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Review

Trends and Recommendations for Enhancing Maturity Models in Supply Chain Management and Logistics

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Abstract: Maturity models (MMs) are strategic tools used to assess and improve the current state of processes, objects, or people, with the goal of achieving continuous performance enhancement. While MMs are applied in various fields, their scope, design, and application criteria within Supply Chain Management and Logistics (SCML) lack comprehensive studies. This article aims to address this gap through a systematic literature review. The review analyzes 137 relevant articles using both bibliometric and content analysis techniques. The bibliometric analysis identifies major contributions, popular journals, and the classification and evolution of key keywords. The content analysis focuses on critical criteria related to the scope, design, and application of MMs. The findings reveal a growing emphasis on models assessing Industry 4.0 readiness and sustainability principles. However, several gaps are identified, including limited attention to optimizing and integrating logistic processes, underutilized and unvalidated MMs, and the absence of comprehensive improvement guidelines. Based on these trends and research gaps, this study proposes five recommendations for future developments that benefit both academics and practitioners. These recommendations aim to address the identified limitations and provide guidance for comprehensive and effective improvement strategies.

Keywords: maturity models; supply chain management; logistics; systematic literature review; bibliometric analysis

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1. Introduction

In an increasingly customer-centric global context, Supply Chain Management and Logistics (SCML) have gained significant importance [1]. Organizations are striving to optimize business performance and foster collaboration among supply chain actors to meet customer satisfaction goals [2]. Trisnawati and Pujawan [3] highlight the impact of supply chain management maturity on operational and organizational performance. Similarly, Souza et al. [4] suggests that higher maturity in supply chain management leads to strategic advantages for organizations. Thus, the concepts of business maturity and business performance are closely intertwined: adopting a systematic approach to monitor and control performance allows organizations to identify areas for improvement and optimization. The literature offers various tools for performance assessment. Estampe et al. [5] compares 16 models for performance measurement and provides a framework to determine the most suitable model based on decision-makers' needs. Other tools and classifications exist: according to Benmoussa et al. [6] models can be categorized as either performance measurement-driven or maturity measurement-driven. The former offer general frameworks for supply chain assessment, such as activity-based costing, balanced scorecard, and supply chain operation reference model. The latter apply maturity concepts in specific activities involved in the supply chain, such as the logistics [7], manufacturing [8], and sales and operations planning [9].

Maturity models (MMs) serve as strategic tools for assessing and improving specific attributes of an entity over time. They show a dual nature, functioning both as assessment tools and frameworks for continuous improvement [10]. Entities encompass a wide range of objects, people, and processes, while attributes vary depending on the application area and external factors. In the field of SCML, examples of attributes include maturity, capability, and diffusion. A relevant example is that of the supply chain management maturity model (SCMMM), which aims to structure and integrate processes across the entire supply chain. These processes need to be defined, managed, measured, and controlled, extending beyond the scope of individual organizations [11]. They encompass activities spanning from supplier relationship management (SRM) to customer relationship management (CRM), incorporating the conventional SCOR processes of plan, source, make, and deliver [12]. These activities are all geared towards achieving continuous performance improvement and generating value for the entirety of the supply chain. For this reason, maturity refers to an organization's ability to continuously improve in a specific discipline [13]. Capability represents the capacity to deploy resources through processes to achieve desired outcomes [14]. Finally, diffusion entails the communication and dissemination of new or innovative elements through social systems [15]. Moreover, MMs serve as valuable tools, enhancing shared knowledge, aiding decision-making, and providing improvement pathways [16].

These tools follow a systematic methodology encompassing the phases of scope, design, and application, often in collaboration with field experts to ensure practical applicability [17]. The practical benefits [18] of MMs in SCML have been confirmed in both the manufacturing [19] and service sectors [20]. For instance, Trisnawati and Pujawan conducted a study to measure the supply chain management maturity of 57 manufacturing companies, aiming to identify the most influential factors [3]. In another study, Werner-Lewandoska and Golinska-Dawson assessed the sustainable logistics management maturity of 190 Polish transportation companies, investigating the impact of factors such as company size and business profile on maturity levels [21]. Zoubek et al. compared 23 companies from the automotive, manufacturing, and electronics sectors to evaluate the overall readiness for Logistics 4.0 [22]. These examples underscore the significance of MMs, as they not only assess individual systems but also facilitate comparison among multiple systems, revealing common factors and guidelines for management and performance enhancement. While the origin of MMs lies in software development, specifically with the Capability Maturity Model (CMM) and the Capability Maturity Model Integrated (CMMI) [23], they are frequently referenced and adapted across various domains. MMs can be categorized into different assessment tools, including CMM-based models, Likert-like questionnaires, and Maturity Grids. CMM-based models define maturity from generic to specific objectives for each process area or dimension [24–26]. Likert-like questionnaires employ questions on a scale to assess maturity [27–29]. Maturity grids, represented in matrix forms, describe best practices for each maturity level [30–32]. Regardless of the assessment tool used, MMs define maturity levels through the use of levels, dimensions, and sub-dimensions. Moreover, entity assessment through MMs can have different objectives [33]. Descriptive models evaluate the current state of the system without making comparisons. Comparative models allow benchmarking between elements but do not provide guidance for improving maturity. Prescriptive models, although less common, emphasize providing improvement guidelines and roadmaps. It is important to note that these three objectives accompany the entire life cycle of a model [34]. Initially, a model is created to describe the current state (descriptive nature), followed by providing guidance for improvement (prescriptive nature), and finally, enabling comparisons between entities (comparative nature).

MMs are practical tools that play a crucial role in evaluating and improving business processes. Despite their usefulness, there is a lack of comprehensive literature reviews that provide a complete overview of MMs in SCML, addressing the needs of both academics and practitioners. Numerous maturity models have been crafted with a specific focus on supply chain management, exemplified by the renowned SCMMM by Lockamy [35] and S(CM)2 by Reyes and Giacchetti [36]. However, scant attention has been directed toward exploring their interrelation, impact, and roles in shaping models that encompass logistics processes in sustainable supply chains [37]. As a matter of fact, existing reviews prove to be limiting, with a specific focus and a small number of analyzed articles (Table 1). Among the most recent reviews, the study by Vance et al. [38] analyzes 19 models for smart manufacturing. Additionally, the review conducted by Correira et al. [39] focuses on the analysis of 11 MMs specifically addressing Sustainable Supply Chain Management. Similarly, Kosacka-Olejnik [40] examines 11 MMs related to logistics in the service sector. Furthermore, Hellweng et al. [41] provides a comprehensive summary of the contribution of 28 MMs to Digital Supply Chains. Other reviews instead only compare selected models without conducting in-depth content analysis. Mittal et al. [42] compares 15 models that contribute to the introduction and application of Industry 4.0 in the manufacturing sector, while Hansali et al. [1], Bvuchete et al. [43] and Cheshmberah and Beheshtikia [44] compare 49, 13, and 28 supply chain management models. Finally, reviews integrating bibliometric and content analyses have also recently emerged, such as those by Angreani et al. [45] and Pavan et al. [46], which are not fully representative due to the small sample size (19 and 17 papers, respectively). In contrast, the recent work by Kucińska-Landwójtowicz et al. [47] addresses this limitation by utilizing a more appropriate sample size for the analysis, covering a considerable time span. However, it is worth mentioning that this bibliometric analysis focuses primarily on organizational maturity models, with SCML being a subgroup within that context. In order for research to advance in a specific area, it is crucial to comprehend the existing state of the literature, recognize prevailing trends and topics of significance, and pinpoint potential opportunities for future enhancements. Therefore, this work aims to fill the former gaps by conducting a bibliographic and content analysis, to present the state of the art of MMs for SCML. It is important to note that the primary objective is to provide an overview of the existing landscape rather than a direct comparative assessment of individual maturity models. More specifically, we aim to answer the following research questions (RQs):

(RQ1) What are the main research contributions to MMs for SCML?
(RQ2) How have the topics evolved and related to each other over time?
(RQ3) What are the key decision criteria for defining, designing, and applying MMs for SCML?
(RQ4) What are the potential future developments for MMs for SCML?

Table 1. Recent literature reviews on MMs for SCML have been categorized based on their research method, content sample, and research focus.

Paper	Research Method			Content Sample		Review Focus
	Bibliometric Analysis	Content Analysis	Comparative Analysis	Horizon	Size	
Kucińska-Landwójtowicz et al. (2023) [47]	X			1980–2019	597	Organizational Maturity
Vance et al. (2023) [38]		X		2013–2022	19	Smart Manufacturing
Pavan et al. (2022) [46]	X	X		2013–2021	19	Sustainable Supply Chain Management
Hansali et al. (2022) [1]			X	1989–2021	49	Supply Chain
Hellweng et al. (2021) [41]		X		2014–2019	28	Digital Supply Chain
Angreani et al. (2020) [45]	X	X		2011–2019	17	Industry 4.0 for manufacturing and logistics
Kosacka-Olejnik (2020) [40]		X		2010–2016	11	Logistics in the service industry
Cheshmberah and Beheshtikia (2020) [44]			X	1995–2019	28	Supply Chain Management
Bvuchete et al. (2018) [43]			X	1989–2016	13	Supply Chain
Mittal et al. (2018) [42]			X	2015–2018	15	Smart Manufacturing and Industry 4.0
Correia et al. (2017) [39]		X		2006–2015	11	Sustainable Supply Chain

Accordingly, the research has three primary objectives. Firstly, it aims to provide a comprehensive view of MMs, including their evolution, clustering, and relationship within the SCML framework. Secondly, it analyzes the research findings based on a classification that highlights the key stages and criteria of MM scope, design, and application. Lastly, by representing the state of the art, it identifies significant research gaps and proposes future enhancements.

As a reminder, the article is structured as follows: Section 2 outlines the materials and methods adopted in this work, including the literature search, bibliometric analysis, and content analysis. Section 3 presents the research results, which are discussed in Section 4, focusing on research gaps and proposing five areas for future enhancements on MMs for SCML. Finally, Section 5 provides the conclusions.

2. Materials and Methods

The methodology of this study employs a three-step approach [48], consisting of a literature search, a bibliometric analysis, and a content analysis (Figure 1). The literature search begins with identifying the topic and determining the relevant databases to be used. Next, keywords are listed, classified, and combined to create a search string for use in search engines (identification phase). The literature search concludes with defining the criteria for article selection through the screening and eligibility phases. The selected articles (inclusion phase) are then analyzed through both bibliometric and content analysis. The bibliometric analysis provides a quantitative assessment of the relevance and scientific evolution of the topic by examining metadata. It helps map the major research contributions in the domain of MMs for SCML (RQ1), then identifies the relationships and evolutions of these topics over time (RQ2). The content analysis addresses RQ3 and RQ4 and involves a qualitative and quantitative interpretation of the included papers. By answering the former RQs, the study aims to provide insights into the major contributions, decision criteria, and future enhancements for SCML MMs.

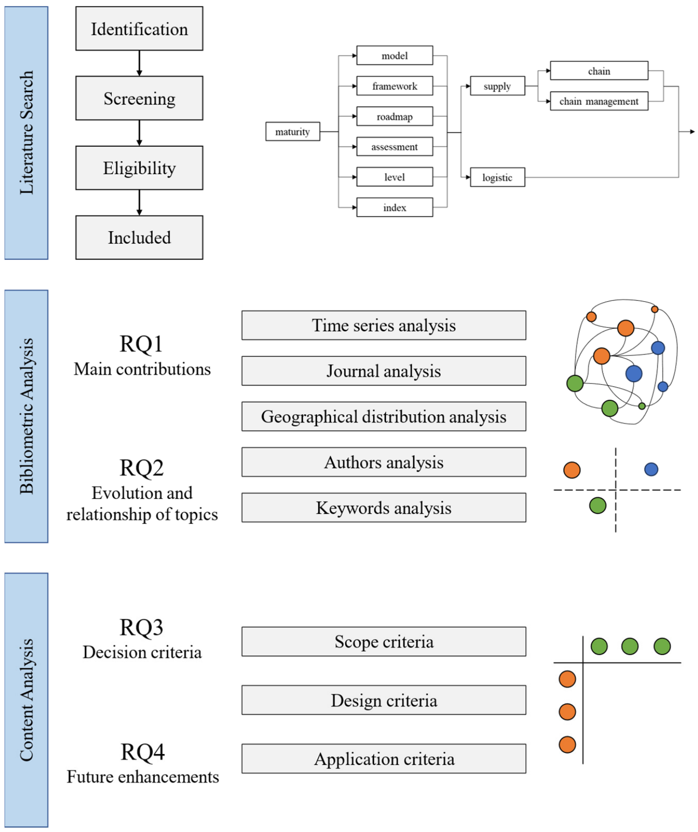

Figure 1. The conceptual framework of this work encompasses three phases: literature search, bibliometric analysis, and content analysis.

2.1. Literature Search

The scientific papers analyzed were selected by using the following approach. The first step of the methodology involves identifying MMs in SCLM. Then, Scopus was chosen as the search engine since it is considered the best research solution for scientific journal coverage [49]. To generate the initial sample of records (identification phase), the identified keywords were combined. These keywords were classified into two semantic areas: Semantic Area 1, related to maturity tools, and Semantic Area 2, related to SCLM. To form the search string, keywords within each semantic area were combined using the 'OR' operator, indicating that any of the keywords could be present. The two groups of keywords were then combined using the 'AND' operator, indicating that both groups of keywords needed to be present in the search results. Additionally, the operator "' was used to maintain the consecutive order of multiple words and the operator '*' was used to include words with the same root but different suffixes. Based on the previous considerations, the following search query was obtained:

("maturity model" OR "maturity framework" OR "maturity roadmap" OR "maturity grid" OR "maturity assessment" OR "maturity level" OR "maturity index") AND ("supply chain" OR "supply chain* management" OR logistic*)*

After inserting the search query on Scopus, the obtained results were further refined through a screening phase based on specific inclusion criteria. The inclusion criteria consisted of selecting articles within the subject areas of 'Engineering', 'Business, Management, Accounting', and 'Decision Science'. Only articles falling under the categories of 'Articles', 'Conference Papers', and 'Reviews' were considered. Moreover, only articles written in English were included in the analysis. The next step involved evaluating the relevance of the articles in relation to MMs for SCML. Initially, a screening process was conducted by reviewing the title, abstract, and keywords of each article. Subsequently, the full text of the selected articles was examined to determine their suitability for the study. Through this process, articles of interest were identified and included in the final sample of scientific papers for further analysis. Cross-referencing was employed to ensure comprehensive coverage and to enhance the robustness of the selected articles. More in detail articles of interest among the selected document references were analyzed, and the most relevant ones were included.

