26th International Conference on Harbor, Maritime and Multimodal Logistic Modeling & Simulation, 011
21th International Multidisciplinary Modeling & Simulation Multiconference

2724-0339 © 2024 The Authors.
doi: 10.46354/i3m.2024.hms.011

Evaluating Supply Chain Performance Through Lean, Agile, Resilient, and Green (LARG) Perspectives: A Comprehensive Framework

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Abstract

This paper proposes a framework for the evaluation of the performance of a supply chain according to the lean, agile, resilient and green (LARG) perspectives. The study builds upon a previous publication by some of the authors, in which a preliminary review of the literature about the typical key performance indicators (KPIs) of the supply chain was presented; in this paper, such analysis is complemented by looking at those studies that have classified the KPIs among the LARG perspectives. Also, the KPIs are categorized by supply chain process, for a more focused evaluation. As a result, a model for performance evaluation across the LARG perspectives is presented. As example of a how to translate this model into a decision tool is also presented.

Keywords: supply chain performance measurement; lean, agile, resilient and green; evaluation model; key performance indicators.

1. Introduction

In today's dynamic and competitive business environment, measuring supply chain performance has become an essential aspect of an effective supply chain management strategy (Lotfi & Saghiri, 2018; Gunasekaran et al., 2004). Performance measurement in supply chains involves the use of metrics and key performance indicators (KPIs) to evaluate various dimensions such as efficiency, effectiveness, and adaptability of supply chain processes. The goal of using these metrics is to gain insights into the current performance level reached by the supply chain overall or at the different levels, and consequently, identify areas for improvement, thus aligning operations with strategic objectives (Parker, 2000).

A well-designed performance measurement system enables decision-makers to monitor the status of their supply chains, ensure alignment with business goals, and respond proactively to changes in the market or operational environment. By systematically measuring performance, companies can uncover inefficiencies, reduce waste, and improve overall supply chain robustness. This measurement framework becomes even more critical when integrating advanced paradigms such as Lean, Agile, Resilient, and Green (LARG) into supply chain strategies (Azevedo et al., 2011). The LARG paradigm represents a comprehensive approach to supply chain management that combines Lean, Agile, Resilient, and Green principles to create a more robust and sustainable supply chain. The *lean* perspective focuses on eliminating waste and enhancing value through continuous improvement and efficiency. Lean practices streamline processes, reduce costs, and improve quality, ultimately leading to a more efficient supply chain. *Agility* emphasizes the ability to quickly respond to market changes and customer demands. An agile supply chain is flexible, adaptable, and capable of rapid adjustments to meet varying requirements and unforeseen disruptions. *Resilient* supply chains are designed to withstand and recover from disruptions, of which the Covid-19 has been a recent example (Jha et al., 2021). Resilience involves risk management strategies, redundancy, and the ability to bounce back from adverse events, ensuring continuity of operations. Finally, *green* principles integrate environmental considerations into supply chain management. Green supply chains aim to minimize ecological impact through sustainable practices such as reducing carbon footprints, promoting recycling, and using eco-friendly materials and processes. The combination of these four perspectives creates a holistic supply chain strategy that not only optimizes performance but also enhances the sustainability and robustness of the supply chain (Carvalho et al., 2011). The LARG framework addresses the need for efficiency, flexibility, durability, and environmental responsibility, making it a vital component of modern supply chain management.

This paper contributes to this line of research by proposing a framework for the evaluation of the performance of a supply chain according to the LARG perspectives. As such, this study builds upon a previous publication by some of the authors (Bottani et al., 2023), in which a preliminary review of the literature about the typical KPIs of the supply chain was presented, with a focus on the food industry. In this paper, such analysis is complemented by looking at those studies that have classified the KPIs among the LARG perspectives, and by deriving, as a result, a scheme for evaluating supply chain performance according to the different perspectives and looking at the various supply chain processes.

