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The Synergy Of Industry 4.0 And Lean Six Sigma: A Framework For Improvement In Circular Economy Generation In The Automotive Landscape

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The industry landscape is today characterised by intense competition, which has been exacerbated by an unanticipated halt in growth rates. The automotive sector has not been able to ignore these profound changes in the nature of the business environment. Techniques like Lean Six Sigma (LSS), and Industry 4.0 have demonstrated in recent years that major cost savings, quality improvements, and shorter production times are all achievable when the techniques concentrate on process performance. A deeper understanding of the many facets of LSS practices is provided by these factors: the Effectiveness of LSS; Organisational Awareness and Leadership Impact; Operational Efficiency and Organisational Culture Alignment; and Striving for Excellence and Customer-Centric Approach. The results highlight the significance of implementing LSS holistically, taking into account both the technical and human aspects. While there is widespread agreement on the overall benefits of these measures, notably in terms of efficiency and waste reduction, there is less consensus regarding their ability to reduce emissions.

Keywords – Industry 4.0; Lean; Lean Six Sigma; Automobile; Circular Economy

1. Introduction

The concept of a Circular Economy (CE) is one that is now gaining traction and is being adopted by businesses across a variety of sectors. The CE is being utilised as a method to cut down on waste in response to the deteriorating state of the ecosystem that is caused by our access to the available resources. According to Kirchherr et al., (2017), the term "the core component of sustainable development" best describes the concept of CE. The implementation of a "CE" contributes to an improvement in the longevity of the organisation. Increase in Profitability, Decrease in Cost, and Concern for the Environment are the Common Motivating Factors Behind Implementation of CE. It has been determined that the CE can reduce the total costs incurred by a corporation. Additionally, it contributes to an increase in the cost reductions achieved by the organisation. (Geissdoerfer, et al., 2017). According to the findings of some recent studies, new forms of business should incorporate principles of circular economies in order to cut down on the amount of trash produced.

The core goal of CE is to decouple economic development actions from their hazardous environmental effects. According to Elia et al. (2017), this goal can be accomplished by changing the unidirectional nature of the economy into a circular one. In addition to this, they have asserted that CE is an alternative to the neoclassical economic model, which is predicated on simple growth and throughput. The philosophy of circularity promotes the reuse of materials and the preservation of natural resources rather than the conventional practise of merely discarding used goods. The biological and technical cycles of CE have been elaborated upon by Zhao, (2020), as their source. They explain that the technical cycle seeks to regard wastes as resources, which in turn leads to the extension of the life-cycle of various products, while the biological cycle places an emphasis on the use of renewable sources of energy, which in turn leads to the regeneration of natural resources that have been extracted. Ghisellini et al. (2016) made the suggestion that when carrying out the implementation of the CE initiatives, effort should be put in at several levels. The levels span from the implementation of the strategy in a single organisation through the enterprises in a community, to the regional or national scale of flows of resources and the results of those flows. According to Geng et al. (2013)'s argument, the CE controls the amount of trash that finally enters the ecosystem of the environment through the application of policy and the development of strategy to support it. Despite the fact that these definitions may be found in published works, CE is most commonly seen as a tool that organisations can use to achieve sustainability projects.

In this study, the promotion of CE would be understood with the help of two concepts – Industry 4.0 and Lean Six Sigma (LSS) with respect to the automobile industry in India. Six sigma is an approach to quality control that has been used by a wide variety of companies. The utilisation of LSS, as shown by the findings of researchers, would further contribute to a reduction in the quantity of waste produced by businesses, which would be a positive development. According to the findings of some studies, this phenomenon is most readily apparent in the manufacturing sectors, where the integration of the two ideas can contribute to a reduction in the amount of waste that is generated by the sectors, hence resulting in a more profitable conclusion.

To prepare for Industry 4.0 India has taken the following steps:

- India has launched a number of measures in an effort to embrace Industry 4.0. As per the IBEF report, the Indian government intends to enhance the manufacturing sector's GDP contribution to 25% by 2025, from the present 16%. India's participation in the Made in India initiative demonstrates its readiness to compete globally. It is prepared to use smart manufacturing to lead the globe.

- Four centres are being established nationwide by the ministry of heavy industries and public enterprises to assist SMEs in implementing Industry 4.0.

