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Lean and Green Manufacturing in operations strategy: cases from the automotive industry

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Abstract
Players in the automotive industry have been adopting different strategies to remain competitive, including product and process innovation, Lean Manufacturing, and, more recently, Green Manufacturing. In this paper, we seek to explore the integration of Lean and Green manufacturing activities from the perspective of Operations Management and Operations Strategy. We carried out case studies at four Original Equipment Manufacturers and two first-tier suppliers in the automotive industry, examining their operations strategies, their Lean practices and their Green practices to discuss whether Lean and Green practices were integrated and aligned with companies' operations priorities. We found that companies have adopted different Operations Strategies considering operations competitive priorities, decision areas subjected to changes, and Lean and Green practices implemented. Cases analysed show different levels of Lean and Green Manufacturing adoption and different levels of integration of Lean practices and Green practices. The study indicates that the implementation of an operations strategy, with the addition of the Environment to the set of competitive priorities and involving the implementation of Lean and Green practices – or the implementation of Green practices in production systems that have already adopted Lean practices –, is a complex management task.

Keywords Green Manufacturing · Lean Manufacturing · Manufacturing Strategy · Vehicle Manufacturing · Case-based research

1 Introduction and research context

Companies are increasingly aware of the need to reduce their environmental footprint. Environmental legislation and growing social pressure are only some of the concerns necessitating this endeavour. To that end, many have sought to implement the so-called Green practices. For industries where Lean practices are widespread, integration of both practices becomes necessary. Therefore, companies must adopt Operations Strategies (OS) that successfully incorporate sustainability as a priority alongside quality, cost reduction, flexibility, and other production priorities. As one such industry, the automotive sector is the focus of this paper.

The 'Lean- Green' approach, or 'Green Manufacturing' (Florida 1996), is the integration of Lean Manufacturing principles with environmentally sustainable practices (Abualfaraa et al. 2020). This approach has been proposed as a strategy to improve business competitiveness (Bhatt et al. 2020; Duarte and Cruz-Machado 2019; Siegel et al. 2019; Sanchez Rodrigues and Kumar 2019) , as it is argued that the integration of Lean and Green practices leads to competitive advantages in operations strategies that translate into sustainable environmental and economic outcomes.

The literature has focused mainly on the synergies between Lean and Green practices (Florida 1996; King and Lenox 2001; Rothenber et al. 2001). Recent studies (De Oliveira et al. 2021; Gholami 2015) emphasise that Lean practices can improve environmental performance due to their focus on waste reduction and efficient use of resources. It has also been observed that Lean culture and

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organisational structure can facilitate the implementation of Green practices, and argued that integration can improve the results of both (Jabbour et al. 2013). For example, Longoni and Cagliano (2015) address the cross-functional involvement of executives and workers in the implementation of an Operations Strategy (OS) that targets Lean production and sustainability.

However, other studies show the implementation of Lean practices may also have a detrimental environmental impact. De Oliveira et al (2021) point out a negative correlation between clean production practices and Lean practices. Rothenberg et al. (2001) observe that adopting Just in Time can result in more carbon emissions.

Regarding the integration and balance of Lean and Green practices, existing studies have developed conceptual frameworks to implement the Lean-Green approach and presented hybrid tools with observed results. A good example is the framework proposed by Souza and Alves (2018). It considers international management standards, such as ISO9001 and ISO14001, while utilising Toyota principles and tools as a basis for execution, as well as GRI sustainability guidelines. About hybrid tools, within Lean-Green literature it is possible to find Lean with added Green practices such as E-VSM - Environmental Value Stream (Aguado et al. 2013), 7s – 5s plus sustainability (Anvari et al. 2011) and safety, TQEM – Total Environmental Quality Management

(Salvador et al. 2017). Some of these studies also present favourable results of Lean-Green implementation, such as energy savings, and reductions in waste, material, and water consumption (Cherrafi et al. 2016).

Yet we are not aware of any contribution with an explicit focus on Lean-Green practices as part of the Operations Strategy content, which also details the possible compatibilities and trade-offs among competitive priorities that may be caused by changes within production decision areas and considers what adjustments could be made to enhance existing compatibilities and avoid trade-offs.

We seek to start the discussion on how Lean-Green practices could be integrated and considered in the operations strategies of some companies in the automotive sector by answering the following research questions:

RQ1: How lean practices and green practices have been adopted by some companies in the automotive industry as part of their operations strategies?
RQ2: What are the configurations of companies' operations strategies considering what competitive priorities are selected and what Lean and Green practices are adopted?
RQ3: Can companies enjoy synergies among operations priorities when implementing Lean and Green practices? Do they have to face trade-offs when the Environment is among operations priorities?

These questions will be discussed through a literature review and case studies carried out in six companies in the automotive industry. This sector was chosen because it provides empirical evidence of the implementation of Lean and Green practices. Lean manufacturing is well-represented and documented (Krafcik 1988; Ohno 1988; Crute et al. 2003; Womack and Jones 2003) and according to Azevedo et al. (2012), the sector has a high level of Lean-Green implementation.

Achieving sustainability in manufacturing operations is currently a major challenge (Ahmadi-Gh and Bello-Pintado 2022) as companies seek alignment with the 2030 Agenda for Sustainable Development and the achievement of the United Nations' 17 Sustainable Development Goals (SDGs). Therefore, the appropriate implementation and integration of Lean and Green practices could be vital to preserve competitiveness while undertaking the difficult task of prioritising environmental objectives alongside other production performance goals.

The remainder of the article is articulated as follows. First, we present a conceptual background and research model with some propositions. Second, we present and justify the research strategy, procedures, and materials employed. Third, we present the results of the case studies and develop a cross-case discussion. Fourth, we discuss the theoretical and managerial implications of the study. Limitations and research paths are also highlighted. We conclude with a synthesis of the study and its contributions.

2 Conceptual background and research model

2.1 Operations strategy (OS)

Operations strategy (OS) – or manufacturing strategy, as various authors call it (Dohale et al 2021, p.1) – is one of the main functional strategies that, besides others such as Marketing, Finance, Human Resources and Research and Development, "… play a crucial role in the success of business strategy…". The inaugural work of Skinner (1969) conceptualised what was then called Manufacturing Strategy and highlighted its importance to the success of an organisation.

OS can be defined as a sequence of decisions that, over time, enable a business to achieve a desired operations structure with a specific set of resources. Hence, OS is a consistent pattern of decision seeking to align the operations function to competitive strategy (Wheelwright 1984).

Kim and Arnold (1996) identify two branches in OS studies namely: (1) The content, representing the decisions made by the corporation for the effectiveness of the strategy, and (2) The process that synergises the stages of strategy formulation and implementation.

In this study we have privileged the content branch of OS, focusing on the operations (or production) competitive priorities and on changes implemented in decision areas to achieve these competitive priorities. Figure 1 provides a depiction of the content branch of OS; it summarises the decision areas of the operations function and the operations competitive priorities of the firm.

Competitive priorities are related to the performance objectives that the operations or production function adopts to align with the company's business strategy and with the overall goals of the operations strategy, such as the increase of productivity and the reduction of defects, cost and lead time (Skinner 1969).

Six competitive priorities were selected for the purposes of this investigation. The first five were borrowed from Garvin (1993), namely, cost, quality, flexibility, delivery, and service. We incorporated a sixth priority 'environment' representing environmental performance (Angell and Klassen 1999; Marcus and Fremeth 2009).

In general, organisations may face two situations when it comes to decisions about competitive priorities. The first, initially presented by Skinner, is one in which it is not possible, with the knowledge available to the organisation, to seek better results simultaneously in two or more priorities. This is due to an incompatibility between priorities. The most important among such priorities must then be chosen over the others, a trade off happens. For instance, a certain company might want to improve the quality of its products while also reducing production costs but find itself unable to do so as one will negatively impact the other. Hence, Skinner (1969, 1974) proposed a focused organisation, capable of high performance in some selected competitive dimensions. So, a luxury car manufacturer may invest in high quality, while a budget one might choose cost reduction, for example. Note that the company, faced with such a situation, may eventually choose to seek, or develop knowledge that can lead to overcoming the existing trade-off, and once more be able to advance in those priorities concomitantly.

A second situation is one in which there is room for simultaneous improvements in two or more priorities, which includes the possibility of progress in one priority facilitating the development of others. The "sand cone" model or the model of cumulative capabilities was proposed by Ferdows and De Meyer (1990), advocating that the organisation can achieve competitive priorities over time and that there is an adequate sequence for their development, with quality being considered the basis for the implementation of other improvements (Flynn and Flynn 2004; Robert Hayes et al. 2007). Boyer and Lewis (2002) point out that Japanese organisations developed productive capabilities following a previously established sequence, and the practices adopted allowed for both cost reduction and quality products.

The study of Bortolotti et al. (2015) illustrates this proposal in Lean implementations and their results support the cumulative capabilities approach. However, Flynn and Flynn (2004) noted that the development of cumulative capabilities is complex and not limited to a specific sequence as it is influenced by several factors.