The initial search string yielded 547 documents. After filtering the results based on reference area, document type, and English language, 293 records remained. Following a review of the title, abstract, and keywords, 149 documents were selected, while 144 were discarded. Subsequently, upon reading the full text, 17 additional results were excluded for various reasons. One document did not directly address SCML, some papers had incomplete (6 of the 17 articles excluded) or nonexistent models (4 of the 17 articles excluded), and others were not focused on processes (6 of the 17 articles excluded), as product or people-oriented. Here are examples provided to clarify the exclusion criteria. Alfaro Santa Cruz et al. [50] presents a model aimed at enhancing inventory management, which comprises two dimensions and seven sub-dimensions that do not align with any maturity level. Benmoussa et al. [6] does not introduce a maturity model; rather, they compare an operational standard with a generic CMMI to assess its applicability as a model-based proposal. Jäger et al. [51] proposes a people-based model for evaluating the excellence of logistics operators. Then by cross-referencing, 5 articles were included, resulting in a final sample of 137 documents. This final sample, consisting of 126 articles and conference papers, along with 11 reviews, was used to analyze the state of the art of MMs for SCML. The analysis employed an integrated approach of bibliometric and content analysis, the methodologies of which are explained in the following paragraphs.

2.2. Bibliometric Analysis

Bibliometric analysis is a research methodology that utilizes algorithms, arithmetic, and statistics to analyze large quantities of data [52]. It provides an objective representation of contributions and relationships between different factors. There are two main categories of bibliometric analysis: performance analysis and science mapping [53]. Performance analysis focuses on research contributions, such as publication metrics, citation metrics, and citation-and-publication metrics. Science mapping, on the other hand, examines relationships through citation analysis, co-citation analysis, bibliographic coupling, co-word analysis, and co-authorship analysis. Network metrics, clustering, and visualization techniques are commonly employed to enhance the analysis. Several authors have recently conducted this type of analysis [54,55], highlighting its usefulness and contribution to research. The development of bibliometric analysis has been mainly facilitated by the availability of bibliometric software, including Bibliometrix [56], VOSviewer [57], and Gephi [58]. For this study, bibliometric analysis was conducted using the VOSviewer 1.6.17 and Bibliometrix 4.0 software, ResearchRabbit [59] tool, as well as a spreadsheet, to analyze the metadata from the 137 selected articles and answer to RQ1 and RQ2. The following analyses were performed:

- Time series analysis: This analysis represents the trend of publications over time and the source types (articles, conference papers, reviews). A spreadsheet was used to analyze the total number of publications per year, which is visualized in a time histogram.
- Journal analysis: This analysis identifies the most relevant journals by examining the total number of publications, the total number of citations, and citations per publication per year per journal. Bibliometrix software was used for this analysis.
- Geographical distribution analysis: This analysis identifies the most active countries in terms of publishing MMs for SCML. The analysis used the geographical location of the research affiliations as a metric, and the results are presented on a geographical map.
- Authors analysis: This analysis identifies the most relevant and productive scholars. A spreadsheet was used to analyze the total number of publications, the total number of citations, and citations per publication per individual author (Equation (1)). The Qualitative Author's Relevance Assessment (QARA) visualization tool was utilized to present the results [55].

$$\mathrm{CPP} = \frac{\text{Total number of citations}}{\text{Total number of publications}}, \tag{1}$$

- Keywords analysis: This analysis examines the relevance, evolution, and ranking of keywords used by authors [60]. The analysis was performed using Bibliometrix and VOSviewer software, and the results are presented through co-occurrence, co-citation, bibliographic coupling networks, trend topics, and thematic maps [61].

These analyses provide insights into the publication trends, key journals, active countries, influential authors, and important keywords related to MMs for SCML.

2.3. Content Analysis

The content analysis is conducted after the bibliometric analysis and aims to answer RQ3 and RQ4. Out of the 137 results, only journal and conference articles were analyzed in terms of content, excluding reviews. This choice was made for two reasons. Firstly, the majority of the academic references cited in the reviews are part of the articles included in the literature search phase. Secondly, we aim to conduct a comprehensive comparison and detailed analysis of the contributions made by each individual MM to the SCML during the content analysis. The content analysis consisted of three sub-phases:

- Scope criteria: This sub-phase involves identifying and classifying the domains of interest of MMs. It includes determining which level of the supply chain the MMs address [39], the focus of the MMs, the type of maturity considered, and the operational processes involved.
- Design criteria: In this sub-phase, the assessment tool, design process, and architecture of the MMs are examined. This includes analyzing the number of levels, dimensions, and sub-dimensions within the MMs [15,33].

- Application criteria: The final sub-phase focuses on the life cycle phase of the MMs [34], as well as their nature and areas of application [46].

The criteria used for both bibliometric and content analysis are summarized in Table 2. These analysis phases and criteria were employed in this work to provide a comprehensive understanding of the state of the art of MMs for SCML, thus addressing the stated RQs.

Table 2. The analyses were categorized based on criteria such as paper identification, scope, design, and application. Each of these criteria was further divided into relevant sub-criteria.

Criteria	Sub-Criteria	Analysis
Paper identification	Publication year	Time series analysis
	Source type	Source analysis
	Publication country	Geographical distribution analysis
	Authors	Authors analysis and citation analysis
	Keywords	Keywords analysis
Scope	Domain	Technologies, operations, green, safety, attributes, other
	Supply Chain Level	Organization, process, network
	Type of Maturity	Maturity, capability, readiness, diffusion, transformation
	Process	Supply chain management, logistics, manufacturing, procurement, sales and operation planning
Design	Assessment Tool	Framework, CMM-based, Likert-like questionnaire, Maturity grid
	Design Process	Theory-driven, practitioner-based, mixed approach
	Architecture	Number of levels, dimensions, and sub-dimensions
Application	Phase	Integration, design, validation, application
	Purpose	Descriptive, comparative, prescriptive
	Sector	Number of evaluations per sector

3. Results

The 137 documents that emerged through the literature search were submitted to the bibliometric analysis, leading to the results described in Section 3.1. As already mentioned, the bibliometric analysis examined the temporal and geographical distribution of articles, as well as journal and author analysis. Additionally, keyword analysis was conducted to identify the relevance and evolution of keywords used in the selected articles. Following the bibliometric analysis, the content analysis was performed on the selected articles, leading to the results in Section 3.2. The content analysis focused on the scope, design, and application of MMs for SCML. The subcategories within each analysis phase were examined to provide a comprehensive understanding of the state of the art of MMs for SCML. Among the results of the content analysis, we included the findings from the scope, design, and application analyses, along with their respective subcategories.

3.1. Bibliometric Results

The analysis of the temporal distribution of publications on MMs for SCML reveals that their application in these fields gained traction in the 2000s [62]. Therefore, the time series analysis conducted in the research paper covers the period from 2001 to 2023. Figure 2 depicts the publication trend, showing that the topic remained relatively inconspicuous until 2015, after which, as a matter of fact, a noticeable growth was observed. The peak year was 2021, with a total of 24 papers (18 articles, five conference papers, and one review) published. It is possible to state that although this topic is particularly recent, there is a growing interest in the scientific community for potential academic and practical contributions. The literature search focused on a specific niche application of MMs, namely

MMs for SCML. However, the results also indicate an increasing interest in broader research trends such as Industry 4.0 [41,45] and sustainability [39,46]. These emerging areas have contributed to the growing number of publications on MMs for SCML. In terms of document type, the majority of the selected papers are articles, accounting for 64% (87 out of 137). Conference papers represent 30% (3 out of 137) of the total, while reviews constitute 8% (11 out of 137).

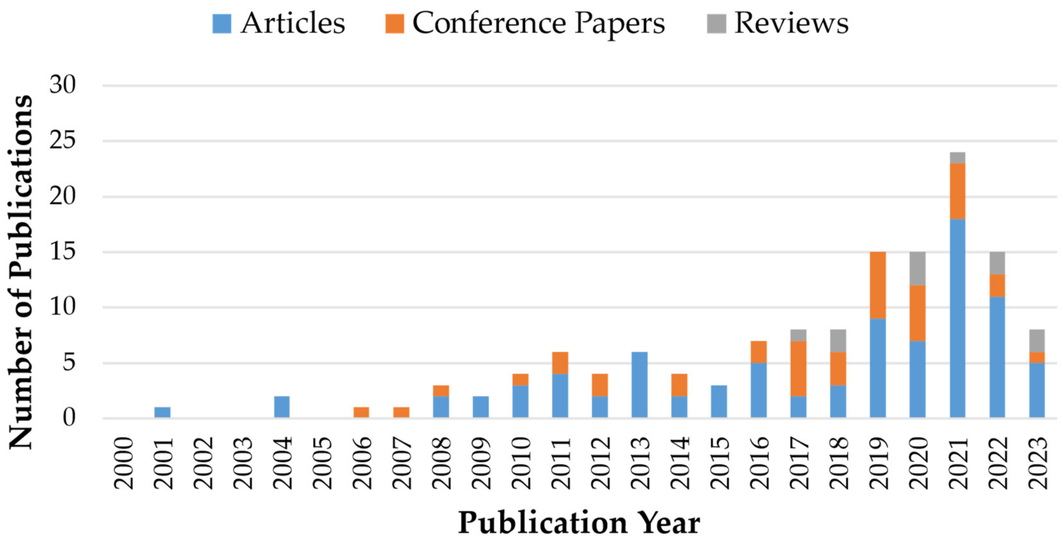

Figure 2. The representation depicts the time series analysis of the selected articles based on publication number and year of publication.

The 137 selected papers on MMs for SCML are distributed across 87 different sources among journals and conference proceedings, resulting in an average of 1.57 publications per source. Most of the sources (65 out of 87) have only one publication, while nine sources have two publications. Only 13 sources have a higher number of publications, ranging from 3 to 6. Table A1 illustrates the temporal evolution of the 13 most productive journals. The top 13 journals contribute to a total of 54 publications, accounting for approximately 39% of the selected articles. The two most prominent sources in terms of publication count are IFIP Advances in Information and Communication Technology (IFIP) and Procedia Manufacturing, both with six publications. It is noteworthy that although the analysis covers a period starting from 2001, most of the influential journals in this field emerged after 2015, coinciding with the significant growth of the topic. An effective representation of the most productive sources is that described by Brandford's Law [63]. This law divides the sources into three zones by decreasing the number of publications distributed according to a geometric series. The first zone, described by the grey rectangle in Figure 3, contains the sources most relevant to the topic of MMs for SCML, which in this case is number 11. Next to the first two sources already mentioned are the International Journal of Production Economics (IJPE—5 publications), LogForum (5 publications), Sustainability (Switzerland) (SUS—5 publications), Benchmarking (BEN—4 publications), Production Planning and Control (PPC—4 publications), Supply Chain Management (SCM—4 publications), Advances in Intelligent Systems and Computing (AISC—3 publications), Applied Sciences (Switzerland) (AS—3 publications), and Business Process Management Journal (BPMJ—3 publications).

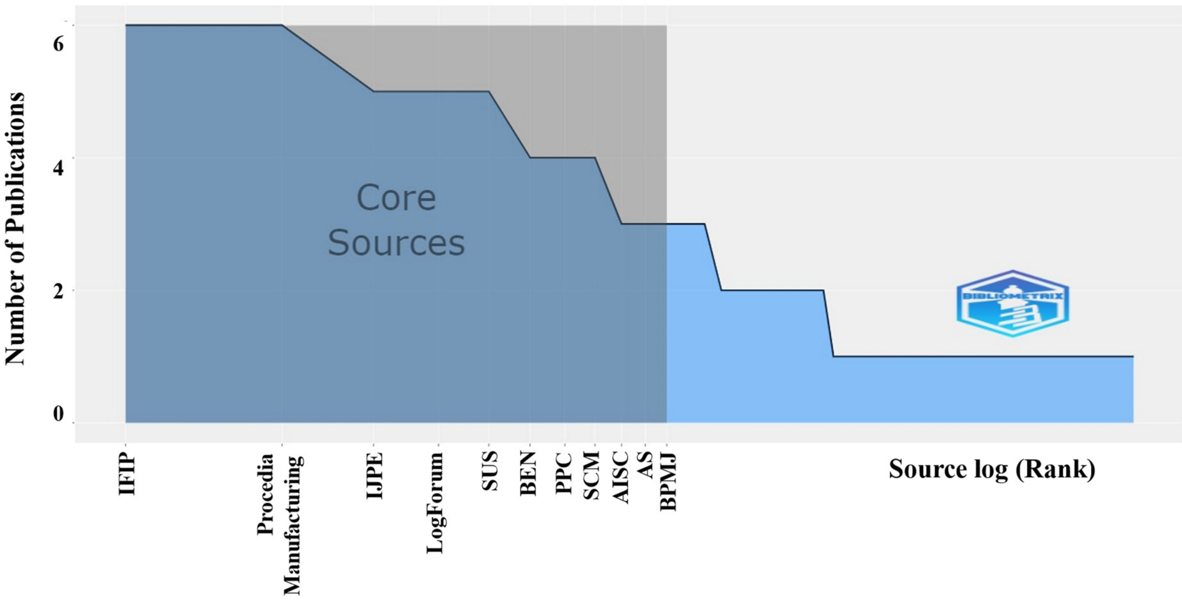

Figure 3. The representation demonstrates Brandford's law, which ranks the sources from the most to the least relevant based on the total number of publications.