- Bengaluru is the site of the establishment of India's first Smart factory. This Internet of Things (IoT) and manufacturing data exchange fuel this smart factory. The Boeing Company is providing money for the development of this Smart Factory at the Indian Institute of Science's (IISc) Centre for Product Design and Manufacturing (CPDM).

- By 2020, the Andhra Pradesh government wants to establish the state as a hub for the Internet of Things (IoT). With the assistance of the business sector, the state government intends to establish ten IoT hubs, which will directly employ 50,000 people across multiple IoT verticals.

- According to reports, the smart factory market is expected to reach $215 billion by 2025 and is being adopted by the majority of the world's main economies.

It is essential to carry out research not only on the part that Industry 4.0 plays in the progression of CE in the automotive industry but also on the progress that CE has made in the automobile industry. There was only a very small number of research studies that focused on the connection between CE, LSS, and Industry 4.0. Because of the possibility that this will speed up the process of removing waste from the automotive industry, it is vital that research be carried out to determine the effect that installing LSS has on what is known as the CE. This can be done by determining the influence that LSS has on what is known as the CE.

2. Review of Literature

Patel & Patel, (2021), developed an understanding of the LSS methodology from its inception and used a critical assessment of the literature to investigate the few LSS dimensions as a study topic. Over the past ten years, LSS adoption as a continuous improvement technique has increased significantly in the manufacturing and select service sectors, including higher education and the healthcare industry. According to the report, although researchers have developed conceptual frameworks for implementing LSS, there doesn't appear to be any case study validation. The integration of LSS and other approaches with a focus on environmental sustainability is a new field of study. Rathi, et al., (2022), established a systematic Green LSS (GLSS) methodology to improve operational efficiency while also ensuring environmental and social sustainability. Furthermore, a top manufacturing company tried the suggested structure. The framework, which was created using knowledge from literature and industry experts, covers the systematic implementation of several Green paradigm, Lean, and Six Sigma technologies from problem identification and evaluation to the maintenance of implemented solutions. To evaluate the performance of society and the environment, lifespan and social life cycle assessments were applied methodically. Yadav, et al., (2023), examined various aspects of the Green LSS (GLSS) methodology, application status, and potential benefits through a detailed literature analysis. This opened up new research directions. Furthermore, a conceptual framework for GLSS is provided by this study. According to this report, GLSS implementation is growing year by year and significantly improving all aspects of sustainability. Businesses apply the lean approach to improve processes by identifying and eliminating various wastes, hence creating value. The Lean methodology, however, minimises waste but is unable to handle process variances and environmental impacts. Six Sigma and green technology requirements were so noted in order to produce eco-friendly items of superior quality at a reduced cost. The six sigma concept identifies and minimises variances to produce dependable process output that adds value. Although this method reduces process variation, it does not lessen the process's detrimental effects on the environment or associated wastes. Citybabu & Yamini, (2024), examined the distribution of LSS 4.0 (LSS 4.0) papers across authors, journals, affiliations, and countries in a thorough analysis of publication trends in reputable repositories such as Web of Science (WoS) and Scopus. The objective of their literature research was to create a conceptual framework for the integration of Industry 4.0 (LSS 4.0) with LSS, with an emphasis on sustainability, operational efficiency, and human issues like ergonomics. Between 2020 and 2022, they noticed a notable increase in LSS 4.0 articles, suggesting that this area of research is becoming more and more popular. Based on keywords, authors, and countries, this study finds the most productive journals and clusters as well as the most prominent writers, pertinent affiliations, and prolific nations.