When it comes to the inclusion of 'Environment' as a new competitive priority, Longoni and Cagliano (2015) argue that trade-offs may arise between the 'environment' priority and the other priorities. Whereas Porter and Linde (1995) contend that it is possible to meet the economic and environmental objectives of products and processes since

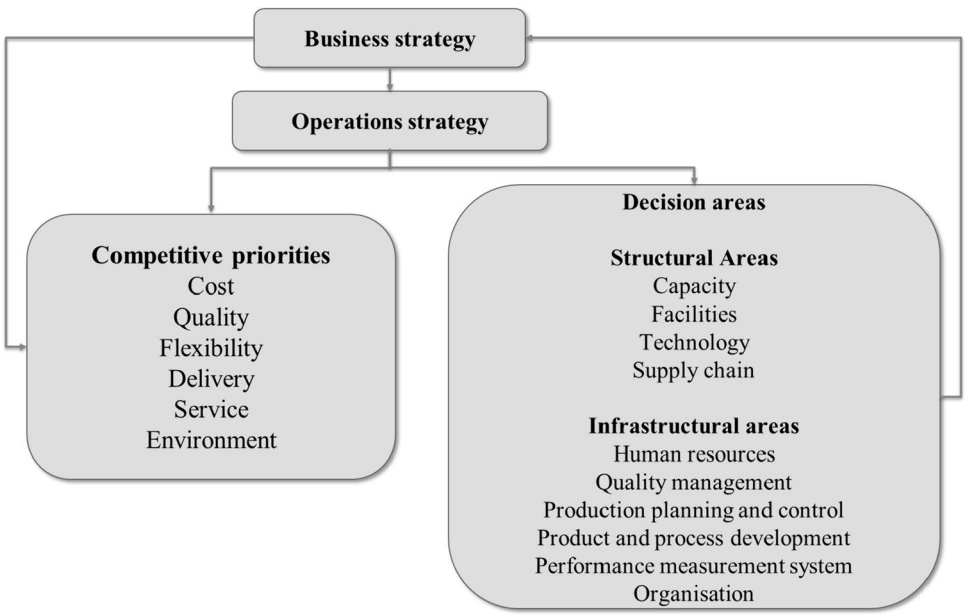

Fig. 1 The content of Operations Strategy (OS). Adapted from (Leong et al. 1990) and Wheelwright (1984)

the preservation of resources generates greater efficiency of the processes.

According to Dohale et al (2021), the operations function or manufacturing function involves structural and infrastructural decisions. Structural decisions, in general, involve high investments and long-term commitments, while infrastructural decisions can be implemented in relatively shorter terms and with lower investments (Choudhari et al. 2010; Miltenburg 2005). Structural decisions encompass capacity, type of process technology and supply. While infrastructural decisions concern human resources, production planning and control, and organisational structure and control (Mirzaei et al. 2016).

While competitive priorities can be indexed in a handful of notions, decision areas in operations are manifold. For this investigation, we have circumscribed ten decision-operational areas summarised in Table 1.

The work of Voss (2005, 1995) asserts that the content branch of OS is concerned with choices in manufacturing leading to a competitive stand. The company secures a competitive edge by making strategic choices relating to its structure and infrastructure. Some examples are 'make-or-buy' decisions, outsourcing, the adaptation of manufacturing and logistics systems, performance measurement systems, and technologies.

2.2 Lean-Green manufacturing

Shah and Ward (2007, p. 791) conceptualise Lean Manufacturing (LM) as "an integrated socio-technical system whose main objective is to eliminate waste by concurrently reducing or minimising supplier, customer, and internal variability". LM can also be understood as a set of principles and practices to eliminate all forms of waste within an organisation (Mostafa et al. 2013). The forms of waste have been categorised into defects, inventory, inappropriate processing, overproduction, waiting, handling, transportation, and talent (Liker 2004).

The most recognisable LM practices are Five-s (5s), Kaizen, Value Stream Mapping (VSM), Just-in-Time (JIT), Single Minute Exchange of Die (SMED), Total Productive Maintenance (TPM), Kanban, Standardised Work, Visual Management, Five-why (5-Why, root cause analysis), and A3 report (Shah and Ward 2007). An ever higher number of organisations from the most diverse sectors of the economy are adopting these practices (Losonci and Demeter 2013).

The Green Manufacturing (GM) concept emerged in the early 1990s. It has been thought of as a 'philosophy', or as an 'operational approach' intended to reduce the negative environmental externalities of production processes, increasing environmental performance while meeting economic objectives (Garza-Reyes 2015).

The first industry implementations of what came to be known as GM can be traced back to the 1970s. These have since been criticised for being 'end-of-pipe' approaches dealing with corrective actions. It was only by the 2010s that GM initiatives were linked to business strategy as proactive approaches (Khan et al. 2020).

As such, GM should now be about the quest to minimise pollution, energy consumption and emissions of toxic

Table 1 Ten decision areas belonging to the content branch of operations strategy

#	Decision area	Main elements	Authors of reference
1	Capacity	Operational capacity, number of units, variety of products	(Slack and Lewis 2011)
2	Facilities	Plant size, layout, number of facilities, location	(Miltenburg 2005; Skinner 1969)
3	Technology	Equipment, use of advanced technologies, systems, process type, maintenance practices	(Miltenburg 2005; Skinner 1996)
4	Supply chain	Degree of vertical integration, policies towards suppliers, supplier relations	(Miltenburg 2005; Slack and Lewis 2011)
5	Human resources	Employment policies, employee skills, compensation systems, incentives, training, degree of specialisation, performance appraisal	(Miltenburg 2005; Skinner 1996)
6	Quality management	Quality policy and quality management systems	(Hayes et al. 2004)
7	Production planning and control	Production scheduling, materials requirement planning, inventory, and production control, planning (input, strategy, and horizon)	(Hayes et al. 2004; Miltenburg 2005)
8	Product and process development	Product design, manufacturing engineering, technological risk, design stability	(Fine and Hax 1985; Skinner 1969)
9	Performance measurement system	System of performance indicators	(Hayes et al. 2004)
10	Organisation	Organisational structure, hierarchy, culture, and management style	(Miltenburg 2005; Skinner 1969)

substances through the development of new processes in the manufacturing phase (Dilip Maruthi and Rashmi 2015; Kleindorfer et al. 2005; Pathak and Singh 2017).

An organisation can apply GM methods to reduce environmental impacts generated by production processes. Some examples are cleaner production, Life Cycle Assessment (LCA), environmental management system, circular production systems, eco-design, Green Supply Chain (GSC), and 3R which stands for 'recycling, remanufacturing, and reuse' (Pampanelli et al. 2014; Paul et al. 2014).

The integration of LM and GM approaches, or "Lean-Green' (LG), has been met with mixed evaluations by scholars.

Some point to the natural synergies between these practices as both have a focus on waste reduction and efficient use of resources (Garza-Reyes 2015). Cherrafi et al. (2017) note that it leads to better results compared to stand-alone implementations, and successful examples of its application have been observed in improvements to environmental performance in manufacturing (Dieste et al. 2020).

However, other authors document the shortcomings of LG (Rothenberg et al. 2001; Dües et al. 2013; Fu et al. 2017). They argue that environmental impact reduction might divert LM which focuses on inefficiency reduction. Trade-offs may then arise between the 'environment' priority and other competitive priorities of the operations strategy.

This paper aims to build on these concepts, addressing Lean-Green as an approach that combines Lean principles and tools with Green principles and tools to enhance the sustainability performance of production systems in terms of economic, environmental, and social dimensions (Abualfaraa et al. 2020).

2.3 Conceptual framework based on operations strategy content

Multiple studies have shown the influence of Lean Manufacturing on environmental outcomes, suggesting that its focus on efficient use of resources (e.g. water and other inputs) translates into environmental benefits (Dieste et al. 2020; Vinodh et al. 2011).

Nonetheless, many find these practices insufficient to achieve desirable environmental results. Siegel et al. (2019) and Ben Ruben et al. (2020) point to the need for changes in decision areas to consolidate the benefits long-term. Others have noted there is no sufficient evidence that LM practices can turn corporate efforts into outstanding environmental performance improvements (Rothenberg et al. 2001). As LM does not necessarily consider environmental impact, organisations must turn to GM practices to account for that (Ng et al. 2015; Ruiz-Benitez et al. 2019). This has also been observed by Garza-Reyes et al. (2018a, b), who point out that while Lean tools, such as TPM and JIT, may lead to a significant improvement in environmental performance, it cannot be guaranteed without the explicit inclusion of green objectives.

Hence, the integration of Lean and Green practices is not only beneficial, due to the observed synergies between them, it is essential to any organisation that sets the 'Environment' as a production competitive priority.

Various authors have already suggested the integrations of these practices and put forth proposals to that end: Changes to company culture and waste elimination (Duarte and Cruz Machado 2017), the addition of environmental indicators to Lean systems (Belhadi et al. 2018), and training programmes focused both in Lean and Green Practices (Cherrafi et al. 2017).

Conceptual frameworks and models have also been presented: Souza and Alves (2018) base theirs on Toyota's house model, Ruben et al. (2017a) employ DMAIC from six sigma to achieve Lean-Green, and Tiwari et al. (2020) establish a framework for sustainable lean production.

Industry examples are also available in the works of Belhadi et al. (2018), Ruben et al. (2017a), Duarte and Cruz Machado (2017), Cherrafi et al. (2016), and Dües et al. (2013), suggesting the importance of integrating Lean and Green practices. Having noted the shortcomings of Lean Manufacturing concerning environmental performance and the work towards the integration of Green Manufacturing practices already present in the extant literature, we draw the first proposition of our investigation:

Proposition 1 *Companies have to implement Green practices when the Environment is a production competitive priority since Lean practices are/were implemented with other objectives.*

Rsponsible manufacturing actions towards the planet resulting in operations efficiency can be considered a competitive priority under the 'environmental' label. This is an emerging priority identified in reviewed studies (Alves and Alves 2015; Susana G. Azevedo et al. 2012; Ruben et al. 2017b; Braglia et al. 2020; Garza-Reyes 2015; Minh et al. 2019; Ng et al. 2015; Souza and Alves 2018; Wong and Wong 2014).

Meeting societal expectations and environmental preoccupations motivates organisations to reduce their footprint on the planet and to enhance the welfare of people. This is a cornerstone of Corporate Social Responsibility (CSR). However, studies point to another reason for organisations to reduce the environmental impacts of their operations; this reason is cost.

Cost reduction and cost containment are circumscribed to more efficient management of policy, people, materials, land, technology, energy, and waste in manufacturing processes. Considering production costs have dramatically increased over the past decade (Gupta et al. 2018),

particularly those of raw materials, salaries, and energy prices; this investigation intends to identify a bi-directional link between cost reduction and containment 'cost', and environmental stewardship 'environment'.

