Assessing Green Logistics Processes: proposal of a Three-Dimensional Maturity Model

S. Ferraro [a)], F. De Carlo [a)], A. Cantini [b)] and L. Leoni [a)]

a. *Department of Industrial Engineering (DIEF), University of Florence, Viale Morgagni 40, 50134 – Florence – Italy (saverio.ferraro@unifi.it, filippo.decarlo@unifi.it, leonardo.leoni@unifi.it)*

b. *Department of management, economics and industrial engineering, Politecnico di Milano, Via Lambruschini 4B, 20156 – Milan – Italy (alessandra.cantini@polimi.it)*

Abstract: Resource utilization, process optimization, and supply chain configuration are pivotal factors in economic growth-oriented contexts. However, economic development cannot neglect environmental considerations. Improvement strategies and tools enable processes, such as logistics, to achieve both economic and environmental objectives. Among the existing tools available to practitioners and academics, maturity models assess the alignment of systems and processes with the best practices across different dimensions and sub-dimensions. Despite the relevance of the topic, limited attention has been given to the development, validation, and application of maturity models for logistics, especially green logistics. Consequently, this article proposes a five-level Green Logistics Maturity Model (GLMM). The GLMM allows for the identification of the current state of a logistics process according to three dimensions: resource, process, and network management. A novel multi-methodological theoretical approach was employed to identify the model elements. Specifically, a literature review was conducted on 16 maturity models for logistics. Moreover, a systematic literature network analysis of 949 articles related to green logistics was carried out using both co-occurrence and thematic map analyses. The primary contribution of this work is to lay the foundation for a practical tool to describe and compare the current state of logistics activities and to identify areas for improvement. The results of this research may be of interest to logistics practitioners, supply chain managers, and researchers for GLMM application toward more environmentally friendly processes.

Keywords: Green logistics, Maturity models, Environmental emission, Supply chain management, Sustainability.

I. Introduction

In a global context increasingly focused on customer satisfaction, supply chain management, and logistics are activities of primary importance. In achieving these goals, organizations are constantly seeking to optimize business performance and collaborations between supply chain actors [1]. However, although in the past it was sufficient to focus on the effectiveness and efficiency of organizational processes, today this focus is taking a back seat [2]. The continuous reduction of available resources and environmental issues have forced organizations to reconsider their priorities and strategies. In this context, economic and environmental objectives must increasingly go hand in hand with the various organizational processes [3]. Among the various processes, logistics plays a strategic and responsible role to benefit from economic results while limiting environmental impacts. To this end, the concept of Green Logistics (GL) has been defined as a management practice that meets environmental, economic, and, to some extent, social objectives [4]. Although the benefits are clear, it is not always easy, especially on a practical level, to identify tools that facilitate the introduction of GL principles.

Generally, following a systematic approach for monitoring and controlling performance allows areas of improvement to be identified for optimization. The literature offers a variety of tools for performance assessment. Estampe et al. [5] compare 16 models for performance measurement, providing a framework that indicates the best model based on the needs of decision-makers. However, there are also other tools and classifications. According to Benmoussa et al. [6], models can be distinguished between performance measurement-driven and maturity measurement-driven. The former models propose general frameworks for supply chain assessment (e.g., Activity-Based Costing, Balanced Scorecard, Supply Chain Operation Reference model) while the latter apply maturity concepts in different activities. Maturity models (MMs) are strategic tools that make it possible to assess a given entity over time to provide indications of the improvement of certain attributes. For this reason, MMs have a dual conception. On the one hand, they are seen as tools for the assessment of an entity, on the other hand, they are regarded as frameworks for continuous improvement according to an attribute [7]. MMs define the maturity level through the use of levels, dimensions, and sub-dimensions. These three elements are necessary for the definition of an entity assessment tool according to a precise attribute.