Ali, et al., (2019), discovered that using CE can result in significant cost savings. The researchers found that there was a reduction in both costs and the amount of energy used. Additionally, it contributes to a rise in the company's savings. The research that was offered in this study provides a concrete and additional explanation as well as illustrations of the contrast between recycling and reuse, which is anticipated to shape the proposed paradigm shift in the process of designing architectural products. The process of recycling entails the processing of waste materials and by-products in order to create new materials. Sharma, et al., (2020), evaluated the transition from linear economy to CE. The purpose of this study was to shed light on the opportunities, challenges, and necessities that small and medium-sized enterprises (SMEs) face as they move from a linear economy (LE) to a CE (CE). Recent research was combed for data that the study used to compile information on the possibilities, barriers, and prerequisites for the transition from an LE to a CE. The CE, sometimes known as the CE, is a strategy that takes a more holistic perspective and advocates for achieving sustainability goals through reclaiming value from waste. Chen, et al., (2022), in their research study evaluated the use of recycling of the resources to enhance the value chain. The researchers used a meta-analysis approach to evaluate the association between CE (CE) practises and enterprise performance. The findings also indicate that the kind of industry, the size of the firm, and the country all have an effect that moderates the connection between CE practices and sustainable performance. Rathilal & Singh, (2018), determined the use of LSS to enhance competitiveness. According to the findings of the research, LSS contributes to an increase in the competitive advantage enjoyed by a manufacturing organisation. The quantitative approaches to research were selected for this study. According to the report, companies had trouble implementing Lean and Six Sigma as stand-alone procedures, and many had trouble translating theory into reality. The poor success rate and restricted general application of an integrated LSS approach were caused by this transition's difficulties. As a result, the suggested LSS framework presents a special chance for the KZN automotive sector to incorporate and make use of both high-quality tools in a manner that is consistent with its management style and industry requirements. Rajput & Singh, (2020), established with a methodology for Industry 4.0 called mixed-integer linear programming (MILP), which would optimize the allocation of items and machines in order to achieve CE and cleaner manufacturing. The proposed concept accomplishes both ethical business practises as well as the establishment of an Industry 4.0 facility by utilising sensors that record information in real time. In this work, the product-machine specific analysis that is necessary to optimise the manufacture of customised and high-end items at low production costs and with minimal energy use is discussed. The purpose of this article was to find ways to reduce the overall cost as well as the energy consumption of the machinery required to set up an Industry 4.0 facility in order to realise the benefits of a CE and environmentally friendly manufacturing.

The above review shows that the importance of CE is suggested by many authors. To extend the current literature, the study here would answer the following research questions –

RQ1: What are the factors associated with LSS and Industry 4.0 in the automobile sector that are essential to hold a CE scenario?

RQ2: How does LSS mediate the relationship of promoting CE through industry 4.0?

The methodological approach undertaken for achieving the answers to these research questions are provided in the next section.

3. Research Methodology

The automobile sector is one of the most prominent ones across the globe where the consumers are found to be increasing at an exponential rate. One of the important aspects of the sector is its integration with technology in recent times. The main focus of the study here is the development of a CE in the emergence of LSS and Industry 4.0. It is essential to choose a research plan that advances the objectives and tackles the research questions. There are many different types of research strategies, such as action research, surveys, case studies, and experiments. Any kind may be tried, depending on the time and resources available. In this investigation, the exploratory research strategy is being used. A well-thought-out research design is essential to any research project because it provides a detailed road map for collecting the data needed to answer the research questions.

The present study used a total of 583 responses based on error estimation and variance calculation while employing the Cochran’s formula to establish the minimum sample size requirement of 384. These responses were collected from the following corporations: Hero Motorcorp Ltd., Nissan Motors, Maruti Suzuki India, Mahindra & Mahindra Ltd., Honda Cars India, Hyundai Motor India, Renault, Tata Motors, Mercedes Benz, Audi India, Skoda India, Volkswagen, MG Motor India, and Toyota Kirloskar. The sampling dynamics across the various departments is shown in table 3.1 below:

Table 3.1: Composition of Samples

Department of the Respondents	**Frequency**	**Percentage**
Manufacturing	194	33.3%
Production	120	20.6%
Maintenance	96	16.5%
Design and Innovation	84	14.4%
Supply Chain Management	60	10.2%
Quality	29	5%
Total	**583**	**100%**

A structured questionnaire is used for collecting the responses from these samples. The questionnaire design is being divided into five parts based on the objectives of the study. The first section refers to a set of preliminary questions which enquire about the knowledge of the respondents towards these terms. The second section includes a total of 17 items that investigate especially about the LSS process and its implications. The next section includes 9 items talking about the use and relevance of Industry 4.0 in the automobile sector. The third section 18 items enquire about the impact of LSS and Industry 4.0 on that of the CE generating factors. Lastly, the demographic representations of the respondents are being asked in the fifth section.

4. Data Analysis

A total of 583 responses were collected from the employees from various departments of 16 automobile companies. Based on that the responses generated are segregated into various groups and descriptive analyses of the same are shown below:

Table 4.1: Frequency distribution of Department of the Respondents

Department of the Respondent:		
	Frequency	**Percent**
Manufacturing	194	33.3
Production	120	20.6
Maintenance	96	16.5
Design and Innovation	84	14.4
Supply Chain Management	60	10.3
Quality	29	5.0
Total	583	100.0

This breakdown offers insights into the distribution of respondents across different functional areas within the organization. Analyzing data based on departmental affiliation can provide valuable insights into department-specific perspectives, needs, or challenges, which can inform decision-making, resource allocation, or organizational strategies.

