Literature review of lean, agile, resilient, green (LARG) in automotive manufacturing industry

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Abstract. The lean, agile, resilient, green (LARG) aspect approach that has been implemented by several industries globally, is an important indicator of industrial performance in the future. Comprehensive implementation of LARG is not easy, especially for companies with limited resources, because it requires the support of relatively expensive machine and equipment technology. Research examining the application of LARG in the manufacturing industry sector in general has been carried out by many researchers, but the tendency is for partial implementation, especially in the manufacturing industry. Along with the development of the Indonesian national automotive industry which continues to grow after the COVID19 Pandemic, each company needs to increase its competitiveness based on LARG with each of its indicators. This study conducted a literature review on the application of LARG aspects in the automotive industry. The purpose of this study is to analyze the implementation of the LARG approach in the automotive industry. The stages carried out in this study are: literature search from journal databases, filtering results based on keywords and criteria, systematic review of filtered papers to provide further understanding. The results of the literature review show that research on the application of LARG in the automotive industry is still carried out partially with dominant lean and green aspects. Meanwhile, the implementation of agile and resilient aspects tends to be limited.

1 INTRODUCTION

According to the 2023 Southeast Asian car market share, 2.18 million cars were sold overall, with Indonesia (675,287 units), Thailand (523,784 units), Malaysia (501,552 units), the Philippines (276,215 units), Vietnam (184,554), Singapore (24,019 units), and Myanmar (2,086 units) having the largest car sales. With total sales of 887,202 units in 2021, 1,048,040 units in 2022, and a projected less than 1 million units in 2024, car sales in Indonesia typically fluctuate (GAIKINDO, 2024). Through downstreaming and raising the domestic component level-TKDN, the government is still working to make the national industry—including the manufacturing industry sector—more competitive. Research on lean and green aspects is still more prevalent in the automobile sector. Using the SCOR model, research [1] examined lean and green features in the automobile component manufacturing sector.

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This study demonstrated that the application of lean and green techniques in the UK automotive component business has an effect on raising competitive advantage, cutting costs, and improving productivity. Human-related aspects, such ineffective manufacturing methods, are typically associated with human components in the industry. Lean manufacturing is currently a crucial instrument in all production industries, including the automotive industry, according to research [2]. According to other studies, there hasn't been much application or analysis of LARG elements in the automobile sector as a whole. The tendency of previous research has only analyzed the implementation of one or two LARG aspects. Research [3] was conducted by measuring the readiness of lean practices through understanding the quality aspects in the Turkish automotive supplier industry. The results showed that the Turkish automotive supplier industry has a high level of lean readiness, especially in the areas of customer relations and top management and leadership, while processes, planning and control, and supplier relations still need to be improved. Research [4] analyzed the implementation of lean manufacturing by involving other aspects: just-in-time (JIT), total quality management (TQM), total preventive maintenance (TPM), and human resource management (HRM). Although the impact of labor unions and plant age is not as pervasive as is generally believed, the study's findings show that lean significantly improves plant operational efficiency by offering compelling evidence for the impact of plant size on lean implementation. According to research [5], the lean production approach helps to improve environmental performance. Reducing material waste and emissions while supporting high resource productivity through fewer production stages is how the green approach is implemented. Employee engagement and training are necessary for the lean concept's ongoing progress. Employee engagement and training are also necessary to improve environmental performance, as suggested by the green idea. The goal of research [6] in Malaysia's automotive sector is to ascertain how Management Innovation (MI) and Green Lean Six Sigma (GLSS) relate to one another. Confirming that MI acting as an intermediary for the Malaysian automotive industry can continue to transform the GLSS practice management system in the Malaysian automotive industry more efficiently and effectively to become the best among competitors in other countries. Machine learning models can be used to create effective soft sensors that can predict a company's level of lean manufacturing based on its level of manufacturing flexibility [7].