Initially, maturity models took root within software engineering with the concept of capability [8], later developing to other operational areas, including supply chain management [9]. Similarly, the concept of maturity has also evolved over time with the advent of research topics such as Industry 4.0 and sustainability. In particular, the topic of sustainable logistics gained prominence around 2010 [10]. Since then, numerous studies have systematically analysed and reviewed the literature in this field. Several noteworthy works have focused on various aspects, including the optimization of freight transport [11], the impact of enabling technologies [12], and performance measurement [13]. Indeed, despite being an emerging topic in research, the literature currently lacks comprehensive logistic maturity models (LMM) [14] and systematic reviews that identify the key elements of maturity modelling in logistics. Even less in-depth is the topic of maturity models for green logistics [15], which appears to be current and relevant. To this end, within this paper, a MM for GL is proposed that considers the resource, process, and network management domains. The development of the MM follows an innovative multi-methodological approach consisting of a Systematic Literature Review (SLR) on the LMMs and a Systematic Literature Network Analysis (SLNA) for the GL principles.

As a reminder, the structure of the article is as follows. In Section 2, the methodology followed is reported, consisting of three phases: literature search, content analysis, and model proposal. Section 3 contains the results of the research. Finally, in Section 4, conclusions and future developments are provided.

II. METHODOLOGY

The work consists of a three-step methodological approach of literature research, content analysis, and model proposal, as reported in Figure 1.

The first step of the literature research identifies the references of greatest interest. This step was carried out separately according to the research approach used in the two research strands. The first strand concerns the identification of LMMs using a SLR approach. At this stage, the aim is to classify by highlighting the shortcomings in the literature. The second strand, on the other hand, considers the selection of references dealing with GL principles using a SLNA approach. Through this analysis, the aim is to cluster the literature to examine domains and subdomains for the GLM proposal. For both threads, Scopus was selected as the search database. In this context, appropriate search queries were used from the combination of keyword groups and logical operators. More specifically, the logical operator 'OR' was used to combine keywords of the same group, while the operator 'AND' was adopted among different groups of keywords. Moreover, the operator '*' was used for single keywords to identify terms with a common root, and the operator 'W/1' which constrains the sequential order between two keywords, allowing for the intermediate presence of any one single word. Both searches were carried out in the fields of title, abstract, and keywords (TITLE-ABS-KEY). It follows that the following search string was used for the topic of LMMs:

TITLE-ABS-KEY ((maturity W/1 model) OR (maturity W/1 framework) OR (maturity W/1 roadmap) OR (maturity W/1 grid) OR (maturity W/1 assessment) OR (maturity W/1 level) OR (maturity W/1 index)) AND logistic*)

while for GL practices the following:

TITLE-ABS-KEY (sustainab* W/1 logistic*) OR (green W/1 logistic*) OR (environment* W/1 logistic*) OR (energy W/1 logistic*)

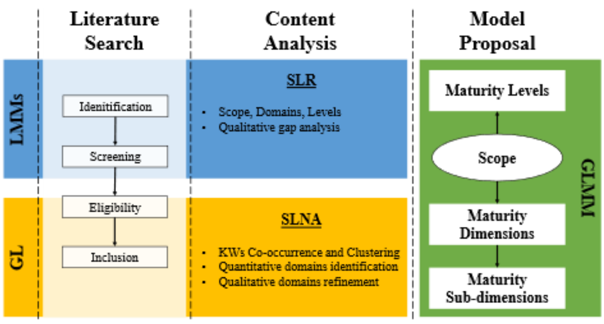

Figure 1. Proposed three-step framework

The identified articles were then filtered using the following inclusion criteria:

- Papers referred to "Engineering", "Environmental Science", "Business, Management, and Accounting", and "Decision Science".
- Papers are limited to 2010 – 2022 time span to consider most of the contribution.
- Papers are limited to articles and reviews.
- Papers are limited to English writing.

In the SLR approach, the remaining articles were screened to include those that were relevant to the development, validation, and application of MMs in logistic operations. The screening process involved reading the title, abstract, and keywords followed by a full-text analysis. The final sample of articles deemed relevant for the investigation was cross-referenced, resulting in a total of 16 articles that were included in the analysis to investigate the main LMMs. To conduct the SLNA methodology and investigate the GL topic, the screening process was less detailed to be time affordable. For this reason, the reading of 1347 titles was carried out, resulting in the selection of 949 sources. For each search query, the partial results obtained by applying the inclusion criteria are shown in Table I.

