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Perspectives and relationships in Supply Chain Simulation: A systematic literature review

Josenildo Brito Oliveira[a,b,*], Renato Silva Lima[a], José Arnaldo Barra Montevechi[a]

[a] Industrial Engineering and Management Institute, Federal University of Itajuba (UNIFEI), Minas Gerais, Brazil
[b] Academic Unit of Production Engineering, Federal University of Campina Grande (UFCG), Paraiba, Brazil

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ABSTRACT

The main purpose of this article is to develop a meta-analysis about the relationships and potential perspectives of modeling and simulation in supply chains. The research methodology used in this paper was a systematic literature review, exploring the state of the art in Supply Chain Simulation. The methodological procedures were based on a systematic literature review and statistical analysis of a sample of papers. The results indicated that modeling and simulation in supply chains can be better integrated. The models could be more sophisticated to capture the dynamics and behavior of these networks. The combination of optimization methods with agent-based simulation is an observed trend. Hybrid simulations involving normative models and empirical applications can be useful to represent the reality of supply chains, generating alternative solutions that improve supply chain performance. The relevance of this article is to analyze the interfaces related to this field of research, in order to establish a theoretical framework that improves the process of modeling, simulation and decision-making in supply chains.

1. Introduction

Participation in Supply Chains (SCs) can generate competitive advantages for the various stakeholders that make up a SC network. Based on the contributions of several authors [61,134,89,56,44,92,104,111,47] we define a SC as an aggregate set of value chains linked by inter-organizational relationships, both upstream and downstream of the leader company in order to deal with all the flows involved (cash, material, goods, and information), from the first supplier's supplier to the last customer of the end customer, as well as the reverse flow of products and returnable and/or disposable products, generating value for the end consumer and for SC stakeholders. However, these relationships and the number of role players can increase the complexity of SCs [40,66], signaling the need for decision support tools that can better deal with the dynamics in SC networks.

Considering the complexity, dynamics and interactions that permeate a SC, computational modeling and simulation (M&S) can support managers in the decision-making process [36]. Furthermore, the SC simulation (SCS) can assist decision-makers in the analysis of various scenarios and the selection of appropriate solutions [72,69], and can also be a useful tool for understanding interactions and improving SC performance. Cross-cutting issues in the field of SC combining M&S have been studied by several authors [132,60,105]. Several of these issues were discussed in articles in a literature review (LR) context, however not referring directly to the relationship between simulation, modeling and SCs. The main motivation for

* Corresponding author at: Federal University of Campina Grande (UFCG), Paraiba, Brazil. Tel.: +55 83 2101 1574.
E-mail address: josenildo.brito@ufcg.edu.br (J.B. Oliveira).

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this research is based on the need to investigate the interfaces and perspectives related to this field of study through a systematic literature review (SLR).

Focusing on the literature reviews conducted by other authors, Santa-Eulalia et al. [149] reported advances in methodological frameworks; however, these frameworks are associated with modeling and agent-based simulation (M&ABS), therefore excluding the broader aspects of Supply Chain Management (SCM). Barbati et al. [14] followed the same line of research, however, focusing on the application of M&ABS in optimization problems. Mustafee et al. [122] conducted a LR about M&S covering the period between 2000 and 2011, but they did not discuss M&S in the context of SCs. Manuj et al. [105] developed a detailed LR addressing discrete events modeling, by providing a systematic process of 8 phases for M&S in SCs and logistics operations. Bellamy and Basole [16] discussed the SCM theme, but with no substantial insights on SCS. Furthermore, it was observed that there is a paucity of articles that discuss the state of the art in SCS.

A key motivation for this research is to identify developments and advancements that can contribute to improving the field of SCS. Key research questions to be investigated in this paper include: What are the main decision support tools applied in SCS? What is the nature of simulation models that are developed to represent SC issues? In addition, this paper seeks to explore perspectives in order to support the theoretical development of the SCS field, creating a historical timeline of the progress made by other researchers. The study may signal certain SC relations and point out possible directions in the M&S in SCs for management purposes. Therefore, this research covers aspects not discussed in other LR papers, such as the methodological classification of simulation models. Furthermore, this paper explores the scientific developments reported in other articles found in SCS literature. It is concluded that the main objective of this paper is to investigate potential perspectives and to identify patterns established in the literature about SCS.

2. Research methodology: a systematic literature review

There are several concepts to define in the field of M&S. Generally, M&S is a field with its own body of knowledge, theories and methodological research, which focuses on the development of models to closely reproduce real-world behavior. For that reason, M&S is a set of tools, techniques, methods, concepts and procedures involved in modeling, computer simulation, visualization and the analysis of a system/event, in order to understand, interpret, improve or test the performance of models, especially those built from real-world systems or applications [84,140]. In this sense, M&S can be used in training, understanding, educating, learning, entertaining, problem solving, and decision support simulations such as a "what-if" analysis, to name but a few applications [156]. One of the most popular applications for M&S is to support the decision-making process. In the strictest sense, M&S offers a set of decision support tools to facilitate the selection of the best alternative solutions to a particular problem, usually modeled from a real-world system, in this case SCs. The methodological framework built for this research paper consider the broadest scope of M&S, as mentioned earlier, and include the analysis of the implementation of simulation models in the reviewed articles.

A LR is an important method for researchers to explore various fields of study [135,152,67]. Articles [e.g. 15,107,125,8] make use of a more descriptive form of LR, not following a systematic approach. The LR method enables the researcher to develop its exploratory research without conforming to rigorous methodological standards. Another method that can be used in exploratory research is the SLR method. According to Cook et al. [43], SLR can support the development of guidelines, as it encompasses the search, selection, critical evaluation and synthesis of primary research results. In order to give a pattern to the SLR, Wong et al. [180] and Kamal and Irani [83] developed frameworks containing the main steps to avoid the likelihood of bias and possible distortions in the research and analysis of data.

Tachizawa et al., for instance [158], apply the contributions of Tranfield et al. [166] and Denyer and Tranfield [49] as a basis method to perform a SLR. One of the strengths of a SLR is its systematic methodology, therefore providing the required criticism in the performance of all research steps. For the purposes of this study, SLR procedures were based on Tranfield et al. [166] and Denyer and Tranfield [49], who developed well-defined stages for the method. Therefore, in order to assess perspectives between M&S and SC, this paper applied the SLR method, which was used in four phases: planning, searching/screening, analysis/synthesis and the presentation of findings. These stages summarize the basic research methodology that was followed for this paper.

2.1. Planning

The first phase was to form a research panel to investigate the SCS subject. The review panel consisted of researchers (advisory group), 3 experts in the SCS domain, one SLR specialist, and 2 graduate students; all members had academic knowledge and practical expertise in this domain. The authors of this paper participated actively in the development of this research. An exploratory search on the theme of research was done in the SCOPUS and Web of Science (WOS) online research bases using title keywords such as “Supply Chain” and “Simulation”. Another search using the words “Supply Chain”, “Simulation”, “Literature Review”, “State of the art” and “Overview” was performed to assess the evolution of the related subjects based on literature reviews. Therefore, Boolean Logic (And/Or/ Not) was used as part of the search process. From the initial analysis of papers in the literature, knowledge and experience of experts and discussions about aspects related to the research topic, the researchers identified gaps in the literature and relationships that could better integrate M&S processes and SC aspects. Table 1 depicts the key issues that were addressed in the LR on SCS. Only selected papers that discussed SCS issues are shown in the following table.

Table 1
Key issues in SCS/LR.

Aspect/authorship	[14]	[16]	[28]	[42]	[79]	[105]	[122]	[149]
Systematic literature review		●			●	●		●
State of the art	●	●			●		●	●
Focus on SC		●	●	●		●		●
Real-world SC applications	●				●	●		●
Purposes			●			●		
Techniques/tools			●			●	●	●
Central themes	●				●	●	●	●
Type of simulation	ABS		●		●	DES	●	ABS
Methodological classification M&S processes (approaches)	●					●		●

Note: ABS (Agent-Based Simulation); DES (Discrete Event Simulation).

An article written by Barbati et al. [14] addressed SC optimization problems, while Bellamy and Basole [16] focused on other SC aspects such as structure, strategy and dynamics. Calderón and Lario [28] discussed the areas of development and SCS applications, however they did not address the critical aspect of real-world SC applications. Cimino et al. [42] reviewed simulation software and programming languages. Jahangirian et al. [79] researched SCS in manufacturing and business applications. Moreover, Manuj et al. [105] created a simulation model development process based on DES. Mustafee et al. [122] reviewed the evolution of SCS without involving the SCS issue. Santa-Eulalia et al. [149] discussed SC planning systems with the focus on modeling techniques based on agents. Despite the contributions of the papers on the SC literature as shown in Table 1, it was observed that there is a paucity of studies that discuss the state of the art of SCS, thus not expanding the research on relevant aspects, as: methodological classification of models; real-world SC applications; relationships between certain types of simulation; and systematic uses of the M&S approach. These aspects represent the main gaps found in literature.

The need for this research is based on a comprehensive literature review related to M&S in SCs. The purpose of this SLR is to analyze the state of the art and perspectives about SCS applications based on the publication of peer-reviewed papers to provide an update of the interface and relationship between M&S and SCs. The objective of this paper is to include and incorporate:

(a) An extensive coverage of the literature about SCS.
(b) A broader scope of simulation models.
(c) An analysis of the in real-world SC applications.
(d) An identification of the most relevant perspectives in SCS.

From the aforementioned research objectives, research questions were formulated according to the study's scope and the identification of gaps in literature, and include:

RQ1: What is the current status (state of the art) of research on SCS?
RQ2: What is the role played by simulation models?
RQ3: What techniques and tools were used in the simulations?

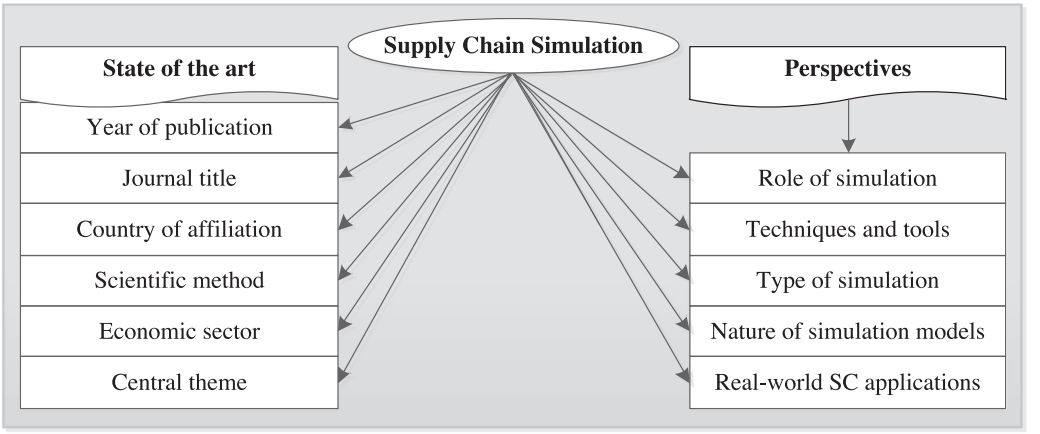


Fig. 1. Research pillars.

