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LEAN SIX SIGMA BARRIERS WITH POTENTIAL SOLUTIONS IN ELECTRICAL VEHICLE ASSEMBLY: A REVIEW

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A B S T R A C T

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. 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 resource essential for the EV assembly process.

1. INTRODUCTION

An electric vehicle (EV) operates through motor and the EV's battery is similar to that used in IC engine vehicles, only larger in size (Hackleman, 1992; Putzig et al., 2021). The various types of batteries: Lithium Ion, , Molten Salt, Nickel Metal Hydride, Lithium Sulphur; of which Lithium Ion ones are more popular (Farmann et al., 2015; Hannan et al., 2018; Iclodean et al., 2017; Lyu et al., 2019; Stroe et al., 2017). The benefits of use of EV’s include, reduced harmful gas emissions, reduced noise pollution, reduced health hazards, lesser carbon footprint, lower running and maintenance costs and fuel conservation (Alimujiang & Jiang, 2020; Benefits of Electric Vehicles, n.d.; Malmgren, 2016). EV’s can also be integrated with the grid as a resource (Joseph et al., 2019; Patil & Kalkhambkar, 2021; Shao et al., 2012; Tan et al., 2016).

The Manufacturing process demands quality and production consistently. To maintain the consistency professionals and organizations tend to implement techniques such as seven QC tools, 5-S principles and Lean six sigma (LSS).These techniques and tools are often adopted by different sectors aiming to improve their process and quality. Likewise, several organizations and companies are aimed to deliver sustainable production with quality as well. And LSS has a key role in improving the sustainable production (Wang et al., 2019). Establishing LSS on companies that are producing renewable energy based products becomes the first step in developing green technology. And hence the proposed study aimed to contribute on sustainable production and improvements in green technology. Owing to that, LSS is one of the common techniques adopted by many companies but some earlier

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studies showed that there are some challenges in implementing LSS for a process (Raja Sreedharan et al., 2018). There were several failures in LSS implementation due to several factors. And thus, the proposed study aimed to explore the challenges in LSS implementation for electrical vehicle assembly.
Promoting the green production and sustainable manufacturing techniques are the main aspect of the proposed study. Here, the study was based on electrical vehicle manufacturing (Wang et al., 2019) which has now paved more way in the path of green technology. There are many initiatives started by the government in promoting electrical vehicle manufacturing. Yet, the industry that produces the necessary components for the vehicles are subjected to carbon foot prints. While aiming to reduce the time taken to manufacture these e-Vehicles, the carbon foot prints can be reduced further. On such circumstances, the proposed study aimed to explore the difficulties in implementing LSS, which in result could improve the time utilization for the process. Further there are several technical, technological, socio-economic, legal and political challenges faced in the assembly of e-Vehicles.

2. LITERATURE SURVEY

There are many research studies have explored the challenges and analysed the implementation of LSS in manufacturing process. However, the studies on LSS promoting sustainability are very few. And here in this section, the studies that have adopted LSS in different sectors are thoroughly reviewed to decide an approach to conduct the proposed study. The research study aimed to design an ecological vehicle using advanced method based on six sigma (Frizziero et al., 2019; Diaz-Ruiz et al., 2022). And the study followed design for six sigma approach to combine methods such as Quality Function Deployment, top-flop analysis, benchmarking. The study made a conceptual design using DFSS to create motorcycle with less polluting ability and had a success in the sign. The Six sigma approach can be used to frame a new design approach to create new products. Also, the importance of six sigma can be seen in small and medium companies and their growth comparing to global competitive market. The study analysed the process variation and its effect on product quality in an automobile part manufacturing industry (Guleria et al., 2021).

The implementation of lean tools and six sigma are evaluated by measuring the key performance indicators prior to the implementation of LSS and after the implementation of LSS. The study used methods like Value stream map (VSM) and DMAIC cycle (Define Measure Analyse Improve and Control) to enhance processes to decrease the rate of rejection. Some quality tools like Pareto chart, Control chart, process capability and fishbone diagram have been utilised for improving the product. The study concluded that the method reduced the rejection rate down to 4 % from 12% and also reduced the delivery time to 11 days from 12 days to customer. LSS have the ability to reduce the waste and improve the process. And implementing the same in renewable energy sector like in the study (Wang et al., 2019) implementing the LSS in the e-Scooter water cooling system, it would endorse the Triple Bottom Line (TBL). The sustainable production promotes the profit, and social responsibilities. The study conducted a case study in a Taiwan industry. The evaluation showed that the time taken for the manufacturing process and the quality of the product were improved, resulting in benefitting economy and ecology.

