electric Vehicles Industry

One potential solution to this barrier is to offer several fundamental courses related to electric vehicles and also some elective courses for niche areas related to electric vehicles, through educational institutes.

4.2.8. Lack of Qualified Human Resources with knowledge of Lean Six Sigma and statistics

One potential solution to this barrier is to offer several fundamental courses related to lean six sigma from educational institutes. The summary of the potential solutions is shown in Table 1.

Table 1 Summary of the potential solutions to 'lean six sigma barriers to electric vehicle assembly' obtained from literature survey and expert survey

Sr. No.	LSS Barrier to EV assembly	Potential solution to 'LSS Barrier to EV assembly' obtained from Literature survey	Potential solution to 'LSS Barrier to EV assembly' obtained from Expert survey
1	In-plant Transportation of Battery Packs	a) On-site battery manufacturing and assembly or a site very near to the EV manufacturer	a) Locating the battery manufacturer near the EV assembly plant, reducing transportation costs and minimizing the risk of damage to the battery packs.
2	Battery Pack Transportation Within the Manufacturing Plant	a) On-site battery assembly near the assembly lines	a) Developing specialized equipment, such as overhead cranes or automated guided vehicles. b) Locating the battery pack assembly line near the final assembly line, reducing transportation distance and minimizing the risk of damage to the battery packs.
3	Integration of EV Assembly with Existing IC Engine-Based Vehicle Assembly Lines	a) Involving dedicated and specialized human resource for assembly of EV	a) Developing a flexible or modular assembly line that can accommodate both IC engine-based vehicles and EVs
4	Integration of Inline Inspection and Testing	a) Optimizing is essential for efficient and scaled-up process.	a) Developing specialized inspection and testing equipment designed specifically for EVs. b) Providing training to inspectors and testers to ensure they have the knowledge and skills necessary to perform their jobs effectively.
5	Manual Assembly	a) Implementation of ergonomic workstations and tools that reduce physical strain and fatigue on assembly line workers. b) Providing training and education to workers on proper lifting techniques, stretching exercises, and other measures to reduce the risk of injury, and increase overall productivity.	a) Implementation of standardized work instructions to minimize the variation in the assembly process b) Developing specialized tools and equipment that can help automate certain manual assembly tasks. c) Providing training and development programs can be implemented to improve the skills and knowledge of workers involved in manual assembly tasks.
6	Rigid Automated Assembly	a) Using flexible assembly lines offers advantages in terms of low-capital investment for low-volume production. b) Using multiple decking to improve the efficiency of the system.	a) Developing a flexible automated assembly system that can adapt to changes in the manufacturing process quickly. b) Using a combination of manual and automated assembly, allowing for greater flexibility in the manufacturing process.
7	Lack of qualified human resource working in the electric vehicles industry	a) Collaboration with educational institutions to develop training programs for students interested in the EV industry	a) Offering several fundamental courses related to electric vehicles and also some elective course for niche areas related to electric vehicle, through educational institutes.
8	Lack of Qualified Human Resources with knowledge of Lean Six Sigma and statistics	a) Providing training to existing employees, allowing them to develop the skills necessary to implement Lean Six Sigma methodology	a) Offering several fundamental courses related to lean six sigma through educational institutes.

5.0 CONCLUSION

The successful implementation of Lean Six Sigma methodology in EV assembly requires addressing several unique challenges, such as the integration of EV assembly with existing IC engine-based vehicle assembly lines, the transportation of battery packs, and the integration of inline inspection and testing. It is possible to overcome these barriers and improve the efficiency and quality of EV production. The potential solutions are:

[1] Assembly of battery near the EV assembly lines,

[2] Uses of overhead cranes or automated guided vehicles, for battery pack transportation.

[3] Use of dedicated and specialized human resources in integrated assembly lines and optimizing the assembly for efficient and scaled-up production.

[4] Develop a flexible or modular assembly line that can accommodate both IC engine-based vehicles and EVs.

[5] Ergonomic workstations to improve efficiency of manual assembly.

[6] Use of combination of manual and automated assembly systems.

[7] The efficiency of the automated system can be further improved by multiple decking.

[8] Greater involvement of educational institutions and industries to develop training programs for students interested in the EV industry, LSS and statistics.

The study underscores the importance of Lean Six Sigma (LSS) in the rapidly growing electric vehicle (EV) industry, aiming for environmental sustainability and economic efficiency. It identifies barriers such as transportation challenges, integration issues, and a lack of qualified human resources. Implications include the need for industry-academia collaboration, technological adaptability, and workforce development. The study emphasizes a global perspective, continuous improvement, and the significance of surveys and comprehensive reviews for effective solutions. Overall, addressing these challenges could lead to positive outcomes for the EV industry in terms of sustainability, innovation, and economic viability.

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Conflicts of Interest

The author(s) declare(s) that there is no conflict of interest regarding the publication of this paper

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