RQ4: What type of simulation was used in SC applications?
RQ5: What is the nature of simulation models that are developed to represent SC issues?
RQ6: How is the evolution of the SCS field considering real-world SC applications?

After developing the research questions (RQs) and the objectives of the SLR, the researchers developed the research protocol, consisting of two stages including: (1) the state of the art, related to the construction and composition of the paper; and (2) perspectives, which refers to the knowledge on SCS developed and discussed in papers found in SC literature. Therefore, the research protocol was developed to include the RQs; the criteria for selection of articles, and other details of the study. Fig. 1 shows the pillars of this research study.

2.2. Searching/screening

Tranfield et al. [166] states that a comprehensive, unbiased search is the main difference between the SLR and a traditional LR. At the stage that deals with the selection and study-quality assessment, the first step was to identify and select research databases. Therefore, fourteen (14) databases were included in this study, such as: ACS Publications, Directory of Open Access Journals (DOAJ), Emerald Insight, Sage Crossref, Engineering Village, Gale Academic OneFile, Scopus, IEEE Xplore, Medline, Scielo, ScienceDirect, Springer Link, Web of Science, and Wiley Online Library. After the identification of the research databases, the reviewers conducted a meta-search, including the tracking of published papers.

The reviewers applied the search engines of databases including, as a search criterion, the keywords “Supply Chain” and “Simulation”. The Boolean logical operator (AND/OR/NOT) was used when the search required more than one criterion, or when the database did not provide more refined filters for research. The meta-search returned 827 papers published in the last twenty-five years. After this step, the following search criteria were used in the search engines of research databases: Title/keywords (“Supply Chain” and “Simulation”), English language; Peer-reviewed papers; Full papers downloaded. After applying these criteria 378 papers were registered. Finally, we excluded 34 redundant papers. Thus, 344 articles were selected for the qualitative assessment. At this stage, the authors read the abstracts, objectives, methods, results and discussions of the 344 articles, in order to select papers that fit in the research questions. Following the study quality assessment of the articles, 189 papers were selected for data extraction. In addition to the articles indexed in the researched journals, the list of publications was expanded, containing conference proceedings and recently published books.

2.3. Analysis/synthesis

In this phase of the research, the objective was to break down the study. Thus, the data of the articles were extracted and transported to a MS Excel® spreadsheet from the coding key terms related to the applicable RQs. The papers were evaluated in detail. The extracted data to MS Excel® spreadsheet were tabulated applying the MINITAB® software package. For some RQs the data were grouped into categories. A worksheet in MINITAB® was created to contain the research topics, facilitating the statistical analysis of the data. The researchers reviewed the data sheet to check possible anomalies in the conversion of MS Excel® spreadsheet data to MINITAB® program. After this step, data were summarized to facilitate analysis. Data were designed in MINITAB® applying descriptive statistics. Therefore, the tabulated data were recorded, stored and processed statistically.

In sequence, the meta-analysis was employed to better support researchers to elucidate the RQs, identifying the most important relationships involving M&S in SCs. Thus, tables and charts helped the authors to interpret the research findings.

The analysis of the results was performed according to the RQs, relating them to the theoretical developments. Reflections and discussions among experts about main perspectives led to the generation of a set of information that could develop insights on the interface between M&S and SC. In this sense, a synthesis of overall findings supported the authors to develop a body of evidence around the main perspectives on SCS discussed in this research. Finally, considering the results of the research, especially the perspective of M&S processes, we assessed the necessity to develop a systematic methodological aiming to improve the applications of simulation in SCs. Hence, by proving this need, a methodological framework could be developed.

2.4. Presentation (Reporting)

Tables and charts were designed to improve the presentation of data, summarizing the main findings of this research. The research results were presented according to a thematic analysis, using an interpretative approach about the most relevant findings extracted from the SLR. The outcomes were presented and discussed sequentially according to the RQs (see Section 2.1). The discussion of the findings served to point out emerging aspects related to SCS. We attempted to relate the contributions of the SLR on SCS to academic developments regarding the research topic, highlighting the most important perspectives. Moreover, the authors sought to update the state of the art in SCS and discuss the perspectives raised from the applications of M&S in SCs. In conclusion, recommendations and developments were suggested for future research. Fig. 2. summarizes the phases of the methodological procedures used in this research study.

3. Findings and discussion

This section presents the findings of the SLR, followed by discussions on the RQs, relating the research pillars and perspectives developed in this study.

3.1. State of the art

This section presents the aspects related to the current status in the SCS field, such as: year of publication; journal title; country of author's affiliation; scientific method; economic sector; and the central theme.

RQ1: What is the current status (state of the art) of research on SCS?

The number of articles published over the years has been researched by the authors. Notice, according to Fig. 3, there was a substantial increase in the number of publications in the field of SCS (■). Between 2011 and 2014, 81 articles were produced, equivalent to 42.86% of the total number of SCS papers published. In only four (4) years, the number of articles has reached nearly half the total. Between 2001 and 2010, 103 (54.50%) articles were published, corresponding to 54.50%. In the years 1992, 1998 and 2000, publication numbers were poor, having only 5 published studies (2.65%). These numbers were compared to papers involving the keywords "Supply Chain Management" in the title. This research was conducted in the Web of Science base and returned with 811 articles published since 1993 (■). In both graphs, shown in absolute numbers, there is a growing trend. This can be best represented in cumulative percentage comparisons between the SCS (▬) and SCM (▬). In conclusion, there is a substantial increase in the number of publications, showing the growth in applications of M&S in SC.

Further, according to Table 2, the above aspects were condensed, showing the top five for each group in descending order. The table also shows the number of occurrences, the relative frequency and the cumulative frequency, both in percentage, followed by a brief analysis.

In the "Journal title" aspect, 99 journals were counted. The first journals obtained at least five records, representing almost a third of all occurrences. Of the 189 occurrences, 24.34% are associated with journals whose editorial scope covers themes of computer science with other areas. This represents 21.21% of registered journals. Along the same lines, 27.51% of the papers were published in journals related to the area of computer science, adding 21 of them. In both cases, involving the area of computer science, the occurrence of papers is 51.85%. However, articles published in the fields of operational research, operations management, and engineering represent 38.62% of the records, indexed in 40 journals (40.40%). The articles published in other areas totaled 9.52% indexed in 17 journals (17.17%). Of the Top 5 papers, four of them relate to the field of computer science. In short, publication of articles involving SCS is intimately associated with journals that focus on computer science.

We have looked at the "country of first author's affiliation", described in authorship, which is the institution of the researcher. It is observed that of the 189 articles analyzed, 81 (42.86%) were written by researchers linked to the institutions of the USA and China, followed by Italy and the UK, both countries adding 13.23%. These five countries accounted for 60.32% of the records, representing 15.15% of the 33 countries observed in this study. It is possible that USA and China continued at the top of the list.

The "scientific method" used in the papers was classified as: modeling and simulation; LR; single case/multiple cases; survey; and secondary data. M&S methods were applied in 116 (61.38%) papers. However, it was observed that many of these articles do not properly use the M&S method as a systematic methodology that assists in the building of simulation

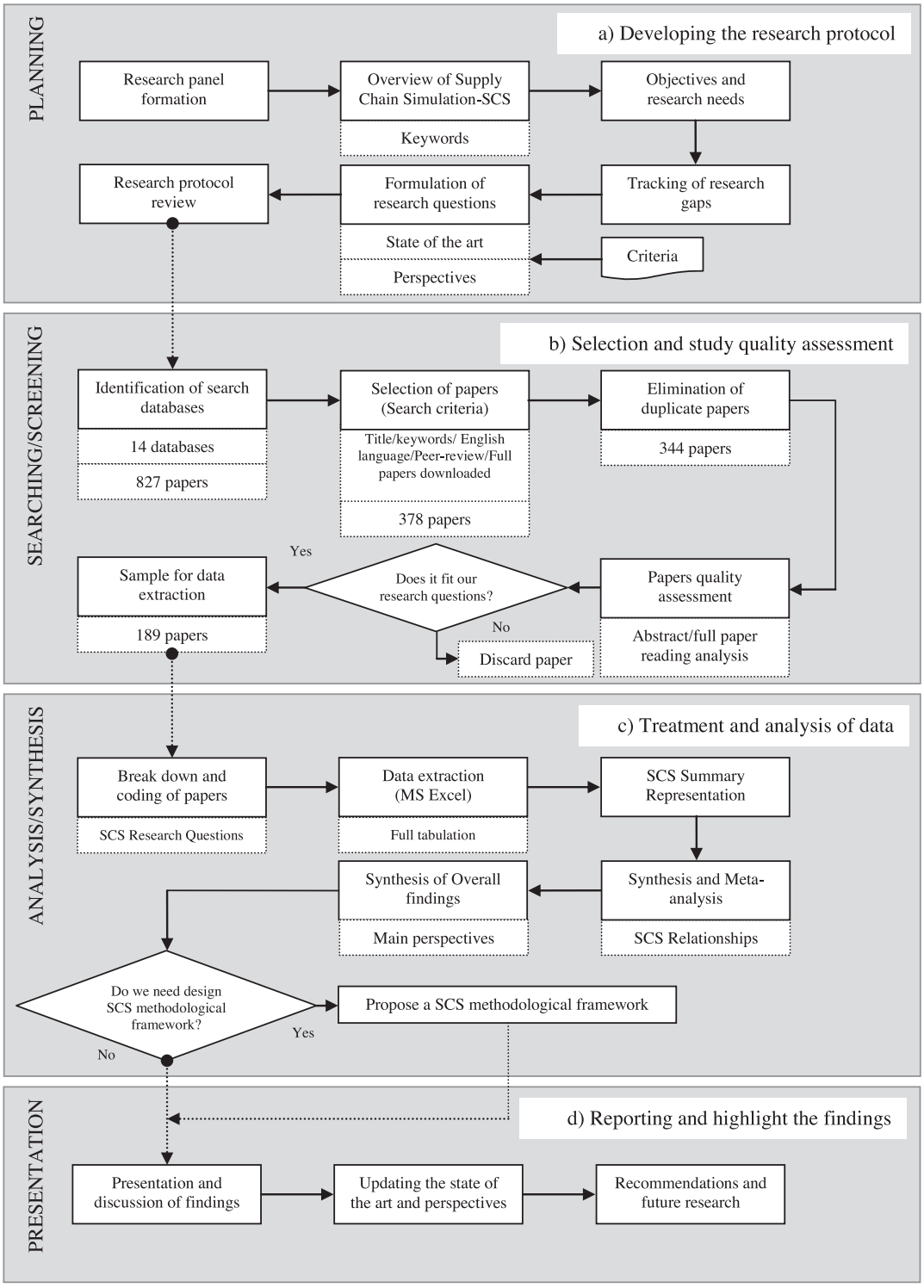


Fig. 2. SCS research framework.