While the total number of publications provides a measure of productivity, it does not necessarily indicate the influence of the journals. To assess the impact of the sources within scientific research, the total number of citations is a relevant metric. On average, the selected journals in the field of MMs for SCML have an average of 36.7 citations each. However, only 12 sources have surpassed the threshold of 100 citations. The most influential sources in terms of citations include the International Journal of Production Economics (1102 citations), the Journal of Manufacturing Systems (528 citations), and Supply Chain Management: An International Journal (403 citations). To determine the combined relevance and impact of the journals, the Citations per Publication (CPP) metric is employed. Table A2 in Appendix A provides a ranking of the 12 journals based on CPP in descending order. Among these journals, the International Journal of Production Economics (220.4 CPP) and Supply Chain Management (68.75 CPP) stand out as both relevant and influential sources.

The 137 documents on MMs for SCML are geographically distributed across 41 territories worldwide. The distribution was determined by identifying the geographical origin of the authors' affiliations. The analysis reveals that Europe, with 100 occurrences in 21 countries, and the Americas, with 41 occurrences in four countries, are the continents with the highest relevance in terms of contributions. Across these two continents, the majority of contributions are concentrated in five countries, which demonstrate a strong interest in the research on MMs for SCML: Brazil (20 occurrences), United States (19 occurrences), United Kingdom (15 occurrences), Germany (14 occurrences), and Poland (13 occurrences). On the other hand, the Asian continent has 18 occurrences spread across ten countries, while the Oceanic continent has nine occurrences in two countries. As a matter of fact, the African continent has the lowest number of occurrences (six) pertaining to the two countries. These regions show relatively less prominence in terms of contributions to the topic compared to Europe and the Americas. Figure 4 provides a visual representation of the geographical distribution of the included documents.

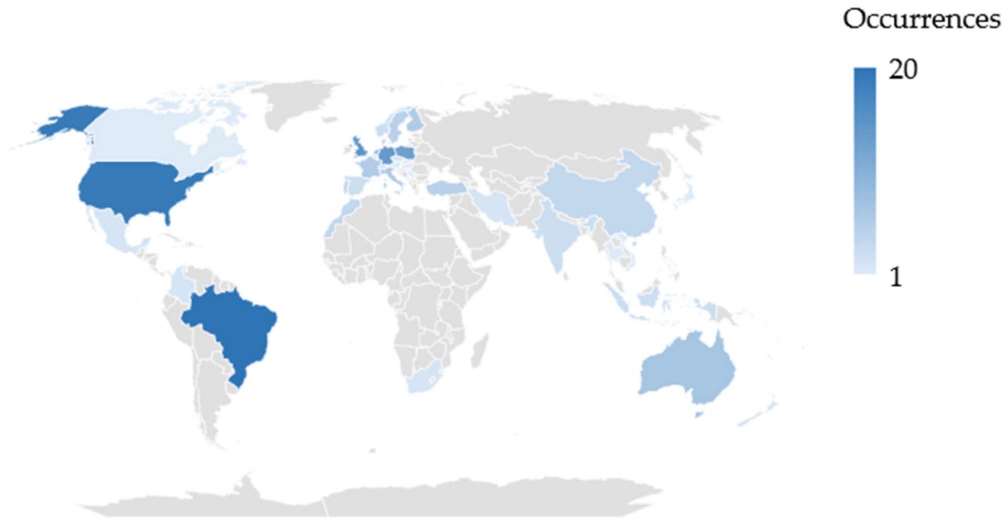

Figure 4. The figure illustrates the geographical distribution of authors' affiliations.

Authors Analysis and Keywords Analysis

The analysis of the 137 articles reveals that they were authored by a total of 377 authors, resulting in an average of 2.75 authors per article. To assess the relevance and influence of individual authors, metrics such as the total number of publications and total number of citations were used. In terms of relevance, the majority of authors (338 out of 377, approximately 90%) are associated with only one publication, and a small portion (39 out of 377, approximately 8%) are associated with two publications. Only nine authors have more than two publications, with the most prominent ones being Werner-Lewandoska K. (7 publications), Kosacka-Olejnik M. (five publications), and McCormack K. (four publications). On the other hand, the following scholars are characterized by the highest number of citations: Wang et al. [17] with 820 citations, followed by Mittal et al. [42] with 528 citations, and Lockamy [11,35] with 339 citations. The combination of relevance and influence was mediated by the CPP metric. Figure 5 shows the analysis results for the nine authors who have at least three publications, arranged in descending order of CPP from 2004 to 2023. QARA tool was used to represent the findings [55]. QARA provides an aggregated view of the most important information for author analysis. In the visualization, the size of the circles represents the number of publications, and the color scale (from blue to red) represents the total number of citations. The connections between circles indicate the time span and continuity of the authors' academic contributions. From the results, it can be observed that authors like Fawcett S.E. and McCormack K. are two of the most influential ones, having the same number of publications and being among the oldest in terms of publishing. A more recent and highly influential author is Garza-Reyes J.A. Indeed, when considering the color scale of the QARA tool, Fawcett stands out as the only one marked with a dark red dot, followed by Garza-Reyes J.A. with two yellow dots, McCormack, and Scavarda L.F. with a yellow dot. Authors such as Thomé A.M.T., Lauras M., Werner-Lewandoska K., and Hellingrath B. are more recent contributors with fewer CPPs. This indicates that the field of MMs for SCML is continually evolving, driven by both established and emerging authors. The visual representation in QARA provides valuable insights into the authors' contributions, allowing for a comprehensive understanding of their publication history and impact.

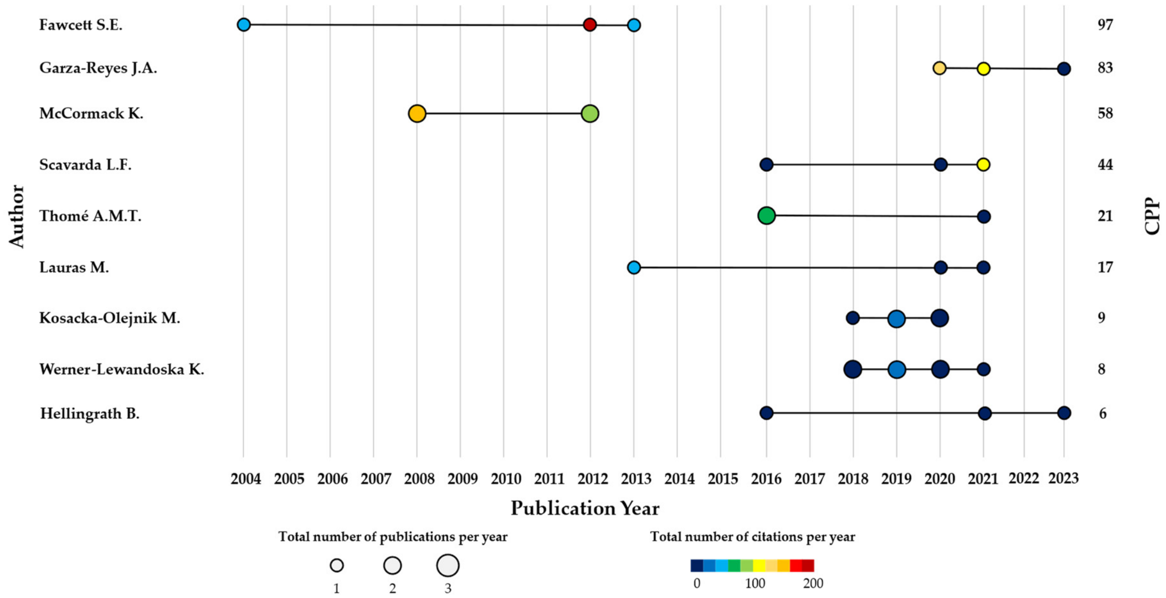

Figure 5. The representation of the most relevant and influential authors with at least 3 publications in the MMs for SCML is performed using the QARA tool. The authors are sorted in descending order based on their CPP value, considering the publication years on a time scale. For each author, their research contribution is depicted by the size of the circles, while the impact is represented by the color of the circles.

Although the QARA tool effectively represents the relevance and impact of individual authors, it does not provide insights into their relationships. To address this limitation, network analysis representations were conducted using the ResearchRabbit and VOSviewer tools. Figure 6 illustrates a relational map between groups of authors exhibiting high content similarity. Out of the 137 papers authored by 377 individuals, only 135 papers were identified. From this set of identified articles (represented by the nodes in green), an additional 40 papers (represented by the nodes in blue) were identified as relevant for similarity. The results primarily span from 1991 to 2018, with a majority of 37 out of the 40 articles falling between 2012 and 2018. Notably, the most significant contributions originate from the works of Röglinger et al. [64], Seuring and Müller [65], and Estampe et al. [5]. To conclude the analysis of the authors, it was intriguing to observe the mutual influence among authors, as well as the relationships between authors who share the same references. To achieve this, co-citation analysis and bibliographic coupling analysis were conducted. In the co-citation analysis, a minimum citation value of 10 was utilized. Out of the total of 377 authors, the most relevant ones were identified, resulting in 161 authors grouped into 4 clusters, as depicted in Figure 7. Conversely, the bibliographic coupling analysis focused on authors with a minimum of two publications, narrowing down the initial 377 authors to a sample of 38, which were then divided into six clusters, as shown in Figure 8. The findings from both analyses reveal that, despite the timeliness of the topic, there is a significant level of mutual influence among authors who share a common set of articles.

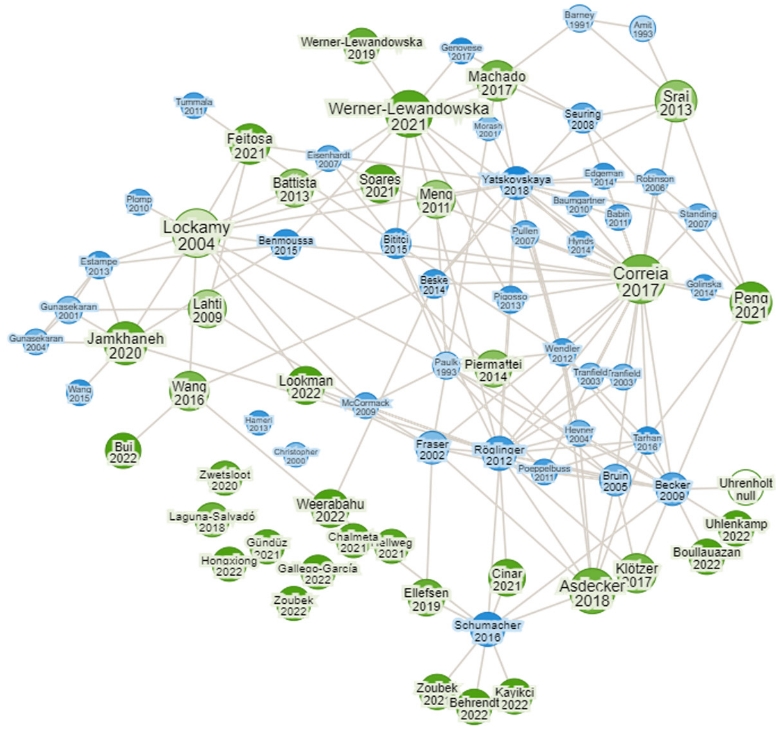

Figure 6. The representation depicts the relationship among papers with the highest degree of content similarity.

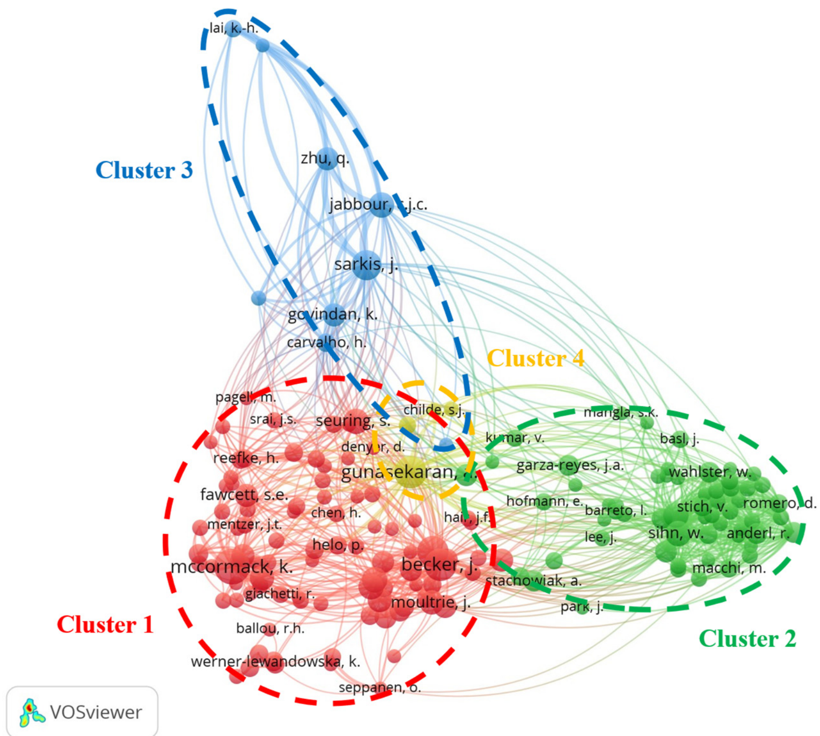

Figure 7. The representation of co-citation analysis to determine the mutual influence among authors in the field of MMs for SCML.

