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Review

Learning from the past to shape the future: A comprehensive text mining analysis of OR/MS reviews☆

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ABSTRACT

This paper provides an overview of the evolution and state-of-the-art of the Operations Research and Management Science (OR/MS) subject area from 1956 to 2019. Using text mining techniques on the content of the title, abstract, and author keywords of papers classified by the Web of Science as literature review studies in OR/MS, we found that there are 76 topical consolidated clusters in the field covering a wide range of reviewed topics. Since 2015, reviews on supply chain risk management and big data analytics have had the highest impact in the field, whereas topics such as Industry 4.0, socio-technical systems, social networks, green supply, sustainable supply chain, and resilience engineering have all received significant attention from researchers. Reviews on analytic hierarchy process were found to be the most impactful overall, showing the high relevance of multi-criteria decision making in the current research and practice contexts. Furthermore, a text mining analysis of the papers citing OR/MS literature reviews showed that optimization continues to be one of the most highly influential methodological contributions of OR/MS to other research areas and that topics such as circular economy, carbon emissions, and social commerce have yet to find some traction in OR/MS research, suggesting future research and multidisciplinary opportunities for the field. Results also show that the research area of Public Administration has been greatly influenced by OR/MS reviews as 16% of all the papers published in that field have cited at least one of the 1744 review papers included in this study. Finally, a summary table of published structured literature reviews per topic (benchmarks, classifications, taxonomies) is presented as a short bibliography of OR/MS review papers.

1. Introduction

The Operations Research and Management Science (OR/MS) community has been at the forefront of knowledge concerned with improving firm operational performance in the manufacturing and service sectors since the establishment of the first OR/MS journals in the early 1950s. Practically from the constitution of OR/MS as a self-standing science field onwards [1], topics such as inventory control, resource allocation, waiting lines, scheduling, and routing have been regarded as the main application areas addressed by OR/MS by applying core methodologies such as exact and approximate analytical solutions, linear programming, queueing theory, algorithmic solutions, and game theory. This can be attested in multiple introductory textbooks [2–4] and revisionist studies [1,5–7]. However, the need to address the business operations paradigm change from a factory-focused environment to a customer-oriented context in the services and manufacturing sectors [8], as well as the calls to make OR/MS research more applicable [9–11], led some researchers to incorporate methods from other research areas into the pool of methodologies used in OR/MS.

The data analytics movement is the most visible example of this phenomenon as it has been regarded by some authors as a very influential and relevant methodological approach in OR/MS [12–14]. Data analytics has been incorporated in the editorial scope of representative journals in the field, such as Management Science, Omega, and Operations Research [15–17]. This assimilation of new methods and application areas into OR/MS research has even been regarded by some authors as a potential problem for the relevance

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of OR/MS as a self-contained area of research, which has led them to suggest that the field has become too broad [11,18], losing its focus and some of its relevance. This concern raises the question of whether some topics and methodologies have become a fundamental part of OR/MS, further consolidating the field into a coherent and unified knowledge base [19], or whether they have only resulted in the dispersion of the field by focusing on topics that are too narrow without much relevance for many other fields (see, e.g., the discussions in [20,21]).

Some previous bibliometric studies have tangentially studied the integration of methodologies and application areas into OR/MS research by analyzing the output of OR/MS journals [22–25] and the bibliometric characteristics of papers included in the Essential Science Indicators (ESI) database [26]. Although these studies have identified the most frequent author keywords associated with recent publications, showing the topics that have been recently studied by some specific journals, there has not yet been a study that is specifically concerned with studying which are the core topics of the OR/MS field as a whole, based on text mining. Text mining techniques are comprehensive analysis tools that can extract more information from the content of the studies than author keyword analysis, e.g., more information about methodological approaches [27] and application areas [28], as they are able to mine relevant words and phrases from various content fields, e.g., titles, abstracts, and full texts. Furthermore, text mining techniques allow the researcher to cover a much wider range of studies than traditional literature review approaches since these only allow authors to comment on a limited set of studies, typically well within the domain of authors' experiences [29]. Traditional literature reviews also often suffer from subjectivity as they lack methodological rigor in a large-scale analysis [30]. In this regard, text mining can help overcome such typical shortcomings of a traditional literature review approach by being an automated procedure that identifies trends and topic commonalities based on objective data.