Work Experience

Table 4.2: Frequency distribution of Work Experience

Work Experience		
	Frequency	Percent
Less than 1 year	76	13.0
1-2 years	137	23.5
2-5 years	211	36.2
5-10 years	99	17.0
Above 10 years	60	10.3
Total	583	100.0

The 583 respondents were collected from respondents having various work experience. This breakdown provides insights into the distribution of respondents based on their work experience levels. Analyzing data based on work experience can help understand how different levels of experience may influence perceptions, behaviors, or responses to various aspects of the survey or study. It's also valuable for tailoring strategies, interventions, or messages to specific segments of the workforce based on their experience levels.

Gender

Table 4.3: Frequency distribution of Gender

Gender		
	Frequency	Percent
Male	281	48.2
Female	302	51.8
Total	583	100.0

This breakdown offers insights into the gender distribution among the respondents, which can be essential for understanding the demographic composition of the surveyed population. Analyzing data based on gender may help identify potential differences in perspectives, behaviors, or needs between male and female respondents. It's also crucial for ensuring diversity and inclusivity in research or survey samples.

Age

Table 4.4: Frequency distribution of Age groups

Age (in years)		
	Frequency	Percent
18-24	36	6.2
25-34	350	60.0
35-44	197	33.8
Total	583	100.0

The breakdown of age provides insights into the age distribution of the respondents, which can be useful for understanding the demographic composition and potentially analyzing how different age groups perceive or respond to certain questions or issues.
The first step in the process is to determine the factors related to Industry 4.0 and LSS in the automobile industry Exploratory Factor Analysis was conducted.

Factor analysis is a statistical technique for identifying and analysing the underlying structure or dimensions (factors) that explain patterns of correlations among a set of variables. It is extensively used in psychology, sociology, economics, and other social sciences. The basic purpose of factor analysis is to reduce data dimensionality by collecting and reflecting shared variance among variables with a reduced amount of factors. All 15 items related to LSS influencing automobile industry were subjected to factor analysis, using the principle component analysis extraction method which was followed by a varimax rotation. This procedure produced four factors where the decision to include an item in a factor was based on the factor loadings being greater than +0.5 (Hair et al., 2019).

Table 4.5 : Results of factor analysis (factor loadings)

	Factor 1	**Factor 2**	**Factor 3**	**Factor 4**
LSS helps in eliminating wastes in the automotive industry	.813			

Impact of Middle management involvement in implementation of LSS practices resulted in overall improvement in your organization	.795			
LSS helps in guaranteeing reliability in the automotive industry	-.792			
LSS helps in promoting CE in automotive industry	.771			
LSS helps in providing continuous improvement in the automotive industry	.641			
LSS practices lead to improvement in overall operational excellence		.889		
Unawareness about LSS Practices among employees of the organization will result in an increase in the cost of implementation of LSS Practices		.853		
Impact of Top management involvement in implementation of LSS practices resulted in overall improvement in your organization		.650		
LSS helps in reducing lead times in the automotive industry			.518	
Current working culture of your organization is appropriate to allow effective implementation of LSS practices			.937	
The benefits achieved at the Managerial level justify the cost of implementation of LSS Practices in the organization			-.902	
Effective implementation of LSS practices in your organization has led to an increase in profitability due to elimination of nonvalue added activities			.676	
LSS helps in pursuing perfection in the automotive industry				.837
Effective implementation of LSS practices in your organization has led to an increase in customer satisfaction				.799

Employees awareness about the strategic gains of LSS practices leads to effective improvement of the organization				.686

The KMO Measure of Sampling Adequacy was conducted to quantify the degree of intercorrelations among the variables and the appropriateness of exploratory factor analysis. The KMO value derived is 0.958 which is above 0.8 and is considered to be meritorious (Hair, et al., 2019). The Bartlett test of sphericity value is below 0.05 indicating that there exists a significant correlation among at least some of the variables. The eigenvalues for both the factors extracted are more than 1. The percentage of variance is 86.637 which is considered to be satisfactory in social science research.