Here, another research study implemented six sigma in higher education institutions. The study analysed eleven factors that determines the successful implementation of six sigma (Maciel-Monteon et al., 2020). The data was collected from schools based on Mexico and performed with confirmatory factor analysis in SPSS AMOS. The study demonstrated how the models could improve the schools by implementing six sigma. Similar to the earlier study, the six sigma was implemented in hospitals to analyse the quality performance of the workers (Ahmed et al., 2018). The study collected data from 15 different hospitals and performed confirmatory factor analysis and structural equation modelling by using SPSS (AMOS).The findings from the study showed the impact of six sigma in the quality performance of the workers in the hospitals.

Here the authors had assessed the impact of six sigma in manufacturing industries of India (Raja Sreedharan et al., 2018). The study conducted an online survey about the impact of six sigma from the individuals whom are employed in manufacturing industries. And the study framed structural equation modelling to test the model fit. And finding from the studies shows that it is essential to practise six sigma in manufacturing industries.

From the literature review, it was observed that, studies have collected data and performed confirmatory factor analysis but didn’t completely evaluate the impact of the proposed model (Kaswan & Rathi, 2019). And it was suggested to perform a practical implementation or validation structural equation model. Also, the collecting data from relevant personnel or expert becomes difficult as they are subjected to busy schedule and the authors have to make a second round of data collection to get sufficient data to analyse (Shrafat & Ismail, 2018). Moreover, the data collected from less participants also makes difficult to validate the data and LSS impacts on the process (Gaikwad et al., 2020). And further many studies suggested to consider large scale and more economic aspects to the study to evaluate the impact of six sigma in terms of value.

There are several technical, technological, socio-economic, legal and political challenges faced in implementing the Lean six sigma for an electrical vehicle assembly. Presently, the lithium-ion battery packs are employed to energize the electric vehicles. Batteries currently cost around 40 percent cost of the EV. The costly battery packs of an electric vehicle require multiple replacements over its lifecycle. Warranties up to 8 years or 1 lakh miles are being offered by most battery manufacturers (Goel et al., 2021). Since, there are limited battery charging stations currently, customers have high priority of the range of distance the EV will run before the need of recharging since they don't want to be stranded due to being out of power. This has in turn resulted in manufacturing of bigger batteries for large and bulky vehicles. In the last decade, technological improvements have leaded to increase in EV power and distance span. The EQXX saloon by Mercedes-Benz, a sleek prototype saloon designed to cover 1,000 km on a single charge has an approximate weight of 1,750 kg by virtue of a better aerodynamic EV design, lighter materials and batteries with high energy-densities. The developments in solid-state batteries may further reduce weight. Government support to increase in battery charging stations and subsidies to compact and less weight EV's can also address the challenge.

One of the important aspects of assembly is the handling of the several components required in the assembly. The electric vehicle components such as batteries, motors, etc. are generally large and heavy (Disrupting the Auto Industry - ABB Digital Robotics 2020, n.d.). This creates challenges in storage and transportation of these components (Disrupting the Auto Industry - ABB Digital Robotics 2020, n.d.). Further, since battery packs are considered central part of the vehicles lower part, transportation will increase the cost of assembly ("Electric Vehicle Challenges 2022," n.d.). Trend of on-site battery manufacturing and assembly or assembly near the assembly lines, is becoming popular ("Electric Vehicle Challenges 2022," n.d.).

Manual assembly lines will also further increase the assembly cost. Another challenge involves the lack of flexibility in the new battery designs which leads to problems in changing automated assembly lines. Technological disruptions are expected even within the EV segment such as developments of solid state batteries wherein the battery shape may also change. Therefore rigid automation cannot be done and the automation system has to be made adaptable in view of the EV advancements (Challen, 2020; Nash, 2019.; "Electric Vehicle Challenges 2022," n.d.)