TABLE I. RESULTS OF INCLUSION CRITERIA

Criteria	SLR on LMMs	SLNA on GL
Keywords	289	3756
Subject Area	167	2715
Time	138	2305
Document Type	76	1401
Language	66	1347
Eligibility	22	949
Included	16	949

The second step of the methodology aims to compare the results of the LMMs with the clusters of GL practices. In particular, the LMMs will be analysed to highlight a qualitative gap analysis. The results of the GL practices will be processed through SLNA co-occurrence and thematic map analyses of the keywords indexed within the selected papers as a strategic diagram classification method [16]. As reported in [17], co-occurrence analysis is based on the evaluation of association strength (AS), which represents the semantic relatedness of two words, in this case, indexed keywords. AS is a value between 0 and 1, such that the closer it is to 0 the less the keywords co-occur and the closer it is to 1 the more the keywords co-occur. Then, using a community detection procedure, K thematic clusters can be identified. For each cluster, it is possible to calculate the Callon Centrality (CC) and Callon Density (CD) values, which make it possible to create the thematic map of the keywords used. CC represents the degree of relevance of the cluster within the domain, while CD represents the degree of development. From the intersection of CC and CD, it is possible to group clusters of keywords and report them in four quadrants [18]. On the top right, there are highly developed and research-relevant topics, labelled as *motor themes*. In the upper left-hand quadrant are very specific themes with few relationships, referred to as *niche themes*. The lower left quadrant describes *emerging or declining themes*, which are underdeveloped topics. Finally, in the lower right-hand quadrant are groups of keywords that are relevant for the search but general in their treatment, referred to as *basic themes*. Instead, the co-occurrence analysis graphically highlights the relevance and relationship of the papers' keywords to refine the choice of dimensions and sub-dimensions, the most relevant references consistent with the results of the thematic map were analysed qualitatively. The relevance of the papers was considered using the Impact Factor (IF) value calculated by Eq.4.

$$IF = TC / PT \quad (4)$$

where TC is the total number of citations and PT is the time elapsed since the year of publication.

Finally, in the third step of the methodology, a MM for GL will be proposed. The foregoing Green Logistics Maturity Model (GLMM) will consider the results of the second step to identify the model elements (levels, dimensions, and sub-dimensions).

III. RESULTS

The relevant information for the design of the GLMM was examined from a quantitative and qualitative point of view. The SLR used a spreadsheet, while the SLNA used the Bibliometrix package from RStudio. In Section 3.1 the detailed results of the LMMs literature review are given, and in Section 3.2 those for GL. The combination of the results in Section 3.3 leads to the GLMM proposal.

A. SLR of LMMs

The 16 LMMs were analysed in detail to identify principles, elements, and gaps. They are presented in Appendix A (Table A1) in tabular form.

As far as the elements of the models are concerned, most propose 5-level assessment tools (9 out of 16) described by 5 dimensions (7 out of 16). When considering management areas most focus on logistics processes (15 out of 16) and to a lesser extent on network (6 out of 16) and resources (3 out of 16). Only the model of [19] considers the three management areas jointly.

The 16 LMMs can be classified into 3 research strands, respectively Industry 4.0 (7 out of 16), business processes (6 out of 16), and sustainability (3 out of 16). Initially, part of the publications focused on the business process strand by proposing maturity models for various sectors, including the transport sector [20]–[22]. Subsequently, much of the attention turned to the industry 4.0 strand with the introduction of the Logistics 4.0 concept [23]–[26]. Only in the last period is the sustainability strand slowly gaining ground. However, with limitations. The model of [27] focuses exclusively on the energy efficiency of logistics providers. Also for logistics providers, the model of [15] considers the impact of tools, strategies, and technologies on the three dimensions of economic, environmental, and social sustainability. Finally, the model of [28] highlights that the strategic improvement of return logistics activity can have an impact on the environmental level of the solid waste management activity.

It could be possible to state that the literature on LMMs has an important gap. Indeed, a general tool in terms of application area that jointly considers resource, process, and network management to optimize logistics processes from an environmental point of view has not yet been proposed.

B. SLNA on GL principles

Once the LMMs have been analysed and the main research gap is highlighted, it is necessary to identify the enabling factors of GL. Some studies, such as [21], [29], [30], identify the elements of MM through literature review, whether systematic or not. However, in most works, the selection of the elements of MMs is reviewed by domain experts by carrying out a hybrid design approach [19], [20], [25], [27], [31], [32]. This design approach, by the way, can be time-consuming if conducted systematically on broad domains in scope (e.g., Logistics 4.0, Green Logistics).