With the help of Exploratory Factor Analysis (EFA), four factors were derived out of 15 items. The first factor is named as the "Effectiveness of LSS", this summarises the main idea of LSS, which is that it helps with waste reduction, dependability, continuous improvement, CE promotion, and the effects of middle management involvement in putting LSS methods into practice. The second factor was named as "Organizational Awareness and Leadership Impact". The significance of organisational awareness regarding LSS methods among employees and the important role that middle and upper management play in successfully implementing LSS practices, which improves overall operational excellence, are reflected in the name of the organisation. The third factor is named as the "Operational Efficiency and Organizational Culture Alignment". This conveys the essence of how LSS contributes to shorter lead times, more profitability by eliminating non-value-added operations, and the need of integrating the organization's current working culture with efficient LSS deployment. It also shows how managerial level benefits and cost justification were taken into account. The fourth factor is named as "Striving for Excellence and Customer-Centric Approach". This encapsulates the pursuit of perfection inherent in LSS practices, the increase in customer satisfaction resulting from effective implementation, and the importance of employee awareness about the strategic gains of LSS practices in driving organizational improvement.

Table 4.6: The factors along with their items are shown in the table below:

Effectiveness of LSS	Organizational Awareness and Leadership Impact	Operational Efficiency and Organizational Culture Alignment	Striving for Excellence and Customer-Centric Approach
LSS helps in eliminating wastes in the automotive industry	LSS practices lead to improvement in overall operational excellence	LSS helps in reducing lead times in the automotive industry	LSS helps in pursuing perfection in the automotive industry

Impact of Middle management involvement in implementation of LSS practices resulted in overall improvement in your organization	Unawareness about LSS Practices among employees of the organization will result in an increase in the cost of implementation of LSS Practices	Current working culture of your organization is appropriate to allow effective implementation of LSS practices	Effective implementation of LSS practices in your organization has led to an increase in customer satisfaction
LSS helps in guaranteeing reliability in the automotive industry	Impact of Top management involvement in implementation of LSS practices resulted in overall improvement in your organization	The benefits achieved at the Managerial level justify the cost of implementation of LSS Practices in the organization	Employees awareness about the strategic gains of LSS practices leads to effective improvement of the organization
LSS helps in promoting CE in automotive industry		Effective implementation of LSS practices in your organization has led to an increase in profitability due to elimination of non-value added activities	
LSS helps in providing continuous improvement in the automotive industry			

The combination of LSS and CE concepts is gaining momentum in both academic research and managerial practice. This integration has shown to enhance overall productivity in manufacturing processes across various industries. While Lean management alone may not fully control processes or eliminate variance, the synergy between Six Sigma and Lean methodologies, along with advancements like Industry 4.0, has demonstrated significant cost savings, improved quality, and reduced production time. In today's dynamic market, companies must balance pricing and availability of goods and services to secure orders without sacrificing product quality. For automobile manufacturers, the challenge lies in finding this balance effectively.

Structural Equation Modelling was employed to test this model, where LSS acts as the mediating variable, CE as the dependent variable, and Industry 4.0 as the independent variable. The statistical technique known as structural equation modelling (SEM) is used to examine the connections between latent and observable variables. Factor analysis, regression analysis, and route analysis are all combined in this thorough method. SEM is very helpful for comprehending the interactions between variables and verifying intricate theoretical models.

Table 4.7: The following hypotheses were formulated for this study

	List of Hypotheses
H01	LSS does not have a significant effect on CE
H02	LSS does not have a significant effect on Industry 4.0
H03	Industry 4.0 does not have a significant effect on CE

The model fit indices values that are generated while conducting the CFA are given in Table below. The Chi-Squared value (=480.392) is found to be significant with $p<.05$ and the CMIN/DF at 2.788. A CMIN/DF value less than 3 represents a fairly good estimation of model fit even with a large sample size.

The table below shows the model fit indices considered and the values generated for each of them.