On cost reduction, studies have documented cost minimisation in manufacturing activities through the implementation of methodologies and practices focusing on the environment (Cherrafi et al. 2016; De Carvalho et al. 2017; Miller et al. 2010; Prasad et al. 2016; Torielli et al. 2010). On cost containment, Ball (2015), and Thanki et al. (2016) note that improvement of an organisation's environmental performance can help minimise the impact of normative or coercive measures introduced through legislation (Ball 2015). The aforementioned insight provides the matter to draft the following proposition:

Proposition 2 *Under a Lean-Green (LG) integrative scheme, the 'cost' priority of operational strategy will be influential to the 'environment' priority, and vice-versa.*

Not only does this proposition imply a potentially resonant link between two manufacturing priorities that might seem incompatible (i.e. cost reduction vs. environmental performance); other competitive priorities of operational strategy, beyond these, might be positively or negatively affected by LG implementation. Hence, organisations simultaneously pursuing LM and GM goals, need to make compromises when facing trade-offs (Kleindorfer et al. 2005; Longoni et al. 2014; Pampanelli et al. 2014; Salvador et al. 2017).

Despite the goal of LG implementation being improving environmental performance in manufacturing by taking advantage of convergent goals and practices between LM and GM, their differences of focus may cause problems. For instance, while the two strategies share the goal of waste reduction, they differ in their conception and emphasis on wastage (De Carvalho et al. 2017). While GM focuses on pollution reduction, LM focuses on manufacturing efficiency (Mollenkopf et al. 2010; Pampanelli et al. 2014). And, when these competing priorities are placed into the melting pot of LG, one tends to be absorbed by the other.

The above examples evidence an incompatibility of targets for any organisation trying to implement LG. And, since the LM notion historically precedes GM; organisations operating in an LM environment are forced to make trade-offs when adopting GM practices. A common trade-off found in scholarly work is the compromise made between 'delivery' and 'environment'.

For example, the Just-in-Time (JIT) approach, which focuses on 'delivery' as a competitive priority, could negatively impact the 'environment' priority of GM. This is because JIT privileges a higher frequency of deliveries in small lots resulting in greater transportation emissions Azevedo et al. 2016; Campos and Vazquez-Brust 2016; Longoni and Cagliano 2015; Mollenkopf et al. 2010; Salvador et al. 2017; Wang et al. 2015).

A second trade-off relates to the balance between 'quality' and 'environment'. In some instances, greater depletion and consumption of resources is required to assure quality in a product; this takes place to the detriment of the environment (Pil and Rothenberg 2003).

A third trade-off is found in the work of Dües et al. (2013) and Sawhney et al. (2007) pertaining to 'flexibility' and 'environment'. The first requires production runs in small batches to allow for more variety in the products. However, this priority increases setups and changeovers that might result in a greater use of resources and environmental toll. Thus, our last proposition is as follows:

Proposition 3 *Lean-Green (LG) integration requires management attention to possible trade-offs between Environment priority and other priorities such as Cost, Quality, and Flexibility.*

Figure 2 offers a graphic array of the main concepts of this investigation linked by the three theoretical propositions.

This conceptual framework was used to steer the efforts in the fieldwork. Following, it is present.

The research design is presented in the following.

3 Research design

Our research has been inductive in essence, as the results emerged from the analysis of the conducted case studies. An initial step of theoretical work was taken, constituting

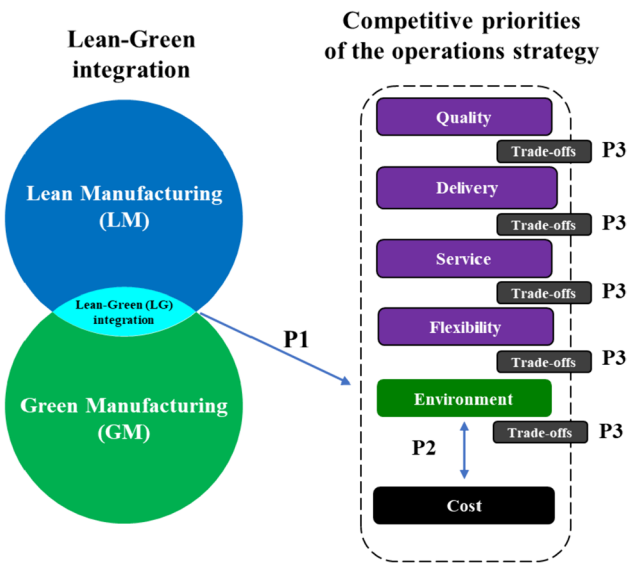

Fig. 2 Conceptual framework of the investigation

the elaboration of propositions drawn from relevant theory selected a priori. As we could not find extant literature with a specific focus on LG practices as a part of operations strategy, this first stage had the purpose of eliciting theoretical expectations from (what is to our knowledge) the combination of these two hitherto disjointed fields of study. Thus, providing a basis for the development of our subsequent empirical work. Our substantial conclusions are drawn from the latter stage and, as such, we classify the study as "case research as theory generation" (Ketokivi and Choi 2014). This stage is characterised by low levels of abstraction. We used the Ketokivi and Choi (2014) case research decision tree (i.e. framework) to determine the emphasis of our case-based research.

It is worth highlighting three conditions of the research design: (1) there were existing theories and literature on Operations Strategy and on Lean and Green practices, although still non-articulated, to support the research questions, (2) it was possible to derive explicit a priori theoretical propositions, and (3) our propositions were context-specific to the automotive industry.

This case research consists of six case studies carried out in assembly companies or at the first tier of supply chains in the automotive industry. This sector was chosen because it has seen the emergence, development, and general adoption of LM practices. Cases from LM implementation have been widely documented with evidence from the automotive sector (Howleg 2007; Womack and Jones 2003). Hence, it was reasonable to assume that the convergence of LG manufacturing practices could also be found and substantiated within this sector.

A convenience sample was drawn by choosing five multinational corporations located in Brazil and one in Canada. The Canadian company was included because we anticipated it could serve as a more developed reference in terms of implementing Green practices. The results of this specific case could then illustrate paths for developing Green practices in other organisations. However, this expectation was not fulfilled. The Canadian company was also a convenient choice because the research team included researchers from Canadian institutions.

Inclusion criteria considered three premises. First, we chose organisations that have implemented LM with subsequent experience on GM execution. Second, we selected entities belonging to two levels of integration in the value chain (e.g. Original Equipment Manufacturers, and first-tier suppliers). Third, we invited participants with considerable knowledge of LM and GM implementation (e.g. manufacturing managers, environmental managers, sustainability managers, etc.) Table 2 summarises the salient features of entities and participants of the study.

The information was obtained mainly from semi-structured interviews with an operations manager and a manager responsible for environmental practices from each company. The interviews were carried out using a script containing open and closed questions to obtain information about the companies' general characteristics, their competitive operations priorities, the operations management elements related to structural and infrastructural decision areas, and the programs and actions implemented. The interviews lasted approximately 150 min. We adopted a manufacturing unit from each company as the unit of analysis to identify and analyse its operations strategy.

In the interview guide, the objective of the questions concerning operations strategy was to identify possible changes that occurred in each manufacturer, over the four years prior to the interviews, related to the competitive priorities of operations, LG practices and decision areas.

About the competitive priorities, we sought to identify which of the priorities and sub-priorities had been emphasised four years prior and which were emphasised at the time of the interview. Thus, the initial analysis made it possible

Table 2 Entities and participants of the investigation

Organisation (entity)	Position in the value chain	Number of workers	Location	Headquarters	Participants
A	OEM	Over 1000	Canada	Sweden	Manufacturing manager Sustainability projects manager
B	OEM	Over 1000	Brazil	Japan	Manufacturing manager Sustainability projects coordinator
C	OEM	Over 1000	Brazil	Japan	Manufacturing manager Facilities manager
D	OEM	Over 1000	Brazil	Italy	Manufacturing manager Environmental manager
E	Supplier, first-tier	Over 1000	Brazil	Germany	Manufacturing manager Environmental manager
F	Supplier, first-tier	Over 1000	Brazil	USA	Manufacturing manager Sustainability director

to identify whether there were changes (of absolute and relative importance – according to the interviewees' perception) in the competitive priorities of the operations. Of particular importance to our study, was the relative position of the Environment priority amongst the other operations competitive priorities. The relative importance of operations priorities is also considered in the research carried out by Gonzáles-Benito (2010, p.780): a recent and important contribution. "In contrast, relative importance refers to the importance given to one objective compared to the importance given to other objectives."

As for operations decision areas, interviewees were invited to point out the changes related to the implementation of Lean and Green practices that had occurred, over the four years prior to the interviews, encompassing structural decision areas (Facilities and Location, Installed Capacity, Product and Process Technology, Vertical Integration) and infrastructural decision areas (Production Planning, Quality Management, Product Development, Supply Management, Work Organization). Based on a series of questions, we sought to identify the configuration of each of the operations areas and the changes made during this four-year period, especially in relation to the implementation of Lean and Green practices.

Regarding LG practices, we sought to identify which practices were implemented and their levels of implementation. We presented questions about a basic set of practices in accordance with the literature on Lean and Green as well as practices added by the interviewees themselves. On the levels of implementation of these practices, the following scale of levels was presented: Nothing was done; Currently at "project" level but not yet implemented; Incipient implementation; Partially implemented; and Fully deployed and tracked.

With these three sets of answers, the operations strategy of each plant could be mapped, and then we could compare the configurations of operations strategies of the selected companies in terms of their operation's competitive priorities, their Lean and Green practices implemented, and their structural and infrastructural decision areas affected by LG implementation.