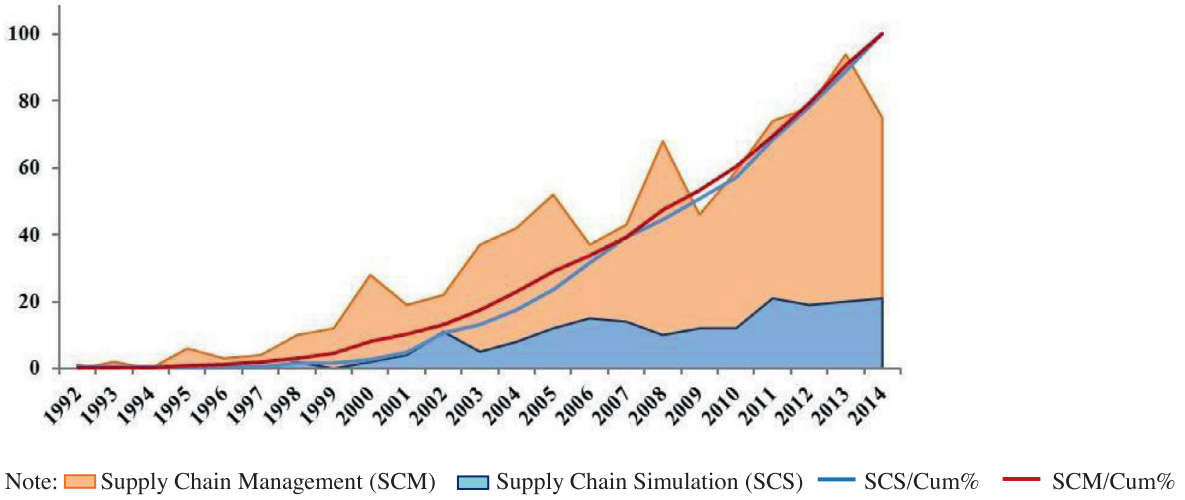


Fig. 3. Articles published per year. (For interpretation of the references to color in this figure, the reader is referred to the web version of this article).

Table 2
Current status on SCS research.

Aspect	TOP 5	No.	%	CUM (%)
Journal title				
International Journal of Production Economics	1st	18	9.52	9.52
Simulation Modelling Practice and Theory	2nd	14	7.41	16.93
Simulation	3rd	11	5.82	22.75
International Journal Advanced Manufacturing Technology	4th	8	4.23	26.98
Computers & Industrial Engineering	5th	6	3.17	30.15
Country of first author's affiliation				
The United States of America (USA)	1st	42	22.22	22.22
China	2nd	39	20.64	42.86
Italy	3rd	13	6.88	49.74
United Kingdom of Great Britain and Northern Ireland (UK)	4th	12	6.35	56.08
Iran	5th	8	4.23	60.32
Scientific method				
Modeling and simulation	1st	116	61.38	61.38
Single case/multiple cases	2nd	62	32.80	94.18
Literature review	3rd	8	4.23	98.41
Survey	4th	2	1.06	99.47
Secondary data	5th	1	0.53	100
Economic/industrial sector				
Unknown	1st	12	12.37	12.37
Automotive Industry/auto parts	2nd	9	9.28	21.65
Health	3rd	7	7.22	28.87
Biofuels/refining/oil	4th	6	6.19	35.06
Electronics Industry/supplies	5th	5	5.15	40.21
Central theme				
Inventory management	1st	21	11.11	11.11
Performance indicators	2nd	20	10.58	21.69
SC behavior assessment	3rd	16	8.47	30.16
Demand management	4th	14	7.41	37.57
Developing games/simulators	5th	11	5.82	43.39

Note: No. (Number of occurrences); CUM % (Cumulative percentage).

models, as advocated by several researchers, for example [12]. The rigorous use of the M&S method can realize significant benefits, reducing the risk that the model might not closely reproduce event behavior or the system to be simulated. The case studies were applied in 62 (32.80%) articles. However, it was found that some features of the method were not observed, for instance, a more detailed study. Since other articles, there was a further increase in the level of description of the case study, for example [70]. The LR method was applied by 4.23%, eight articles [168,108,42,102,122,159,2,76]. The authors searched specific issues pertaining to M&S, such as: decision-making; commercial software; collaboration patterns; importance of M&S for small and medium enterprises among others. Survey and secondary data methods totaled three (3) articles; two and one, respectively [163,9,37].

Table 3
Categorization of proposals.

Role played by SCS models	No.	Ranking	%	CUM%
Understand and/or diagnose problems/SC	48	1st	26.52	26.52
Improve the performance of SC variables	45	2nd	24.86	51.38
Test and evaluate new scenarios/projects/models	39	3rd	21.55	72.93
Support the decision-making process	23	4th	12.71	85.64
Develop games/simulators	9	5th	4.97	90.61
Predict potential outcomes	7	6th	3.87	94.48
Validate models and/or experiments	6	7th	3.31	97.79
Using M&S for teaching and education	4	8th	2.21	100
Total	*181*		*100*	

"Economic/industrial sector" refers to the segment to which the SC belongs, either because there was a real application of M&S, or because there were papers which used a characterized generic SC model. Thus, it was possible to identify the economic/industrial sector of the SC in 97 (51.32%) of the 189 papers studied. This study identified 42 productive sectors. Of the 97 papers 58.76% are related to SC belonging to the industrial sector, while 27.83% of them mention SC linked to the service sector. The "Unknown" category refers to the omission of the SC, as shown in papers, such as Refs. [103,42,77]. The main highlights are for the automotive industry [133, 57, 174] with 9.28% and the health sector [124,39,64].

The "central theme" aspect relates to the main topics discussed in the papers. In the analyzed sample, themes were recorded. The TOP five topics obtained at least ten occurrences, totaling 43.39% of the sample. Inventory management was a prominent topic. For example, [145] applied the M&ABS to improve inventory management and order processing. In second place was the performance indicators topic with 10.58% of the total occurrences. This theme was typically associated with decision variables and has been widely studied by researchers. [50], for example, evaluated the efficiency of a SC based on the average of the perfect order performance. Still, 16 papers focused on SC behavior assessment, for instance [63,150,178]. Demand management was covered by 11 articles, with a number of papers applying M&S to explore the bullwhip effect [77]. In 5.82% of articles the central topic of research was developing games or simulators. Therefore these were the main topics highlighted in this research.

In conclusion, this section presented a picture of the current state of research on SCS. In the next section, the main findings of this research are presented and discussed by linking the perspectives on M&S and SC.

3.2. Perspectives about SCS

This foundation of research relates specifically to the content developed in the field of M&S linking applications to SCs. Five RQs were designed to meet the objective of this paper: RQ2, RQ3, RQ4, RQ5, and RQ6.

RQ2: What is the role played by simulation models?

In this question, the authors of this research sought to verify the main value proposition of each paper. Thus, we analyzed the reasons that could justify the application of M&S in SC. The value propositions identified in the papers were grouped into categories, according to [13–156] on the directions of M&S, adapting them for the purposes of this research. Thus, value propositions were transcribed, analyzed, and clustered to fit the criteria of the authors cited. Table 3 shows the distribution of papers according to the categorization of value propositions.

Eight articles were removed from the assessment for not having used M&S or being related to the LR, for example [163,108,159,9]. In the first proposal, the articles sought to understand certain aspects of the SC and / or to describe problems associated with the simulation. This role assumes more descriptive characteristics. The authors who aimed to better understand the SC operational aspects made use of more descriptive and empirical procedures in 26.52% of the papers. [38], for example, applied M&S to identify key factors which caused the failure of SC activities. In 45 papers, 24.86%, the authors sought to improve the performance of some variable in the SC from the axiomatic problem solving approach, as seen in the works of [20,5]. The combined use of optimization methods and M&S was observed in some papers whose aim was to improve the decision-making variables performance, as presented in [167,165]. M&S can also support to test and evaluate scenarios, for example, to verify the viability of projects, testing the accuracy and consistency of models, assessing the effects of possible alternatives for a given problem, to develop a sensitivity analysis, and several other purposes. For instance, [10] combine three methods to evaluate supplier selection mechanisms. This third group of proposals was identified in 21.55% of papers

Assisting managers in decision-making processes is also a critical role of M&S. In this sense, M&S takes a technical perspective as a tool for decision support that can actually leverage the results of the SC members, as shown by [94], whose authors apply the concept of distributed simulation in the semiconductor industry. On the other hand, in 9 (4.97%) articles the authors used the conceptual basis of M&S to develop games or simulators for various purposes. Other roles assumed by M&S, as to predict potential outcomes, validate experiments or models, and to use simulation for educational purposes accounted for 9.39% of the papers analyzed. The first three groups represent 72.93% of all cases, with descriptive perspectives occupying the 1st and 3rd positions and prescriptive SCS roles the 2nd position.

RQ3: What techniques and tools were used in the simulations?

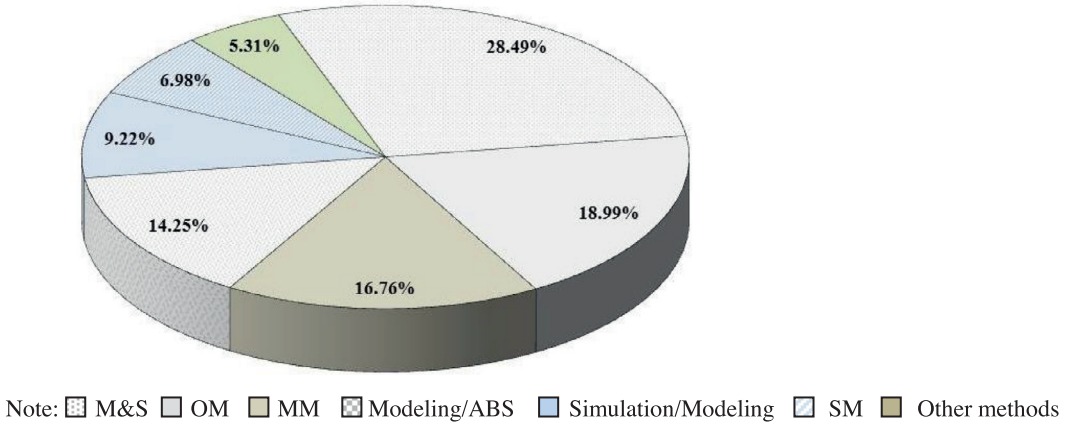


Fig. 4. Techniques and tools.

The literature review conducted for this study showed that numerous key techniques and tools are available which can be used in combination or in an individualistic manner. The majority of the articles reviewed indicate that the use of tools in combination is more popular, for example [81,34,65], including M&S [100]. Due to their similar characteristics, 33 techniques were condensed into groups. This study noted 358 occurrences. Fig. 4 shows the top six groups identified in the literature review.