The remainder of the paper is structured as follows. Section 2 reviews the studies relevant to this paper, and in particular, those papers which KPIs relating to the LARG perspectives are used, implemented, analyzed or newly proposed with reference to the SC context. The framework derived from those studies is presented in section 3. In section 4, some considerations are made on how the proposed framework can be translated into a decision-making tool, by coupling it with known decision methods. Finally, section 5 concludes by summarizing the key findings of the study, highlighting the advancements and the limitations, and suggesting future research directions.

2. Literature analysis and KPIs mapping

Literature offers some studies that analyzed expressively the LARG perspectives of supply chain processes and suggest appropriate KPIs for measuring the relating performance, such as possible find in Ventura et al. (2024) in which a review of literature and research steps for a full integration is presented.

A summary of those studies is proposed in Table 1 and commented below.

Table 1. List of LARG-related studies.

Source	Perspectives analysed
Carvalho et al. (2010)	Lean, Agile, Resilient, Green
So (2010)	Lean
Carvalho & Cruz-Machado (2011)	Lean, Agile, Resilient, Green
Carvalho et al. (2011a)	Lean, Agile, Resilient, Green
Carvalho et al. (2011b)	Lean, Green
Azevedo et al. (2011)	Lean, Agile, Resilient, Green
Azevedo et al. (2012)	Lean, Green
Espadinha-Cruz et al. (2012)	Lean, Agile, Resilient, Green
Azevedo et al. (2013)	Resilient, green
Khan et al. (2014)	Lean, Agile, Resilient, Green
Govindan et al. (2015)	Lean, Resilient, Green
Azevedo et al. (2016)	Lean, Agile, Resilient, Green
Jamali et al. (2017)	Lean, Agile, Resilient, Green
Sen et al. (2018)	Resilient, Green
Zanjirani et al. (2019)	Lean, Agile, Resilient, Green
Al-Refaie et al. (2020)	Lean, Agile, Resilient, Green
Devsalar et al. (2020)	Lean, Agile, Resilient, Green
Salleh et al. (2020)	Lean, Agile, Resilient, Green
Amjad et al. (2021)	Lean, Agile, Resilient, Green
Anvari (2021)	Lean, Agile, Resilient, Green
Sahu et al. (2022)	Lean, Agile, Resilient, Green

As can be seen from the list in Table 1, most of the studies refer to the whole set of LARG perspectives, while some other studies have evaluated some perspectives only; in this case, the most frequent pairs of perspectives are lean and green or resilient and green. All the studies listed in Table 1 have obviously provided specific KPIs for the evaluation of supply chain performance under the various LARG perspectives. From a detailed analysis of the KPIs proposed in each paper, we derived an indication of the most frequent performance indexes for each perspective under examination. The frequency of occurrence of the KPI was implicitly taken as synonym of the popularity of the index in the scientific community, but also of its usage among industries, as most of the studies reviewed have proposed real case implementation of the performance evaluation models. The screening of the studies led to the set of KPIs listed in Table 2 for the four LARG perspectives.

Table 2. List of KPIs from the LARG-related studies and frequency.

Perspective	Index	Frequency
Lean	% material loss due to operations	12
	Stock level	12
	Cycle time	11
	Total ordering time	10
	FTL or LTT deliveries	10
	Design hours	9
	Inventory costs	8
	Capacity utilisation	8
	Operational production time	8
	Overall Equipment Effectiveness	8
	% marketing cost	8
	Effectiveness by sector	7
	% integrated and motivated employee	7
	% development cost	7
	% hours of training per year	6
	Customer satisfaction	5
	Impact of changeovers of total production hours	5
	Productivity by sector	4
	% profit on sales	4
	% average monthly sales	3
	Accuracy of forecasting	2
Agile	Customer service	14
	Accuracy of delivery or % of delivery errors	12
	Coordination among supply chain members	11
	Timeliness of delivery	10
	Delivery flexibility	9
	Proximity to suppliers and customers	9
	% bottlenecks	7
	Supplier involvement in product development	7
	Timeliness	6
	Frequency of delivery (N° actual deliveries/N° scheduled deliveries)	5
	Defect rate	5
	Inventory velocity	4
	Number of nodes in the SC	4
	% overtime hours	2
	Inventory turnover rate	2
	PCR testing costs	2
Resilient	Availability of alternative supplies	11
	Stock coverage	10
	Stock service ratio	10
	Mean time between failures	8
	Distribution channel single/omni/multi channel	8
	Maintenance ticket management	8
	Forecast adjustment time	7
	% demand satisfaction	7
	Standardization of components	6
	Product customization	6
	Average downtime time	5
	Net promoter score	5
	% lost sale	5
	Mean time to preventive maintenance	4