We were aware of the broad range of factors that conditioned each decision made in each company, as well as the fact that each priority could require actions in various areas, and, finally, that one action (in one area) could have an impact on more than one competitive priority. Nevertheless, when possible, we aimed to indicate the clearest relationship between actions or practices and priorities.

Supplementary data was also collected from secondary sources, such as journal articles and the companies' websites. Information collected about the specific industry segment and about each company was important to examine the companies' competitive strategies, as well as for the explanation we offer herein. The information obtained from the interviews regarding the activities of operations strategies of the manufacturers in the automotive sector was also considered. As mentioned earlier, competitive strategies constitute an important contextual factor for the discussion on operations strategies.

To analyse the data, we observed Yin's (2017) recommendations for multi-case research studies: moving from individual case reports to cross-case examination.

In summary, the method adopted for the case studies was mainly based on the semi-structured interviews conducted with operations managers of the six selected companies. The analysis of changes that occurred in the four years preceding the interviews could reveal which competitive dimensions were prioritised in that period and which Lean and Green practices were implemented in the decision areas.

The findings revealed a unique pattern of changes in each manufacturer.

4 Results

This section presents a comparative analysis of the case study results. We begin by identifying and analysing the competitive priorities of the six manufacturers. We then point out the main decision areas mentioned by the interviewees as important for the implementation of Operations Strategies. Next, we present the LM and GM practices implemented by companies and then analyse them from the OS perspective.

4.1 Operations strategies

We start by identifying the companies' operations competitive priorities. We asked interviewees about the relative importance of the following priorities: 'Quality', 'Delivery', 'Service', 'Flexibility', 'Environment', and 'Cost'. Table 3 presents an arrangement of competitive priorities ranked in six levels: the first priority being the most important and the sixth priority being the least.

Organisations A, E and F considered Quality to be the most relevant priority. Companies C and D report Quality as their second priority in order of importance. And though company B ranks Quality the lowest among our sample, as its third priority, they emphasise its importance to their corporate strategy, stating it is the key to improving service and customer satisfaction. Interviewees from all companies evoked the urgent need to focus on improvements to Service and Environment.

The emphasis on Quality manifested by all the organisations can be attributed to its important role in the automakers' competitive strategies, to the high safety levels expected in the automobile industry, and to the operations management systems adopted that require, for example, compliance to ISO 9001 standards by all participating organisations.

Table 3 Ranking of participant's competitive priorities based on the content branch of operations strategy

Organisation	First priority	Second priority	Third priority	Fourth priority	Fifth priority
A	Cost/Quality	Flexibility/services	Environment	-	-
B	Delivery	Environment	Quality	Service/cost	Flexibility
C	Cost/Delivery	Quality	Environment	Service	Flexibility
D	Delivery	Quality/Service	Flexibility	Cost	Environment
E	Quality	Cost	Flexibility	Service/Delivery	Environment
F	Quality	Cost/Delivery	Environment/ Flexibility	Service	-

Cost and Delivery were also identified as important competitive priorities. The importance given to Cost was put forward by evoking current market conditions, as in a state of economic turbulence, organisations tend to focus on Cost containment and reduction. Participants agreed on a wiser use of production factors to reduce negative financial results, and they tried to keep Cost reduction efforts from affecting Quality in its various dimensions. Regarding Delivery, respondents stated that their organisations struggle to maintain low inventory levels in multiple stages of production. Flexibility and service are of lesser importance to all the companies (except A).

None of the organisations considered Environment a top priority and, for most, it is not among the top ones. However, all participants reported incorporating Green manufacturing practices into their operations. Environmental goals, such as reducing energy, water, material consumption, and reducing waste, were adopted. Manufacturer B is noteworthy in this regard, being the only to deem Environment as high as its second most important priority. Despite that ranking, the company assesses that this priority does not yet provide it with a competitive advantage, and both the production and environmental managers argued that more actions are still needed to achieve operational improvements in this area. The sustainability project coordinator added that they are investing in marketing to inform customers of their environmental efforts, thus aggregating value to their products. This may help the company to secure an advantageous position.

Companies A, C and F placed Environment third in their priorities. Interviewees from company A mentioned that a good level of environmental integration with operations and the joint work of employees is considered a pillar of the company's management system.

At Company F there is a program to motivate workers to carry out pollution reduction projects, but it is still an isolated initiative. Interviewees understand that the environment is an urgent factor for companies, stating that environmental actions can be a determining factor for survival in the global market.

Companies D and E considered the Environment as the last competitive priority in production. Environmental Sustainability is not considered an important factor for the competitiveness of company E. It was observed in company D that environmental factors are integrated into its production systems, but it was argued that management has currently focused more on projects to reduce lead time and increase quality.

All selected companies evidence that the Environment is among the priorities considered, reporting actions that target sustainability with varying degrees of scope, integration to the rest of its operations, and importance to business competitiveness. Interviewees from all companies argued that environmental impact is considered in all projects, and projects focusing on improvements to Quality, Delivery, Flexibility, and Cost reduction that result in negative environmental impact are not approved. Nonetheless, Environment is often given less importance than other priorities, notably Cost and Quality. Case B is an exception, ranking Environment above both, but even this organisation does not yet see it as a source of competitive advantage. It is also relevant that companies C, D, E and F reported that projects must achieve a return on investment within two years to be approved, potentially constraining the viability of Environmental actions.

As presented, companies define decision areas to implement actions and practices to achieve competitive priorities, and to promote adjustment to market conditions or competitive strategy requirements. We questioned interviewees about the relative importance of production decision areas. In line with what was indicated about competitive priorities, the main decision areas mentioned for the implementation of Operations Strategies were Quality Management, Capacity, Development of new products/materials and Supply Chain.

Company A attaches great importance to Quality Management and Development of new products and materials. Company B considers Human Resources and Quality Management to be the most important areas. Company C emphasised that Quality Management is the most important in the current competitive scenario. Company D assigned more importance to Capacity, Supply Chain and Quality Management. Company E and F demonstrated an equilibrium between actions in facilities, capacity, supply chain, quality management and development of new products/materials attributing great importance to all of them in its operations strategies.

An important observation regards Supply Chain management: organisations A and B demonstrated a low level of action in this area, arguing they already have a well-established relationship with their suppliers. The other companies are trying to develop actions and programs to improve their Supply Chain.

It is important to note that the integration of Lean and Green practices requires changes in several decision areas with the use of cleaner technologies, green certificates in quality management such as ISO14001, environmental performance indicators, workers specialised in environmental techniques, integration and training of suppliers to improve environmental performance, products with less environmental impact and changes in the organisational structure to better integrate the "environment" function with others.

In summary, it was possible to observe that the companies selected for the case studies adopted different OSs, which are manifested in the choice of their main competitive production priorities, in the decision areas that receive more attention and, as we will see below, in the sets of Lean and Green practices implemented. Although environmental priority rarely figures as the main competitive priority, there is evidence that it is gaining importance and, that some companies have already faced trade-off situations.

Valuing the environment should bring greater complexity to OSs, as it adds a dimension to competitive priorities; can give rise to synergies or trade-offs between competing priorities; and promotes changes in various decision areas.

On the side of possible synergies or compatibility between competitive priorities, the cases illustrate, for example, initiatives to incorporate objectives to reduce environmental impacts in quality management systems and in cost reduction programs. It should be noted that synergies between environment and quality, or between environment and cost, promote the incorporation of initiatives to reduce environmental impacts in programs that affect different decision areas such as quality management and cost reduction programs. On the trade-off side, interviewees point to situations in which projects are rejected because they could increase environmental impacts or are rejected because they do not bring minimum levels of return on investment. But a low value assigned to environmental priority may mean that initiatives to reduce environmental impacts will be delayed or ignored in trade-off situations.

4.2 Lean-Green (LG) integration

This section presents the state of implementation of Lean and Green practices and the level of integration between them for each company. Respondents were asked to evaluate each practice using the following scale: Nothing done; Currently at "project" level but not yet implemented; Incipient implementation; Partially implemented; or Fully implemented and tracked.

4.2.1 Lean manufacturing practices

These companies have been implementing Lean since the 1990s, citing Cost reduction and Quality improvement as the main motivations for the adoption of such practices, in line with their competitive production priorities. In Table 4 we present some Lean Practices and their levels of adoption in each company. The practices Kaizen, Visual Management, 5S and 5 Whys are fully implemented in all companies. Company B is the only that has almost all the practices implemented, only TPM is still partially deployed. Also included is the Karakuri practice, which is a low-cost automation, and QCC quality control circle, in which a group of workers identify, analyse, and solve problems.

Company F has around 45% of lean practices fully implemented, the others are partially implemented. Tier meetings (daily leadership meetings) are included in their production system.

Company C has approximately 55% LP fully implemented and is trying to improve in JIT, since it is still at an incipient stage of implementation and Delivery is one of the company's main competitive priorities.

At the same level is company D, also beginning to implement JIT and Cellular Manufacturing. Company A presents 45% LP fully implemented and considers that Standardised Work and Total Productive Maintenance are still incipient.

Company E has 55% LP fully implemented, but JIT is not implemented, and neither is Pull production, as it is still being "designed". The absence of these two practices in company E is due to its focus on practices to improve quality performance.

Table 4 highlights the dominant position of organisation 'B' with regard to the implementation of LM; ten of the eleven practices in the repertoire were fully implemented and monitored. As for the rest of the participating organisations, LM practices were not fully consolidated. All organisations recognised that LM efforts were aligned with their corporate strategy.

We identified how these practices are monitored within the companies by asking about the adoption of ten LM performance metrics that are summarised in Table 5.

The presence of performance metrics such as FTT, OTIF, OEE, Percentage of Defects in Non-Conforming Parts, Productivity and Takt Time has been identified in practically all organisations. According to participants, these indicators are used to measure quality, efficiency, and delivery in relation to manufacturing processes.