The first technique discussed here is M&S. In this study, M&S does not represent the function of a method, but rather a technique that was used to support the development of modeling. M&S means that the modeling aspect is first performed which is then followed by the simulation of some scenario. Several articles, such as [60,99,171,39], have used M&S to achieve their goals. Approximately 18.99% of all the cases considered in this group applied the M&S technique. One of the strengths identified in these papers was the application of OM for problem solving purposes in SCs.

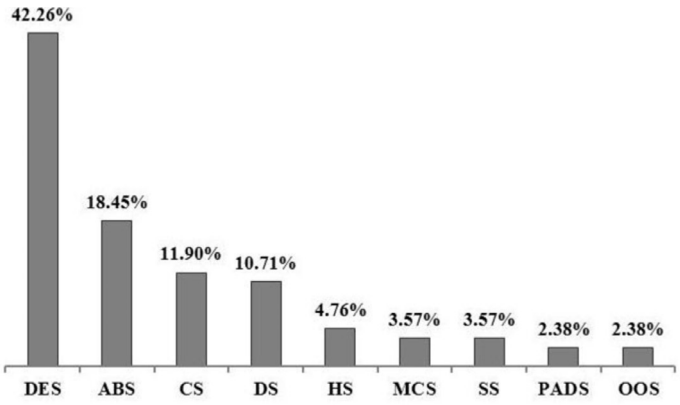
The integrated application of OM/M&S can be seen, for example, in [50]. Some methods have been identified and include particle swarm [65], multi-objective programming [169], mixed integer programming [120], genetic algorithms [173], simulated annealing [157], neural networks [147], and data envelopment analysis [181]. Furthermore, other results indicated strong evidence for mathematical modeling (MM) in simulation as described in the papers of [9,137,170]. The main research effort of the authors, such as [135,93,183,165,146], was the design and development of models with prescriptive characteristics, using most applications as a normative function.

The modeling technique and/or ABS technique is listed in fourth place, being an integral part in 9.22% of all the papers considered in this group of six tools and techniques. For this technique, three perspectives were identified in the papers, including the focus on agent-based modeling; focus on M&ABS, and the focus only being on ABS. Attributes of SC, according to authors, such as [182,126,5], might suggest, that for some cases the use of M&ABS are applicable. For certain problems, managers can make use of this tool to better understand the SC operation. In 6.98% of cases researchers focused more on modeling or simulation, that is, either one or the other. In this sense, various types of models and simulation were applied in the articles that were reviewed.

Finally, to close out the Top six groups, statistical methods (SM) accounted for 5.31% of the records. The authors applied statistical tools to validate, for example, the outcomes of the modeling or to generate scenarios. Selected statistical tools include ANOVA [41], Design of Experiments [50], forecasting methods [95], and Bayesian Network [141]. In short, the first six groups of techniques and tools represent 71.51% of the total occurrences. The first three categories correspond to half of the total occurrences.

An analysis of the most applied software tools in SCS was performed. Of the 189 articles reviewed, 63.49% used the software mentioned in this study. In 19.58% of the papers the use of software was present; however, its identification was not possible. In 10 (5.29%) articles the authors did not apply any software tools. In the review for this study, 53 different types of software have been recorded. The TOP 10 most used computational tools account for 59.86% of applications, 85 papers, and include: Arena® (14.08%), Matlab® (9.86%), Java® (7.74%), iThink® (4.93%), Anylogic® (4.22%), C++ ® (4.22%), Extendsim ® (4.22%), Promodel ® (4.22%), Simprocess ® (3.52%); and MS Excel ® (2.81%). [31] used the Arena® software to design a resilient SC. The Matlab® program, used in 14 studies, contains a module called Simulink, which was used in several mathematical models [138,88]. Programming in Java® was applied in 11 papers, for example [33, 175]. The aim of this study was not to compare software tools, as [42], but to assess the programs most used in the SCS. A large part of the software packages used in the M&S of SCs are still commercial packages, though some of it have versions available for the academic community.

RQ4: What type of simulation was used in the SC applications?



Note: CS (Continuous Simulation); DS (Dynamics Simulation); HS (Hybrid Simulation); MCS (Monte Carlo Simulation); SS (Stochastic Simulation); PADS (Parallel and Distributed Simulation); Object-Oriented Simulation (OOS).

Fig. 5. Types of simulation.

The type of simulation usually considers the nature of the system that you want to model and simulate. The characteristics of the model variables can guide the choice of the type of simulation. Fig. 5 shows the percentage distribution of the types of simulation according to the analyzed sample.

From the reviewed articles, twenty one (21) were excluded from this statistic: eight (8) were about LR, and thirteen (13) were games/simulators, adding up to 168 papers. It was found that DES is present in most of the research papers (42.26%) considered. In several cases DES was important to simulate aspects of the real world. This method has been widely used in the context of the SC. [30], for example, applied DES to analyze the distribution processes in an Oil SC. However, it has been observed that there is an increase in the number of applications that use ABS in SCs [97].

Even incipient, research on the use of ABS in SCs seems promising. There are situations where DES cannot capture the dynamics of the event or adequately treat the agents and the variables associated with them. In this SLR, 31 articles that worked with ABS (18.45%) were found. In the past 10 years, there were 28 articles published on the topic, 18 between 2011 and 2014. For instance, [185] proposed a dynamic model to reproduce the behavior of an agile SC using ABS. [100] created an integrated model based on agents to verify the relationship between inventory, production and transportation. [154] discuss the attributes that allow the classification of a model (DES or ABS), such as: modeling approach (top-down/bottom-up); thread of control (centralized/decentralized); dynamic entities (passive/active); queues/flows analysis; behavior modeling; and input distributions. When a process is continuous by nature or when the SC is relatively complex, DES has several limitations [93]. ABS may constitute a simulation to address the weaknesses of the DES, as it is appropriate to model more complex systems.

According to Fig. 5, CS was used in 11.90% of all papers. This type of simulation is more appropriate, for instance, when it is desired to model continuous manufacturing processes (e.g. Chemical Industry). MM is widely used in this type of simulation. [134] applied a fuzzy SC model combined with simulation to determine the inventory levels and order quantities. DS was found to be used in 10.71% of the papers considered. This type of simulation is based on the concept of system dynamics, which was developed by [61]. The strengths of DS are, for example, modeling a large number of entities; enabling a better understanding of the system; facilitating the use of descriptive, judgmental, and numerical data [70], for example, applied DS to study the short product life cycle. However, DS is not suitable for decisions involving optimization, prediction or comparison. HS was also observed in this study, representing 4.76% of the articles. Other types of simulation (MCS, SS, PADS, and OOS) amounted to 11.90%. In short, DES and ABS together represent 60.71% of the applications. In many situations these types of simulation can be suggested to model aspects related to SC, given the complexity of these types of arrangements.

RQ5: What is the nature of simulation models that are developed to represent SC issues?

The nature of simulation models refers to the type assumed by M&S. Therefore, the models were classified according to the methodological proposal of [116,8], classifying them in four categories: Axiomatic (normative/descriptive) and Empirical (normative/descriptive). Fig. 6 illustrates the distribution of papers according to the nature of the models.

Together, AD and ED models represent 56.61%, or 107 articles. For computational purposes, several models were developed to understand the behavior of some aspects related to SC, as seen in [96,174], which authors used the AD approach. In ED classification, it was observed that some models, for example [128,177], were developed from general characteristics of a SC in the form of a generic model. Thus, many of these models assume a more descriptive function. Sometimes such a modeling approach abstain from the dynamics that are present in real SCs. Articles that use the AN approach generate a generic model in which solutions are tested, for instance, to minimize the impact in the SC operation. Of the 48 papers whose models were categorized as AN, 43 (89.6%) made use of generic models. A solution to this problem is developed from

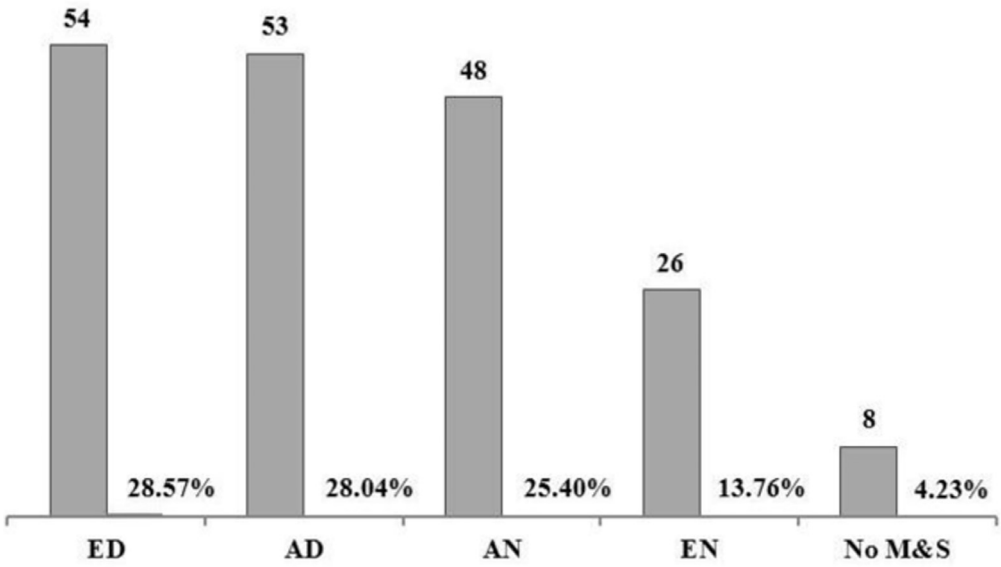


Fig. 6. Nature of simulation models.

Table 4
Real-world SC applications.

SCS applications	No.	%
Generic SC model	82	43.39
Real-world SC model	82	43.39
No application	14	7.41
Characterized generic SC model	11	5.82
Total	*189*	*100*

theoretical research, as seen in [136], whose authors proposed a methodology to stabilize systems with complex dynamics such as SCs.

In the EN approach, a solution is sought to solve a practical problem which is modeled from the real-world SC. Normally, implementations in SCs follow the steps of conceptual and computational modeling, development and application of the solution. For [17] this would be a more complete scientific approach. In this research it was found that some articles, such as [35,130,31,148,155], fit into this approach, even without a more rigorous application of the method. The AN / EN approaches commonly assume a more prescriptive role. In 8 articles the method of M&S has not been applied although the authors did mention it in their LR sections.

RQ6: How is the evolution of the SCS field considering real-world SC applications?