	Punctuality of payments	4
	% rate of rework or changes	4
	Mean time to repair	3
	Average downtime time	3
	Average customer seniority	3
	Range breadth	1
Green	CO2 emission	17
	Energy consumed from fossil and renewable resources	16
	% raw material cost	16
	Electricity consumption	16
	Waste ratio	13
	% waste cost	12
	% smart working	12
	Water consumption per unit produced	9
	% compliant products	8
	Sanitation costs	5
	Human equity	2

As can be seen from Table 2, among the lean indexes (derived from 19 documents), the most recurring ones refer to the loss of materials during production activities and to the stock level; both indexes have a quite high frequency of usage (12 occurrences). Time-related indexes (e.g., cycle time and total ordering time) and the efficiency of deliveries (FTL/LTT deliveries) complete the top-5 indexes by number of occurrences. An index relating to timeliness of delivery was also found among the top-5 KPIs of the agile perspective; other recurring indexes of this perspective refer to typical service factors (e.g., delivery flexibility or accuracy of delivery). As far as the resilient perspective, double/multiple sourcing strategies (availability of alternative suppliers) are the most recurring option; stock increase is recognized as a suitable strategy for making the supply chain more resilient. Other top indexes in this perspective include aspects related to the machine functioning (e.g., mean time between failures or maintenance management). Finally, recognized indexed in the green perspective refer to well-known impacts of supply chain processes, such as CO2 emissions or energy, electricity and water consumption.

3. Framework development

The set of indexes proposed in the previous section was organized into a framework covering the typical supply chain processes, such as: 1) supply; 2) production; 3) distribution/sale; and 4) reverse logistics. To be more precise, each KPI was associated to the pertinent supply chain process. The corresponding framework, in its integrity, is shown in Figure 1. Besides listing the KPIs, the framework also includes suggestions for some supporting technologies (mainly related to the Industry 4.0 area), highlighted by the rhombuses in Figure 1, as well as indications of the best practices for each process, which are highlighted by rectangles in the same figure.

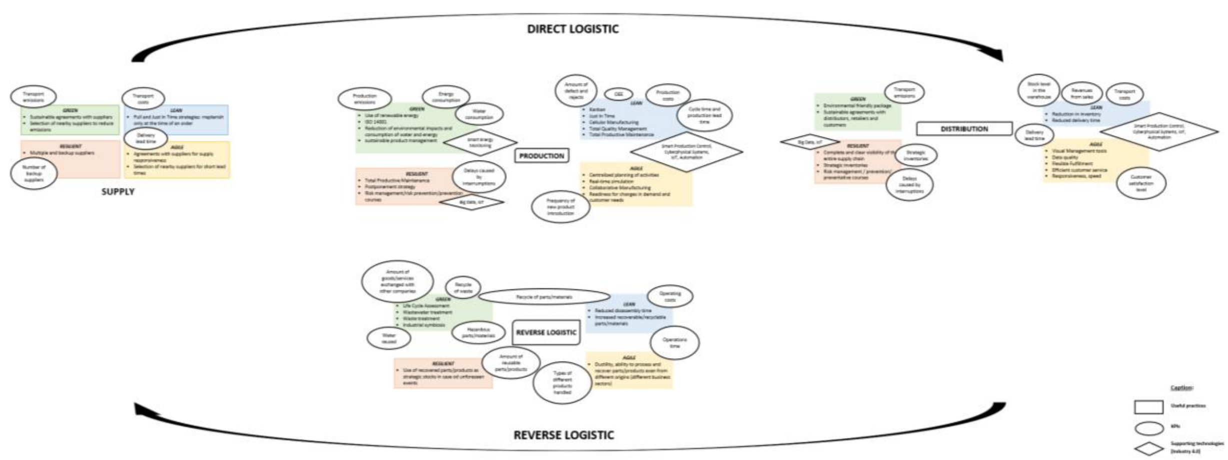

Figure 1. scheme of the framework.