This paper aims to address this gap and contribute to the discussion regarding the development of OR/MS as a science by investigating which topics can be regarded as consolidated topics in OR/MS, even if they have not been traditionally associated with this research field, and which of these topics have had the highest impact overall. To do so, we carried out a text mining analysis of literature review papers published in journals classified in the Operations Research & Management Science category of the Web of Science [31] since literature review papers cover topics that are already consolidated and have developed into a mature stream of research.

After identifying the main topics in OR/MS by accumulating statistics on the most frequent terms included in literature review papers, we use these results to identify core and emerging topics that have received significant attention from the field in terms of both the number of publications and citation counts. Using comprehensive results from text mining, we also highlight topics that could be the subject of future reviews and provide the reader with a bibliography of OR/MS structured literature review papers for different consolidated topics in the field. Finally, while OR/MS has been influenced by other research areas and has incorporated their tools and methods, it has also influenced external research areas with common research topics such as Management and Engineering [32,33]. However, there is still a lack of research regarding the specific topics stemming from OR/MS that have influenced different research areas, other than the ones traditionally associated with OR/MS. In this study, we therefore also use text mining analysis to investigate this issue.

Following this introduction, we present in the next section an overview of previous research related to this study. Section 3 explains the methodology of this research, while Section 4 describes which are the consolidated topics in OR/MS, based on text mining results. Section 5 shows how OR/MS has influenced other research areas. In Section 6 we present some research opportunities for future OR/MS reviews. Finally, the discussion and conclusions are presented in Sections 7 and 8, respectively. A full bibliography of reviews classified by their topics can be found in the supplementary material (Tables C1 and C2) of this study.

2. Related research

There are two streams of research associated with this study. The first set of papers is a data-driven set of papers, where papers mostly focused on bibliometric analysis are included. The second set of papers discusses the development and evolution of OR/MS as a science from a revisionist point of view, where questions such as what actually constitutes OR/MS research and what is its applicability and influence have been investigated. Due to their relevance for this study, both streams of research are reviewed in this section.

2.1. Bibliometric studies in OR/MS and Operations Management

The availability of bibliographic databases such as Web of Science (WoS) and Scopus and their bibliometric tools, e.g., Journal Relationships in WoS [34], as well as the emergence of software to conduct bibliometric analysis, e.g., VOSviewer [35], CitNetExplorer [36], and *bibliometrixR* [37], has created an era of widespread bibliometric analysis investigation in all areas of research [38]. This trend has not escaped the OR/MS field, as shown by the wide variety of bibliometric studies in this field, presented in Table 1. Table 1 describes the scope, aim, and methodology of previous bibliometric studies in OR/MS and Operations Management (OM). In addition, Table 1 shows the unit of analysis of each bibliometric study as these studies can be focused on different entities, such as journals, authors, countries, institutes, documents, and topics. For the papers that focus on identifying relevant research topics based on bibliometric data, Table 1 also presents the data source, i.e. titles, abstracts, or author keywords, that was used by the researchers to extract the papers' content.

The most common types of bibliometric analysis have been the ranking of journals in OR/MS and OM (see, e.g., [46–48]) and the study of the research output of a specific journal (see, e.g., [22–25,42,43]) where the most prolific authors, countries and institutes are identified, and clusters of topics are analyzed. Mainly with the help of bibliometric analysis software [35–37], these studies have identified the co-occurrence network [52] of author keywords, the co-authorship relations among institutions, and co-citation networks among journals. From bibliometric studies, we can see that the topics and methods of data envelopment analysis, decision making, heuristics, inventory, mathematical programming, scheduling, simulation, and supply chain management, have all been fundamental topics for OR/MS journals such as the European Journal of Operational Research [22], the International Journal of Production Research [41] and Omega [43]. Results from those studies also suggest the emergence of topics such as healthcare, multi-criteria decision making, risk management, or sustainability over the last 10 years.

Liao et al. [26] mention that "*there is a lack of discussion on hot topics and future directions based on keywords analysis*" since most bibliometric studies only focus on output analysis; therefore, Liao et al. extended the results from previous bibliometric studies who were focused on single journal output by studying highly cited papers in the Operations Research & Management Science subject area classification in the period 2008-2017 from the ESI database of highly-cited papers [53]. They identified that the terms of *supply chain management* and *logistics* gained interest from 2012

Table 1
Previous bibliometric studies in OR/MS and OM.