Table 4.8: Model Fit Indices of the Measurement Model

Model Fit	**Accepted Value**	**Indices**	**Description**	**Value Status**
CMIN/DF	<3	2.788	CMIN/DF (Chi-Square/degrees of freedom) index measures the ratio of the model chi-square statistic to its degrees of freedom. A lower value indicates better fit. Typically, a CMIN/DF value less than 3 is considered indicative of a good fit.	Good Fit
GFI	>0.9	0.911	GFI (Goodness of Fit Index) measures the proportion of variance in the observed variables explained by the model. A value greater than 0.9 suggests a good fit, indicating that the model explains a large proportion of the variance in the data.	Good Fit

NFI/TLI	>0.9	0.936	NFI/TLI (Normed Fit Index/Tucker-Lewis Index) compares the fit of the estimated model to a baseline model (usually the null model). Values greater than 0.9 indicate a good fit, suggesting that the estimated model fits significantly better than the baseline model.	Good Fit
RFI	>0.9	0.904	RFI (Relative Fit Index) is another index that compares the fit of the estimated model to a baseline model. Values greater than 0.9 indicate a good fit, suggesting that the estimated model provides a better fit to the data than the baseline model.	Good Fit
IFI	>0.9	0.958	IFI (Incremental Fit Index) compares the fit of the estimated model to the independence model (a model where all variables are uncorrelated). Values greater than 0.9 indicate a good fit, suggesting that the estimated model fits significantly better than the independence model.	Good Fit
CFI	>0.9	0.957	CFI (Comparative Fit Index), measures how well the estimated model fits the independence model. It works similarly to IFI. A good fit is shown by values larger than 0.9, which implies that the estimated model fits considerably better than the independence model.	Good Fit
RMSEA	<0.06	0.46	The difference between the observed data and the model's projected values is measured using RMSEA (Root Mean Square Error of Approximation), which accounts for model complexity. A good fit is shown by a number smaller than 0.06, indicating that the model closely matches the observed data.	Good Fit
RMR	<0.05	0.35	The difference between the observed and model-implied covariance matrices is measured by RMR, or root mean square residual. A good fit is defined as a number smaller than 0.05, indicating that the model closely matches the observed data.	Good Fit

As observed in the above table all the indices to determine the model fit of the measurement model show good values generating an acceptable measurement model. This indicates that the data collected for the study are fit enough to formulate the model for the study.

The path coefficients generated in the model have Chi-Square value of 176.879 at a probability level of .000. The significance level of each path is mentioned in Table 37 below along with their standardized coefficients.

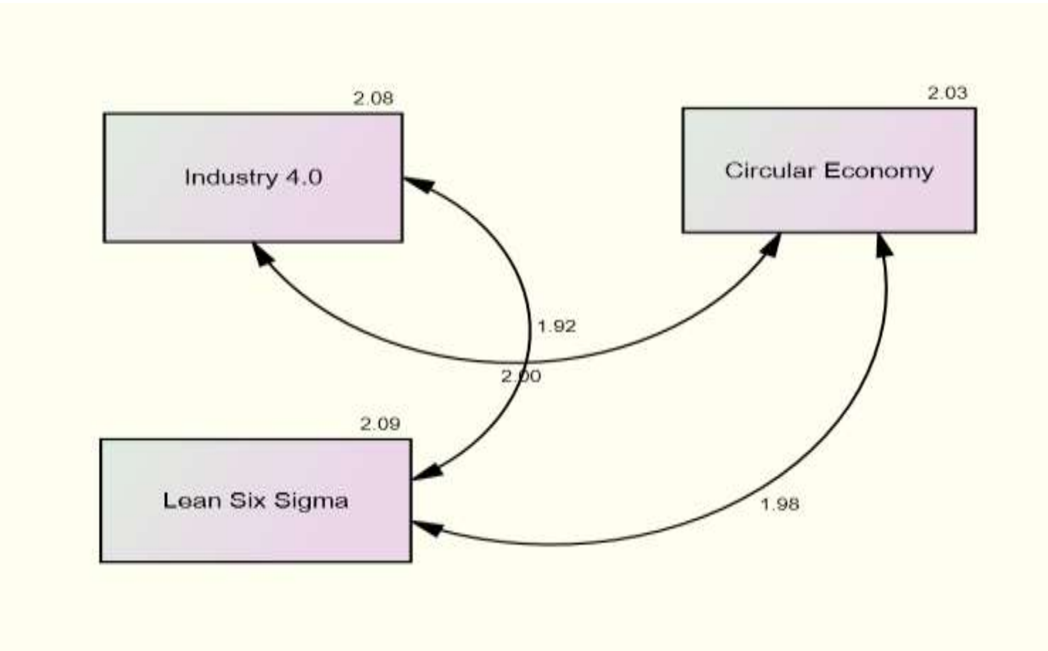

Fig 4.1: Path Diagram

Table 4.9: Estimates of Path from the Conceptualised Structural Model

Path			**Estimates**
Circular_Economy	<-->	Industry 4.0	1.041
LSS	<-->	Circular_Economy	1.011
LSS	<-->	Industry 4.0	.977

The relationship between CE and Industry 4.0 has a path estimate of 1.041, indicating a positive correlation. The relationship between CE and LSS has a path estimate of 1.011, also indicating a positive correlation. The relationship between LSS and Industry 4.0 has a path estimate of 0.977, which suggests a slightly weaker positive correlation or possibly a weak negative correlation. These values provide insights into how these concepts relate to each other within the context of the analysis or model.