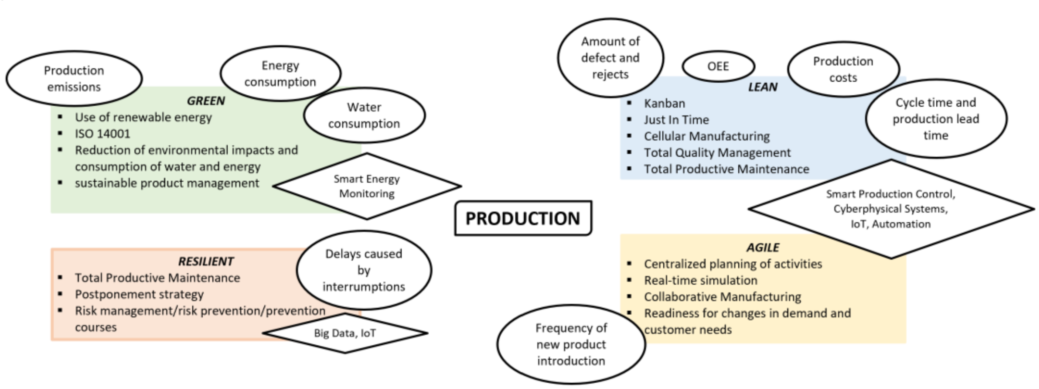

Figure 2. Details for the “production” process.

For a better understanding of the framework, a detailed example is provided in Figure 2 referring to one of the processes listed above, i.e. production. As can be seen from Figure 2, the categorization of the KPIs still follows a grouping into the four LARG perspectives, according to the classification proposed in Table 1. Looking, e.g., at the green perspective, relating indexes refer to emission in manufacturing activities, energy and water consumption; best practices in this field encompass the usage of renewable energy sources, the adherence to ISO 14000 standards, the reduction of consumptions, and the application of sustainable product management strategies. Finally, smart energy monitoring tools can help enhance the green performance of the production process. Similar considerations can be easily derived for the remaining perspectives of this process and extended to supply, delivery and reverse logistics processes.

4. Computational procedure

Following the classification framework described above, it is easy to calculate the overall supply chain performance at different levels. Obviously, an overall performance can be computed by taking into account the four perspectives and the whole set of KPIs, but if interested, a decision maker could evaluate, e.g., the system's performance against one specific perspective (e.g., the "green" performance) or, alternatively, the performance of a specific supply chain process.

To support the process of performance evaluation, a computational model is currently being developed, following the structure of the framework and enabling the computation of a performance score at different levels of the system, as explained above. In particular, the Analytic Hierarchy Process (AHP; Saaty, 2004) appears as a suitable decision-making tool for reproducing the structure of the framework under the four perspectives and support the performance evaluation process. In line with the AHP model, the four perspectives of the framework must be organized into a hierarchical structure (Figure 3), and a weight has to be assigned to each perspective for judging its importance in the LARG framework. For a preliminary evaluation, it is recommended to assign the same weight to each perspective, but obviously, depending on the specific context, the decision-maker is free to determine a different weight for each perspective. In this case, the Saaty's scale must be used for making pairwise comparisons among the perspectives and to compute the weight of each perspective.

Figure 3. hierarchical structure of the framework.