In this research question the proponents of this study try to analyze the current circumstances in the SCS field from real-world applications. As shown in Table 4, it was sought to examine whether the M&S developed in the papers was applied to a real-world SC. Eighty-two articles applied the method based on a theoretical generic model. There was no application to a real-world SC, since the nature of most of these models is axiomatic (descriptive/normative). [29], for example, applied a generic SC model to research pricing coordination mechanisms. The applications of M&S in real-world SCs achieved the same percentage as the generic SC models. For instance, [73,31,174] applied the M&S in the automotive sector, while [137,75] used the semiconductor industry as study subject. In 7.41% of the articles there was no application of M&S. In eleven cases the simulation model was generic, generated from the characterization of a SC economic sector [139,7]. However, adding the number of generic models the percentage rose to 49.21% of all reviewed papers.

Considering the analysis of key research questions based on the outcomes obtained, a timeline is presented to demonstrate relationships that indicate an important growth of SCS field. The relationships, shown in Fig. 7, refer to the following aspects: evolution in the number of published articles, main types of simulation used, real-world SC applications, and descriptive approach (axiomatic/empirical).

As seen in the chart (Fig. 7), there was a clear growth in the number of published articles involving SCS. In the medium term this increase can be maintained. One of the possible hypotheses to explain this growth may be the ability of simulation methods to deal with complex systems, especially SCs. Comparing the two types of simulation, it is observed that the DES followed the growth path of the articles, although the ABS has begun to grow only from the year 2010. As for the simulation method, 56.61% of the articles have taken a more descriptive approach in SCS applications.

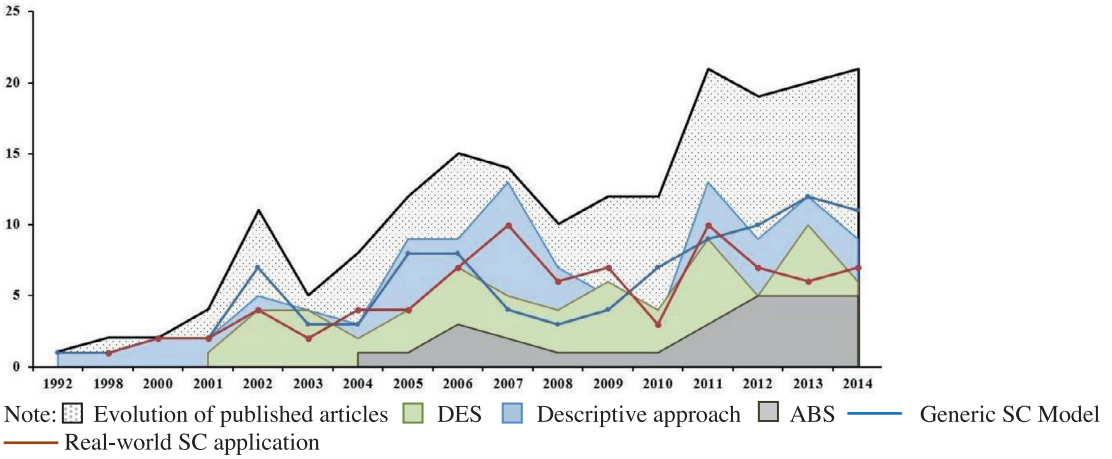


Fig. 7. SCS evolution and timeline.

Since 2001 it is noted that the DES and the descriptive approach had, although not in the same proportion, growth spurts and decreases, with the exception of 2007 and 2009. This result may indicate a relationship linking DES to descriptive purposes concerning aspects modeled in SCs. An increase was noted, albeit unstable, in the number of real applications of SCS from 2005. From 2008, there was a more stable growth in applications that use generic models. In this sense, further research can be developed based on real-world SCS applications. M&S must take more interventional characteristics to develop sustainable solutions that improve the SC performance. Therefore, given the complexity of the business environment, SCS should be considered to solve practical problems suggested by real-world SC models. RQ6 analyzed the % of papers that applied M&S in real-world, not having examined the use of specific real-world SCS models.

We ascertained and analyzed the main benefits reported in real-world SC applications in order to present the actual gains from the adoption of SCS in the real life. In reported cases, one of the most important aspects is the use of SCS as a set of tools that leverages and improves the decision-making process, providing managers with more accurate information on the best alternatives for solving problems [24,64,70,184]. In this sense, the reliability of managers increases and the risks and uncertainties related with their decisions are reduced. Minimizing costs and investments were the greatest benefit observed in the papers, some of it is achieved through the implementation of improvements suggested by M&S [81,106,117,127]. The most significant reductions were observed in costs related to inventory levels [172,176]. In terms of cost, other advantages are the possibility of the models that permit the assessment of the financial sustainability of companies [8,155] and to improve the costing process [99].

The improvement in the overall performance of SCs was an important benefit provided by M&S [6,85]. Performance measures signaled numerous benefits to SCs regarding the quality, efficiency and productivity in operations [32,52,82], such as; reducing lead times [72,130,74] and inventory levels [30,77,148], increased inventory turns [176], increased delivery reliability [168]. For [161], SCS was an important tool to investigate SC performance. Quick response to the demands / requirements of consumers [106,113] and increased availability of the product [144] reflect the improvement of the overall SC performance.

Advantages include the ability to capture and understand the SC behavior, its interactions and dynamics [37,64,138]; reproduction and analysis of different policy scenarios and solutions [20,146]; improvement in understanding and the evaluation process of various impacts on the SCs [171]; SC (re) configuration or (re) design, business processes or operations, making it more flexible and more resilient to the environmental perturbations [31,160]; improvement in distribution, production and supplies processes [1,128,32,101]; adjustments in relationship capacity/demand [148]; advances in the sharing of data and information and communication among the SC members [150,148]; greater awareness, learning and business education [74,37]; agility and accuracy in the selection of suppliers and facilities [184,37]; improving the coordination mechanisms [151]; speed in introducing new products [70].

Specifically with regards to the use of simulation optimization, the benefits reported in the papers are clear and highly significant. This was obtained through the variable balancing (trade-offs), involving, for example, capacity and demand [6], service level and costs [39], and through the design and optimization of parameters in the models [77,147]. A major advantage that simulation models allow is to incorporate the risks and uncertainties for projects [54,150]. Managers can develop and implement mitigation alternatives to deal with the vulnerabilities from the SC environment, making it more robust [85]. In short, the advantages and practical benefits obtained from real-world SC applications can bring competitive advantage to companies, raising its performance and ensuring the satisfaction of SC members, and customers. [78] highlights the advantages and disadvantages of simulation to model SCs.

In contrast, a major challenge for companies is reducing operating costs without affecting the service level desired. Sometimes, this implies to adequately quantify inventory levels to meet performance standards that meet the needs of end users and SC members. In this sense, to design a global optimal strategy that meets diverse SC players seems to be a major

Table 5
Relationship between research questions.

Questions RQ5	AD	%	AN	%	ED	%	EN	%
RQ2 role played by SCS models								
Understand and/or diagnose problems/SC	21	61.76	2	5.13	24	68.57	1	4.17
Improve the performance of SC variables	3	8.82	26	66.67	1	2.86	15	62.5
Test and evaluate new scenarios/projects/models	10	29.41	11	28.21	10	28.57	8	33.33
Total	*34*	*100*	*39*	*100*	*35*	*100*	*24*	*100*
RQ4 type of simulation								
DES	13	34.21	18	41.86	27	69.23	13	65
ABS	12	31.58	9	20.93	5	12.82	5	25
CS	7	18.42	11	25.58	1	2.56	1	5
DS	6	15.79	5	11.63	6	15.38	1	5
Total	*38*	*100*	*43*	*100*	*39*	*100*	*20*	*100*
RQ6 real-world SC applications								
Generic SC model	39	75.0	42	93.33	–	–	–	–
Real-world SC model	6	11.54	2	4.44	45	93.75	24	100
Characterized generic SC model	7	13.46	1	2.22	3	6.25	–	
Total	*52*	*100*	*45*	*100*	*48*	*100*	*24*	*100*

challenge. Another difficulty of simulation models is representing the dynamic and market volatility, especially when you wish to adjust the production and distribution capacity of the SCs to the variations in demand. Modeling, simulation and control of the bullwhip effect is still a subject that challenges researchers and managers. Several aspects also hinder the development of models that can capture and reproduce SC behavior, such as geographical dispersion between SC members and consumer market; short validity periods of products (e.g. pharmaceutical industry); terms and trading conditions; interactions generated in the organizational hierarchy levels (operational, tactical and strategic); synchronization of multiple flows switched among SC players; low visibility and delays in information.

Risks, uncertainties, disruptions and the stochastic nature of SC elements make M&S more challenging, since SC have a dynamic and complex behavior. Other adjacent challenges were identified in this SLR and include: access, consistency and robustness of data; adoption of appropriate procedures for verification and validation of results; complexity of the model to represent a SC, making M&S costly and time consuming; difficulties and costs associated to the implementation of the proposed solutions by modeling; need for experts with in-depth knowledge of real SC; issues related to the coordination of efforts to model and simulate, especially in cases that requires the integration of models; applying techniques that best fit the described problems, etc.

Undoubtedly, one of the major challenges to be overcome by practitioners and researchers in the SCS field is the lack of research and methodologies that can facilitate and streamline the process of performance of SCS. On the progress and developments in the SCS methods, few insights [163,168] were observed, some dealing with approaches for more specific topics, as ABS [90,100], simulation optimization and multi-agent [109], uncertainties [132,131]. [105], for example, developed eight steps, where some of it is previously established in the literature to design, implement and evaluate logistics and SC models, although only based on DES. Some contributions were important [51,57,69]; however, new research efforts should be directed towards the creating of efficient methods that can improve the implementation of M&S in real-world SCs. This is the greatest challenge faced by companies in practice with regards to M&S in SCs. Therefore, the views of [115] about SC modeling provide important insights for identifying challenges and opportunities in this issue.

3.3. Relationships and interfaces

The analysis of other research variables allowed to establish some relationships, as shown in Table 5, involving the nature of simulation models (AD, AN, ED, EN), explored in RQ5; and the following RQs: RQ2, RQ4, and RQ6. The articles that seek to better understand aspects of SC have a more descriptive application (AD + ED), 45 articles. Those papers that have improved some aspects in modeling, 26 of them were based on theoretical concepts and 15 articles sought the increase based on a real case study. Articles which aimed to test and evaluate new alternatives obtained similar performance results. Associating the type of simulation with the simulation method, it is evident that DES is used more for cases of real-world SCs with a primarily descriptive nature. DES was not applied as much as those from more theoretical models. ABS was mainly applied in conceptual models, representing 21 articles (AD/12 + AN/9). Therefore, researchers can further explore this type of simulation, especially when M&S are designed to investigate emerging issues in real cases of SCs.

Considering its analytical nature, CS was mainly used using the axiomatic approach, starting with the statistical and mathematical concepts in the literature. This represents 18 of the 20 analyzed articles (90%). DS was less applied using the EN approach, only in single case, indicating areas for further research. The application of M&S in real SCs was approached with the simulation method. The theoretical framework provides the basis for generating the generic model assuming, therefore, axiomatic features, adding up to 39 (AD) and 41 articles (AN).