Table 4 Description and ranking of Lean Manufacturing practices identified across participating organisations

Organisation	Kaizen	5 s (Five S)	Visual Management	5 why / Ishikawa's fishbone	Cellular Manufacturing	Standardised Work	Value Stream Mapping	Poka-Yoke	Total Productive Maintenance	Pull Production / Kanban	Just-in-Time	Score of LM implementation
B	4	4	4	4	4	4	4	4	3	4	4	43
C	4	4	4	4	4	4	3	3	3	3	2	38
F	4	4	3	4	4	4	3	3	3	3	3	38
D	4	4	4	3	2	4	4	3	4	3	2	37
A	4	4	4	4	4	2	3	3	2	3	3	36
E	4	4	4	4	3	3	4	4	3	1	0	34
Score per practice	24	24	23	23	21	21	21	20	18	17	14	

Point attribution. Nothing has been done = 0; Currently at project level but not yet implemented = 1; Incipient implementation = 2; Partially deployed = 3; Fully deployed and tracked = 4

4.2.2 Green Manufacturing (GM) practices

Unlike LM practices, whose motivations for implementation were Cost reduction and Quality improvements, the GM practices in these organisations resulted from legislative requirements, market rivalry, and Environmental relevance to Operations Strategy. They report some Green practices were adopted even before Lean ones to comply with environmental law. However, all the organisations based in Brazil (B, C, D, E and F) currently see opportunities for environmental improvements that go beyond what is required by law. Company A was the only to offer alignment with its Operations Strategy as the main reason for implementing Green practices.

The bulk of GM practices emerged years, or even decades, after LM practices in the organisations studied; in the early 2000s, in most cases, and as late as 2016 for company 'D'. Only in organisation 'A' GM practices were under the responsibility of an operations manager; in the other organisations, environmental specialists were in charge of Green practices.

We identified fourteen GM practices in the selected organisations. Table 6 provides a collection of such practices. For the sake of simplicity, we present these practices across two axes. In the columns, we list GM practices, and in the rows, we rank the organisations in descending order.

Fully implemented GM practices in all organisations were Environmental Management, Waste Management, Recycling Program, Publication of reports with environmental information, and Effluent treatment. Participants mention that their respective corporations are trying to implement the concept of circularity focusing on doing more with the same resources and acknowledging all stages of their products' lifecycle. This assertion is corroborated by the companies' sustainability reports.

Below we present the percentage of Green practices fully implemented by each company and comments on the general state of implementation of these practices.

Organisation 'C' ranks the highest in GM implementation, which may be due to its Green Global Management program. Organisations 'B' and 'C' have 71 % of GM practices fully implemented (though they differ in practices with partial implementation and thus C achieved a higher score). For instance, company 'B' conducts product life-cycle analysis, and company 'C' has this practice partially implemented. Reverse Logistics is still in the project phase in organisation 'B', and partially deployed in organisation 'C'.

Organisation 'F' is just below at 64% implementation of GM practices according to our metrics. We identified Supplier environmental accreditation as a practice that has not yet been implemented. Moreover, Environmental education, and the company's Inter-process resource sharing program are still in incipient stages. It is important to highlight that this company pioneered a cleaner production program, but

Table 5 Lean Manufacturing (LM) performance metrics identified in participating organisations

LM Performance Metric	Organisation					
	A	B	C	D	E	F
Average Cycle Time		✓	✓	✓	✓	✓
First Time Through (FTT)	✓	✓	✓	✓		✓
On Time in Full (OTIF)	✓	✓	✓	✓	✓	✓
Defect percentage on non-compliant parts	✓	✓	✓	✓	✓	✓
Value added time percentage			✓	✓		
Productivity	✓	✓	✓	✓	✓	✓
Takt Time	✓	✓	✓	✓	✓	✓
Overall equipment effectiveness (OEE)	✓	✓	✓	✓	✓	✓
Health and safety	✓					
Absenteeism	✓					

Legend. Checkmark ✓ denotes presence, blank case denotes absence of metric

its scope is currently limited to isolated initiatives that are not fully integrated to production.

We assessed organisations 'A'and 'D' with 57% implementation of GM practices.

Environmental accreditation of suppliers, and Environmental education programs are absent in company 'A'. These same practices are only partially deployed in organisation 'D'. Organisation 'A' has also partially deployed Interprocess resource sharing programs, a practice organisation 'D' has not developed yet.

Organisation 'E' is placed at the bottom of the ranking with a cumulative of 43% implementation of GM practices fully deployed. According to excerpts from interviews and published reports analysed, this organisation seeks to structure its actions and processes to improve its environmental competencies.

All organisations stated their intent to explore actions relevant to circular economies. Regarding strategic alignment to sustainability, all of them reported strategic and operational targets with metrics.

Organisations 'B', 'C', and 'E' mentioned the use of Hoshin Kanri policy management to plan and deploy their strategic goals. These corporations also evoked the target of carbon neutrality aiming for the year 2050. Delving into the operational aims of each corporation, we introduce, in Table 7, a list of identified metrics that the organisations employ to track GM performance improvements.

It is worth noting that some of the GM metrics identified intersect with the LM practices of the corporations. This means that while the metric is listed as 'green' in consulted literature, the interviewed organisations also consider it part of their 'lean' management systems.

Common GM performance metrics found in all organisations were the quantification of waste generation, GHG emissions, energy consumption, materials utilisation, and water consumption. We also note that organisation 'D' considers GM metrics to be integrated in their Lean production system. The presence of GM metrics is relevant to our study and their integration with LM metrics is even more significant. This presence corroborates the importance of Environmental stewardship or 'Environment' as a competitive priority that organisations uphold and keep track of.

4.2.3 Lean and Green integration

This subsection offers the results of a cross-case analysis on Lean and Green integration in the organisations studied from the operations strategy perspective. First, we present a comparison of the levels of Lean and Green implementation. Further information is then offered about changes in decision areas when Green is implemented in the Lean-oriented production system and how managers deal with possible trade-offs caused by the inclusion of the Environment in their OSs.

Based on the OSs and practices adopted by the organisations studied, it is possible to compare them in a graph. Figure 3 offers a view of the relative positions of the organisations studied in relation to their implementation of the relevant practices. We emphasise that our intention is only to promote a discussion about the implementation of these practices as parts of the OSs, and not to compare the performances of these organisations – the method we have adopted would not allow such a comparison. The horizontal axis represents the state of GM implementation, ranging from practices not implemented to full implementation of most practices. Similarly, the vertical axis offers the stages of LM implementation by organisation in ascending order, from not implemented to fully implemented.

Figure 4 highlights company 'C' as the most advanced in GM implementation, whereas company 'B' is ahead of all other organisations in LM practices. The high level of implementation of

Table 6 Description and ranking of Green Manufacturing practices identified across participating organisations

Organization	Environmental management	Waste management policy	Recycling program	Effluent treatment	Published environmental reports	Water consumption reduction	Energy conservation program	Material consumption reduction	Product life cycle analysis	Cleaner production program	Reverse logistics	Inter-process ressource sharing	Environmental community education	Supplier environmental accreditation	Score of LM implementation
C	4	4	4	4	4	4	4	4	3	4	3	3	3	4	**52**
B	4	4	4	4	4	4	4	4	2	1	1	4	4	3	**47**
F	4	4	4	4	3	4	4	4	4	4	3	2	2	0	**46**
D	4	4	4	4	4	4	4	2	4	2	3	0	2	2	**43**
A	4	4	4	4	4	4	4	3	2	4	2	2	0	0	**41**
E	4	4	4	4	4	2	2	4	2	2	2	2	2	2	**40**
Score per practice	**24**	**24**	**24**	**24**	**23**	**22**	**22**	**21**	**17**	**17**	**14**	**13**	**13**	**11**	

Point attribution. Nothing has been done = 0; Currently at project level but not yet implemented = 1; Incipient implementation = 2; Partially deployed = 3; Fully deployed and tracked = 4

Green practices in company C and Lean practices in company B is in line with the changes reported by the participants to the companies' decision-making areas, which will be explained subsequently.

Regarding the LM practices implemented, organisations 'C' and 'F' are practically at the same level. Organisations 'A' and 'D' are also very close. Organisation 'E' is notably below, which can be attributed to the lack of implementation of pull production and JIT. With respect to GM practices, organisation 'C' is the first, slightly above 'B'. 'F' is next, followed by 'A' and 'D'. 'E' occupies the last position again. This makes sense given each organisation's environmental priorities, as well as the fact that green initiatives are only at a nascent stage in the case of company 'E'.

Having established that context, we must turn to the qualitative aspects of LG integration, which relate to changes in decision areas when Green practices are integrated into the Lean-oriented production system. In Table 8 we present the LG integration by the practices implemented in the decision areas. In general, two similar aspects in all companies were the inclusion of the Environmental Management System in Quality Management through ISO14001 certification, and the inclusion of Green practices in Product Development with a focus on sustainable products, such as electric vehicles. Furthermore, Human Resources was identified as including Green aspects, but for companies C and F only incipient changes were found.

Below we present a few relevant practices of each company concerning LG integration so that comparisons and patterns may later be observed.

The reports from company A evidence a good level of integration, noting that LM and GM practices are a part of the organisation's 'operational excellence' strategy, and thus included in its long-term planning. It employs LM and GM coordinators working side by side, ensuring the alignment of goals and metrics. The results from both practices are also reported to the same leader. Further measures include: a search for cleaner technologies, Environmental training to Human Resources personnel, and Environmental performance indicators in production.