Further, robots are likely to be used for assembling motors, smaller components and sub-assemblies. Automation is desirable for rotor assembly with close tolerances. Currently, components cameras, mechanical, ultrasonic and solid-state sensors and radar are used for high-volume production. Light Detection and Ranging (LiDAR) is used for advanced driver assisted vehicles including self-driving (König et al., 2021). These systems are beginning to be used in mass production. High performance computerisation costs required for automation will also further reduce due to mass production (EVs Are Still 45% More Expensive To Make Than Combustion-Engined Cars 2020, n.d.). The battery, motor, power electronics, and high voltage traction lines, also increase the assembly costs and time. Gupta et al. studied the design of electric bicycles to figure out how to make a basic, low-cost electric bicycle with efficient control (Gupta et al., 2022).

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 percent capital saving is possible (Improving BEV Market Profitability through Reduced Structural Costs | McKinsey 2020, n.d.).

Assembly process involves Begin-of-Line-Tests, inline function tests, and End-of-Line-Tests. Inline tests ensure that the added value is not lost. Further, inline inspection is carried out for cooling and ventilation components, wiring harness, connectors, etc. for defect-free production. Moreover, functionality tests such as that of the press-out forces and the balance quality or the magnetization, are also included in the assembly process. (Strama-MPS_Produktbroschuere_E-Mobilitaet_EN.Pdf, n.d.). Therefore, the complexity of the assembly process is increased as optimising is essential for efficient and scaled-up production (ABB, 2021).

Considering the cost of assembly, another challenge lies in the integration of EV assembly in the existing conventional assembly lines (Maschke, 2010), which will be a cost-effective method for EV assembly (Yin et al., 2021). This can be achieved by involving dedicated and specialised 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 (Yin et al., 2021). One human resource related challenge which exists is the lack of trained professionals in the field of EV, LS and statistics applied to automotive industries (Shirey et al., 2017; Bhasin, 2012; Chakravorty & Shah, 2012).

The critical barriers have been identified and classified under four broad categories, namely, 1) Transportation and handling, 2) Assembly line processing, 3) EV assembly integration, 4) Human resources and training, as shown in Figure. 1. The broad challenge areas along with their sub-areas and the potential solution of each area based on the literature survey is shown in Table. 1.