The same logic is to be applied to the KPIs belonging to each perspective, for which a ranking of importance has to be determined. Actually, in a real implementation, it would be preliminary necessary to determine the relevant KPIs for each perspective. The lists provided in Section 2 can be seen as guidelines to this end, as the KPIs were retrieved from the literature and some of them are recognized to have been used very frequently. Nonetheless, the decision-maker could select a different combination of KPIs, a subset of them or alternative KPIs compared to those suggested in this paper. After determining the KPIs relevant to the evaluation, again the Saaty's scale is to be used for making pairwise comparisons among the KPIs belonging to the same perspective, to derive their relative importance. Supposing that there are *n* KPIs in a given perspective, the number of necessary pairwise comparisons will be $\frac{n(n-1)}{2}$. Each comparison (say, between KPI_i and KPI_j, with $i,j=1,..n$) involves answering the following question: *compared to KPI_i, to what extent is KPI_j more/less important?* The answer must be provided using the previously mentioned Saaty's scale, whose numerical values range from 1 (equally important) to 9 (extremely more important); reciprocal values denote opposite situations (i.e., lower importance), on the same scale. Also, when making more comparisons it is usually appropriate to check the consistency of the results; this can be made by computing the consistency index (CI; Salomon and Gomes, 2024, as follows:

$$CI = \frac{\lambda_{max} - n}{n - 1} \tag{1}$$

In eq.1, λ_{max} denotes the largest eigenvector of the pairwise comparison matrix. The data are assumed to be consistent is $CI \leq 0.1$; otherwise, the evaluation must be repeated until consistency is reached. Again, the pairwise comparisons can be somehow supported by the outcomes presented in section 2, as, for instance, the occurrence of a KPIs can be taken as synonymous with its relative importance, at least in the scientific community.

Once this procedure has been completed for all perspectives and processes, the whole set of weight will be available for each KPIs of the framework; then, the next step is the evaluation of the system's performance against each KPI. In this respect, two aspects need to be taken into consideration. The first one is that each KPI needs a clear definition in terms of computational procedure. Again, this can be either derived from the available literature, as various studies also include details about how to compute each KPI; alternatively, the decision-maker can choose an appropriate computational procedure for a KPI, depending on the specific aspect to be emphasized or on possible customization of the KPI itself. The second point to be addressed is to clarify whether the evaluation of the performance is again comparative or if one single alternative is being evaluated. In this latter case, basically the decision-maker is evaluating the performance of its current system or process, while in case of a comparative evaluation, more alternative configurations could be suitable for the same supply chain or process, and the best one must be selected. In both cases, again the AHP procedure can support the evaluation.

As a final result, the decision-maker can thus derive:

- An evaluation of the performance of the whole supply chain under examination, under the four LARG perspectives, or an evaluation of the performance of a specific process, or against one of the LARG perspectives; or
- A comparative evaluation of the LARG performance of various alternative supply chain or process configuration.

5. Discussion and conclusions

The paper proposes two operative tools for the evaluation of the performance of a supply chain according to the LARG perspectives: a framework and a model for performance evaluation.

A company decision-maker could approach to these instruments in order to find a support in identification of a criteria for evaluate the performance of the whole supply chain or of a single process.

The framework provides some useful KPIs for the evaluation of the performance and also different supporting technologies or instruments for the improvement of the LARG perspective.

Moreover, a computational model based on AHP decision-making tool is proposed and developed, following the structure of the framework and enabling the computation of a performance score at different levels of the supply chain. In this way a company could monitoring the performance of its processes and supply chain.

The future developments of this study concern in the testing phase with the application of the tools presented above to case studies, considering different industrial sectors and different actors of the supply chain, in order to test the effectiveness of the framework and of the computational model.

A further development could be the implementation of other decisional approaches in addition to the AHP one and the consequent analysis of the different results.

The authors are already designing a multi-objective model of linear programming for the definition of the best strategy of implementing the supply chain with different objective function corresponded to the LARG parameters.

Finally, an additional development could be the computerization of the tools by app or technological instruments for improving the applicability of the methods to the companies.

Funding

This research was funded by the National Recovery and Resilience Plan (PNRR), Mission 04 Component 2 Investment 1.5 "Creation and strengthening of Ecosystems of innovation, construction of territorial leaders of R&D" – Next Generation EU, call for tender n. 3277 of 30/12/2021; MUR Project Code: ECS_00000033; research programme title: Ecosystem for Sustainable Transition in Emilia-Romagna (project acronym: ECOSISTER), awarded to the University of Parma and to the University of Bologna.

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