The evidence presented by Organization 'B' indicates that Lean and Green are also well integrated. Participants from organisation 'B' mentioned that environmental gains are included in kaizen objectives. Furthermore, teams from organisation 'B' are planning, analysing and approving kaizens considering environmental criteria in all initiatives. The use of management tools was inherited from Lean, and Green performance indicators are considered in its production system. Interviewees also mentioned that facility improvement projects consider environmental aspects. Examples include changing the energy matrix of transportation equipment to electricity, the integration and training of suppliers in environmental matters, and the implementation

Table 7 Green Manufacturing (GM) performance metrics identified in participating organisations

GM Performance Metric	Organisations					
	A	B	C	D	E	F
Amount of waste generated	✓	✓	✓★	✓★	✓★	✓★
Greenhouse gas emissions	✓	✓	✓	✓★	✓	✓
Energy consumption	✓★	✓★	✓★	✓★	✓★	✓
Materials utilisation	✓	✓	✓	✓★	✓	✓★
Consumption of toxic materials and substances	✓	✓				✓
Water consumption	✓	✓★	✓★	✓★	✓★	✓
Scrap metal management	✓					
Spills containment	✓★					

Legend. Checkmark ✓ denotes presence; Stard ★denotes integration with the 'Lean' production system of the organisation; blank case denotes absence of the metric

of an environmental purchasing guide. With regard to Human Resources, interviewees stated that environmental aspects are incorporated into training and Quality Circles (QC). In addition, they carry out activities to engage all employees in Lean and Green, such as suggestion programs and awards for improvement initiatives.

In organisation 'C', the integration of Lean and Green was not clearly visible. However, this organisation presented definite traits of Green orientation. Interviewees mentioned training programs in Green management and interventions by Green teams to improve processes with regard to environmental impact. It was mentioned that operations employees receive introductory training on Green practices when they begin their activities at the company and that there are programs with suppliers to reuse packaging and improve the environmental performance of their own operations. Regarding the Performance Measurement System, the environmental performance indicators included in the company's management system are not directly integrated with Lean but are under the same organisational unit; and it was said that there are aggressive recycling and emissions targets. Lean and Environment in company C are subordinate to the same unit in the organisational structure and there is a corporate Green business program. However, it was detected that

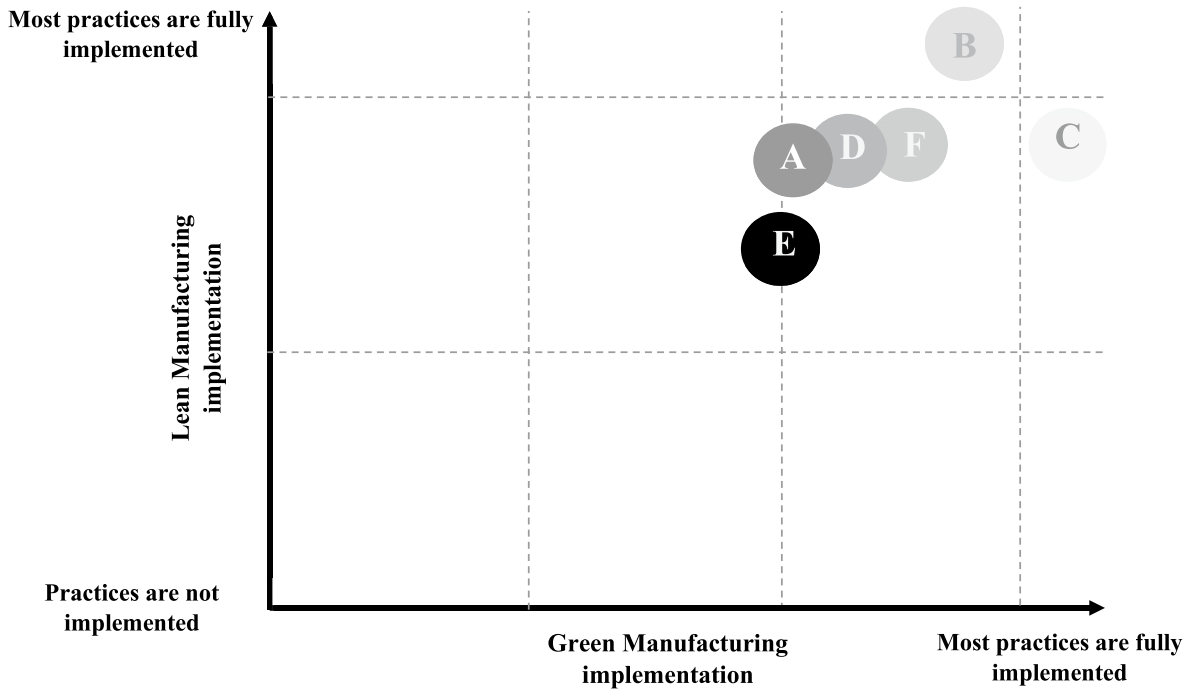

Fig. 3 Lean versus Green manufacturing implementation in participating organisations

Fig. 4 Interpretive framework of Lean-Green Manufacturing in operations strategy. Source: The authors

Green initiatives are implemented in a way that is disconnected from the lean management system.

In the case of organisation 'D', the 'environmental' priority constitutes a pillar of its management system. Company 'D' seeks reductions in energy and water consumption. It also aims to minimise waste of materials. Similar to organisation 'A', its GM projects, goals and indicators are created and monitored jointly between the production and environmental management teams. Targets for environmental operational indicators have been established as part of the company's corporate strategy. Furthermore, like company B, alternatives are considered at the facilities to reduce energy consumption. Company D is focused on designing equipment to reduce emissions, and equipment procurement decisions weigh aspects of consumption of water and energy. Another evidence of LG integration concerns Human Resources. It was mentioned that there is training for all employees in all management pillars, including the Environment. Employees are also encouraged to think about improvements to reduce environmental impact.

In contrast, Company E presents evidence of a low level of LG integration. This company relies on its environmental area to develop and monitor GM indicators. For example, the variable 'remuneration for environmental goals' is established and guided by the company's environmental specialists. However, training focused on environmental preservation is incipient in its production system. It was possible to identify that the company is implementing a corporate policy on Environment, safety and health protection, but there are no integration actions with Lean practices.

Finally, although Company F presents an intermediate level of implementation of Lean and Green practices, the results showed that there is a low level of LG integration. It was mentioned that most green initiatives occur in isolation. These constitute projects to reduce energy consumption and to reduce emissions from equipment. There are also collaborative efforts with suppliers and customers to share information about the environmental impact of operations. Company F focusses on innovation and has formalised Life Cycle Management as it incorporates environmental, health and safety considerations into new product development. However, sustainability practices are still based on isolated and specific initiatives in the production system.

It is worth highlighting that organisation 'E' is a first-tier supplier to the automotive industry and, as such, it did not consider the Environment a higher priority until recently. Regarding organisation 'F', the data did not reveal any indication of LG integration. Representatives of organisation F suggested that LM and GM practices have been implemented in parallel until now.

As noted, the cases present different evidence regarding Green practices in their Lean systems, which suggests different levels of LG integration. They do not show any changes regarding LG in the Technology area, and only low integration in Human Resources, through specific Green training. The lowest level of integration was attributed to Companies E and F. They did not demonstrate any Green integration in Capacity, Facilities, Production Planning and Control and Organization. Also, company F demonstrated a low level of change in Human Resources as stated by their Operations Manager: there are some isolated training initiatives undertaken by leaders who include green practices in the kaizen checklist. D did not present any change in performance management measurement, noting that only indicators of worker safety were added to their Lean system.

When comparing the levels of LG integration among the organisations, we identify that the adoption of the 'environment' as an emerging competitive priority is influential to their overall ranking.

It is evident from the cases that prioritising the environment promotes substantial changes in several decision areas. And there are organisations that only promote specific initiatives related to the environment, without concern for possible integration between Lean and Green practices.

Considering how the priorities Environment and Cost are ranked, the changes in decision areas, and the level of LG deployment and integration; the results are evidence that these companies have different OSs configurations. These results are consistent with the content branch of OS suggesting that different characteristics of the strategy-content will result in varied OSs configurations (Jagoda et al. 2016; Ward

Table 8 Integration of LG practices in Decision Areas

Company	Integration of LG practices in Decision Areas
A	*Technology: S*earch for cleaner technologies that result in less environmental impact *Human Resources:* Inclusion of environmental aspects in the Lean training as well as quality and efficiency aspects *Quality Management:* Inclusion of ISO14000 environmental management certification *Product Development:* Development of more sustainable products, such as electric vehicles *Performance Measurement System:* Inclusion of environmental performance indicators in the Lean production system. Deployment of Strategic environmental targets for 2050 *Organisation:* Lean Management is disseminated to all, one leader but everyone has a little responsibility. There is an integration in the structure of the organisation, from the decision-making process and direction to the achievement of goals. The lean and green results are reported to the same leader
B	*Facilities:* Lean Design of the facilities considering environmental aspects, such as lighting design for lower energy consumption *Technology:* Switching the energy matrix of transportation equipment to electricity *Supply Chain:* Integration and training of suppliers to improve the environmental performance of their operations and implementation of an environmental purchasing guide *Human Resources:* Inclusion of environmental aspects in the training and Quality Circles (QC) as well as quality and efficiency aspect. Also, activities for the engagement of all employees in Lean and Green, such as suggestion programs and awards for improvement initiatives *Quality Management:* Inclusion of ISO14000 environmental management certification *Product Development:* Development of more sustainable products, such as electric cars *Performance Measurement System:* Environment in the factory floor KPIs, such as electricity consumption, waste overall per assembly line and KPI's per vehicle: kg of co2 per vehicle. Strategic environmental targets for 2050. Use of Hoshin Kanri for deployment of strategic goals to operations *Organisation:* Focus on team integration for Kaizens, integration and validation of environmental specialists for any project. Integrated organisational structure but with a specialised corporate environmental department
C	*Facilities:* Alignment with suppliers for the packaging of components to go beyond the possibility of recycling and seek alternatives for reuse *Supply Chain:* integration and training of suppliers to improve the environmental performance of their operations and implementation of an environmental purchasing guide *Human Resources:* Training of the environmental team to make the leaders aware of the common responsibility of everyone for environmental performance Alignment with suppliers for the packaging of components to go beyond the possibility of recycling and seek alternatives for reuse *Quality Management:* Inclusion of ISO14000 environmental management certification *Product Development:* Development of projects for reuse of component packaging *Performance Measurement System:* Environmental performance indicators included in the company's management system not directly integrated with Lean but under the same management. Aggressive targets for recycling and emissions *Organisation:* Environmental specialists under the management of maintenance and utilities. Environment and operations under the same directorate in the organisational structure
D	*Facilities:* Design of the facilities considering environmental aspects, such as lighting design for lower energy consumption *Technology:* Design of equipment to reduce emissions. Project decisions weigh aspects of green, water and energy consumption for the acquisition of new equipment *Human Resources:* Training for all employees on all management pillars and the environment is included. Employees are motivated to think about improvements to reduce environmental impact *Quality Management:* Inclusion of ISO14000 environmental management certification *Product Development:* Development of more sustainable products, such as electric cars *Performance Measurement System:* Environmental performance indicators for operations. There is the deployment of the global strategy to the operations *Organisation:* Management based on technical pillars (safety (occupational safety), cost of deployment, focused improvement, autonomous maintenance, quality control, logistics and customer service, early equipment management people development, environment and energy, for all changes. The improvement projects occur in an integrated way and consider all technical pillars
E	*Technology:* Equipment acquisition projects focused on emission reduction, water and energy consumption *Supply Chain:* Integration with suppliers for compliance with product safety and environmental performance requirements *Human Resources:* Development of training for the integration of everyone involved, such as the presentation of the VSM with the flow and possibilities for improvement. There is incipient work to include the environment in the improvement initiatives *Quality Management:* Inclusion of ISO14000 environmental management certification *Product Development:* Development of more sustainable products, such as products that can be recycled and in case of incineration emit fewer toxic gases *Performance Measurement System:* Beginning of the deployment of strategic goals to achieve the sustainability objectives for 2050 through Hoshin Kanri that seeks to deploy these targets to performance measures of the operations *Organisation:* Inclusion in the management system of a corporate policy for environment, safety, and health protection but there are no actions for integration with practices Lean