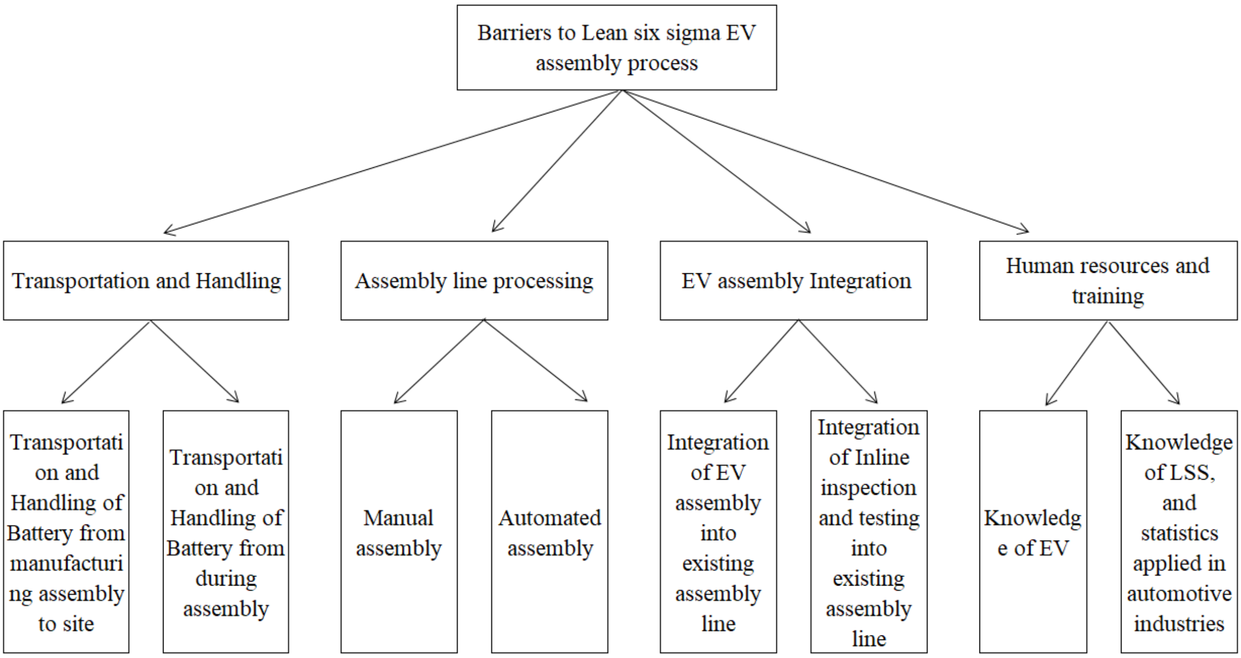

Figure 1. Barriers to Lean six sigma EV assembly process
(Shirey et al., 2017; Nash, 2019.; Disrupting the Auto Industry - ABB Digital Robotics 2020, n.d.; "Electric Vehicle Challenges," n.d.; Improving BEV Market Profitability through Reduced Structural Costs | McKinsey 2020, n.d.; Strama-MPS_Produktbroschuere_E-Mobilitaet_EN.Pdf, n.d.; Bhasin, 2012; Chakravorty & Shah, 2012; ABB, 2021; Maschke, 2010; Yin et al., 2021)

3. CONCLUSION

The assembly process is critical for manufacturing of electric vehicles. A cost-effective and seamless EV assembly process is the need of the hour. Implementation of lean six sigma to the assembly process will make the process cost-effective. However various barriers hinder the implementation of LSS to the EV assembly. The barriers include transportation and handling of EV components to the assembly site and during the assembly, use of manual assembly processes, lack of flexibility in the automated assembly lines, integration of the EV assembly with the conventional EV assembly, and the lack of trained professionals in the field of EV, LSS and statistics applied to automotive industries.

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Appemdix

Table 1. Broad challenge areas along with their sub-areas and the potential solution

Broad Challenge area	Challenge	Potential Solution	References
Transportation and Handling	One of the important aspects of assembly is the handling of the several components required in the assembly. The electric vehicle components such as batteries, motors, etc. are generally large and heavy. This creates challenges in the storage and transportation of these components.	The trend of on-site battery manufacturing and assembly or assembly near to the assembly lines, is becoming popular	(*Disrupting the Auto Industry - ABB Digital Robotics 2020*, n.d.)
	Further, since battery packs are considered central part of the vehicles lower part, transportation and handling will increase the cost of assembly.	A dedicated EV assembly line with one decking point between the skateboard and upper hat is best-suited.	("Electric Vehicle Challenges," n.d.; *Improving BEV Market Profitability through Reduced Structural Costs | McKinsey 2020*, n.d.)
Assembly line process	Also, manual assembly lines will also further increase the assembly cost. The battery, motor, power electronics, and high voltage traction lines, also increase the assembly costs and time.	The automation system has to be made adaptable in view of the EV advancements. Robots are likely to be used for assembling motors, smaller components and sub-assemblies. Automation is desirable for rotor assembly with close tolerances.	(Nash, 2019; "Electric Vehicle Challenges," n.d.)
	Another challenge involves the lack of flexibility in the new battery designs which leads to problems in changing automated assembly lines.	The automation system has to be made adaptable in view of the EV advancements. Flexible lines enable manufacturers to swiftly amend production at low cost in the short run.	("Electric Vehicle Challenges," n.d.; *Improving BEV Market Profitability through Reduced Structural Costs | McKinsey*, n.d.)
Integration of EV assembly	Considering the cost of assembly, another challenge lies in the integration of EV assembly in the existing conventional assembly lines.	Converting an existing system to an EV assembly line is more economical, even for start-ups.	(*Improving BEV Market Profitability through Reduced Structural Costs | McKinsey 2020*, n.d.; Maschke, 2010)
	Integration of Inline inspection and testing into existing assembly line. This increases the complexity of the assembly process.	Optimizing is essential for efficient high-volume production.	(ABB, 2021; *Strama-MPS_Produktbroschuere_E-Mobilitaet_EN.Pdf*, n.d.), 1-20.
Human Resource and training	One human resource related challenge which exists is the lack of trained professionals in the field of EV applied to automotive industries.	One human resource related challenge which exists is the lack of trained professionals in the field of EV, LSS and statistics applied to automotive industries.	(Shirey et al., 2017; Bhasin, 2012; Chakravorty & Shah, 2012)
	One human resource related challenge which exists is the lack of trained professionals in the field of LSS and statistics applied to automotive industries.	One human resource related challenge which exists is the lack of trained professionals in the field of EV, LSS and statistics applied to automotive industries.	(Shirey et al., 2017.; Bhasin, 2012; Chakravorty & Shah, 2012)