By examining whether Industry 4.0 can adopt lean manufacturing, research [8] examines the relationship between Industry 4.0 and lean manufacturing that has not yet developed to its full potential. Some manufacturers are reluctant to adopt Industry 4.0 since it is an expensive process. Given the necessary investment and the unrealized rewards, this study also offers significant insights into firms' conundrum of whether they can commit to Industry 4.0 [8]. The influence of lean manufacturing on environmental performance in the Moroccan automobile industry is examined in research [9], which adds to the body of knowledge on green manufacturing and demonstrates the beneficial effects of lean manufacturing techniques on environmental performance. Finding environmental selection criteria for suppliers and creating a framework that will allow decision makers to assess and rank green suppliers are the goals of research [10]. To examine the significance of operational life cycles, green practices, and other aspects while choosing suppliers, data was gathered from a variety of automakers. Expert choice software has been used to select the best suppliers based on a variety of green practices, and this study helps to create a framework that will allow managers to find green suppliers for the sustainability of their businesses.

The purpose of this study is to analyze the application of the LARG approach in the automotive industry so that it can provide an overview of research that has been conducted by researchers globally.

2 Methods

This research begins by collecting various literature in the form of journal articles, proceedings, book chapters, from various sources, such as Google Scholar, Research Gate, Proquest, Academia.edu, and other sources using the keywords "lean, agile, resilience, green, automotive industry". Furthermore, the literature obtained is selected for its suitability, then classified based on the author's name and country, year of publication, research objectives, analysis used, research results and a summary of the literature that has been obtained to answer the research questions as previously mentioned.

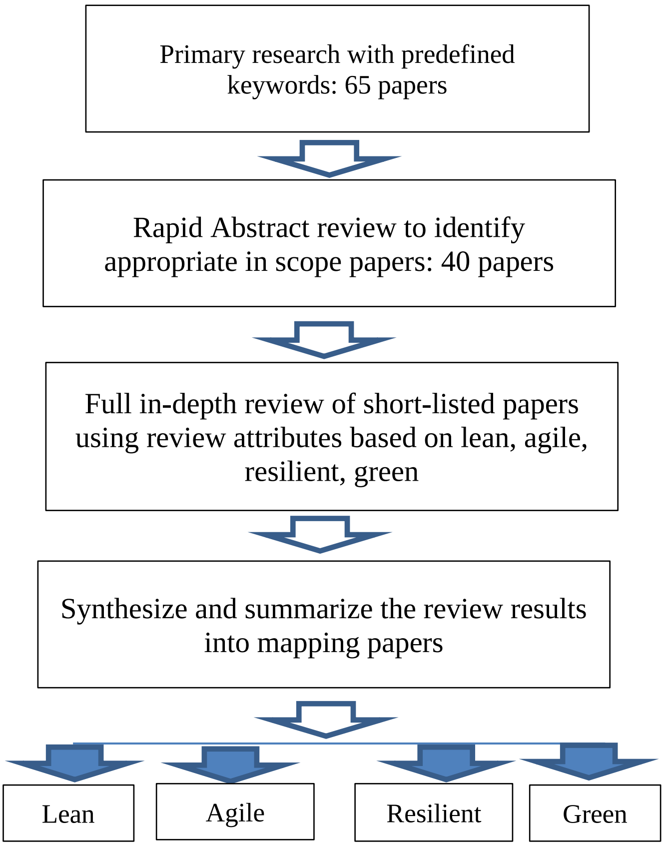

Fig. 1. Study framework.

3 Results and Discussion

Research [11], examines the application of agile supply chain management by identifying the most appropriate agile enablers to be implemented by companies based on market characteristics related to connecting competitive bases, agile attributes, and agile enablers. Research [12], conducts an agility assessment in the manufacturing industry on the aspect of supply chain contracts aimed at developing an agility evaluation framework in manufacturing companies. Research [13], shows how additive manufacturing can help the ASP (Automotive Spare Parts) industry to shift from existing make-to-stock practices to more efficient inventory management and a make-to-order model that saves costs while also achieving resilience and sustainability by providing a source of spare parts support for discontinued vehicle models. A conceptual case model is developed and tested with a proposed truck manufacturing that supports AM (Additive Manufacturing) closer to the end customer. Research [14] looks into the extent, advantages, and issues of using agile approaches by a few car firms in the Czech Republic's Liberec and Central Bohemia regions. Agile transformation was not seen an urgent strategic goal by the automobile firms assessed in this study, even if they gave their agility maturity a high rating. Project, program, and research and development management were the most flexible company operations. Simultaneously, it was evident to the respondents that greater flexibility and the capacity to react swiftly to changes in the market were necessary. R&D, program, and project management were the most flexible departments. Not a single company that participated in the survey gave their agile maturity a high rating.