Table 4.10: Path Analysis

Path	**Standardized Coefficients**	**p-value**
LSS→CE	0.22	.000
LSS→Industry 4.0	0.28	.000
Industry 4.0→CE	0.15	.000

The directional link between the variables in the model is shown by the path diagram and analysis. "CE" relates to the idea of putting CE methods into practice, "Industry 4.0" denotes technological improvements in the industrial sector, and "LSS". The coefficients denote the magnitude and orientation of the associations among the variables subsequent to standardising them to a mean of 0 and a normal deviation of 1. For every unit change in the independent variable, they show how the dependent variable changed.

This demonstrates the coefficients' statistical significance and indicates whether or not the observed link between the variables is statistically significant. The observed link is statistically significant if the p-value is smaller than a predefined significance level. The fact that all of the p-values in this instance are presented as ".000" indicates that all associations are statistically significant at the 0.001 level, which means that the null hypothesis—that the coefficients are equal to zero—is strongly rejected.

The findings of the route analysis show a strong correlation between Industry 4.0, LSS, and the adoption of CE principles. More specifically, Industry 4.0 adoption has a good impact on CE practice implementation, and the implementation of CE practices has a positive influence on LSS adoption. From the significance level generated it is seen that the null hypotheses are rejected.

Table 4.11: Status of Hypotheses

	List of Hypotheses	**Status of Hypotheses**
H01	LSS does not have a significant affect on CE	Rejected
H02	LSS does not have a significant affect on Industry 4.0	Rejected
H03	Industry 4.0 does not have a significant affect on CE	Rejected

5. Discussion

LSS and CE concepts are increasingly being integrated in academic research and real-world implementations across a range of industries. Lean, Green, and Six Sigma (LGSS) methodologies are all independent, yet they all aim to enhance an organization's production and transaction processes. Literature suggests that they are distinct from one another operationally. In order to reduce waste and advance sustainability, the CE concept seeks to establish closed-loop systems where resources are recycled, repurposed, and regenerated (Geissdoerfer et al., 2017). These CE strategies are made possible in large part by Industry 4.0 technologies like big data analytics, smart manufacturing, and the Internet of Things (IoT). They allow the effective use of resources, improve process transparency, and offer real-time data.

Structural Equation Modelling (SEM) was used to test the link between these ideas empirically. To investigate the connections between latent and observable variables, structural equation modelling (SEM) is a comprehensive statistical method that incorporates factor analysis, regression analysis, and path analysis (Hair et al., 2014). LSS serves as a mediating variable in this model, whereas Industry 4.0 is the independent variable and CE is the dependent variable. The strength and direction of these associations can be inferred from the path estimates obtained from SEM analysis. Industry 4.0 and the CE have a strong positive association (path estimate of 1.041). This implies that the adoption of CE principles is greatly facilitated by developments in Industry 4.0. Comparably, the path estimate of 1.011 between LSS and the CE shows a strong positive correlation, suggesting that implementing the concepts of the CE improves the efficacy of LSS techniques. Industry 4.0 and LSS are estimated to be on a 0.977 path. It is possible that Industry 4.0 has less of an immediate influence on LSS adoption than it does on the CE, even though this link is still positive. The reason for this could be because although Industry 4.0 technologies offer the data and instruments needed for process improvement, more managerial work may be needed to achieve the organisational and cultural changes needed for LSS (Sony & Naik, 2020).