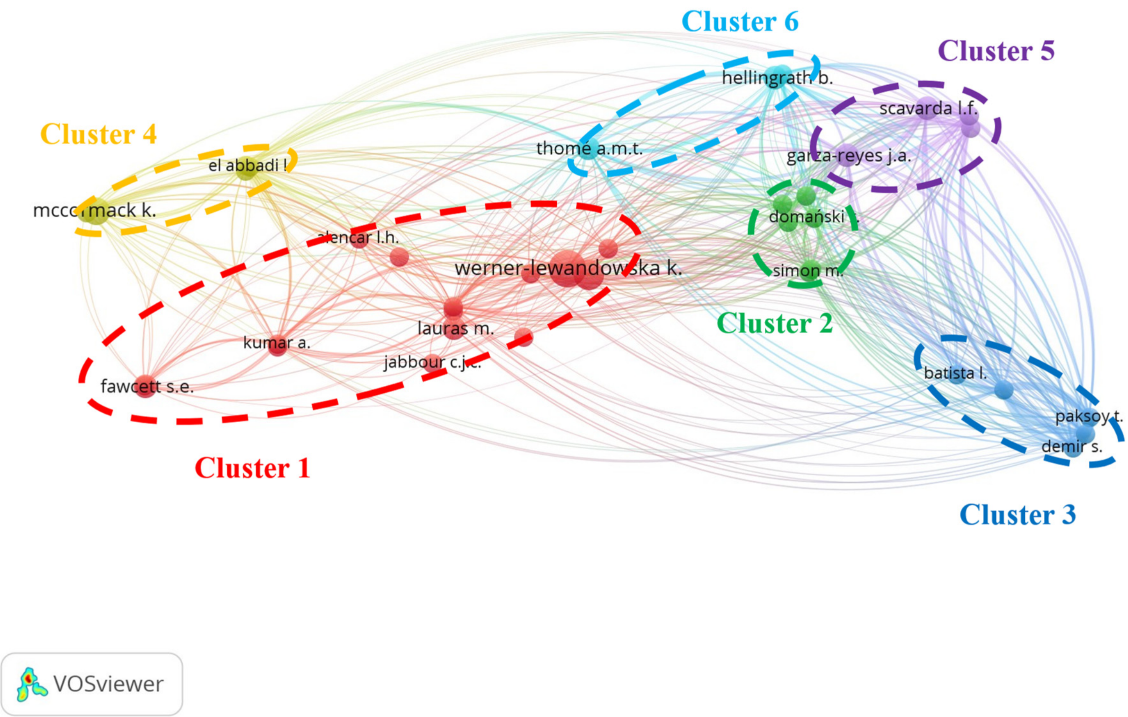

Figure 8. The representation involves conducting a bibliographic coupling analysis to identify the relationship between authors who share common references in the field of MMs for SCML.

The keyword analysis was represented by using two graphic visualization tools: the co-occurrence map and the thematic map. The co-occurrence map displays the relevance and relationships between keywords based on co-occurrence analysis. The analysis considered index keywords and utilized a minimum occurrence value of 3. Figure 9 illustrates the results, focusing on 43 keywords out of a total of 544, which were classified into six clusters. Appendix A (Table A3) provides additional information on the clusters, occurrences, and total link strengths (TLSs) of the keywords. The top five most frequently occurring keywords are "maturity model" (Occurrence = 31, TLS = 109), "supply chain management" (Occurrence = 27, TLS = 88), "supply chains" (Occurrence = 26, TLS = 91), "software engineering" (Occurrence = 11, TLS = 44), and "sustainable development" (Occurrence = 11, TLS = 43). These keywords form the foundation of the research on MMs for SCML. Notably, the keyword "logistics" has fewer occurrences (Occurrence = 3, TLS = 7) compared to other frequently used keywords. Within these, it is interesting to note that the context of software engineering is persistent, revealing that MMs have established themselves within that area. Furthermore, the term "sustainable development" is also gaining ground within this theme. The 43 keywords were grouped into six clusters, each representing specific focus areas. Cluster 1 (red) consists of 12 keywords related to the topic of digital transformation and Industry 4.0. Cluster 2 (green), comprising nine keywords, reflects performance optimization, mathematical models, and data analysis. Cluster 3 (blue), with eight keywords, focuses on the application of MMs in the areas of supply chain and logistics. Cluster 4 (yellow), containing seven keywords, explores sustainability and sustainable development. Cluster 5 (purple), consisting of five keywords, is specific to the maturity modeling. Finally, Cluster 6 (pale blue) encompasses only two keywords specific to the construction and project management sector.

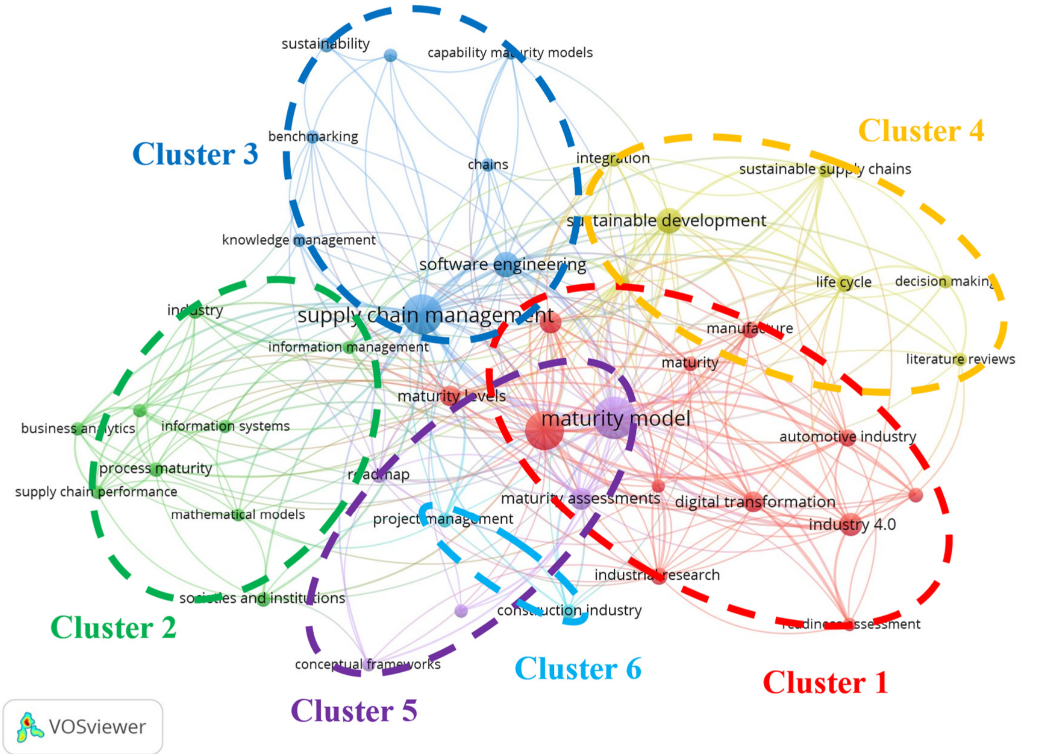

Figure 9. The representation of the co-occurrence map to visualize the relationship among index keywords.

The thematic map, on the other hand, allows groups of keywords to be analyzed according to four classifications [61]. This map analyses the groups of keywords by means of two quantities on two orthogonal axes. The first quantity shows the degree of relevance (centrality) of keywords, while the second shows their degree of development (density). The intersection of the two dimensions divides the space into four quadrants representing different subject areas. On the top right are the highly developed and research-relevant areas labeled 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. Although the thematic map reports the results of a specific range, several studies use this technique dynamically to represent the evolution of keywords within the scientific research [66,67]. For this reason, three time periods were selected, which, in this case, divided the 137 selected scientific papers almost evenly. The three reference sub-periods are the intervals 2001–2016 (44 publications, approx. 32%), 2017–2020 (46 publications, approx. 34%), and 2021–2023 (47 publications, approx. 34%). Figure 10 shows the thematic map for the three sub-periods and that of the entire time interval. An analysis of the keyword groups reveals five clusters of interest: (1) supply chain management, (2) maturity model, (3) risk management (describing conceptual frameworks and accident prevention), (4) digital transformation, and (5) sustainability. In the first sub-period, from 2001 to 2016, six clusters are identified, including the most relevant ones with a low degree of development. The cluster with the highest number of occurrences is the supply chain management cluster (38 occurrences out of 10 keywords), which is positioned as an emerging or declining theme, followed by the maturity model cluster (34 occurrences out of 10 keywords) as a basic theme. The risk management cluster (eight occurrences out of four keywords), on the other hand, is a niche theme in this period. The second sub-period, from 2017 to 2020, turns out to be the most populated one, recording nine clusters of keywords with a high concentration in the areas tending towards the bottom right. In this sub-period, the maturity model cluster is the most relevant one (22 occurrences out of six keywords), remaining within the basic themes. Similarly, the supply chain management cluster (10 occurrences out of two keywords) remains within the lower left-hand quadrant with a tendency towards decline. Little change is recorded in the risk management cluster (four occurrences on two keywords), which continues to be a niche theme. Among the five new clusters, it is interesting to note that of digital transformation (4 occurrences out of two keywords), which is positioned within the basic theme. The last period, from 2021 to 2023, sees seven clusters of keywords positioned towards the upper right direction. Among the above-mentioned clusters, only the maturity model cluster (34 occurrences out of seven keywords) is persistently positioned toward relevant motor themes. A similar shift in direction but with greater intensity is that of the digital transformation cluster (10 occurrences out of three keywords), which moves from basic theme to motor theme. Finally, the sustainability cluster (seven occurrences out of three keywords) stands out of interest among the emerging or declining themes, affirming the trend on the concept of sustainable development also within the MMs for SCML. Overall, over the entire reference period, it can be stated that five clusters (out of a total of nine) are of relevance or recurring over time. With a high degree of relevance, the supply chain management cluster (76 occurrences out of 18 keywords) is positioned in the motor themes. Therefore, this topic appears to be relevant for the domain of MMs for SCML but has become general in nature. The recurring clusters with the highest degree of development are those of the maturity model (135 occurrences out of 25 keywords) and digital transformation (31 occurrences out of 10 keywords). In particular, the digital transformation cluster is disputed between niche theme and motor theme. In fact, in recent years, several authors have started to deal with readiness MMs [22,68] and transformation MMs [69,70] in view of the digitization process. Finally, the risk management cluster (five occurrences out of two keywords) appears to be declining, and the sustainability cluster (13 occurrences out of five keywords) is emerging, within which the theme of logistics is reiterated. The research is therefore taking an emerging approach to these two themes, which are aligned with the current work of Werner-Lewandowska and Golinska-Dawson [21] for assessing the maturity of sustainable logistics.

3.2. Content Results

The analysis of keywords through the co-occurrence map and thematic map provided insights into the most frequently treated topics, their relationships, and their development over time. These results serve as the foundation for a detailed content analysis, which allows for an examination of the topic's development across different conceptual areas [71]. The content analysis focuses on three main stages of MMs: scope, design, and application. Each MM exhibits specific characteristics in terms of conceptual domain, level of application, and operational process. The keyword analysis revealed domains such as digitization (Industry 4.0) and sustainability, which are developed through process activities related to SCML, including manufacturing, sales and operation planning, and procurement. MMs also consider different areas of the supply chain, starting from process activities within individual organizations and extending to groups of organizations forming a network. Furthermore, MMs can be classified based on the improvement objective they aim to achieve, such as maturity, readiness, or transformation. The first section of the content analysis focuses on the conceptual area of defining MMs for SCML. The design of MMs follows a procedural approach outlined by previous research [15,33], although not all works strictly adhere to these steps. The design process can be driven by academics (theory-driven), practitioners (practitioner-based), or a combination of both (mixed approach). The design also encompasses the structure of MMs, including the number of levels, dimensions, and sub-dimensions. Additionally, a maturity assessment system needs to be established, which involves classifying models according to assessment types that vary in complexity and practical use, such as frameworks, CMM-based approaches, Likert-like questionnaires, or maturity grids. The second section of the content analysis focuses on the subject area of

MM design, while the final section examines the application of MMs. Although MMs have practical potential and can be descriptive, comparative, or prescriptive in nature [34], not all MMs are applied. Some MMs are only defined through design or integration or validated for single or multiple industry cases. Therefore, the content analysis will report the scope, design, and application of MMs for SCML. For a complete overview of the content analysis, please refer to Appendix B, specifically Table A4.

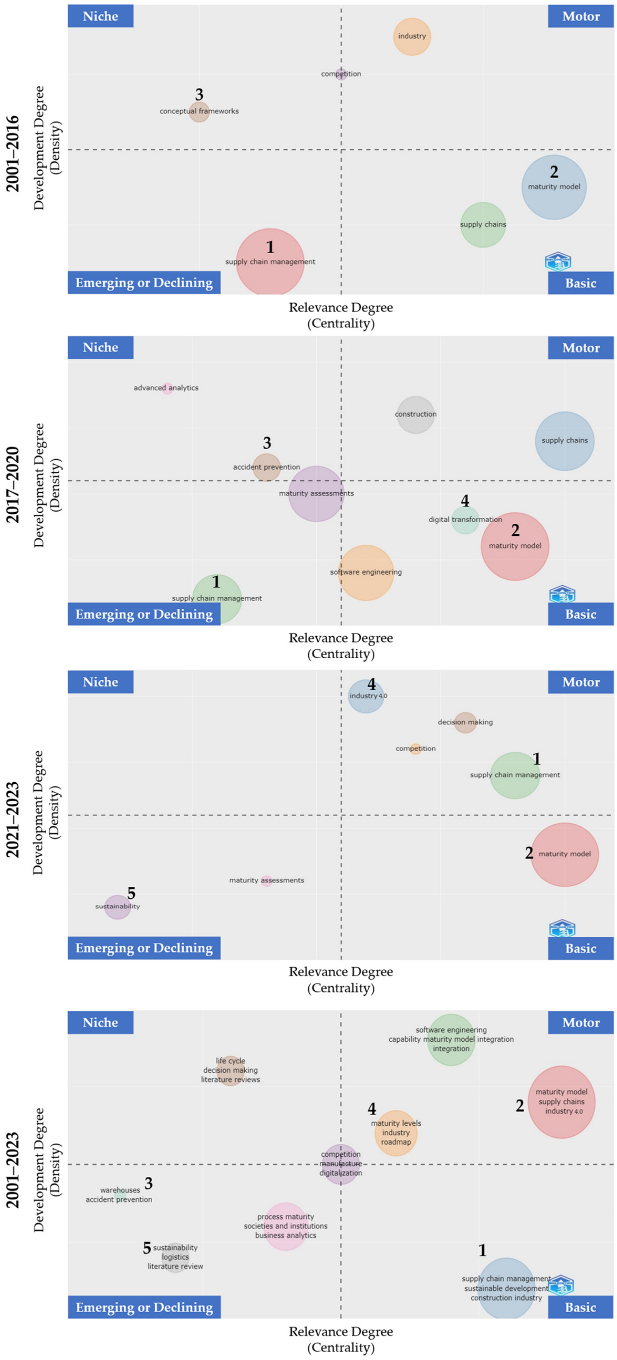

Figure 10. The representation involves visualizing the evolution of keywords using a thematic map. Index keywords are classified into distinct clusters and positioned in four quadrants, indicating the level of relevance and development for each cluster. The evolution is presented across three-time intervals: 2001–2016, 2017–2022, and 2021–2023, allowing for dynamic keyword analysis. Additionally, the entire time interval of 2001–2023 is considered, providing a static keyword analysis. Five relevant clusters were identified for static and dynamic analyses: (1) supply chain management, (2) maturity model, (3) risk management, (4) digital transformation, and (5) sustainability.