The characterized generic model had a higher occurrence in AD, 7 articles. For models that had practical application in SCs, 69 followed the characteristics of a real-world SC, using M&S to reproduce their behavior, however, more descriptive

Table 6
Relationship between RQ4 and RQ2.

RQ4 type of simulation	RQ2	Improve		Test | evaluate		Understand		Others roles	
		No.	%	No.	%	No.	%	No.	%
DES		17	37.78	23	58.97	16	33.33	15	30.61
ABS		9	20.00	4	10.26	13	27.08	5	10.20
CS		7	15.56	3	7.69	2	4.17	8	16.33
DS		4	8.89	1	2.56	9	18.75	4	8.16
Others types		8	17.78	8	20.51	8	16.67	17	34.69
	Total	*45*	*100*	*39*	*100*	*48*	*100*	*49*	*100*

Table 7
Summary of relationship between RQ2, RQ5, RQ6 and RQ4.

RQ	DES	ABS	CS	DS
2.	Test | evaluate	Understand | diagnose	Improve	Understand | diagnose
5.	ED	AD	AN	AD | ED
6.	Real-world	Generic	Generic	Characterized generic

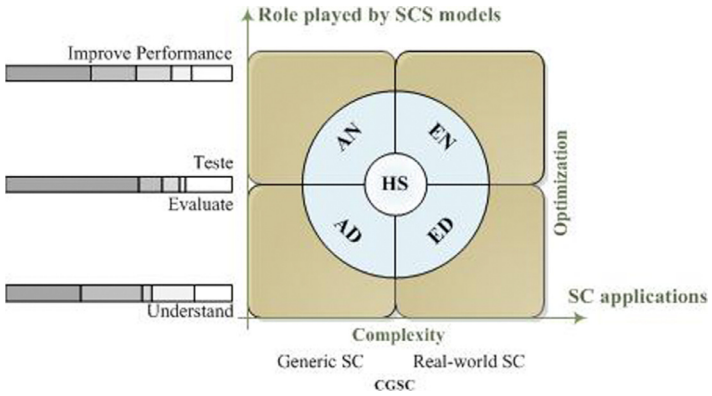


Fig. 8. SCS model interfaces.

models were found with a total of 45 (ED). Twenty-one articles assumed a more normative character (EN). It means that the number of more aggressive modeling, designed to improve performance or to solve critical problems in SC, could be increased. Table 6 illustrates the central relationship between the role of simulation models and the applied type of simulation (RQ4 versus RQ2). The findings demonstrate that DES and ABS simulations are commonly used when you want to understand the SC and improve performance. When you want to test and evaluate alternatives, DES was used more in 23 articles, against 4 in which ABS were primarily applied. As RQ2, DES is mostly applied to test, compare and evaluate scenarios. In this case, comparing the DES and ABS, there is a large difference in favor of the first type of simulation. Therefore, Table 6 shows the % composition of the main roles fulfilled by simulation models according to RQ4.

Considering RQ2, RQ5 and RQ6 and their relationship to the type of simulation used (RQ4), Therefore, Table 7 identifies the predominant category in every aspect analyzed according to the percentage obtained in RQ4.

The aspects analyzed in research questions RQ2, RQ4, RQ5 and RQ6; Tables 5–7, led to the development of a diagram (Fig. 8) containing interfaces that help to explain the main characteristics of simulation models evaluated in this study.

The importance of simulation models is directly connected to the modeling aims. When there is a need to solve some kind of problem in the SC, the relevance of simulation and optimization methods grows to improve the performance of the phenomenon or studied variable. DES, with 37.78%, was the main type of simulation used for this role, followed by ABS, according Fig. 8. For the purpose of testing and evaluating scenarios and models, DES obtained the largest percentage (58.97%). Once more, DES and ABS were the most popular mechanisms to understand aspects of the SC and/or diagnose problems.

Simulation models may be developed considering, for example, the complexity of the SC. This complexity increases in situations where the model is constructed from a real-world SC. For generic SC applications, for instance [112], models are usually theoretical developed from the literature. Such models are abstracted of the dynamics and interactions that are present in real-world SCs. However, when you want to understand the behavior of some aspect of the SC, the model assumes a more descriptive purpose (AD/ED). Instead, normative perspective is used predominantly when you want improve

Table 8
SCS – Winter simulation conference review.

Aspect	TOP 3	No.	%	CUM%
Year of publication				
2010–2011	1st	23	46	46
2012–2013	2nd	18	36	82
2014	3rd	9	18	100
Country of author's affiliation				
USA	1st	24	48	48
Germany	2nd	6	12	60
Brazil	3rd	3	6	66
Scientific method				
M&S	1st	36	72	72
Single case/multiple cases	2nd	12	24	96
Literature review	3rd	2	4	100
Economic/industrial Sector				
Semiconductor industry	1st	6	21.43	21.43
Food	2nd	2	7.14	28.57
Oil industry	3rd	2	7.14	35.71
Central theme				
Inventory management	1st	5	10	10
Risks/costs	2nd	4	8	18
Processes and production systems	3rd	4	8	24
Role played by SCS models				
Test and evaluate new scenarios/projects/models	1st	14	28	28
Improve the performance of SC variables	2nd	12	24	52
Understand and/or diagnose problems/SC	3rd	8	16	68
Techniques and tools				
Modeling and/or simulation	1st	23	46	46
Simulation and optimization methods	2nd	11	22	68
Mathematical modeling (MM)	3rd	7	14	82
Software tools				
Arena®	1st	11	22	22
Java®	2nd	6	12	34
Anylogic®	3rd	3	6	40
Type of simulation				
DES	1st	24	48	48
HS	2nd	10	20	68
OOS	3rd	3	6	74
Nature of simulation models				
AD	1st	18	36	36
AN	2nd	16	32	68
ED	3rd	8	16	84
Real-world SC applications				
Generic SC model	1st	21	41.18	41.18
Real-world SC model	2nd	14	27.45	68.23
CGSC	3rd	14	3.92	72.44

the performance of some aspect of the SC (AN/EN). Moreover, depending on the purpose of the simulation, the circle in the center of Fig. 8 suggests hybrid combined models (HS). For example, some variables/events can be modeled applying AD perspectives (e.g. service level), while others may take normative empirical features (e.g. minimizing transportation costs).

4. Conference proceedings review

In addition to peer-reviewed journals, this SLR on SCS was extended to papers published in conference proceedings, especially one of the most important events in simulation field, the Winter Simulation Conference (WSC). Procedures for applying the SLR followed most of the steps presented in Fig. 2. The search was conducted in the WSC database (www.informs-sim.org). The first search returned 87 articles published in the last five years (2010–2014). After applying the filters and qualitative analysis of the papers, the data were extracted from a sample consisting of 50 articles. Some articles that did not show the words "Supply Chain" in the paper title were kept in the study, since the content was directly related to the RQs, for example [27,164,142,46]. Therefore, Table 8 summarizes the main findings of this research, highlighting the TOP 3 positions in the reviewed aspects.

The most publications were in 2010, 16 (32%), followed by 2013, with 13 papers. In 2014, 9 articles (18%) were published. Considering the institutional affiliation of the first author, USA is the country that is the most published, almost half of the publications, followed by Germany and Brazil, both with 18%. Compared to the review of articles published in journals, US remained first with 42.86%. Chinese authorship was observed in one article. In 2014, little more than half of the articles

Table 9
Summary aspects – 2013 | 2014 WSC.

Aspect	2013–2014 WSC
Country of author's affiliation	USA
Scientific method	M&S
Economic/industrial sector	Semiconductor industry
Central theme	Risks/costs | processes and production systems
Role of simulation	Improve the performance of SC variables
Techniques and tools	M&S
Software tools	Arena® | Java®
Type of simulation	DES
Nature of simulation models	AN
Real-world SC applications	Generic SC model

were published by authors of American institutions. Sixteen countries were recorded regarding the affiliation of the first author.

M&S was the most used scientific method in the WSC, with 72%, followed by case studies and multiple cases (24%) and finally LR, with 2 papers [86,123]. Nineteen economic sectors were recorded, between generic SC and real-world SC models. The leading sector is the semiconductor industry, with 32.58% of all cases reviewed. In WSC, there is a section for publishing papers whose application is the semiconductor industry. The following sectors all had 2 papers and include the food, oil and sugar cane sectors, all with an equal market share at 7.14%. In 22 cases (44%), there was no reference to the economic sector.

Thirty-seven subjects involving SCS were recorded in the WSC, highlighting inventory management (10%), risks/costs (8%), processes and production systems (8%). Other themes had equal participation (4%), such as: competition/cooperation; developing games/simulators, programming language, information systems/information technology and sustainability. It is noted that the inventory management theme also ranked first in the peer-reviewed papers.

Contrary to what was observed in peer-reviewed papers, the main role of M&S in the WSC is to test and evaluate new scenarios/projects/models in the SCS theme, representing 28% of cases. Jain et al. [80], for example, created a multi-resolution model for SC sustainability analysis. In the last two years, eight research studies aimed to improve the performance of SC variables, showing the relevance of M&S, while providing a decision support tool for solving problems.

Lakshmanan [91], for instance, applied simulation to provide an efficient heuristic solution, aiming to understand the overall reliability of the SC from the evaluation of critical bottlenecks and the analysis of different scenarios (What-if). The third ranked role was to understand and/or diagnose problems/SC (16%). Rosseti et al. [142], for example, investigated the effect of aggregate demand on the performance measures of an inventory system.

In the technical and tools aspect, modeling and/or simulation was most used highlighting the DES [e.g. 18,129,45], HS [e.g. 22,59,162], SD [e.g. 23,12], OOS [e.g. 142,143] and SS [179]. In 11 (22%) articles, simulation was combined with optimization methods. Forstner and Mönch [62], for example, proposed a model for estimating the objective function based on the profitability, taking into account SC stochastic behavior. MM was used in 7 of the 50 papers, such as Meng et al. [110], who developed an analytical model to quantify the optimal reserve capacity and realization time by modeling the manufacturers and suppliers.

Thirty-six papers used simulation software tools. Arena® software is the most widely used in SCS, being mentioned in eleven (30.55%) papers, followed by Java® (16.67%), Anylogic® (8.33%) and Extendsim® (8.33%). In 12 articles, it was not possible to identify the software tool used for the simulation. In two research studies no software was used. In addition to the software mentioned, an additional eleven were recorded in this SLR (PowerSim®, AutoShed AP®, MS Excel®, Netlog®, Simpy®, ProModel®, Siman®, SimChain®, Vensim®, SysML® and @Risk®). In both reviews, conference proceedings and journals, Arena® led the software applications. [58], for example, applied this commercial package to model the flow of product and risk factors associated with disruptions and quality issues in a SC. The results show that commercial packages are responsible for most of the applications.