In this article, a novel approach using the SLNA methodology was pursued for the selection of MM elements. The GL results show the presence of a number of clusters k = 4. Clusters are labelled according to the keyword with the highest number of occurrences within the cluster.

The cluster labelled "logistics" is found to be *motor theme* (88 keywords 1369 total occurrences), the cluster of "sustainable development" as *basic theme* (83 keywords and 1360 total occurrences), the cluster of "green logistics" as *niche theme* (76 keywords and 1064 total occurrences), and finally the cluster of "carbon" as *emerging or declining theme* (2 keywords and 38 total occurrences).

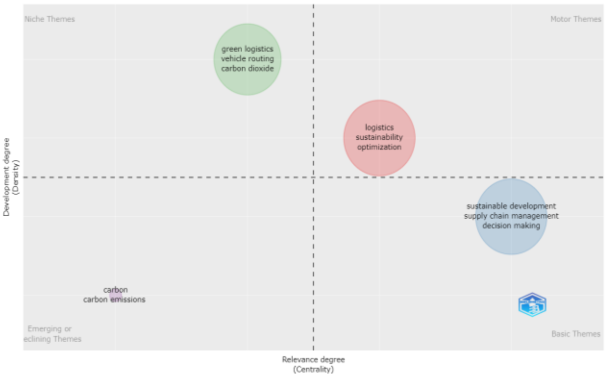

Figure 2. Thematic map of GL principles

C. GLMM Proposal

The SLR analysis showed that only 3 LMMs deal with the concept of sustainability, within which GL is included. However, these LMMs only address logistics providers or reverse logistics and not entire logistics processes that affect any organization. Besides, the thematic map allowed us to identify an appropriate number of dimensions of 4. However, using the 4 dimensions results in an exclusively quantitative design approach. To mediate the quantitative approach with a qualitative one, three recurring patterns of resource management, process management, and network management were identified within the four dimensions. The three patterns are also consistent with the SLR results for LMMs.

The GLMM proposal is shown in Figure 3. The model is based on the three dimensions of ***resource management*** (D1), ***process management*** (D2), and ***network management*** (D3). In turn, the three dimensions consider two sub-dimensions respectively.

Several management and design approaches identify the reduction of emissions, energy consumption, and waste [3], [4], [33], as a pivotal point. However, in addition to reduction, evaluation [3] and emission prediction systems [34] must be employed. Aligned with these principles are strategies that assess the condition of products and services at the end of their use. Instead of complete production from scratch, other strategies, such as reuse, remanufacture, and recycle [2], [31], [32], are more environmentally friendly. According to these considerations, the two sub-dimensions of resource management are ***emission assessment, reduction, and prediction*** (S1.1) and ***material reuse, remanufacture, and recycle*** (S1.2).

From an operational point of view, the principle for pursuing good practices for sustainable logistics is the choice of transport mode according to the phase of the logistics process. Indeed, not all transport modes are appropriate for the first-, mid-, and last-mile logistics phases [37]. For this reason, it is relevant to employ systems for the evaluation and selection of single or combined modes [10]. Once the appropriate system is identified, it is necessary to move on to process optimization. Various approaches, especially from operations research, emphasize the importance of routing in reducing operating costs, environmental emissions [38], and energy consumption [39]. Vehicle routing problems must be considered in the different application cases, where vehicles may be single, multiple, or fleets [40]. Based on what has been identified in the literature, the two sub-dimensions for process management are ***single and multiple transportation mode selection for first-, mid-, and last-mile logistics*** (S2.1) and ***route planning and optimization of single, multiple, and fleet of vehicles*** (S2.2) respectively.

Finally, the third dimension considers network management (D3). Within this dimension, both material and information flows are considered. The former is used for a periodic evaluation [41] of the best network configuration, while the latter is used to deploy collaboration strategies between network actors [42]. Several models propose supply chain [43] and reverse logistics network [44] design approaches from a green perspective. To this end, the two sub-dimensions identified for the third dimension are those of ***configuration and reconfiguration of forward, reverse, and closed-loop supply chains*** (S3.1) and ***horizontal, vertical, and lateral collaboration strategies*** (S3.2).