3.2.1. Scope Criteria of MMs for SCML

MMs are used to evaluate and improve systems that consist of processes, objects, and people. They represent the progress of a system within specific focus areas or domains [72]. The domains can vary in nature and can be related to different aspects. In the literature, researchers have identified various domains for MMs. For example, Correia et al. analyzed the domains of "sustainability" and "supply chain sustainability" in their literature review [39]. Kayikci et al. proposed dimensions and sub-dimensions within the domains of "industry 4.0" and "circular economy" [73]. Excluding the reviews, in the analysis of the 126 articles, six domains were identified to classify the focus areas for which MMs were developed, validated, or applied. These domains include operations, technologies, attributes, green, safety, and others. The operations domain covers MMs that directly address activities related to SCML. The technology domain encompasses tools that enable technological digitization in supply chain and logistics management processes, including the artificial intelligence [74], big data analysis [75], and cybersecurity [76]. The attributes domain includes elements that determine specific characteristics of management processes, such as flexibility [77], alignment [78], or innovation [79]. The green and safety domains represent concepts related to environmental and social sustainability. The last domain includes elements that do not fit into the other domains and do not share common characteristics with each other.

The 126 articles were then analyzed by means of a content analysis, whereby subdomains were identified and subsequently counted by a number of occurrences. Furthermore, as some of the documents belonged to different domains, the relationships between domains are analyzed. In Figure 11, a circular relationship diagram shows the occurrences of the individual subdomains and relationships. The relationships within the diagram are represented by lines such that the thicker the line, the greater the occurrence of relationships. From the results, the solid line indicates the value of one relationship between two elements, while the dotted line indicates the value of two relationships. The analysis identified 39 subdomains, respectively 11 for the operations domain, eight for technologies, 11 for attributes, two for green, three for safety, and three for other. Among the 39 subdomains, those registering the highest value of occurrences are Industry 4.0 (technologies domain with 35 occurrences), Supply Chain (operations domain with 22 occurrences) and Sustainability (green domain with 19 occurrences). The subdomains themselves have the highest number of occurrences, as can be seen from the outgoing lines. In addition, the three subdomains presented are interrelated, highlighting hybrid topics such as Supply Chain 4.0 [80,81], Logistics 4.0 [82,83], green supply chain studies [84,85], and smart and sustainable supply chain transitions [86,87]. On the other hand, from an aggregate point of view, the most important domains are those of Technologies and Operations, recording a value of 51 and 50 occurrences.

Based on the domain analysis, process activities emerge as a crucial element shared by all the examined MMs. While the focus of the literature search was to identify the current state of MMs for SCML, it became evident that these two activities were not the sole processes considered. For instance, Machado et al. proposed a MM for assessing sustainability in operations management [88], and Xing et al. developed and validated an MM for measuring the maturity of procurement activities in the construction sector [89]. Furthermore, there are frequent connections between the supply chain, logistics, and other activities, such as manufacturing [90–92]. Within the 126 analyzed articles, several specific activities were identified, in addition to supply chain management (79 occurrences) and logistics management (36 occurrences). These included manufacturing (13 occurrences), sales and operation planning (3 occurrences), operations management (1 occurrence), and procurement (1 occurrence). Each of these activities can be examined from different perspectives. For example, supply chain management activities may aim to improve individual processes [93,94], relationships between organizational processes [95,96], or relationships between actors in the network [97,98]. In particular, enhancing the maturity of the entire supply chain is crucial to establish strong relationships with suppliers upstream and customers downstream, thereby creating value across the entire supply chain [79,87,99,100]. This is why activities such as CRM and SRM are frequently examined in models that approach maturity from a strategic and collaborative perspective. Similarly, other activities may also aim to enhance maturity based on this hierarchical representation of levels. As Correia et al. emphasized [39], MMs address different hierarchical levels within the supply chain (i.e., organization, process, network). The results indicate a greater focus on MMs that target organizational maturity (64 occurrences) rather than maturity across the entire supply chain (34 occurrences). Additionally, the research exhibits less interest in the process level (39 occurrences), although there is a more balanced distribution within the operations classification. For detailed findings on operations and supply chain levels in the analyzed MMs, please refer to Table 3.

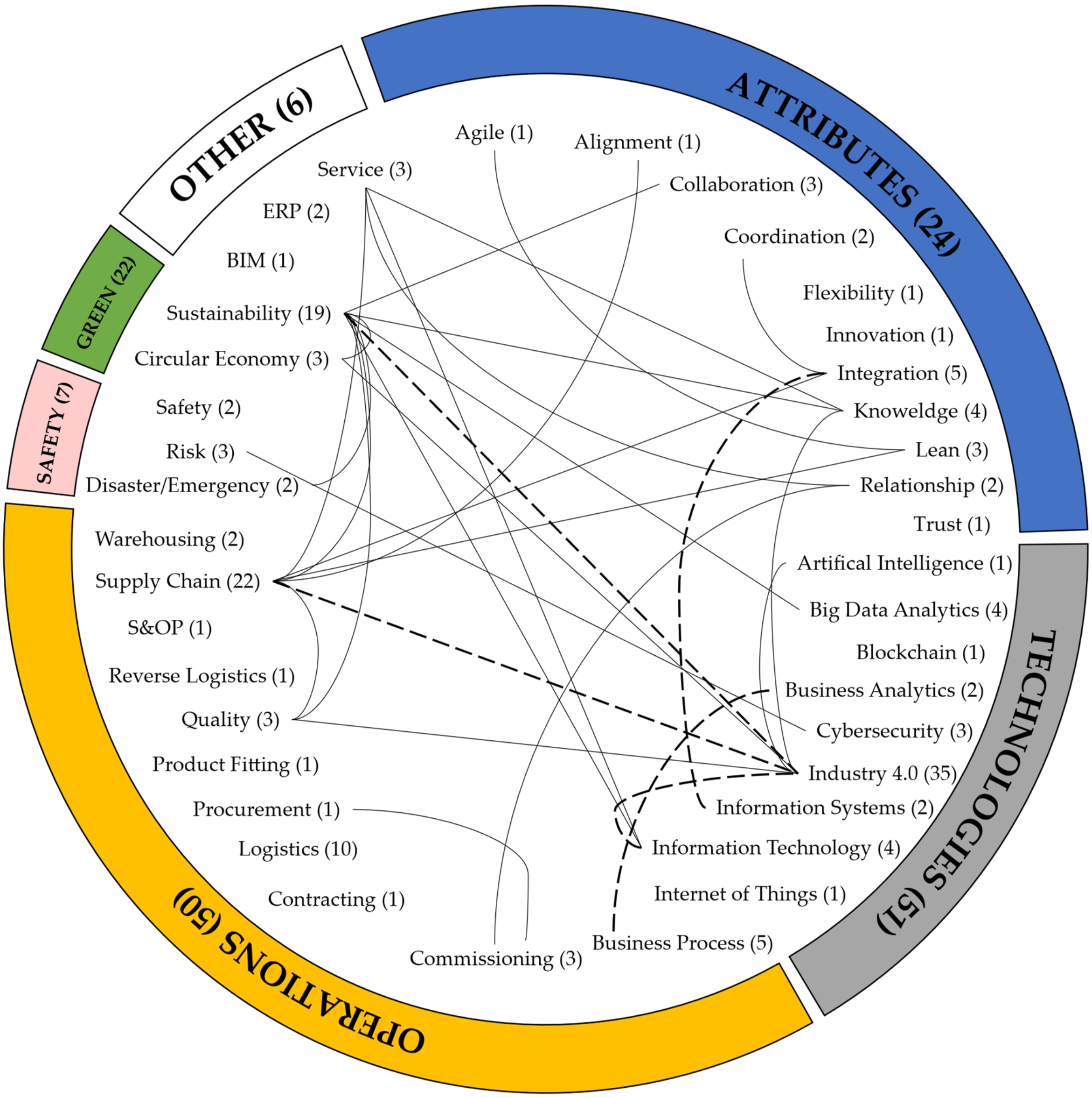

Figure 11. The representation illustrates the occurrence (given in parentheses) and relationship (described by solid lines for one relationship and dotted for two) between the main scopes of MMs for SCML using a circular relationship diagram. Each scope is classified into one of the 6 clusters identified in the research.

Table 3. The results reveal the type of process considered and the level of the supply chain (SC) to which they are related.

Operation/SC Level	Organization	Process	Network	Total
Supply Chain	32	19	28	79
Logistics	20	14	2	36
Manufacturing	7	4	2	13
Sales and Operation Planning	1	1	1	3
Operations Management	1	-	-	1
Procurement	-	1	-	1
General	3	-	2	5
Total	64	39	34	

As observed in the keyword analysis and supported by other authors [88], thematic areas and dimensions within SCML undergo evolutions over time, driven by specific research streams like the industrial revolution and sustainable development. Likewise, the concept of maturity also evolves. Initially, MMs for SCML were defined based on the notion of maturity as the ability to continuously improve through process optimization [13]. Shortly after, the concept of capability gained traction. Maturity and capability are often interconnected since industrial-level process optimization relies on the effective utilization of resources to attain desired outcomes and vice versa. In recent years, two additional noteworthy concepts have emerged: readiness and transformation. Readiness is assessed before a process commences [73] and is often associated with the introduction of technological tools and automation, particularly in the context of Industry 4.0 [22,34,68]. On the other hand, transformation stems from the principles of sustainable development and circular economy [86,101]. Figure 12 illustrates the evolution of these concepts, with maturity being the oldest and most prevalent (90 occurrences). Capability started gaining attention around 2008 (20 occurrences), followed by readiness in 2016 (12 occurrences), and transformation in 2021 (6 occurrences). Additionally, there are two less prominent concepts in SCML: diffusion [102] and immaturity [91]. The concept of diffusion refers to the capacity of a system to acquire, assimilate, and utilize knowledge. On the other hand, the concept of immaturity measures the criticality of processes that are not yet ready for a continuous improvement approach.

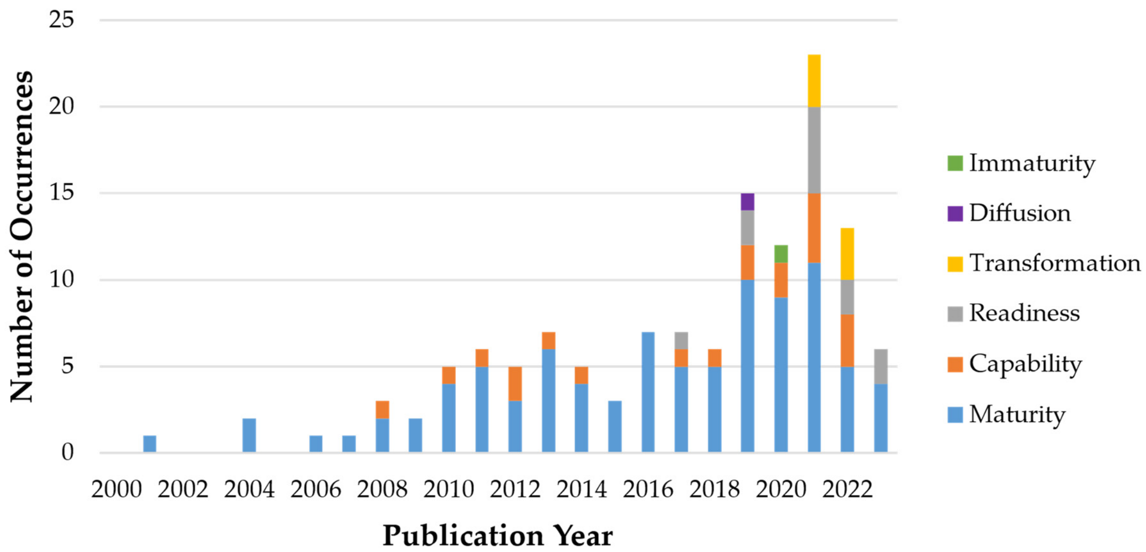

Figure 12. The representation showcases the time series analysis of selected articles based on their publication number and year. The results, categorized by maturity type, reveal a trend in recent years where an increasing number of models focus on readiness and transformation.

3.2.2. Design Criteria of MMs for SCML

The scoping phase is essential for determining a MM in terms of its domain, supply chain level, and maturity type. On the other hand, the design phase involves making decisions about how to develop the MM. Initially, MMs were often based on practical projects or applications, prioritizing results over research methodology or decision criteria. To address the lack of a structured methodology, researchers like De Bruin [33] and Mettler [15] proposed procedural steps for designing MMs, which have become a reference for many studies. Accordingly, the first step is to identify the need for an MM and clarify its application domain (covered in the scope section of MMs for SCML, i.e., Section 3.2.1, in this work). In the second step, decision criteria for designing the MM are established, and an applicable tool is proposed for validation. In the last step, the validated MM is applied (to address the identified need) and continually improved over time in response to changes in the application domain. This section will analyze the decision criteria of the design process to determine whether the knowledge base characterizing the MM's elements is academic (theory-driven), practical (practitioner-based), or a mixed approach. Additionally, the most frequently used maturity assessment tool among the 126 selected articles for content analysis will be examined. Finally, the complexity of the MMs will be reported by identifying the number of levels, dimensions, and sub-dimensions involved.