Although digital manufacturing systems can support wider societal objectives and increase industrial sector resilience, the biggest effects are probably going to be felt at the lowest levels [15]. Resilience, resources, redundancy, and speed are the four primary components of the resilience index, according to a study by [16]. The automobile industry needs to embrace nine characteristics of capacity and reject five elements of vulnerability, according to an Iranian study on supply chain resilience [17]. The difficulties, prospects, tactics, and robustness of the supply chain in the context of EVs (electric cars) and the developing automotive revolution were covered in a research [18]. Scholars examine the significance of cooperation, creativity, and adaptability in reviving mobility via the automotive and electric vehicle revolutions. Stakeholders may promote positive change and help ensure the automobile sector has a resilient and sustainable future by embracing innovative technologies, implementing agile tactics, and comprehending supply chain dynamics. Through a case study of the Serbian automotive industry, research [19] was carried out to identify the factors influencing sector resilience, resilience models, and estimate the levels of component factors. A basic resilience model was tested, and the levels of resilience components were ascertained. The resilience paradigm serves as the foundation for the growth and upkeep of businesses as well as the sector as a whole. Because the automotive industry is a conventional one that receives state support in the form of various measures, current resilience models do not adequately address its needs. According to research by Nunes and Bennett [20], the three largest automakers in the world are implementing a number of environmental programs that include green operating practices. There is a contextual relationship between these techniques in the adoption of green supply chain management, according to research on the Indian automotive industry [21]. High ratings result from effective interactions between lean and green implementation in automotive industries, according to research by [22].

An investigation on whether internal departments of automotive OEMs have varying perspectives on specific risks was carried out in research [23]. This was accomplished by surveying European OEMs to find out how they felt about key elements of risk-based variables. According to the study's findings, the supply chain realignment must be successful in lowering costs while simultaneously enhancing delivery and collaboration conditions across the OEM spectrum. The European automotive market can be positioned as a robust and powerful market participant going forward in this manner. A consistent and coordinated understanding of risk-based elements across many departments and firms is a fundamental requirement for this. According to research [24], studies of regional economies and sectors heavily emphasize the idea of resilience. Regional economies and regionally based industries that have lost their competitive advantages, are resistant to change, and are stuck in a slow but persistent downward trajectory due to shocks, disruptions, and interventions—whether policy-oriented or not—are better described by resistance, according to this research. Making sense of the various resistance resiliencies has important policy ramifications.

The application of LARG in the manufacturing and automotive sectors has been the subject of numerous studies [25], [26], [27], [28], [29], and [30]. According to research [31], lean-L, agile-A, resilient-R, and green-G are the most crucial factors to take into account when evaluating the supply chain's competitiveness in the automotive sector. Interpretability and numeric-linguistic interfaces are the methods used by this researcher. The supply chain may become more sustainable and efficient by resolving the real contradiction between the management paradigms of lean, agile, resilient, and green [26]. A more competitive and sustainable lean supply chain with the agility required to provide quick response, resilience to disruption, and environmental harmony can be achieved through the practical implications of this suggested model, which can serve as the foundation for additional research in the lean, agile, resilient, and green paradigms [27]. Companies must apply a number of LARGs in order to increase the supply chain's competitiveness, agility in responding to client demand, and ability to handle unforeseen interruptions. They also need to be environmentally conscious and reduce non-value-added procedures [28]. A shared integrated approach for lean, agile, resilient, and green practices in the automobile sector supply chain was developed by Meleki & Machado's [29] study. Based on the enterprise 2.0 methodology, the study [30] created a framework for evaluating the LARG index in global supply chains to gauge the leanness, agility, resilience, and greenness of industry operations. Lean manufacturing and related flexibility data gathered from 46 auto component businesses in Maharashtra, India, served as the foundation for research [7]. To create lean manufacturing soft sensors, a total of 29 distinct machine-learning models from seven architectures were investigated. Based on their production flexibility, these soft sensors were taught to categorize automakers into high, medium, and low lean manufacturing.