Reference	Scope	Aim	Unit of analysis	Data source for topic analysis
[39]	OM field (6 journals)	Review of production and operations management literature by identifying the core areas of research	Topics, research methods	Abstract
[40]	OM field (5 journals)	Use of Latent Semantic Analysis to discover the intellectual structure of OM	Topics	Abstract
[26]	OR/MS field (ESI database)	Bibliometric analysis of highly cited papers	Journals, countries, institutes, topics	Title, author keywords, keywords plus
[41]	Journal	Evolution in the interest of topics throughout the years	Topics	Title, abstract,author keywords
[28]	Journal	Identify the core areas of research for a particular journal	Topics	Abstract
[27]	Journal	Identify the most common research methods in a journal	Research methods	Abstract
[22–25,42,43]	Journal	Overview of the output of a particular journal	Authors, countries, institutes, topics	Author keywords
[44]	OR/MS field (WoS database)	Bibliometric analysis of the field	Journals, authors, countries, institutes	No topic analysis
[45]	OM field (11 journals)	Identify the most prolific authors and institutions in the field	Authors, institutes	No topic analysis
[46–48]	OR/MS or OM field	Ranking of journals in OR/MS or OM	Journals	No topic analysis
[49]	OR/MS field (WoS database)	Identify the most prolific countries and journals and how authors in some countries tend to concentrate their publications in certain journals	Journals, countries	No topic analysis
[50,51]	OR/MS field (WoS database)	Identify the most prolific universities	Institutes	No topic analysis
This study	OR/MS field (WoS database)	Identify the core topics in the field, emerging topics, and the influence of OR/MS on other research areas	Topics	Title, abstract,author keywords

to 2015. They concluded that 18 and 21 papers, respectively, contained those keywords in that period, but they observed a significant decrease in output on these topics during 2016 and 2017. On the contrary, the research terms of *fuzzy set* and *TOPSIS* gained relevance in the 2016-2017 period. Liao et al. also presented information on the 12 most common *keywords plus* from WoS [54] and their evolution over time as well as a *word cloud* of the most frequent words included in the titles. However, Liao et al. [26] only considered 20 topics.

Previous studies have used author keywords as the main data source to present the evolution of topics and their interrelationships. However, as there is a limit on the number of keywords that authors can choose and keyword identification depends on authors' criteria, the relevance of a topic could be understated by solely basing a study's conclusions on author keywords. This is caused by the dispersion of keywords into very different terms, as Liao et al. [26] found that almost 83% of the 2214 author keywords that they considered appeared only once, which limits the effectiveness of using only author keywords to produce the critical mass needed to find the most relevant and frequent topics in a whole research field such as OR/MS.

Text mining techniques have commonly been used in bibliometric studies to gain insights into the structure of different fields. Text mining techniques are a set of techniques used to automatically extract context and meaning from the text [55] in a set of documents (corpus) in order to acquire insights about the content of the whole corpus [56]. The process of text mining involves tasks such as document preprocessing, text indexing, and topic clustering, as shown by Tseng et al. [57]. Document preprocessing helps to build and manage the corpus, e.g., document curation, parsing, and segmentation. Text indexing helps in the tasks of punctuation removal, word/term extraction, and stop-word filtering, which are repetitive tasks carried out by an algorithmic approach. Finally, topic clustering includes activities such as term selection, document/term clustering, and cluster naming. Topic clustering activities provide the most value in summarizing and extracting meaning from the corpus since they help identify what are the most relevant terms of the corpus, e.g. the most frequent terms, and support the task of finding commonalities among words/terms and documents. The interested reader is referred to the work by Berry et al. [58] for a more comprehensive explanation of text mining techniques.

One of the most straightforward text mining techniques is the one implemented in VOSviewer [35,59], which allows the user to extract one-word terms from the title and abstract of the document, or automatically extract author keywords, and build clusters based on the number of co-occurrences among the terms (see, e.g., [22,24,42]). Some studies have investigated the contents of papers' abstracts via more complex clustering approaches in text mining, such as Latent Semantic Analysis (LSA), to identify the main topics of research in a subject area. LSA is a technique that helps to identify clusters of documents, as opposed to clusters of terms, based on commonly occurring terms. While term co-occurrence clustering methods such as the one supported by VOSviewer identify topics based on terms, LSA classifies documents into mutually exclusive clusters. Thus, topics in LSA are described both by similar documents and their associated co-occurring terms. For instance, Manikas et al. [39] used LSA to discover the core areas of research in OM, considering six representative journals in OM. They identified 18 clusters of topics and studied their evolution over time. Manikas et al. found that some research clusters such as line balancing, machining, and quality have witnessed a decrease in output devoted to such topics in recent years, whereas other clusters, including service operations, supply chain design and supply chain management, have witnessed an increased output. Furthermore, they found that the use of mathematical programming as a research methodology has significantly increased. Manikas et al.'s LSA was built including one- and two-word terms to identify topic clusters, e.g., *chain, supply* and *network* to build the cluster of *supply chain design*, and classify the considered papers into one of the 18 clusters.