The majority of simulation models are axiomatic, representing 68% of cases considered. Descriptive models account for 35%, while the normative models are 32%. It shows that most models are developed from generic SC models [55,53,87,45]. Empirical models represented 28% of the papers. The majority of the empirical papers are ED. In terms of SC models applications, generic models represent the majority of the sample, 68%. Purely generic models contributed to 42% of all papers. In 28% of the papers that were considered there was the implementation of M&S based on real-world SC applications. Characterized generic SC models from an economic sector represent 26%. Table 9 shows a summary of the issues reviewed in the last two years of the WSC.

Other works published in conference proceedings were also analyzed, as The International Conference on Harbor, Maritime & Multimodal Logistics Modelling and Simulation (HMS) and European Modeling & Simulation Symposium (EMSS). In HMS, twenty one works were published between 2009 and 2014. 2009 and 2014 had the highest number of publications, 6 each. Germany is the country with the highest number of publications, six articles (28.57%). Main subjects discussed were inventory management, transportation and risks/costs. The primary role of M&S in the reviewed articles was to improve the performance of the model variables/SC, recorded in eight papers (38.09%). Some applications of M&S in real-world SCs

were recorded [e.g. 19,71,21] in vehicle, frozen food and wood industries. In EMSS, between 2005 and 2013, there were 12 recorded articles. The year 2008 recorded the highest number of publications, five papers (41.67%). Italy was the country with the highest number of publications (50%). Inventory management and SC design/configuration were the most noted issues in four works. The objective of improving the performance models variables/SC was recorded in six articles (50%). Techniques of M&S and simulation optimization methods were mentioned in 4 articles.

Text books recently published, as in [113,119] highlight important applications of M&S in the logistics and real-world SCs. Hennet [68] proposed a model to compare production and ordering policies in a SC under the influence of the bullwhip effect. Through a generic SC model, Merkuryeva and Napalkova [114] analyze different types of optimization methods based on simulation applied to the SC planning problem for products in the maturity phase of their life cycle. In this case, the authors applied a multi-objective genetic algorithm to solve the problem associated with a hybrid simulation. Bruzzone et al. [25] proposed a model for a fresh food SC to improve the management of operations and reconFig. the logistics network. The authors highlighted the importance of M&S to test methodologies and develop decision support systems based on optimization techniques. Affenzeller et al. [3] illustrate various applications of simulation and optimization in the real world. In this book, the authors highlight topics, such as designing a European logistics network for bio-waste; inventory optimization; optimization of the transport of steel slabs activities; simulate the material flow; among other cases. Such examples of real cases demonstrate the advantages of using a combination of simulation and optimization techniques for decision making.

5. SCS methodological framework: guidelines for implementation

In this SLR we observed a lack of methodologies designed to facilitate the introduction of SCS. Based on the insights obtained in this SLR and realizing the generic fundamentals of M&S, we developed a SCS framework with a systematic methodology to better support the implementation of M&S models. The proposal is to avoid the likelihood of bias in modeling aspects related to SCs which may compromise the performance of the SCS. As depicted in Fig. 9, guidelines were developed to support the implementation of M&S in SCs. The SCS guidelines are categorized into four main phases: (1) conceptualization, (2) modeling, (3) model solving, and (4) implementation. Despite these phases having been researched in the literature, this framework proposes to adapt these, already well known, phases to improve the implementation of SCS, offering better support to modelers. Given the limitations of specific methodologies for SCs, the idea is to encourage the development of new contributions in the field of SCS.

5.1. Conceptualization phase

According to the topic of interest of the research, the first step is to clearly define the problem and objectives of M&S. The problem can be practical, generally identified in real-world SCs, or extracted from gaps in the literature. The SCS objectives can be set according to the role of M&S recorded in this survey. Several subjects identified in this SLR may be the focus of modeling, especially those less mentioned, such as vulnerability and integration. The choice of the SC should consider the nature of the problem you want to solve. Thus, the model can be developed from three perspectives including: real-world SC, generic SC or a combined model, incorporating characteristics of both types of SCs being real-world and generic. The SC managers can hire specialized services for the work of M&S or use their own experts.

In the next step, the SC specialist must conFig. or combine the SCs. Usually a generic SC can be characterized from theoretical bases available in the literature. For a real-world SC other characteristics should be considered such as dynamics, interactions, and complexity of the network. The models developed from real-world SCs require simplifications, since the complexity of the interactions and operations makes it difficult to capture several aspects. Some criteria for delimitation of the SC may be applied, such as: the organizational maturity of the SC members; levels of integration; relationships among SC players; etc. Complexity theory and a systemic approach can support the modeler in this exploratory phase.

SC configuration should consider several aspects, such as: scope, assortment of products, SC business processes, flows, competences, flexibility, governance, structure, members' value chains, partnerships and relationships, and a performance measurement system. If the focus is on the SC process, the SCOR model can be used to delimit the SC. There are several uses of the SCOR in the real-world SCs, which focuses on the improvement of SC processes. It is a framework that adds business processes, performance metrics, best practices and tools to improve the SC performance. Nevertheless, for applications in real-world SCs, the SCOR model can also guide the M&S in generic SCs. However, it should be noted that one of the biggest criticisms of the SCOR model is its low flexibility. SC configuration can be realized with the support of numerous tools, as: DS, Value Stream Mapping (VSM), IDEF-SIM [118], Business Process mapping/management (BPM), Failure Tree Analysis (FTA), Petri Net (PN), SIPOC (Suppliers, inputs, process, outputs, and customers), flowcharts, Bayesian Networks (BN), etc. After the configuration step, the decision-making variables for the model must be identified and selected considering its nature. Thus, the variables can be discrete, continuous or hybrid. It is important to consider the relationship between the input and output variables. DOE tool can assist analysts to model the decision variables. Therefore, the decision-making variables should be chosen in line with the objectives of the modeling.

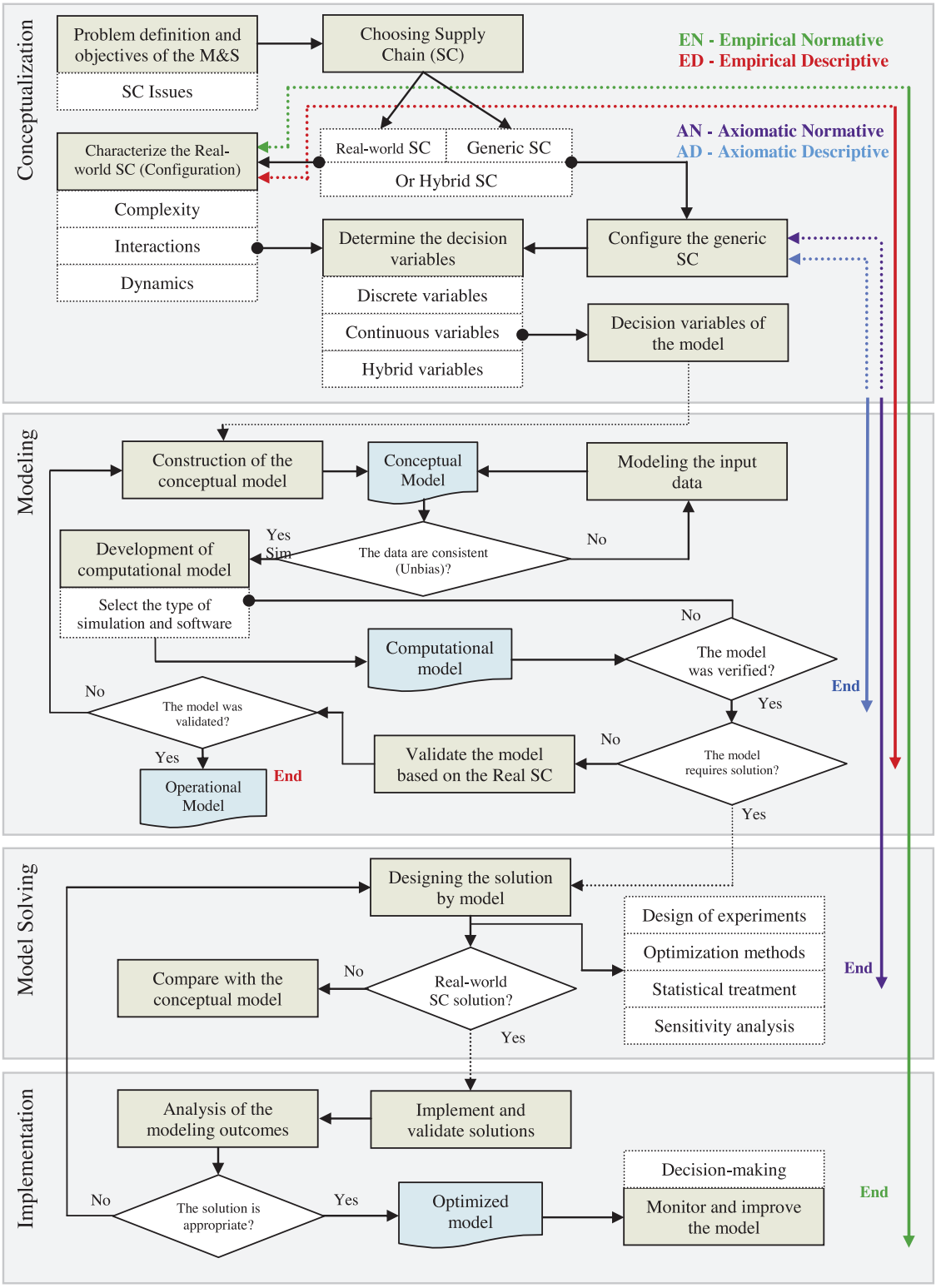


Fig. 9. SCS methodological framework.

5.2. Modeling phase

SC characterization, nature of simulation models and decision variables create the platform for the development of the conceptual model (CM). The CM is the main foundation for the construction of the SC, showing what and how the SC will be modeled. The development of the CM must be supported by the conceptualization phase, comprehending SC scope; level of detail; nature of the decision variables, pointing the relationship input/output; assumptions and simplifications, and verification/validation procedures of the model. Although most SCs exhibit complex behavior, a CM must be simple, parsimonious, measurable, useful, feasible, flexible, and applicable, generating value for users of SCS. In addition to methods and tools mentioned in the literature, the SCOR model can be applied to develop the conceptual model itself, since it provides tools for mapping and detailing processes, set performance metrics and benchmarking, and to delimit the SC scope. Use of the SCOR model in SCS can be identified in [31,129,136,177]. CMs should be developed based on the nature of the simulation model (EN, ED – Empirical, AN, AD – Axiomatic). After the construction of the CM, the generated information should be reported and recorded in detailed documents.

The next step refers to the data collection for the decision variables. The data that will be used in a computational model can be generated in 4 ways: extracted from real-world SC, created from modeler, appropriate from literature, or numerical simulation from a random generator. Depending on the purpose of the study in SCs, an enormous amount of data may be required. Modeling the input data step is important to test some properties of the data as consistency, robustness, accuracy and traceability. The collected data should receive statistical processing applying tools, like: hypothesis tests; graphical analysis; ANOVA; Chi-Square Goodness of Fit Test; etc. If the data are inconsistent, they should go back to the input data modeling step. Otherwise, incorrect data will be applied in the computational modeling. At this stage, the CM used to represent aspects of the SC is converted into a simulation model containing the data and decision-making variables.