The resilience aspect in the automotive industry tends to be under-researched. Research [32], conducted a study by reviewing three years of data from an assembly line producing 500 cars per day. Analyzed the impact of the spread of the COVID-19 virus on assembly line efficiency and suggested improvements to strengthen assembly line resilience. Research [33], confirmed that the overall findings obtained from the refined article review stated that in countries like India, the automotive industry needs to have the right management commitment to supply chain sustainability and resilience rather than government rules and regulations. The implementation of lean manufacturing that is widely confirmed is reducing waste. Research [2], stated that the benefits observed after the implementation of individual or combined lean manufacturing techniques are reduced cycle time, elimination of non-value activities, clean, tidy, and hygienic workplaces. In addition, there will be smooth production flow, increased productivity, reduced production costs, employee engagement, order documentation, inventory reduction, and disruption with better intra and inter-connectivity for quick and responsive decision-making. The study focused on different manufacturing sectors to see the effect of lean manufacturing techniques applied to improve process capabilities and reduce waste [2]. The study [34] analyzed the time for various connecting rod manufacturing operations in an industry. Confirmed the factors that affect production time among different operators and operations. Using the software the study found the optimal layout for connecting rod manufacturing. The study was conducted by applying lean methodology in the management of consumables in the maintenance workshop of an industrial company by reducing the volume of materials and rearranging their placement [35].

Lean and agile aspects were carried out by Ref. [31] aiming to propose an index to assess the agility and leanness of each company and its supply chain in the automotive industry. This study confirmed the fairly easy application of the suggested agile-lean index in a real-world supply chain setting. This index allows to assessment the agile and lean behavior of the company and its related supply chain, which is translated into an index score to compare the company's supply chain system and competitors [31].

Table 1. Recapitulation of LARG topic articles on the automotive industry.

Paper Identity	L-A-R-G aspects studied			
	Lean	**Agile**	**Resilient**	**Green**
Sunmola et al., (2024) [1]	v	x	x	v
Palange & Dhatrak (2021) [2]	v	x	x	x
Garza-Reyes et al., (2015) [3]	v	x	x	x
Shah & Ward (2003) [4]	v	x	x	x
Sabadka (2014) [5]	v	x	x	v
Moh Zamri et al., (2013) [6]	v	x	x	v
Sekhar *et al*., (2023) [7]	v	x	x	x
Sanders *et al.,* (2016) [8]	v	x	x	x
Bouazza et al., (2021) [9]	v	x	x	v
Gupta & Vijayvargy (2021) [10]	x	x	x	v
Haq & Boddu (2017) [11]	x	v	x	x
Galankashi *et al.,* (2019) [12]	x	v	x	x
Jothi et al., (2023) [13]	x	v	v	x
Revutska & Antlová (2022) [14]	x	v	x	x
Fowler *et al*., (2023) [15]	x	x	v	x
Sambowo & Hidayatno (2021) [16]	x	x	v	x
Kaviani *et al*., (2020) [17]	x	x	v	x
Kolasani (2024) [18]	x	x	v	x
Arsovski (2010) [19]	x	x	v	x
Nunes dan Bennett (2010) [20]	x	x	x	v
Luthra *et al*., (2013) [21]	x	x	x	v
Duarte & Machado (2017) [22]	v	x	x	v
Britsche & Fekete (2024) [23]	x	x	v	x
Sweeney et al., (2020) [24]	x	x	v	x
Azevedo et al., (2013) [25]	v	v	x	x
Carvalho & Cruz-Machado, (2011) [26]	v	v	v	v
Carvalho *et al.,* (2011) [27]	v	v	v	v
Cabral *et al.,* (2012) [28]	v	v	v	v
Meleki & Machado (2013) [29]	v	v	v	v
Fazendeiro *et al.,* (2013) [30]	v	v	v	v
Azevedo *et al*., (2012) [31]	v	v	x	x
El Ahmadi & El Abbadi (2022) [32]	x	x	v	x
Khot & Thiagarajan (2019) [33]	x	x	v	x
Balamurugan *et al.,* (2020) [34]	v	x	x	x
Pombal *et al.,* (2019) [35]	v	x	x	x
Soni & Kodali (2012) [36]	v	v	x	x
Govindan *et al.,* (2014) [37]	x	x	x	v
Hazen *et al.,* (2011) [38]	x	x	x	v
Solke *et al.,* (2022) [39]	v	x	x	x
Alefari *et al.,* (2017) [40]	v	x	x	x