In addition, Kulkarni et al. [40] proposed the use of LSA to discover the intellectual structure of OM by extracting one-word terms included in papers' abstracts published in 5 representative journals in OM. With this method, they identified 24 topics that could be classified into seven overall clusters: operations strategy, supply chain management, production lot sizing, inventory management, operations modeling and analysis, job shop scheduling, and reviews of OM research. Kulkarni et al.'s results show how OM journals have changed their focus from manufacturing-related topics such as production lot-sizing, operations modeling and analysis, and job shop scheduling towards a supply chain management focus.

Finally, Romero-Silva and Marsillac [41] conducted a study where they accumulated statistics on the most frequent and relevant two- and three-word terms included in the title, abstract, and author keywords of all the papers ever published in one specific journal. With that information, they were able to map the output and citation trends of the most frequently considered topics over the years and shed some light on the lack of correlation among different topics, suggesting research gaps and future research opportunities.

2.2. Studies on the evolution and influence of OR/MS

In 1988, the Committee On the Next Decade in Operations Research (CONDOR) presented a roadmap [60] for the development of promising research topics to create more impactful OR research and practice in society. This report reviewed the actual impact that certain established OR methodologies/applications, such as network flow modeling, network queueing models, mathematical programming, simulation modeling, inventory control, and Markov decision processes, have had in monetary terms in the 70s and 80s in the public and private sectors.

Furthermore, the CONDOR report mentioned five promising areas for the development of impactful research, namely, optimization (non-linear, multi-objective, and discrete), stochastic processes (generalized semi-Markov decision processes, stochastic programming, simulation, statistical inference, and characterization of uncertainty), the interface between OR and Artificial Intelligence (decision support and expert systems, and heuristic search techniques), modeling issues in OR (stakeholders adaptation to lack of performance, robustness and estimation gaps, the trade-off between modeling effort and modeling accuracy, transient behavior, and regeneration), and applicability of OR in manufacturing and logistics under the challenges of flexible manufacturing (design and operational management of manufacturing processes, and distribution decisions under real-time information).

More recently, Sodhi and Tang [18] conducted a SWOT analysis on the OR/MS field. Sodhi and Tang identified as one of OR/MS's strengths the assimilation of many methods from different research areas, e.g., applied mathematics, computer science, economics, engineering, and statistics. Furthermore, they also suggested some areas of opportunity for OR/MS, for instance, revenue management in retail, gaming, and entertainment; mathematical modeling for the lean manufacturing approach; exploitation of real-time information to improve supply chain operations, product design, marketing, and customer service; risk management in a globalized context; and OR/MS involvement in reducing the impact on the environment through reverse logistics.

Paucar-Caceres [6] discussed how OR/MS research evolved into a more multidisciplinary field by introducing 'soft OR' methods into the pool of techniques of OR/MS. Paucar-Caceres classified simulation, optimization, forecasting, mathematical programming, inventory control, Markov analysis, PERT, decision trees, the transportation and assignment problem, queueing theory, and statistical process control as traditional OR/MS methods/topics; whereas approaches, such as soft systems methodology, strategic choice approach, cognitive mapping, and systems thinking were regarded as 'soft OR' methods.

Ranyard et al. [12] argue that business analytics could disrupt OR/MS practice. To assess the degree of usage of different OR approaches in practice, Ranyard et al. applied a survey to OR-based consultants. They found that spreadsheet modeling is the most commonly used OR-related technique, followed by basic statistics, optimization, strategic planning tools (cost-benefit analysis, performance management, balanced scorecard, scenario planning), simulation, forecasting, advanced statistics, scheduling, and decision support systems. Considering the 23 techniques included in their survey, they carried out factor analysis with varimax rotation to identify commonalities among respondents based on their used methods. From this exercise, Ranyard et al. identified six components: problem structuring methods (PSM), traditional OR, business analytics, revenue management/forecasting/financial analysis, spreadsheets, and project management and quality. Results from that survey also found that 38% percent of respondents use traditional OR methods, while 31% use PSM, 25% business analytics, and 61% of all respondents have used all these three methods, showing the applicability of very different OR approaches. Ranyard et al. furthermore found evidence that PSM are more used in the UK than in other parts of the world.