The expert should define the type of simulation and software. The major types identified in this simulation SLR can be applied in computational development (DES, ABS, CS, DS, and HS). DES was used in most cases; however, for more complex SCs models, ABS and HS may provide more useful results. Most commercial software packages meet the SCS objectives. However, more specific applications can be developed using programming languages. Other software (e.g. Anylogic®) may even develop the ABS. The choice of software depends on the analysis of aspects such as: purchase price, support costs, computational cost, usability, tools, etc. Software should support the processing and analysis of the decision variables. Thus, the expert can develop and test the SC computational model.

The next step is to verify and validate (V&V) the computational model. Various methods can be used to verify the simulation model performance; some more interesting for SCs cases, for example, modular implementation and verification, step by step, checking the interactions between SC model elements and the relationship input/output. Verification can be performed by comparing the CM and simulation model. The participation of experts and SC members in the simulation model review process and evaluation of animation and visual display of the computer model relative to output measures are key verification techniques. Most simulation software has tools, such as debugging; trace; error review, etc. The data collected should be incorporated into the computer model for setting up and carrying out experiments. Another interesting verification tool is to change input parameters and analyze all possible decision variables that affect the outputs (measures) generated by the computer model. The model outputs can be compared to historical data, data sets extracted from the literature, and actual data. If the model fails the test, it must return to the development stage. If the model requires a solution, in accordance with the purpose of the simulation, then it proceeds to the model solving phase. Otherwise, the expert will validate the computer model. A purely AD model (blue flow) fulfills the steps of the conceptual phase and partly the steps of the modeling phase followed by the verification step.

After the verification phase, the computational model, developed from a real-world SC, must be validated to guarantee that the collected and generated data are consistent and coherent according to the conceptual model created. Several validation techniques have been identified in this SLR. Statistical techniques are the most applied tools to validate models. The data generated by computational models may be compared to the collected data set from a real-world SC. In this case, hypothesis testing can be applied to test the consistency of the data generated (e.g. *t*-test, ANOVA). Other procedures may also be applied, such as: regression analysis, cause–effect graphing, predictive validation, face to face validation (real-world SC expert), predicate calculus, confidence interval, etc. Negative results in the model validation phase may be linked to failures in the development of the conceptual model. Procedures of V&V can be observed in [128,160]. The computational model may be certified, or receive a conformity certificate issued by a third party [e.g. 12]. In sequence, an operational model is created, which is able to be implemented. After the implementation of the operational model, results are analyzed and decisions are made. A purely ED model (red flow) meets all steps of the phases of conceptualization and modeling.

5.3. Model solving phase

The main focus of this phase is the resolution of a problem specified in modeling. This phase is designed to meet, in most real-world SC models, the following objectives: improving the performance of SC decision variables; testing and evaluating of new scenarios, projects or models; and supporting the decision-making process.

Some methods identified in this SLR contributed significantly to the development of solutions required by the problems. Given the nature of the variables and the input/output relationship, DOE tool was applied to identify the most influential variables in the model performance. Other application of this tool has been in the economic and operational design of the

scenarios to be analyzed, allowing you to select those that actually change the SC performance. The insertion of optimization methods (OM) to M&S was frequently used in the reviewed papers. This main objective of this practice, known as simulation optimization (SO), is to generate optimal solutions for the variables you want to improve, minimizing or maximizing the value of the performance measures (objective function). In this sense, OM provide great results to the decision-maker, generate appropriate solutions for solving problems in SCs, especially when these techniques determine equilibrium conditions among conflicting variables [11]. Linear programming (LP), mixed-integer linear programming (MILP), and mixed-integer nonlinear programming (MINLP) were the optimization techniques used the most in this SLR.

Statistical treatments can generate alternative solutions; however, it does not have the ability to develop the best solutions such as, for instance, scenario analysis. Sensitivity analysis is another technique that can provide interesting results, as it can determine the most significant factors affecting overall performance of the SC model. Other specialized tools in the selection and ranking of alternatives can determine the best options for solving the problem, as: Fuzzy Logic; and Analytic Hierarchy Process (AHP). In this step, the solution is designed for EN and AN models. If the solution is not generated for a real-world SC, it must be compared with the conceptual model to verify if the proposed solution meets its characteristics. Otherwise, the solution generated in this stage should be implemented in practice (real-world SC). Thus, the proposed solution chosen by the decision maker must be applied through the confirmation experiments by changing the values of parameters and input variables for the SC to obtain optimal results. The simulation based on the model AN (purple flow) follows this phase.

5.4. Implementation phase

The solution created for a real-life SC should be implemented and validated. In practice, the SC managers will change the values of the input parameters through the implementation of organizational actions that can improve system performance. After a certain period of time, new data on the SC performance (outcomes) must be collected and statistically processed, in order to validate the proposed solution, assessing if there was improvement in the decision variables. Some validation procedures mentioned in Section 5.2 can be applied to assess the efficiency and accuracy of the solution.

After this step, the outcomes of the modeling are analyzed. If the solution is not adequate, we should turn to the development of new solutions, once the solutions may not have been well developed. From a practical viewpoint, several solutions may be developed, some requiring more complex implementations. Otherwise, it generates the optimized model that will be used in decision-making, containing the optimal parameters of the input variables. This model is the benchmark for new improvements in the system. The computer model will produce the observed results from the real-world SC performance, since the confirmation experiments were validated. Therefore, the optimal model is designed considering that the solutions to the proposed problem were appropriate in accordance with the conceptual model developed from real-world SC. The next step deals with the monitoring of the performance of decision-making variables. If needed it provides feedback for the previous steps to continually improve the model's functionality. The SC managers can to monitoring through computer systems, reporting, performance measurement systems, etc. In this way managers can strengthen the decision-making process to improve SCM. A major difficulty of the modelers is to update and improve the simulation models in order to follow the changes and dynamics in SCs. The design of this model follows an EN perspective (green flow).

6. Conclusion and future directions

The SLR has proven to be a significant technique for the exploration of literature in scientific research. The contributions of Tranfield et al. [166] and Denyer and Tranfield [49] provide an important guide for researchers to conduct their searches better, reducing the likelihood of bias and avoiding distortions in the research findings. Thorough research that uses the SLR can be identified in [26,48,153,83,4], which perform, with rigor, this method. The detailed evaluation of the literature reviewed allowed a more robust analysis about the SCS theme. SLR increases the chances of success in an exploratory survey, providing the researcher with a denser overview of the bibliographic data of technical articles. The outcomes in time and resource savings are visible, as the sampling directs the search to qualify the research process, and improve data processing and analysis. SLR can help identify emerging issues, incipient or future developments in scientific research, and enable understanding of the evolution of the state of the art in certain topics.

There was an increase in the number of articles published since 1992. New developments of future researches, integrating M&S to SCs could be directed to journals that deal with aspects associated to operations management and decision-making. The combination of M&S with optimization methods, focusing on performance improvement, seems to be a trend on the rise. In addition to inventory management, other issues could be explored in SCS, such as reverse logistics. The simulation methods converge for a more descriptive approach, although more normative treatments contribute significantly to the generation of alternative solutions based on the M&S method. This can make the SC more competitive and have superior performance. The applications of real cases were found primarily in SC related industries. New research studies could be developed in SCs present in the service sector. The integration of M&S and SC can satisfy several objectives, such as to simulate the behavior of agents, control of business processes exchanged among agents, develop sensitivity analysis (What-if), etc.

For highly complex interfaces in SCs, M&ABS has emerged as a robust tool that can generate significant results for companies. In some cases, DES cannot be applied with due success, suggesting possible uses of M&ABS; however, it is still

widely used. Most articles develop SCS based on generic models, sometimes, eschewing the dynamics and complexity of real-world SCs. Thus, hybrid combinations of models, associating meta-models to the reality of a SC as real system could be more useful. While methodological systematic, M&S applications observed in papers does not satisfy the rigor required to approximate more accurately the behavior of a real-world SCs to the simulated model. The use of M&S in SCs may contribute significantly to support decision-making. Recognizing the relevance of SCS role in improving the performance of SC networks is a critical aspect that can generate value for organizations.

This paper presented an extensive coverage of the literature on SCS. Considering the results obtained in this research, we conclude that M&S in SC has been widely applied in recent years, especially to real-world SC applications. The integration between M&S and SC may contribute to the evolution of the SCS field, since it presents great opportunities for research and development. The authors of this research sought to explore and broaden the discussion on simulation models used in SCs, for example, analyzing the perspective of the nature of modeling, and even more, developing a diagram entitled "SCS model interfaces", which supports the methodological analysis of simulation models. Key interfaces and perspectives were discussed regarding the SCS subject, including the development of a methodological framework that incorporates guidelines and some actions to facilitate the implementation of M&S in SCs. It is important to note that the reviewed papers did not focus its research on the development of methodologies for the SCS field.

In addition to the proposed framework that has been developed based on contributions already made in the literature, our systematic methodology incorporates relevant aspects of the SCS theme, of which several tools were identified in the reviewed papers; It differs from existing approaches in the following ways: it improves the conceptualization phase, directing and detailing efforts to SCs; it integrates the SC framework characteristics (AD, AN, ED, EN) associated with the nature of simulation models [17]; it suggests the feedback of M&S process for continuous improvement purposes of SCs; the 4 stages suggest and guide the application phase and furthermore clearly relate the role of M&S in SCs to the various SCS phases, for example, improvement by OM, the performance variables (Model solving phase); and it can improve the implementation of SCS. In contrast, there are two major challenges to be overcome including: the lack of research methodologies in SCS implementation; and the growing dynamics and complexity of SCs. The SLR that was conducted for this paper support these findings and the authors therefore suggest the following as future research directions: implementations of SCS methodological frameworks in real-word SCs; increasing research efforts to improve existing methods or develop new methodologies; apply principles and tools using a systemic approach to facilitate the development of models closer to the reality of SCs.

In addition to the reflections and suggestions mentioned, other aspects that can be deployed in future research include: model and simulate aspects to consider the complexity, dynamics and interactions among SC members, aiming to improve performance and optimize resources; align the type of simulation and techniques available to the objectives of modeling, trying to extract from the techniques the best possible results; focus more on conceptual modeling, which is still overlooked by some experts. Failure to fulfill this important step can generate results that do not represent the reality of the SC that was modeled. The combination of M&S, optimization methods and M&ABS in SCs seems to be a trend as it may enable better SC performance. Some papers combined M&S and optimization techniques; nevertheless the amount of papers that combine M&ABS and OM is still incipient, constituting opportunities for future research. Therefore, this SLR presented important insights for those who want to deal with SCS.

Notes: The full list of references for the sample articles can be obtained in the supplementary material. To have full access to research data, please contact the authors.

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Supplementary materials

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