When conducting scientific research, it is crucial to understand the current state of the interest field before proposing new contributions. In the context of MMs, analyzing the existing literature helps identify elements that can potentially be incorporated into the tool under definition [33]. The more detailed the research, the better the qualitative analysis for defining MMs. Some studies even conduct systematic literature reviews, albeit limited in number [7,30,75,80,101]. These analyses often have specific scopes and fields of application, such as humanitarian supply chain MMs [103], supply chain quality management 4.0 MMs [104], and supply chain risk management MMs [105]. This approach, which bases MM development on scientific knowledge, is known as a theory-driven approach. However, there may be instances where the literature is insufficient [16] or fails to reflect current developments for proposing a new MM. In such cases, an alternative is to consult experts in the field and integrate their knowledge with the insights gained from the literature [21,106–108]. These approaches are known as practitioner-based or mixed approaches. Among the analyzed articles, it appears that most MMs for SCML adopt a mixed approach (58 occurrences) and a theory-driven design process (52 occurrences) compared to practitioner-based approaches (four occurrences).

Regardless of the design process, the main objective of a MM is to assess the degree of an entity based on various attributes. To achieve this, the use of levels, dimensions, and sub-dimensions is necessary and characteristic of a comprehensive MM [10]. However, not all MMs include these elements, such as the number of maturity levels [3,9,76,90], and many do not indicate dimensions and sub-dimensions [26,97,98]. There is no established rule in the literature for determining the number of maturity levels. Some studies rely on expert judgment [109], while others use statistical clustering techniques [88]. However, it is considered a good practice to strike a balance between complexity and generality when determining the appropriate number of levels [14]. Too many levels can make the tool overly complex and less practical, while too few levels can oversimplify the assessment. Based on the literature, most MMs fall within the range of three to six levels, with the highest occurrence for five-level MMs (75 occurrences). As the analysis delves into dimensions and sub-dimensions, the number of elements increases. The number of dimensions covered by the models ranges from zero to 22, while sub-dimensions range from zero to 117. Specifically, the majority of MMs use four dimensions (28 occurrences), followed by three dimensions (24 occurrences) and five dimensions (22 occurrences). It is interesting to note that several MMs have been influenced by the SCOR model in terms of selecting the number and types of dimensions, as seen in [11,35,110–113]. In fact, since this study concentrates on process-based models within SCML, the activities of plan, source, make, and deliver are common across various contexts or industries. While not widely adopted, some models also incorporate the return phase after the four aforementioned phases [7,114]. In terms of sub-dimensions, 46 occurrences indicate the absence of sub-dimensions. Figure 13 illustrates the relationship between the number of levels, dimensions, and sub-dimensions, with the size of the circumference representing the occurrence of MMs.

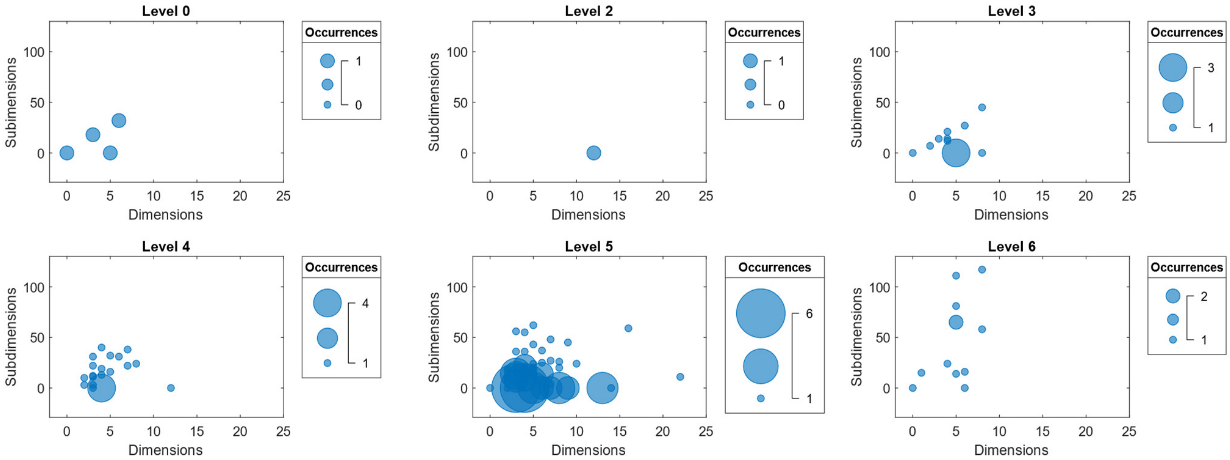

Figure 13. The representation highlights the architecture of MMs for SCML by examining the relationship between the number of levels, dimensions, and sub-dimensions commonly employed.

From the elements of MMs, we can identify the tools used for maturity assessment. According to [115], maturity assessment tools can be categorized into three major types based on their complexity. The simplest type is maturity grids, which typically present activity descriptions for each maturity level in a matrix or table format (e.g., [114,116]). A more complex type is Likert-like questionnaires, where respondents quantify their adherence to best practices on a numerical scale from one to n by answering specific questions (e.g., [117,118]). The most complex type is CMM-based MMs, which include both generic and specific objectives for each focus area and maturity level (e.g., [24,119]). In addition to these typologies, two less prominent types have been identified in the literature. Maturity frameworks are collections of frameworks that offer guidance for achieving best practices without providing a systematic approach [119]. On the other hand, roadmaps provide guidelines for improving maturity levels [120]. However, many roadmap proposals are considered too general and not useful for users [15]. Among the analyzed MMs for SCML, Likert-like questionnaires (63 occurrences) and maturity grids (50 occurrences) are the most frequently used assessment tools. Less commonly used are CMM-based models (6 occurrences), maturity frameworks (three occurrences), and roadmaps (one occurrence). It can be concluded that most researchers propose assessment tools that are not overly complex and allow for easy usage, such as questionnaires or matrix-based assessments. Table 4 summarizes the results regarding maturity assessment tools and design process approaches.

Table 4. The results provide insights into the assessment tool and design approach used in MMs for SCML.

Assessment Tool/ Design Process	Theory-Driven	Practitioner-Based	Mixed	Other	Total
Maturity grid	24	2	23	1	50
Likert-like questionnaire	20	2	38	3	63
Framework	3	-	-	-	3
CMM	3	-	3	-	6
Roadmap	-	-	-	1	1
Other	2	-	-	1	3
Total	52	4	58	6	

3.2.3. Application Criteria of MMs for SCML

The last classification analysis focused on the application of MMs for SCML. To recap, MMs go through three stages: development, validation, and continuous application. Many research studies propose new MMs to address gaps in the literature, while others enhance existing MMs or use them as a reference. For example, Cubo et al. [121] proposes a Supply Chain Quality Management MM based on Fernandes et al.'s proposal [122]. Mettler uses the dimensions of the General Practitioner Information Systems Measurement Model as a foundation for a MM in supplier relationship management in hospital settings [123]. Similarly, Bueno and Alencar [124] integrate Reyes and Giachetti's tool [36] to measure the maturity of Brazilian rail transport suppliers. Regardless of the stage of use, these MMs are applied with specific purposes [33]. Descriptive MMs provide a snapshot of an entity's current state, whether it's a process, object, or person, without specifying improvement points or objectives. In contrast, prescriptive MMs, based on the entity's current state, aim to guide it toward a future state by providing improvement guidelines [69]. Comparative MMs, on the other hand, serve as benchmarking tools to compare business processes, organizations, or industrial sectors at different levels [21]. The use phase of the MM (development, validation, application) and the MM's objective (descriptive, comparative, prescriptive) are closely linked, representing the evolution phases of the MM's life cycle, as pointed out by De Carolis et al. [34].

Most of the research shows a strong inclination towards the development of new MMs (104 occurrences). MM validation is also relevant (68 occurrences), while MM application (24 occurrences) and integration (24 occurrences) are less influential. Different approaches can be followed for the development of a MM, including theory-driven, practitioner-based, or mixed-design approaches. Theory-driven approaches commonly rely on literature research, whereas practitioner-based approaches make use of empirical development tools such as interviews [87,125,126], focus groups [8,16], and Delphi studies [18,36,127]. Analytical approaches, such as AHP [10,128,129], fuzzy theory [100,109,130], and principal component analysis [131], are less frequent but still noteworthy. In terms of MM validation, case studies are the most commonly used tools, while empirical analysis [132] and simulation hold lesser importance [89]. Case studies are also frequently employed for MM applications (Figure 14). Among the various industrial sectors, the automotive sector (13 occurrences) and manufacturing in general (11 occurrences) are most commonly considered, although many MMs do not specify the sector of application (21 occurrences). Case studies serve as both descriptive and comparative tools. For example, Cavalcante and Souza validate their MM by assessing the current status of four fashion companies [105]. Similarly, Gustafsson develops and validates a MM based on 13 companies in the retail sector [133]. Some examples of applied MMs with a comparative purpose include Siebelink et al.'s comparison of BIM maturity in 53 manufacturing companies [134], Beelaerts van Blokland et al.'s application to 16 automotive organizations [135], and Huang and Handfield's evaluation of the relationship between ERP and supply chain management maturity in 250 organizations [136]. Regarding the three purposes of MMs for SCML, those of a descriptive nature hold the greatest relevance (73 occurrences), followed by comparative MMs (38 occurrences) and prescriptive MMs (15 occurrences).

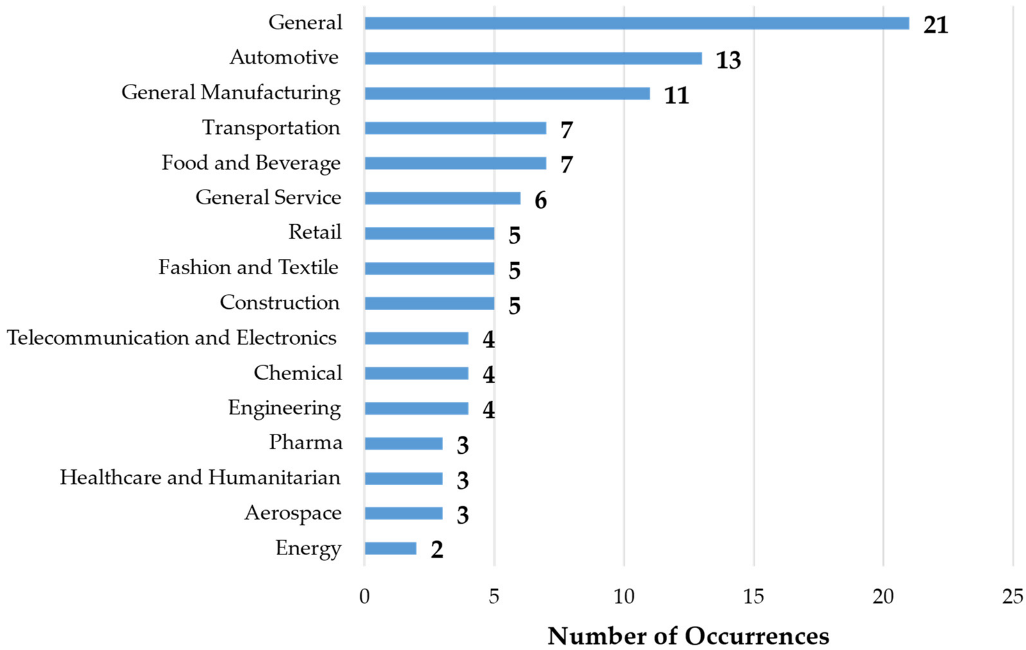

Figure 14. The representation showcases the type of sectors where MMs for SCML find applications. The identified sectors are presented in descending order based on their occurrence frequency.

4. Discussion and Future Enhancements

MMs are powerful tools that enable the analysis of current states in specific focus areas, aiming for continuous improvement. Indeed, according to various scholars, the concept of performance measurement and management is not only relevant but often serves as the starting point for assessment and continuous improvement initiatives. In some cases, performance management is even regarded as a distinct dimension within the model [2,18,77]. They provide a pathway from a low-level situation to a higher-level one [137], which can be assessed both qualitatively by adhering to specific benchmarks and quantitatively through performance indicators [25,89,138]. Numerous studies have examined the practicality of these tools in various industries [139,140] and different inter- and intra-organizational processes [110,111]. MMs have proven to be useful for both structured companies and small to medium-sized enterprises [112,138,141–143], as well as in industrialized and emerging developing countries [8,107,144]. In this study, we aimed to address four research questions (RQs) concerning significant research contributions (RQ1), the evolution of topics over time (RQ2), key criteria for definition, design, and application (RQ3), and potential future developments (RQ4). Through bibliometric and content analyses, it becomes evident that within the realm of SCML, MMs are increasingly interesting tools (see Figure 2) that integrate well with other industrial processes, particularly manufacturing and procurement (see Table 3). Integration is also observed between the academic and practical realms, requiring close collaboration for the development and validation of MMs (see Table 4). Additionally, the concept of maturity is not predefined but rather adaptable to external phenomena, demonstrating the flexibility of these tools (see Figure 12). However, the literature highlights some shortcomings. In terms of definition, six domains were classified using a circular relationship diagram, with a majority focused on operational activities and the use of advanced technologies. While the integration of enabling technologies in digitization processes facilitates operational performance and generates economic results, there are limited references to environmental and social interests. The increasingly emphasized triple bottom line conception, which aims to achieve sustainable development, does not appear to be of interest in MMs for SCML. From a hierarchical perspective, although the research mainly focuses on supply chain and logistics processes, the results indicate varying concepts. Most MMs are used at the organizational level to assess the current state of the entire organization, while higher network and lower process levels receive less attention.