A final paper worth mentioning is the paper from Meredith and Pilkington [32] since they studied how different research areas associated with OM influence each other. Meredith and Pilkington investigated how knowledge is transmitted from journal to journal, considering 30 top journals related to the OM field in the period between 1980 and 2009. They identified three types of journals based on the ratio between citations received by the journal and total references included in the journal. Sources, transmitters, and sinks described journals that create knowledge, journals that transmit knowledge, and journals that only use the knowledge, respectively. With this classification, Meredith and Pilkington mapped the transmission of knowledge among groups of journals representing different subject areas. They found that, in the 2000s, practice-oriented journals and Marketing journals were highly influenced by other fields by referencing many journals outside their group, but they were not commonly cited by journals outside their group. On the contrary, Engineering, OM, and OR/MS journals were highly cited by journals in different subject areas. The Engineering, Management, and OM areas had a reciprocal relationship with OR/MS as they are referenced by documents in OR/MS and cite papers in OR/MS. Thus, their results suggest the high interconnectedness among OR/MS, OM, and Engineering research fields.

Studies investigating the evolution of the OR/MS field agree on which are the core methods and application areas in OR/MS. Some of those studies have further suggested that OR/MS has assimilated various methods from other research areas. Table 2 shows a synthesis of methods and topics which have been generally regarded by previous authors [1–4,6,12,18,60] as traditional methods/topics OR/MS. It also shows some topics that OR/MS has assimilated in their pool of modeling tools and application areas.

Despite the fact that there is a general agreement on which are the traditional OR/MS topics, there is still a lack of agreement on whether (and which) non-traditional OR/MS methods have actually been incorporated into OR/MS research. Furthermore, to the best of our knowledge, there has not been any study that tries to uncover which are the core topics in the whole OR/MS field, including a big sample of journals and years, and studying what has been the evolution regarding the interest in those topics. While Kulkarni et al. [40] and Manikas et al. [39] did conduct investigations on the composition of the OM field by mining OM's research output using LSA, their results were limited because they only considered a small sample of journals (five and six, respectively) and they

Table 2
Synthesis of methods and application topics traditionally regarded as the core content of OR/MS vs. non-traditional assimilated methods and topics.

Traditional OR/MS methods and methodological approaches	Traditional OR/MS application topics (objects of research)	Purported methods and topics assimilated by OR/MS
Optimization	Scheduling	Artificial intelligence
Mathematical programming	Inventory control	Business analytics
Simulation	Transportation networks	Problem structuring methods
Markov decision processes	Forecasting	Revenue management
Queueing theory	Quality control	Risk management
Decision analysis	Manufacturing and service operations modeling	
Statistical analysis		

extracted one-word term data, which provided only limited contextual information to fully understand topic relevance.

In this study, we analyze the content of titles, abstracts, and author keywords of all papers classified as review papers in the Operations Research & Management Science in the Web of Science (WoS) database [31] using text mining techniques to gain a better understanding of which are the main constituting and consolidated topics in OR/MS. We also aim to extend the conclusions from Liao et al. [26] regarding the evolution in the interest of different methods and topics in OR/MS throughout the years by taking into account more topics and a longer timeframe than Liao et al., i.e. 20 topics from 2008 to 2017 by Liao et al. against 76 topics from 1956 to 2019 in the current study.

3. Methodology

3.1. Data source and data preparation

This study considers the papers classified as literature review papers in WoS [31]. This type of paper was selected because review papers cover topics that are already consolidated in the field and have developed into a mature stream of research, which provided us with a stable sample of already relevant topics in OR/MS. Using literature reviews as the basis for identifying the main topics in the field allowed us to work with a filtered database of already relevant topics. We used the WoS database as it is a widely regarded database for research evaluation [61–64]. Furthermore, previous research [26,44,51] has also specifically used the category classification of WoS for conducting bibliometric analyses in OR/MS.

In a preliminary search test, we found that the WoS classification algorithm considers every paper containing the terms *review* or *survey* in their database (title, abstract, author keywords) as a review paper, while it may be that the term *review* is associated, for example, with consumer reviews (see, e.g., [65,66]), or that the term *survey* could be associated, for instance, with an empirical study based on a big-scale questionnaire (see, e.g., [67,68]). Furthermore, the WoS database also seems to directly consider the classification of papers as reviews, which are provided by the journals, without further processing. As a result, errors in the classification of a paper as a literature review paper, when the document is not an actual literature review/survey (see, e.g., [69,70]), will produce a misclassification in the WoS database. This issue has been previously reported by Donner [71]. Due to this issue with the WoS classification of literature review papers, we excluded misclassified documents from the search, which were commonly related to customer/online/product reviews and with empirical, survey-based papers. The actual search string prepared to acknowledge this issue can be found in the Appendix.