Based on the adoption of one or more of the GL practices, any organization can identify its logistics process according to five maturity levels.

- L1 - The process is completely immature because the organization has no awareness of the impact of its processes.
- L2 - The process is partially immature because the organization has partial awareness of the impact of its processes.
- L3 - The process is neither immature nor mature because the organization has a partial awareness of the impact of its processes and partially involves resource, process, and network management activities.
- L4 - The process is partially mature in that the organization has complete awareness of the impact of its processes and partially performs resource, process, and network management activities.
- L5 - The process is fully mature as the organization is fully aware of its impacts and periodically engages in resource, process, and network management activities.

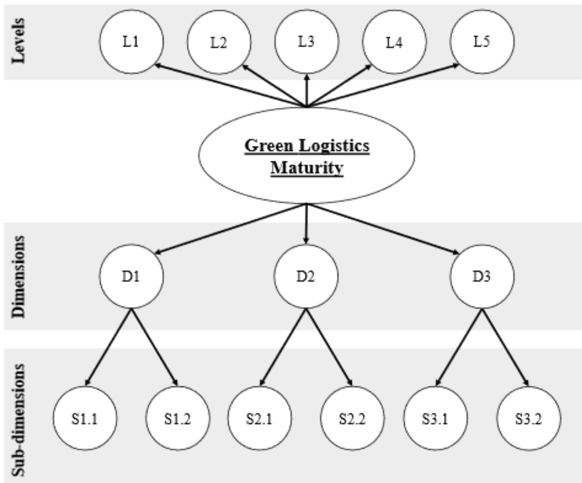

Figure 3. GLMM proposal

IV. Conclusions and Future Developments

With a view to zero-emission and a green transition, the sustainability of processes including logistics is increasingly necessary. Various systems, including MMs, enable the achievement of these goals. However, no MM in the literature provides guidance on the maturity of GL considering the critical issues of resource depletion, process complexity, and supply chain uncertainty. To this end, a maturity-based tool for GL was proposed within this article. The design of this tool followed a novel multi-methodological approach consisting of three steps: literature search, content analysis, and model proposal. More in detail, the SLR methodology was applied for a gap analysis on 16 LMMs and an SLNA on 949 articles for the quantitative and qualitative identification of GL dimensions and sub-dimensions. The combination of results enabled the design of the five-level GLMM described by three dimensions: resource management, process management, and network management.

GLMM is an innovative tool within the area of supply chain and logistics management from both an academic and practical point of view. However, the model shows various limitations that can be developed in possible future developments. From a design point of view, the identification of dimensions is exclusively based on the strategic diagram method of the thematic map in the SLNA phase. A possible future development could be the use and comparison of other co-word analysis methods such as hierarchical cluster analysis and social network analysis. Also in this phase, the source dataset could be improved from a qualitative point of view by using a thesaurus of common words. Another major limitation of the GLMM is that the tool follows a theoretical approach that lacks validation and practical application. To this end, further future development could be to validate the tool by designing a structured questionnaire and analysing the significance of the model elements using structural equation modelling tools. Finally, another limitation is the very nature of the model. GLMM is a useful tool for describing the current state of green practices, but it is not completely effective for achieving an improved future state. Therefore, a final future development could be to indicate guidelines and strategic roadmaps for improvement and advancement between maturity levels, thus defining a prescriptive MM.

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Appendix A. FIRST APPENDIX

TABLE AI. LOGISTICS MATURITY MODELS

Ref.	L	D	ES	R	P	N
[26]	6	5	-	-	X	-
[29]	3	5	-	-	X	-
[19]	5	5	-	X	X	X
[15]	5	3	X	X	X	-
[25]	5	5	-	-	X	-
[27]	5	3	X	X	X	-
[24]	4	7	-	-	-	X
[31]	5	6	-	-	X	X
[28]	4	8	X	-	X	X
[22]	6	5	-	-	X	X
[30]	3	9	-	-	X	-
[23]	5	3	-	-	X	-
[21]	6	5	-	-	X	X
[32]	5	3	-	-	X	-
[20]	5	6	-	-	X	-
[45]	5	5	-	-	X	-

L = number of Levels, **D** = number of Dimensions, **ES** = Environmental Sustainability, **R** = Resource management, **P** = Process management, **N** = Network management.