The direction toward MMs that prepare for transformation, whether digital or sustainable, highlights the current lack of already digitized and sustainable processes. While readiness and transformation MMs are useful for practitioners, the concepts of digitization and sustainability are well-established in academia. Therefore, research should shift focus towards providing guidance for the continuous improvement of processes, organizations, and networks that already embrace sustainable development principles or have undergone the fourth industrial revolution. It may be beneficial to not only assess the current level of maturity but also provide clear guidance on the introduction and enhancement of these practices through the development of detailed guidelines or roadmaps. However, existing MMs for improvement are lacking in terms of detailed roadmaps, as pointed out by Correira et al. [39]. Without comprehensive roadmaps or guidelines, MMs serve well in assessing current and future states but are not suitable for achieving desired levels of maturity. Therefore, additional maturity assessment tools that employ systematic approaches should be designed to complement existing maturity assessment tools [145]. Finally, the design and development of these instruments should not solely remain academic endeavors. Rather, to validate and demonstrate the usefulness of MMs, it is necessary to increase the number of studies that encompass the validation and application phases.

Based on this evidence and the dynamic topics evolution, Figure 15 presents five recommendations for future research improvements aimed at providing a comprehensive and well-structured response to RQ4. These recommendations are further elaborated upon in the subsequent discussion.

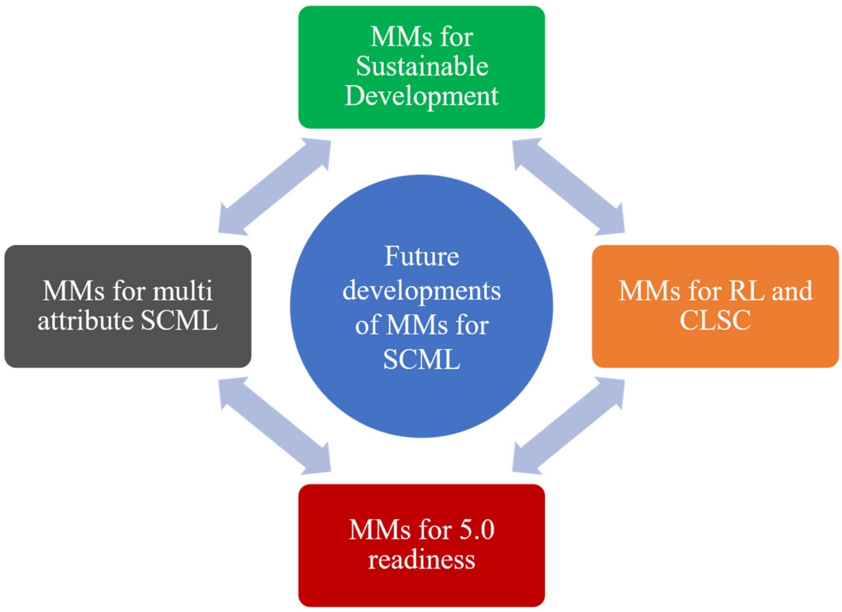

Figure 15. Recommendations for future developments in MMs SCML.

- **MMs for SCML**: Santos-Neto and Costa's research [146] revealed that MMs for SCML constitute only about 5% of the total MMs analyzed. This percentage is still low, indicating a need for further studies, particularly in the field of logistics. Logistics is relatively underexplored compared to the broader domain of supply chain management, especially in terms of process and network considerations. The content analysis results also indicate an emerging interest in logistics, warranting increased attention.
- **MMs for sustainable development**: Boullauazan et al.'s work [16] highlights that MMs can serve as tools for measuring sustainability. However, most research in this area primarily emphasizes economic goals, overlooking environmental and social objectives. While there is a growing body of research on environmental sustainability,

social sustainability has received less attention. To address this imbalance, it is essential to propose MMs that integrate all three sustainability goals based on the Triple Bottom Line framework.

- **MMs for reverse and closed-loop supply chains**: Many existing MMs predominantly focus on information and physical product flows in a forward logic. However, MMs for SCML rarely consider the return process or the integration of forward and reverse logistics (RL) [113]. An example that considers the return process is mentioned in [147] for the proposal of a reverse logistics MM. Incorporating these elements is crucial for defining closed-loop supply chains (CLSCs) and embracing the circular economy paradigm, which aligns with current sustainable goals [74]. Future research should address this gap.
- **MMs for 5.0 readiness**: The concept of Industry 5.0 extends the principles of Industry 4.0 by emphasizing a more human-centric approach. Recognizing the increasing importance of operators and their interactions with technologies and organizational processes from a social standpoint, future MMs should integrate process-oriented, object-oriented, and people-oriented attributes. This approach enables the assessment of performance efficiency based on the maturity of operators, the utilization of advanced technologies, and optimized processes.
- **MMs for multi-attribute SCML**: Recent disruptive events, such as the pandemic, have exposed the insufficient preparedness of supply chains and the inefficiency of logistics networks in responding to unpredictable situations. In the current dynamic, uncertain, and complex environment, lean, flexible, resilient, and sustainable approaches are vital. Relying solely on single attributes is risky, necessitating the integration of multiple attributes. For example, incorporating lean and agile paradigms has been proposed [148]. Future research should focus on developing multi-attribute MMs to enhance SCML practices.

5. Conclusions

The concept of MMs, initially applied in software management, has gained traction in various industrial processes, including SCML. However, existing reports on MMs have been either too specific or lacking in depth. To address this gap, a comprehensive literature review has been conducted in this article using a methodological and systematic approach. The review process involved several steps in answering four RQs. Firstly, a literature search was performed, resulting in the identification of 137 articles related to MMs for SCML published between 2001 and 2023. Secondly, a bibliometric analysis was conducted to objectively examine the major contributions, relationships, and dynamics among various factors, addressing RQ1 and RQ2. These factors include journals, authors, and keywords. Lastly, a content analysis delved deeper into the scope, design, and application of MMs, addressing RQ3 and providing a detailed exploration of the tools used.

The discussion of the literature review yielded several important findings, including the ever-growing interest in MMs for SCML, particularly in recent years. Notably, approximately one-third of the publications were concentrated between 2021 and 2022, with a focus on digitization and the sustainability of business processes. These MMs primarily revolve around supply chain management as a core topic. However, logistics is identified as an emerging theme that has been gaining momentum, thanks to the contributions of a small group of authors. This highlights the need for further research and development in the field of logistics within the context of MMs for SCML.

MMs are commonly recognized as tools that facilitate continuous improvement, guiding the transition from an initial state to an optimal state. However, the content analysis revealed that the prescriptive characteristic of tools within the SCML field is not given priority. The proposed MMs in the literature are often descriptive and comparative in nature. Closing this important research gap calls for the ambitious goal of developing detailed guidelines and improvement roadmaps. Moreover, the validation and application of MMs for SCML are frequently overlooked, despite their significance in bridging the gap between research and practice. The research gaps go beyond the domain of MM design and application; they also extend to the identification of unexplored research topics. To address these gaps and answer RQ4, the article proposes five recommendations for specific research strands. These identified strands mainly focus on the development, validation, and application of MMs for sustainable development, the circular economy, and Industry 5.0. The recommendations offer valuable contributions to the field. Furthermore, the literature review conducted in this article is up-to-date and comprehensive, making it useful for researchers and practitioners who intend to develop or apply the identified MMs.

The work conducted in this study has some limitations that can be addressed in future research. First, the research was limited to a single scientific database (Scopus) and utilized a process-focused search string. As a result, the article primarily focused on SCML MMs, neglecting the inclusion of people-based, object-based, and potential integration concepts. Additionally, other important activities in industrial contexts, such as manufacturing and procurement, were not considered in terms of processes. Consequently, the presented results may not provide a completely comprehensive view. Future research should aim to overcome these limitations by incorporating a broader scope and addressing these areas of research, thus making valuable contributions to the field.

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Appendix A

Table A1. The depiction illustrates the temporal evolution of 13 sources that have published at least three articles.

Source	Publication Year																	
	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	Total
IFIP Advances in Information and Communication Technology											2		1	1	2			6
Procedia Manufacturing												2	2	2				6
International Journal of Production Economics										3	1				1			5
LogForum													1	3		1		5
Sustainability (Switzerland)											1				3	1		5
Benchmarking									1						1	2		4
Production Planning and Control													1		2		1	4
Supply Chain Management		1											1	1	1			4
Advances in Intelligent Systems and Computing													2	1				3
Applied Sciences (Switzerland)													1			2		3
Business Process Management Journal									1						2			3
International Journal of Quality and Reliability Management																1	2	3
Proceedings of the International Conference of Industrial Engineering and Operations Management												1			2			3
Total		1							2	3	4	3	9	8	13	7	4	54

Table A2. The representation highlights the 12 most influential sources based on the decreasing number of citations per publication (CPP), indicated in the fifth column. The CPP value is calculated by dividing the number of citations (fourth column) by the number of publications (third column).

Source	Reference	Number of Publications	Number of Citations	Number of CPP
Journal of Manufacturing Systems	[42]	1	528	528
Transportation Research Part E: Logistics and Transportation Review	[75]	1	266	266
International Journal of Production Economics	[10,17,88,109,149]	5	1102	220.4
Supply Chain Management: an International Journal	[35,36]	2	403	201.5
Data Base for Advances in Information Systems	[62]	1	129	129
Business Horizons	[108,150]	2	237	118.5
Journal of Management Engineering	[151]	1	106	106
Technovation	[152]	1	76	76
International Journal of Operations and Production Management	[136,153]	2	145	72.5
Expert Systems with Applications	[140]	1	71	71
Supply Chain Management	[80,110,126,133]	4	275	68.75
Journal of Modelling in Management	[118]	1	65	65

Table A3. The table presents key information derived from the co-occurrence analysis of keyword indexes with a minimum of three occurrences. The first column indicates the cluster to which each keyword belongs. The third and fourth columns display the number of occurrences and the total link strength (TLS) associated with the identified keywords (second column).

Clusters	Keywords	Occurrences	TLS
Cluster 1	supply chains	26	91
	industry 4.0	9	32
	competition	8	31
	maturity levels	7	33
	digital transformation	7	27
	automotive industry	5	23
	industrial research	5	24
	manufacture	5	24
	manufacturing industries	4	16
	maturity	4	16
	industrial management	3	13
	readiness assessment	3	13
Cluster 2	industry	4	14
	process maturity	4	19
	societies and institutions	4	13
	business analytics	3	14
	information management	3	13
	information systems	3	15
	mathematical models	3	12
	performance	3	17
	supply chain performance	3	15
Cluster 3	supply chain management	27	88
	software engineering	11	44
	sustainability	4	4
	benchmarking	3	10
	capability maturity models	3	9
	knowledge management	3	11
	logistics	3	7
	chains	3	9
Cluster 4	sustainable development	11	43
	life cycle	5	25
	capability maturity model integration	4	22
	sustainable supply chains	4	21
	integration	4	17
	decision making	3	11
	literature reviews	3	9
Cluster 5	maturity model	31	109
	maturity assessment	8	30
	roadmap	4	17
	warehouses	3	6
	conceptual frameworks	3	8
Cluster 6	project management	4	15
	construction industry	4	12

Appendix B

Table A4. Content analysis of the 126 articles based on analysis criteria. Representative acronyms were used for the analysis criteria of SC level (O = Organization, P = Process, N = Network), Type (M = Maturity, C = Capability, R = Readiness, T = Transformation, D = Diffusion, IM = Immaturity), Process (SCM = Supply Chain Management, L = Logistics, M = Manufacturing, P = Procurement, S&OP = Sales and Operation Planning, OM = Operations Management), Assessment Tool (F = Framework, CMM = CMM-based, L = Likert-like questionnaire, MG = Maturity Grid, O = Other), Design Process (T = Theory-driven, P = Practitioner-based, H = Hybrid, O = Other), Phase (D = Development, I = Integration, V = Validation, A = Application), Purpose (D = Descriptive, C = Comparative, P = Prescriptive).

Reference	Scope				Design					Application		
	Domain	SC Level	Type	Process	Ass. Tool	Design Process	Lv.	Dim.	Sub.	Phase	Purpose	Sector
Correia et al. [99]	Sustainability	O	M	SCM	L	H	5	4	22	D + V	C	Manufacturing (5)
Demir et al. [154]	Industry 4.0, Sustainability	O	R	SCM	L	H	5	2	6	D + V	D	Automotive (1)
Hajoary et al. [132]	Industry 4.0	O	R	M	L	H	4	6	31	D + V	D	Manufacturing (1)
Hellweg et al. [155]	Industry 4.0	O	M	SCM	L	H	2	3	18	D + V	D	Aerospace (1)
Pereira et al. [156]	Industry 4.9, Logistics	P	M	L	CMM	H	5	6	14	D + I	D	-
Tiss and Orellano [157]	Industry 4.0	P	M	SCM	L	H	4	3	14	D + V	D	Engineering (1)
Balouei Jamkhaneh and Safaei Ghadikolaei [125]	Service, Supply Chain	N	C	SCM	L	H	4	4	19	D + V	D	Service (1)
Behrendt et al. [90]	Industry 4.0	N	M	L, M	MG	T	-	3	18	A	D	-
Bui et al. [104]	Industry 4.0, Supply Chain	N	M	SCM	MG	T	4	4	-	D	C	-
Boullauazan et al. [16]	Industry 4.0	N	M	L	L	H	5	5	-	D + V	D	Retail (11)
Hongxiong and Xiaowen [69]	Industry 4.0	N	T	SCM	MG	H	5	3		D	P	-
Gallego-García et al. [158]	Industry 4.0	O	C	M	O	T	5	8		D + V	P	-
Kayikci et al. [73]	Industry 4.0, Circular Economy	N	R	SCM	L	H	6	8	117	D + V	D	Textile (4)
Lookman et al. [79]	Innovation	O	C	L	MG		5	4	22	D + V	D	Transportation (52)
Tetik et al. [137]	Logistics	O	M	L	L	T	3	5	-	D + V	C	Construction (3)
Uhlenkamp et al. [117]	Industry 4.0	O	M		L	T	3	6	27	D + V		-
Uhrenholt et al. [101]	Circular Economy	O	T		MG	T	6	6	-	D	D	-
Weerabahu et al. [30]	Industry 4.0	N	T	SCM	MG	T	4	4	-	D	D	-
Zoubek et al. [22]	Industry 4.0	P	R	L			6	5	14	A	C	Automotive (13), Engineering (16)
Barbalho and Dantas [27]	Industry 4.0	P	M	L	L	H	5	6	37	A	P	Food and Beverage (1)
Caiado et al. [109]	Industry 4.0	O	R	L, SCM	L	H	5	3	7	D + V	P	Manufacturing (1)
Cavalcante de Souza Feitosa et al. [105]	Risk	O	M	SCM	MG	T	4	3		D + V	D	Fashion (4)
Chalmeta and Barqueros-muñoz [93]	Big Data Analytics, Sustainability	P	M	SCM		H	5	6	-	D + V	P	Transportation (1)
Çınar et al. [68]	Industry 4.0	O	R	L, M, SCM		T	5	4		D + V	D	Automotive (1)