The search was carried out on August 7th, 2019 in the WoS database [31] and included all publication years of English-written papers published in journals classified as review papers in the WoS subject area of Operations Research & Management Science. A total of 1744 review papers were included in the database for further analysis. Information was gathered for each paper's title, abstract, author keywords, publication year, journal, times cited, authors and their institutions, as well as the complete list of references included in the paper. A database was built with this information. To carry out the text mining exercises, the content of titles, abstracts, and author keywords was merged into a single field to be able to consider them all in a single text mining effort.

Finally, using the database of 1744 review papers, we retrieved information about all the papers that have been indexed in WoS in the last decade (2010 to November 19th, 2019) and which have cited any of the 1744 review papers. This forward search allowed us to investigate the impact of OR/MS review papers in very different subject areas, such as Psychology or Geology, in recent years, and produced a database of 62,952 documents.

3.2. Text mining and latent semantic analysis

This study uses a combination of three methods to build information about the most relevant and consolidated topics in the history of OR/MS. The first method is a relatively straightforward method that uses the capabilities of VOSviewer [35] to extract author keywords. This method has been used in multiple previous studies [22,24,25,42]. Furthermore, the user interface of VOSviewer enabled us to acquire information directly from the WoS database about the most frequent author keywords in a bibliographic database and easily generate illustrations about keyword co-occurrence to start gaining insights about the structure of the field. Therefore, VOSviewer was selected over other bibliometric tools such as CitNetExplorer [36], bibliometrixR [37], and Gephi [72] because of its straightforward approach and the easier interpretability of the network illustrations.

After gathering information on the most frequent author keywords, a simple text extraction exercise was carried out using the *tm* package for *R* [73] to extract the most frequently used two-, three- and four-word terms (also called *ngrams* – combinations of words) included in the documents' title, abstract, and author keywords. One-word terms were not included in the initial text mining analysis because of their general lack of context [41] and ambiguity into forming clusters (see, e.g., [26,28]). To conduct the analysis, the most common English stop-words (e.g., *for, and, or*), very frequent irrelevant terms (e.g., *papers, articles, important, results*), and punctuation were removed. The resulting term-document matrix (TDM), which shows the number of occurrences of each term in every document, was then analyzed to remove sparse terms that appeared in less than 0.1% of the documents in order to consider only terms that are relevant to multiple documents (in this case, two or more documents). Furthermore, the TDM was then converted from a numeric to a binary matrix (bTDM) to reduce the impact of highly used terms in single documents, i.e. instead of counting the total number of occurrences of one term in one document, each term was counted only once per document (see [41] for a thorough explanation of this text mining procedure).

To summarize the topics covered by OR/MS review papers into synthesized topics and identify redundant (e.g., *data envelopment, data envelopment analysis, envelopment analysis*) and highly related terms, the results from the simple text extraction exercise were then used to conduct a Latent Semantic Analysis (LSA) through the singular value decomposition technique [74] with the *lsa* package for *R* [75]. LSA was selected as a text clustering technique because we wanted to identify both the documents associated with a topic and the terms associated with that topic in the same classification [76], which is something that a clustering technique based only on keyword co-occurrence cannot accomplish. Furthermore, LSA has been shown to be effective in uncovering the patterns of very different research areas [77–80], identifying research trends [81,82], and supporting content extraction in a wide variety of applications [83]. We specifically used the LSA methodology proposed by Kulkarni et al. [40] and Kundu et al. [84] to have a straightforward interpretation of the LSA term and document loadings through *varimax* rotation (see [40] for the details of this methodology).

We followed the recommendations from previous studies to select the number of clusters for the LSA [85], based on the sample size of the documents. Thus, an initial number of 100 clusters was selected for reducing the dimensions of the TDM containing 1744 documents. From the resulting LSA, irrelevant and low LSA-loading terms, e.g., *differences (and) similarities, increasing interest, threefold (.) first, main contribution, researchers (and) practitioners, wide variety, point (of) view*, were discarded to have a more representative matrix. Furthermore, documents were also classified into different LSA-generated clusters, depending on their rotated factor loadings using the criterion from Guan et al. [28]. This criterion resulted in 72% classified documents. Clusters with similar high-loading terms and documents were further merged, e.g., *safety culture, safety climate,* and *safety performance* were all high-loading terms in three different clusters associated with safety so they were merged into one single cluster named *safety culture, climate and performance*.