The automotive sector has particular difficulties in striking a balance between sustainability, quality, and cost. The survey's highest mean score of five indicates that respondents firmly think LSS principles play a major role in constructing a sustainable future. For automakers, who have to keep prices down and ensure environmental compliance all while maintaining high standards of quality, this is essential. Regarding the effect of LSS in lowering emissions, the lowest mean score of 4.01 shows a perception gap. Lean creates value by eliminating waste from the process and enhancing lead time and process flow. Alternatively, Six Sigma identifies and minimises variation to produce consistent process output that adds value. Combining the two methods results in a new generation of quality improvement tools called LSS. The advantages of applying LSS include less errors and reworks, decreased inventory levels, quicker production, less space needed, less transportation, less waiting, and higher staff motivation. In light of this, there are a lot of shared objectives between LSS and sustainability. Even though. LSS is very good at cutting waste and increasing operational efficiency, it may not have as much of an impact on lowering emissions if it doesn't incorporate other environmental management techniques. This emphasises the necessity of an all-encompassing strategy that blends LSS with focused sustainability projects in order to accomplish broad environmental goals (Cherrafi et al., 2016). By examining the mean scores of ten items, the study investigates views towards CE practices in the automotive sector. The findings demonstrated broad consensus among stakeholders regarding the need for large financial investment in order to implement CE, indicating a serious worry regarding economic hurdles. This is consistent with other research that found high upfront costs to be a significant barrier to the adoption of CE. It also covers expenses associated with new technologies, changes to the infrastructure, and redesigns of current manufacturing processes. To promote CE practices, it could be required to implement encouraging policies or offer financial incentives. Exploratory Factor Analysis (EFA) was employed to extract key components of LSS implementation within the automobile industry, analyzing 15 items to identify four distinct factors: "Effectiveness of LSS," "Organizational Awareness and Leadership Impact," "Operational Efficiency and Organizational Culture Alignment," and "Striving for Excellence and Customer-Centric Approach."LSS and CE ideas are closely related, and this is important for both practical and scholarly applications. LSS improves process efficiency, product quality, and cost savings by fusing the waste-reduction emphasis of Lean management with the variability-reduction objectives of Six Sigma. Lean, on the other hand, might not be able to completely resolve process variations, requiring the statistical rigour of Six Sigma. In order to reduce waste and promote sustainability, the CE seeks to establish closed-loop systems for resource reuse, recycling, and regeneration. CE practices are made possible by Industry 4.0 technology, which offer real-time data, improve transparency, and make effective resource usage possible. Securing regulatory support for financial investments, promoting a continuous improvement culture, utilising Industry 4.0 technology for data collecting and process automation, and combining LSS and environmental management systems to achieve comprehensive environmental goals. Long-term sustainability and increased customer satisfaction are ensured by integrating LSS with organisational culture and upholding a customer-centric philosophy.

6. Con

7. clusion and Future Outlook

Four essential components that perfectly capture the spirit of LSS deployment have been effectively found in this study through the application of exploratory factor analysis. A deeper understanding of the many facets of LSS practices is provided by these factors: the Effectiveness of LSS; Organisational Awareness and Leadership Impact; Operational Efficiency and Organisational Culture Alignment; and Striving for Excellence and Customer-Centric Approach. The results highlight the significance of implementing LSS holistically, taking into account both the technical and human aspects. Organisations can maintain a competitive edge in their particular markets, improve customer happiness, and improve operational performance by addressing these elements.

Several important recommendations for industry stakeholders are produced by the study on the interaction of Industry 4.0, LSS, and the CE in the automotive industry. First and foremost, automakers need to embrace Industry 4.0 technologies head-on and make significant investments in them. This covers the use of robotics for automation, AI for predictive analytics, and IoT for real-time monitoring. Purchasing these technologies can help sustainability objectives in addition to improving operational efficiency. To maximise operational benefits, Industry 4.0 technology must be integrated with LSS processes. LSS concepts should be incorporated into automotive firms' technical frameworks to optimise workflows, lower unpredictability, and eradicate waste. Strategic decision-making should benefit from the wealth of data produced by Industry 4.0 technologies. To fully utilize the insights from big data, automakers must make investments in reliable data management and analytics solutions.

The study's conclusions provide various directions for further investigation. First and foremost, longitudinal research is required to investigate the long-term effects of LSS deployment on organisational culture and performance. Investigating the relationship between LSS and cutting-edge technologies, such Industry 4.0, can yield insightful information about how digital transformation can improve LSS procedures. Automation, IoT, and advanced data analytics combined with LSS may provide more effective and efficient operational improvements. The study points to a number of directions for further investigation. Comparative research between several automotive industry sectors may be able to reveal opportunities and problems unique to a given industry. Additional investigation may also examine the influence of governmental regulations and monetary incentives on hastening the implementation of CE strategies.

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