Table 8 (continued)

Company	Integration of LG practices in Decision Areas
F	*Technology:* Projects to reduce energy consumption and emissions of equipment *Supply Chain:* Integration with suppliers and customers for sharing information about the environmental impacts of operations *Human Resources:* Individual initiatives to suggest improvements *Quality Management:* Inclusion of ISO14000 environmental management certification *Product Development:* Focuses on innovation and has formalised Life Cycle Management as it incorporates environmental, health, and safety considerations into new product development *Performance Measurement System:* Adoption of indicators at the basic level, including safety indicators in daily management, but still no environmental performance indicators for operations, only sustainability indicators at the corporate level. In addition, a report is made to the automakers on the environmental performance of emissions *Organisation:* Structure by certifications that follow the levels of implementation of Lean practices by areas. The aspects and practices for sustainability are still based on isolated initiatives and with very specific people, departmentalised and disintegrated into the production system

et al. 1996). Table 9 offers a synthesis of the OSs configurations found in the cases. We summarise our evaluation of the content of the OS of each organisation considering ten decision areas, competitive priorities, trade-offs, and Lean-Green integration.

As expected, none of the reviewed organisations ranked 'environment' as the first competitive priority of their OS. We note that for all organisations (except B), the Cost priority appeared above environmental concerns. All companies in the dataset privileging Cost experienced lower levels of LG implementation. However, this result does not suggest a detrimental relationship between Cost as a competitive priority and LG integration. This is corroborated by organisations 'A' and 'C' that attribute great importance to Cost and still achieved outstanding levels of GM implementation.

Furthermore, it was possible to observe different configurations of operations strategies in the cases. These differences appear in the order of competitive priorities, in the way in which decision areas are shaped and in the levels of adoption of practices. We observed that quality is prioritised by many of the companies examined in this research. Company B's configuration considers the environment as the second competitive priority, ahead of cost, as already mentioned, and presents a high level of integration of Lean and Green practices. According to those interviewed at this company, decisions about Lean and Green are made based on the consensus of the environmental management, lean management and operations departments, which work in an integrated manner.

The cases of companies A and D, for example, present other configurations: the Environment priority is behind cost, and Lean and Green are integrated to an extent; initiatives are often carried out together, but there are still disintegrated practices: for example, some green projects do not involve lean professionals. Company C is quite different, as it has the highest observed level of Green practices, but the Environment is not the main priority in its operations strategy. Company C also does not present a high level of Lean and Green integration.

The last configuration was observed in organisations E and F: environmental priority is behind cost and they have a very low level of integration between Lean and Green practices, only isolated initiatives could be observed.

These configurations differ mainly in the importance attributed to the Environment priority, the relative importance of other competitive production priorities, the levels of adoption of Lean and Green practices, the corresponding changes in Decision Areas and, also, the levels of LG integration. It is reasonable to assume that the importance of the Environment priority in the operations strategy should influence the implementation levels of Green practices and LG integration, but the cases in this research whether due to the quantity or diversity of configurations identified - do not allow for relations such as this to be inferred. However, they reinforce the complexity of implementing production strategies and managing LG practices in organisations.

5 Discussion

This study has focused on detailing Lean-Green practice implementation and the configuration of operations strategies of some companies in the automotive sector. This section aims to provide a detailed analysis of that data concerning our theoretical framework and initial propositions.

Regarding Proposition 1 "Companies have to implement Green practices when Environment is a production competitive priority since Lean practices are/were implemented with other objectives". The environment was not indicated as a first priority in any of the cases and as a second priority in only one of the six cases. Nonetheless, it has already acquired notable relevance to the companies studied. This is in line with a global context of growing environmental concerns, which translates into increasing pressures from legislation, activism, and society at large. Corporations paying attention may go beyond acquiescing to these pressures and find environmental stewardship a source of competitive

Table 9 Content of the Operations Strategy (OS) of each organisation considering ten decision areas, competitive priorities, and lean-green integration

Organisation (manufacturer)	Ranking of 'Environment' as a competitive priority	Main trade-off	Capacity	Facilities	Technology	Supply Chain	Human Resources	Quality Management	Prod. Planning & Control	Prod. & Process Development	Performance Measurement System	Organization (decision area) ✓	LM implementation level	GM implementation level	Lean-Green integration level
			Decision areas—alignment to operations strategy												
B	**2nd priority** 'Environment' ahead of 'Cost'	'Environment' over 'Cost'	r	✓	✓	✓	✓	✓	r	✓	✓	✓	●●●	●●●	●●●
A	**3rd priority** 'Cost' ahead of 'Environment'	'Cost' over 'Environment'	r	✓	✓	r	✓	✓	r	✓	✓	✓	●●	●●●	●●
D	**Last priority** 'Cost' ahead of 'Environment'	'Cost' over 'Environment'	r	✓	✓	r	✓	✓	r	✓	✓	✓	●●●	●●	●●
C	**3rd priority** 'Cost' ahead of 'Environment'	'Cost' over 'Environment'	r	r	r	✓	~	✓	r	✓	✓	✓	●●	●●●	●
F	**3rd priority** 'Cost' ahead of 'Environment'	'Cost' over 'Environment'	r	r	✓	✓	~	✓	r	✓	r	r	●●	●●	●

Table 9 (continued)

Organisation (manufacturer)	Ranking of 'Environment' as a competitive priority	Main trade-off	Decision areas—alignment to operations strategy										LM implementation level	GM implementation level	Lean-Green integration level
			Capacity	Facilities	Technology	Supply Chain	Human Resources	Quality Management	Prod. Planning & Control	Prod. & Process Development	Performance Measurement System	Organization (decision area) ✓			
E	Last priority 'Cost' ahead of 'Environment'	'Cost' over 'Environment'	r	r	✓	✓	✓	✓	r	✓	~	r	••	•	•

Legend

✓ Changes in decision areas identified

~ Incipient changes identified

r No changes in decision areas identified

••• High implementation levels

•• Medium implementation levels

• Low implementation levels

advantage. All the companies interviewed have mentioned environmental concerns and showed decent levels of Green implementation, even those that ranked Environment last in their list of priorities. Measuring the effectiveness of implemented practices was out of our scope, but their presence should be evidence in itself. Since all companies also present levels of Lean implementation, the combined adoption of Green practices shows that Lean was insufficient to address environmental concerns, whatever the origin of these concerns may be for each company. Should current environmental trends progress, as all evidence from climate science suggests that they will, it is reasonable to extrapolate that the Environment should occupy a position of ever-increasing protagonism among production competitive priorities. Thus, its incorporation into organizations' operations strategies, and the consequent need for the implementation of Green practices and their integration to already deployed Lean systems, shall also become vital.

Our second proposition concerns this integration effort: "Under a Lean-Green (LG) integrative scheme, the 'cost' priority of operational strategy will be influential to the 'environment' priority, and vice-versa. ." As for trade-offs, all companies cite negative environmental impact as a constraint on project approval. Another commonality among our sample was a stated two-year deadline for return on investment, a potential trade-off between Cost and any other production priority. This might be particularly relevant to environmental projects, but further research is required into that hypothesis. Other Cost-Environment-specific trade-offs could not be found. We have observed that compatibility spaces between competitive priorities are explored in the implementation of programmes that address Quality and Environment, and Cost and Environment simultaneously. Further LG compatibility is exemplified by the adoption of common performance metrics.

Other examples from our results regard changes in decision areas with the inclusion of green practices. Most of these changes occurred in Quality Management, with the inclusion of ISO14001; Product development; Performance Measurement Systems with environmental performance indicators; and Human Resources, with the adoption of training in green practices. Company A and Company B demonstrated a good level of LG integration, presenting the most changes in the decision areas with Green practices integrated into Lean systems. One of the situations mentioned by these companies was the integration of the operations and environment team to make decisions such as project approval. Companies D and F informed the existence of programmes to motivate workers to develop projects focused on improving the environment.