Finally, a selection of one-, two- and three-word terms was performed using the lists of the most frequent author keywords (extracted with VOSviewer) and most frequent and high-loading terms from the LSA to carry out a simplified analysis on the correlation among topics and other topics and subject areas. This list was created to provide a summarized analysis of the dataset with a reduced number of terms by simply identifying which documents contain which terms. To build this concise list we combined the results from the author keyword extraction from VOSviewer and the term extraction from the text mining. Thus, a final concise terms list (CTL) with both high LSA-loadings and highly occurring terms was built to conduct the analysis. In this manner, terms containing similar terms were effectively synthesized by one term, e.g., *safety* contained terms such as *safety management* and *safety culture*, or *risk* contained terms such as *risk management, risk analysis*, and *risk assessment*.

Simple text mining and LSA were carried out for the two databases (reviews and citing papers). However, because of the significantly higher number of documents contained in the OR/MS-citing articles database, two different paths were taken for this database. First, text mining was only carried out including information of the title and author keywords from all the documents, as including the abstracts significantly increased the size of the database and the computational effort of the text mining algorithm and LSA. Second, since the number of documents was much higher, we selected 200 dimensions as an initial number of clusters to perform the LSA. Further examination of similar high-loading terms and documents among different clusters also resulted in the merging of some clusters for OR/MS-citing papers, e.g., *artificial neural networks* and *neural networks* clusters were merged into one cluster.

A summary of the methodologies applied to the two databases can be found in Table 3, where the input information and the results of each text mining methodology are shown depending on the database. For example, Table 3 shows that, for the database containing the review papers (REV), 1744 documents were used in the simple text mining exercise, resulting in 881 two-, three- and four-word non-sparse terms contained in at least 0.1% of documents. These non-sparse terms were then used to run the LSA, which, after further analysis, resulted in 76 consolidated clusters with 378 high-loading terms. The LSA classified 72% of the papers as belonging to one of the 76 clusters, based on the commonality of the terms. Then a list of 378 high-loading terms and a list of the 360 most frequent author keywords (found in at least 0.2% of the documents) were used to select the terms that could better consolidate the topics and methods contained in OR/MS literature reviews. This final exercise produced a list of 74 terms, which were found in 84% of the reviews.

3.3. Network visualizations

In order to analyze the relationships that OR/MS topics have with other topics and other subject areas, we built co-occurrence matrices [52] of the outputs of the three used text mining procedures. A term-term matrix (TTM) was built to identify the interrelationships among topics. To build this matrix, we multiplied the binary term-document matrix (bTDM), which is a matrix showing which terms (shown in the matrix's rows) can be found in which documents (shown in the columns), by its transpose to find how often one term co-occurred with another term in a document. The term-term matrix (TTM) was calculated in the following manner:

$$TTM = bTDM * bTDM^{T} \quad (1)$$

Term-term correlation plots such as the one shown in Section 6.2 were built using the package *corrplot* for R [86], whereas heatmaps, used in Sections 4 and 5, were built using the package *gplots* for R [87].

4. Consolidated topics in OR/MS

The set of papers classified as literature reviews in the WoS [31] category of Operations Research & Management Science resulted in 76 groups. Table 4 shows these groups as well as the number of review papers (# Rev.) assigned to each cluster, the sum of citations received by all the reviews assigned to each cluster, and the highest (relevant) loading terms per cluster (with a varimax rotation factor loading higher than 0.03 – a threshold that was based on a closer inspection of term relevance to the constituting documents of different clusters). Because the majority of clusters contained papers focusing on either advancing a methodological approach or studying an object of research (possibly using some of the methodological approaches), we also classified the clusters and terms into either one of those two options for a more detailed analysis. This is shown as "content class" in Table 4.

The most populated cluster is the cluster of *supply chain topics*, which was constituted by reviews dealing with very different issues in the supply chain, e.g., closed-loop supply chains [88], integrated production/distribution planning in supply chains [89], or supply chain coordination [90]. The cluster of *resource and machine scheduling* is the second biggest cluster and it groups reviews dealing mainly with machine scheduling in a shop floor setting, i.e., parallel machines, flow shops, and job shops. Review papers dealing with the *vehicle routing problem* constitute the third biggest cluster grouping documents proposing different optimization procedures (e.g., heuristics, metaheuristics, or exact algorithms) for solving the vehicle routing problem. Review papers dealing with

Table 3
Summary of the text mining methodologies applied to the databases.