Notes:
v: discussed x: not discussed

The study of Ref. [36], was conducted by evaluating the reliability and validity of the lean, agile, and leagile supply chain constructs in the Indian manufacturing industry. Principal component analysis was conducted on these constructs to identify the pillars of each type of supply chain followed by evaluating the reliability and validity of these pillars to establish the underlying constructs. The results of this study also succeeded in creating a lean, agile and leagile supply chain framework. Research [37] focused on identifying barriers to the implementation of green supply chain management (Green SCM) based on procurement effectiveness. It was confirmed that 47 barriers were identified, both through literature review and discussions with industry experts and through questionnaire-based surveys from various industry sectors. Important priority barriers were identified through an analytical hierarchy process, as well as sensitivity analysis investigating the stability of priority rankings. Research [38] also conducted a study on the green aspect of the supply chain through a survey method used to collect data from a diverse sample of 533 respondents. The data were analyzed through ANOVA to test the hypothesis, with findings indicating that consumers perceive products made through some green reverse logistics (GRL) practices to be inferior to new products in terms of quality. However, the study also confirmed that there was no difference in perceived quality between products made from recycled materials and new products. The implications of this study suggest that the implementation of some GSCM practices does not necessarily lead to competitive advantage, which may hinder the spread of GSCM.

Decision Trees, Discriminants, Naive Bayes, Support Vector Machines (SVM), K-nearest neighbor (KNN), Ensembles, and Neural Networks (NN) are the seven machine learning architectures. Some Indian automakers have implemented sensor-based lean production. Using the auto regressive with exogenous variables (ARX), autoregressive moving average with exogenous variables (ARMAX), output error (OE), and Box Jenkins (BJ) methodologies, research [39] implemented 23 lean manufacturing models that were developed based on the system identification structure. Based on validation indicators including FIT%, mean squared error (MSE), final prediction error (FPE), and the number of model parameters, the relative performance of each predictive model was compared. In order to sustain and enhance worker performance in a lean manufacturing system, research [40] examined the quality components of lean leadership. This method is unique since it examines lean from the viewpoint of the leader in a lean production system to enhance worker performance. Other researchers also conduct study that examines the organizational aspect.

Lean tools generally consist of: Kaizen, 5S, value stream mapping (VSM), visual control, kanban, standardize work, poka yoke, single minute exchange of dies (SMED), continuous flow, total productivity maintenance (TPM), lot size reduction. Green tools refer to: environmental management system (EMS), life cycle assessment (LCA), environmental emission control, 3R (reduce, reuse, and recycle), pollution prevention, green supply chain practice, design for environment (DfE), the use of environmentally friendly raw materials, The use of alternate sources of energy, ISO 14001. Agile tools generally include aspects of management style, decision-making authority, control, fundamental assumptions, knowledge management, communication, organizational structure, customer role, organization, development model, quality control, visibility. Resilience tools consist of: creating & increasing redundancies, building flexibility, changing corporate culture, collaboration, leadership, innovation.

4 Conclusion

To make the automotive industry more competitive, lean, agile, resilient, and green practices are being implemented. The sub-indicators for lean, agile, resilience, and green are the foundation for determining the degree of LARG implementation. In general, the automotive sector tends to integrate LARG gradually and partially. One of the reasons for this is that each of the lean, agile, resilient, and green sub-indicators needs resource support and preparedness. It is evident from the literature search that the shortcomings of studies that use LARG comprehensively may present a chance for future LARG-based research.

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