Table A4. *Cont.*

Reference	Scope				Design					Application		
	Domain	SC Level	Type	Process	Ass. Tool	Design Process	Lv.	Dim.	Sub.	Phase	Purpose	Sector
Cubo et al. [121]	Quality, Supply Chain	P	M	L, SCM	L	T	5	5	20	D + I	D	-
Deniaud et al. [86]	Industry 4.0, Sustainability	O	T	SCM	MG	T	6	4	24	D	D	-
Ehrensperger et al. [70]	Industry 4.0, Information Technology	N	T		MG	H	5	7	-	D + V	D	Telecommunication (1)
Gunduz et al. [87]	Industry 4.0, Sustainability	P	T	SCM	L	H	5	10	24	D + V	D	Automotive (1)
Hansali et al. [9]	Sales and Operation Planning	P	M	S&OP		T				A	D	Automotive (1)
Modica et al. [82]	Industry 4.0	O	M	L		T	4	7	22	D	D	-
Peña Orozco et al. [144]	Integration, Supply Chain	P	M	SCM	L	H	5	9	20	D + I + V	P	Agrifood (99)
Peng et al. [28]	Information Technology, Sustainability	O	C	SCM	L	T	5	7	4	D + I + V	D	Food and Beverage (1)
Saari et al. [31]	Circular Economy, Sustainability	P	R	M	MG	H	5	7	-	D	D	-
Santos et al. [78]	Alignment, Supply Chain	O	C	SCM	F	T	5	4	21	D + I + V	P	General (3)
Soares et al. [100]	Lean	P	M	SCM	MG	H	5	7		D + V	D	General (3)
Trisnawati and Pujawan [3]	Supply Chain	N	M	M, SCM	L	H	-	5	-	A		Manufacturing (57)
Uraipan et al. [76]	Cybersecurity	O	C	SCM	L	T	-	6	32	D + I + V	D	General (9)
Wagire et al. [130]	Industry 4.0	O	R	M	L	H	4	7	38	D + V	D	Automotive (1)
Wehner et al.	Sustainability	O	M	L	MG	H	5	3	14	D	D	-
Werner-Lewandowska and Golinska-Dawson [21]	Sustainability	O	C	L	L	P	5	3	36	D + V	C	Transportation (199)
Wijbenga et al. [126]	Supply Chain	P	M	L, SCM	MG	H	5	4	14	D + V	D	General (1)
Zoubek and Simon [83]	Industry 4.0	P	R	L	MG	H	5	5	14	D	D	-
Büyüközkan et al. [81]	Big Data Analytics	O	M	SCM	L	H	5	5	15	D + V	C	Transportation (1)
Caiado et al. [8]	Industry 4.0	P	M	M	MG	H	4	4	-	D	P	-
Frederico et al. [80]	Industry 4.0	N	M	SCM	MG	T	4	4	40	D	D	-
Grest et al. [103]	Disaster/Emergency	N	M	SCM	MG	T	4	3	11	D + V	D	Humanitarian (1)
Ho et al. [2]	Collaboration	N	M	SCM	L		5	16		A + V	D	Textile (2)
Márquez-Gutiérrez et al. [91]	Logistics	O	IM	L, M	L	T	3		-	D + V	C	Furniture (1)
Peukert et al. [92]	Industry 4.0	N	M	L, M	F	T	2	12	-	D + I + V	P	Automotive (1)
Unny and Lal [95]	Blockchain	O	C	SCM	MG	T	5	5	-	A	D	-
Werner-Lewandowska [13]	Logistics	O	M	L	L	T	6	5	65	D + A	C	Service (2000)
Werner-Lewandowska and Kosacka-Olejnik [120]	Logistics	O	M	L	L		6	5	65	D + V + A	P	Transportation
Yigit Ozkan et al. [141]	Cybersecurity	N	C		L	T	4	4	13	I + V + A	D	General (9)
Zwetsloot et al. [29]	Safety	O	M		L	H	5	14	-	A	C	General (19)
Bastas and Liyanage [127]	Quality, Supply Chain, Sustainability	O	M	SCM		H	6	8	58	D + V	P	Chemical (1)

Table A4. *Cont.*

Reference	Scope				Design					Application		
	Domain	**SC Level**	**Type**	**Process**	**Ass. Tool**	**Design Process**	**Lv.**	**Dim.**	**Sub.**	**Phase**	**Purpose**	**Sector**
Batista et al. [142]	Knowledge, Sustainability	O	C	SCM	MG	T	4	3	12	D + I + V	D	Food (6)
Beelaerts van Blokland et al. [135]	Supply Chain	O	C	SCM		H	4	2	3	I + V	C	Automotive (16)
Ellefsen et al. [74]	Artificial Intelligence, Industry 4.0	O	R	L	L	T	5	3	-	I + V	C	Fashion (2), Transportation (2)
Gaur and Ramakrishnan [129]	Internet of Things	P	M	M	L	H	5	9	45	D + V	D	General (8)
Gustafsson et al. [133]	Product fitting	P	M	SCM	MG	H	3	2	7	D + V	D	Retail (13)
Krowas and Riedel [138]	Industry 4.0	O	M	L	L	T	5	4	12	D + V	C	Ceramic (1)
Marco-Ferreira and Jabbour [84]	Sustainability	N	M	SCM	MG	T	3	8	-	D + V	C	Automotive (1), Agrifood (2), Batteries (2)
Oleśków-Szłapka and Stachowiak [159]	Industry 4.0	P	M	L	MG	H	5	3	-	D	C	General (17)
Oleśków-Szłapka et al. [116]	Industry 4.0	O	M	L	L	T	5	3	-	A	C	General (17)
Stachowiak et al. [102]	Knowledge, Industry 4.0	P	D	L	L	H	5	3	-	D		-
Stiles et al. [97]	Safety	N	R	SCM	L	T	5	-	-	A	C	Construction
Werner-Lewandowska and Kosacka-Olejnik [7]	Logistics	O	M	L	L	T	6	5	111	D	C	-
Werner-Lewandowska and Kosacka-Olejnik [20]	Industry 4.0, Information Technology	O	M	L	MG	H	6	1	15	D + A	C	Service (2000)
Yahiaoui et al. [143]	Supply Chain	O	M	L, SCM	MG	T	3	4	14	D + V	D	Automotive (1)
Arunachalam et al. [75]	Big Data Analytics	P	C	SCM		T	4	5	32	D	C	-
Asdecker and Felch [118]	Industry 4.0	O	M	L	L	H	5	3	15	D + V	C	-
Olejnik and Werner-Lewandowska [147]	Reverse Logistics	P	M	L	MG	T	5	6	25	D	C	-
Salvadó et al. [94]	Disaster/Emergency, Sustainability	P	M	SCM	MG	T	5	3	7	D + V	C	Humanitarian (1)
Siebelink et al. [134]	Building Information Modelling	O	M	SCM	MG	T	6	6	16	D + I + V	C	Construction (53)
Werner-Lewandowska et al. [114]	Logistics	P	M	L	MG	T	6	5	81	D	C	-
De Carolis et al. [34]	Industry 4.0	P	R	M	L	H	5	5	18	D	D	-
Ferreira et al. [85]	Sustainability	O	M	SCM	L	T	3	8	45	D + V	C	Pesticides (2), Battery (2), Automotive (1)
Johansen et al. [96]	Collaboration, Sustainability	O	M	SCM	L	H	5	2	18	D	D	-
Klötzer and Pflaum [19]	Industry 4.0	O	M	M	MG	H	5	9	-	D	D	-
Machado et al. [88]	Sustainability	O	C	OM	CMM	H	5	8		D	P	-
Razik et al. [160]	Warehousing	P	M	L	MG	T	3	4	21	D + V	C	Steel (1)

Table A4. *Cont.*

Reference	Scope				Design					Application		
	Domain	SC Level	Type	Process	Ass. Tool	Design Process	Lv.	Dim.	Sub.	Phase	Purpose	Sector
Umeda [161]	Supply Chain	O	M	SCM	MG	T	5	3	-	D	D	-
Bueno and Alencar [124]	Logistics	O	M	L, SCM	L	H	5	6	170	I + A	C	Transportation (3)
Fischer et al. [77]	Flexibility	N	M	SCM	MG	T	5	5	-	D	D	-
Ho et al. [24]	Collaboration	O	M	SCM	CMM	T	5	3	16	D	C	-
Mendes et al. [10]	Supply Chain	N	M	SCM	L	H	5	3	15	D + V	C	Beverage (1)
Oliva [149]	Risk	P	M	SCM	L	H	5	4	8	D + V	D	General (168)
Radosavljevic et al. [18]	Supply Chain	O	M	SCM	L	H	5	8	-	D + V	D	General (132)
Wang et al. [17]	Big Data Analytics	P	M	L, SCM	F	T	5	2	-	D	D	-
Huang and Handfield [136]	ERP	P	M	SCM	L	H	5	4	-	A	C	Manufacturing (111), Finance (33), Retail (29)
Rendon [106]	Contracting	P	M	SCM	L	P	5	5	62	A	D	-
Souza et al. [4]	Business Process	O	M	SCM	L		5	13		I + A	D	General (288)
Boyson [152]	Cybersecurity, Risk	N	C, M	SCM	MG	H	3	3	14	D	D	-
Hermans et al. [162]	Commissioning	P	M	SCM	MG	H	5	8	-	D	C	-
Poli et al. [25]	Sustainability	O	M	SCM	CMM	H	5	5	43	D + V	D	Pharma (1)
Reefke et al. [98]	Sustainability	N	M	SCM	MG	H	6	-	-	D + V	P	-
Battista and Schiraldi [113]	Logistics	P	M	L	CMM	T	5	5	13	D + V	D	Fashion (1)
Cuenca et al. [163]	Coordination	N	M	S&OP	MG	T	5	9	-	D + V	C	Ceramic (1)
Foerstl et al. [153]	Coordination, Integration	O	M	SCM	L	H	3	4	12	D + I + V	C	General (148)
Jin et al. [164]	Integration	O	M	SCM	MG	H	4	4	-	D + V	D	General (60)
Okongwu et al. [131]	Sustainability	O	M	SCM	L	H	5	4	8	D + V	C	Aerospace (5), Automotive (5), Construction (5), Electronics (5), Energy (5), Food (5), Chemical (5), Pharma (5), Retail (5), Telecommunications (5)
Srai et al. [14]	Sustainability	N	C, M	SCM	L	T	5	5	24	D + I + V	C	Aerospace (1), Energy (1), Pharma (1), Automotive (1), Retail (1), Electronics (1), Chemical (1), Service (4), Engineering (1)
Fawcett et al. [150]	Trust	N	C	SCM	MG	H	4	3	3	D	D	-
Lu et al. [128]	Service, Warehousing	P	C, M	L	L	H	5	3	14	D	D	-
Oliveira et al. [140]	Business Analytics, Business Process	N	M	SCM	L		5	13		A	D	General (788)
Trkman et al. [139]	Business Analytics, Business Process	N	M	SCM	L		5	13		A	D	General (788)

Table A4. *Cont.*

Reference	Scope				Design					Application		
	Domain	SC Level	Type	Process	Ass. Tool	Design Process	Lv.	Dim.	Sub.	Phase	Purpose	Sector
Frick and Schubert [26]	Information System, Integration	O	M	SCM	CMM	T	3	-	-	D	D	-
Meng et al. [151]	Construction, Relationship	N	M	SCM	MG	H	4	8	24	D + V	D	Construction (1)
Mettler [123]	Information Technology, Relationship, Service	P	M	SCM	MG	H	5	4	36	D + I + V	D	Healthcare (15)
Netland and Alfnes [165]	Supply Chain	P	M	SCM	L	H	5	7	48	D + V	D	General (11)
Schubert and Legner [26]	Information Systems, Integration	O	C	SCM	MG	H	5	3		D + V	D	General (112)
Xing et al. [89]	Construction, Procurement	P	M	P	L	H	5	6	14	D + I + V	D	-
Bauernschmitt and Conradie [107]	Knowledge, Service	N	M	SCM	MG	P	4	12	-	D + I	D	-
Garcia Reyes and Giachetti [36]	Supply Chain	O	C, M	SCM	L	H	5	2	10	D + V	D	General (2)
Niemi et al. [166]	Knowledge	P	M	SCM	MG	T	5	4	-	D + I + A	P	General (2)
Söderberg and Bengtsson [112]	Supply Chain	N	M	SCM	L	H	5	4	-	A	D	Manufacturing (15)
Lahti et al. [111]	Supply Chain	N	M	SCM	L	T	4	5	16	D	D	-
Lin et al. [119]	Lean	P	M	SCM	F	T	5	23	11	D + I + V	D	Automotive (1)
Lockamy et al. [11]	Business Process	N	M	SCM	L	H	5	4	-	V + A	P	General (18)
McCormack et al. [110]	Supply Chain	N	M	SCM	L	H	5	4	-	V + A	D	General (478)
Qiao and Zhao [167]	Logistics	O	C	L		T	5	4	13	D + I + V	D	Transportation (1)
Vaidyanathan and Howell [168]	Supply Chain	N	M	SCM	MG	T	4	3	-	D	D	-
Zhao et al. [148]	Agile, Lean, Supply Chain	O	M	SCM	MG	H	4			D	D	-
Fawcett and Magnan [108]	Supply Chain	N	M	SCM	MG	P	4	2	10	D	D	-
Lockamy [35]	Business Process	N	M	SCM	MG	H	5	4	-	D	D	-
Holland and Light [62]	ERP	O	M	S&OP		H	3	5	-	D + I + V	C	General (24)

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