Therefore, even at a stage in which companies are beginning to prioritise the Environment dimension, the complexity it adds to the management of operations

strategy is already apparent. This priority, added to the set of operations competitive priorities, presents new compatibilities and trade-offs. Changes must then be made to relevant decision areas so that the organisation is ready to adequately deal with these new elements. Thus, proposition 3 *"Proposition 3. Lean-Green (LG) integration requires management attention to possible trade-offs between Environment priority and other priorities such as Cost, Quality, and Flexibility*." is reinforced by the case studies carried out in this research. The complexity of managing the implementation of the strategy is increased with the addition of the Environment priority and with the expansion of the set of practices that can be adopted.

It is also interesting to note, with regard to the integration of Lean and Green practices, that:

- in most cases, Green practices have been implemented in environments where Lean practices have already been implemented – which was a starting point for this research; - there is learning in implementing practices. Companies accumulate knowledge with the implementation of Lean that can later be used in the implementation of Green; - practices are implemented with certain production objectives and that the implementation of Lean or Green will advance according to the alignment of practices with such competitive priorities;
- the implementation of Lean is already well established and associated with objectives such as improving quality, reducing costs and reducing waste;
- the implementation of Green can be associated with the same objectives above, promoting the integration of practices and the development of management programs already adopted;
- the implementation of Green may also aim at other objectives that may conflict with Cost Reduction, for example, at least in the short term, which will require compromises between competing priorities – decision on levels to be achieved of priorities – and choices regarding implementation Lean and Green practices;
- the integration of practices can be facilitated because indicators and performance measures can be common. Given a well-defined set of performance measures, it is possible to assess how much the implementation of practices contributes to achieving competitive priorities;
- the implementation of Lean was already requiring changes in several decision areas and that the implementation of Green requires the same;
- integration is facilitated with the training of workers in Green practices and with an organizational arrangement that integrates Lean and Green teams;
- integration is facilitated when changes in the different decision areas are made with the perspective of integrating practices;
- changes and implementation of Green practices become more complex when they require changes in structural decision areas such as technological changes in products and processes.

The case research involved identifying the operations strategies adopted by the companies, considering their production competitive priorities, and the decision areas where changes were implemented and Lean and Green practices adopted. It was observed that companies have adopted different strategies, in which the Environment priority appears in different positions among priorities. In only one case it is among the first two priorities. In the others, it is attributed less importance than Quality, Cost and Delivery. It was expected that the implementation of Green practices would be conditioned by the relative position of the Environment priority among competitive priorities, by the possibility of trade-offs between the Environment priority and other priorities, and by the Lean environment already installed. However, with the selected cases, it is not possible to confirm this notion. A pattern did not emerge from our sample with regard to the various configurations of Environment priority and Green implementation, nor could it be found in the variety of prior levels of Lean implementation.

The opposite is true for trade-offs, as all companies' reports are similar in that regard, which does not correlate with their different Green levels. It is also worth mentioning that the implementation of Green practices, in a certain sequence and within established deadlines, from the perspective of the theory developed on Operations Strategy, should follow a plan in which operations competitive priorities, the production environment determined by practices already implemented, and the configuration of decision areas are considered (Garvin 1993; Dohale et al. 2021).

In Fig. 4 we summarise the results and highlight that the study reveals instances of compatibility, such as shared performance metrics, and trade-offs, particularly in project approval timelines. The complexity of managing operations strategy increases with the incorporation of environmental priorities, necessitating changes in decision areas. The study underscores the importance of management attention to potential trade-offs in the integration of Lean-Green practices, highlighting the intricate nature of this evolving operational landscape. Additionally, the research identifies key factors influencing the integration process, including the sequential implementation of Green practices, learning from Lean implementations, and the role of performance metrics. The findings also indicate that while there is no clear pattern regarding the configuration of environmental priorities and Green implementation, and the need for a strategic and nuanced approach to Lean-Green integration in the automotive sector.

Finally, based on these analyses, companies may find areas of compatibility between Lean objectives of cost reduction, quality improvement and waste reduction with the environmental priority, and for this to be truly integrated, it is necessary to face the challenge of managing jointly Lean and Green practices.

6 Concluding remarks

6.1 Theoretical implications

The discussion about the implementation of Lean and Green practices and their integration can be enriched when supported by the foundations of Operations Strategy theory. This research, in which five case studies were carried out, illustrates the diversity of production strategies adopted and the complexity of implementing these strategies and implementing Lean and Green practices.

As a competitive priority, in the cases studied, the "environment" was classified in second, third or fifth (last) position among competitive production priorities, which could lead to situations of compatibility or trade-off with other competitive priorities.

Regarding possible areas of compatibility, knowing that Lean practices are already widespread in the automotive industry, it was interesting to see that their implementation could serve different purposes such as improving quality or reducing costs and, at the same time, reducing environmental impacts. There is evidence in the cases studied (and in the statements of the interviewees) that reinforce the proposition that Green practices need to be implemented for companies to achieve the desired results of reducing environmental impacts.

The cases also illustrate the complexity of implementing production strategies in situations where the Environment is one of the competitive priorities. Green practices must be added, changes must occur in several decision areas, the management of Lean practices and green practices must be unified. Regarding possible compromises between the Environment priority and other competitive priorities, there are indications that these situations may arise, bringing even more complexity to the implementation of the strategy and the implementation of LG practices. In this situation, the integration of the LG (and its management) becomes even more important, so that situations in which compliance with one priority occurs at the expense of another are avoided. It is possible that this type of situation will arise more frequently as the Environment priority comes to occupy more important relative positions.

It is also interesting to note that the cases of companies C and F, which presented more pronounced levels of implementation of Green practices, illustrate situations in which such practices are implemented independently and even before the implementation of Lean practices. This goes against the assumption that Lean always comes before Green in the automotive industry. However, a lower level of LG integration may increase the risk of trade-offs between competitive priorities.

Finally, based on the results of this study, we posit that Lean-Green can be defined as an operations management approach that promotes the joint and integrated implementation of Lean practices and Green practices, seeking to balance the Environment priority with other competitive priorities, such as Cost, Quality, Delivery and Flexibility, according to their positions in the operations strategy.

6.2 Managerial and practical implications

Some practical implications for companies in the automotive industry can be indicated here. Managers looking to implement LM, GM, or an articulation of both (i.e. LG) can consult practices and performance metrics identified in this research.

Furthermore, managers who know Lean and wish to incorporate Green practices into their production processes can use the insights from this study to align Green practices with their operations strategies. Some steps or requirements are suggested:

1. Consider the Environment as a competitive priority: prioritizing actions that seek to improve environmental performance in improvement processes, as well as including environmental performance indicators that allow the effective management of this competitive priority in conjunction with other priorities;
2. Focus on reducing waste and in the consumption of energy, water and materials, considering that such a focus is compatible with the Lean approach;
3. Evaluate potential compatibilities and trade-offs between competitive priorities in the decision process about which Lean and Green practices to implement (and in what order), seeking to integrate and manage them in order to align them with strategic objectives and;
4. Implement necessary changes in decision areas in order to adjust practices already implemented or implement new practices, such as life cycle approach, green supply chain, considering the possible environmental impacts of the entire supply chain, from raw materials to final products.

Also, Tables 4, 5, 6, 7 and 8 detailing practices implemented and performance indicators utilised in the study serve as valuable tools for managers seeking to enhance their companies' Lean and Green initiatives. By providing a comprehensive overview of the specific practices associated

with different levels of Lean and Green integration, as well as the corresponding performance metrics, these tables offer actionable insights for decision-makers. Managers can utilise this information to identify effective strategies that align with their organizational goals, thereby improving their company's competitiveness. These Lean and Green practices and performance indicators facilitate a targeted and informed approach to decision-making, empowering managers to implement tailored strategies that optimise both Lean and Green practices, fostering sustainability and efficiency in their operations.

This research seeks to contribute to improving knowledge about the joint management of Green practices and Lean practices in the automotive sector, adding the perspective of operations strategy to the discussion.

In the automotive industry, where Lean practices are widespread, the implementation of operations strategies must require the integration of Lean and Green practices, or the harmonious implementation of Green practices in Lean environments, to be efficient and effective. The cases examined here illustrate the adoption of different action strategies in terms of the priorities selected, the decision areas affected, and the practices implemented. Each strategy should require a specific effort to implement Green practices. Depending on the selected competitive priorities and other factors, such as legislation, the companies studied in this research followed different paths in choosing Green practices and in the effort expended in their implementation (presenting different practice configurations and practice implementation levels). The cases analysed represent different situations, but it was possible to identify that efforts to integrate LG practices involved the training of human resources in Green practices, the adoption of metrics common to Lean and Green practices, and organizational arrangements that promote the integration of Lean and Green Teams, as well as the inclusion of initiatives aimed at reducing environmental impacts in existing improvement programs.

6.3 Limitations and further research

The present study has limitations. Conceptually, to our knowledge, a way of evaluating possible articulations of actions, changes and practices to operations competitive priorities is not yet comprehensively developed in the literature. Such an assessment could have allowed a discussion of possible articulations in the case studies. We have limited this study to identifying configurations of production strategies and levels of implementation of practices.

In the methodological vector, as it was not a longitudinal study, it was not possible to discuss the implementation of practices and their articulation over time, which could enrich the discussion of how practices are implemented. Furthermore, the research is based on a survey of interviewees' perceptions, a common limitation in case research studies.

The empirical limitations are related to our choice of participating companies. Our sample was purposeful and based on ease of access to automakers. Finally, the study of LG integration from the perspective of operations strategy is still at an early stage in the literature. As it gains importance, with more research involving numerous samples, the discussion of the implementation of LG practices in operations strategies will be greatly enriched.

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Declarations

Competing interest The authors declare that they have no known competing financial interests or personal relationships that could appear to influence the work reported in this paper.

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