Methodology	OR/MS Reviews (REV)		OR/MS-citing papers 2010-2019 (CITE)	
	Input	Output	Input	Output
Simple text mining	Titles, abstracts and author keywords; 1744 documents	881 non-sparse terms (at least in 0.1% of documents)	Titles and author keywords;62,952 documents	769 non-sparse terms (at least in 0.1% of documents)
Latent semantic analysis (LSA)	881 non-sparse terms	76 clusters; 378 high-loading terms; 72% classified papers	769 non-sparse terms	200 clusters; 478 high-loading terms; 71% classified papers
Selection of concise terms list (CTL)	378 high-loading terms + 360 author keywords (at least in 0.2% documents)	74 terms; 84% papers covered	478 high-loading terms + 173 author keywords (at least in 0.2% documents)	102 terms; 71% papers covered

different kinds of combinatorial optimization problems with various approaches comprise the majority of the papers included in the fourth biggest cluster of *combinatorial optimization*.

Within the most highly-populated clusters, we can find traditional OR/MS topics/methods such as inventory modeling and control, production planning and control, manufacturing systems modeling, capacity planning, simulation of manufacturing systems, and mixed/integer/linear programming. However, LSA results also suggest that topics/methods that have been assimilated by OR/MS [12,60] from other research areas, such as, data mining, artificial intelligence, and machine learning, now are also constituting methodologies in OR/MS. Irrespective of cluster size, Table 4 can be seen as a compendium of mature and consolidated topics/methods in OR/MS as it provides an overview of the topics and methods that have been subject to many review papers in OR/MS.

The recent interests that some of the topics have received can be seen in the citation patterns of review papers since 1980, shown in Fig. 1. Fig. 1 shows, via a heatmap, the z-score [91] of the number of citations received in a certain year by all the review papers classified in a certain cluster, separated by objects of research and methodological topics and by citation trends in the last 20 years (2000 to 2019). Z-scores were used to transform the number of citations per cluster for the same year to a standard normal distribution to be able to directly compare values for different years. This was done because the total number of citations per year can differ significantly, e.g., the number of citations in more recent years has been significantly higher than in earlier years due to the increased number of publications in all fields. A red color in the heatmap represents a high relative number of citations in a certain year (a z-score higher than 3 per year), whereas a dark blue color represents a low relative number of citations each year (a z-core lower than 0 per year). On top of Fig. 1, we also show the color key where the reader can identify the equivalences between colors and z-scores, and where the number (count) of cells in the heatmap with a particular z-score are also shown.

The trends identified in Fig. 1 were estimated by calculating the slope of the linear regression between citation year and z-score of the number of citations for each cluster and then further standardizing the resulting values of the cluster slopes. This was done to have a straightforward manner to identify upward and downward trends, irrespective of the magnitude of the slope values. Clusters with standardized slopes greater than 0.5, i.e. more than 0.5 standard deviations of the sample of slopes of all clusters, were defined as having an upward trend, whereas clusters with standardized slopes lower than -0.5 were defined as having a downward trend. Otherwise, clusters were defined as having a stable trend in terms of received citations. See Fig. A1 in the Appendix for a comparative analysis to Fig. 1, showing the number of reviews published per year for each cluster.

The highest concentration of relative citations in the last ten years have been received by reviews in the clusters of *supply chain topics, vehicle routing problem, and multicriteria decision making*, being that *supply chain topics* received a significant positive trend in the last four years. Other interesting upward trends in the last five years can be seen in the clusters of *data envelopment analysis, data mining and analysis, operations management, supply chain management, supply chain network*, and *supply chain risk management*. On the other hand, clusters such as *capacity planning/mathematical programming, decision analysis methods, decision support, modeling of manufacturing systems, neural networks, project scheduling, revenue management*, and *statistical process control* have all a negative citation trend in the last twenty years. Interestingly, review papers associated with the cluster of *analytic hierarchy process* had a decrease in the relative number of citations in the 2000s but in the last decade, they have a positive citation trend. The opposite is true for the papers classified in the cluster of *resource and machine scheduling* because they received a high number of citations between 2001 and 2014 but have received a significantly lower relative number of citations in the last five years.

A closer examination of term-term interrelationships is shown in Fig. 2, where the TTM of review papers is illustrated as a co-occurrence network of terms included in the LSA list (378 terms). Node size in this co-occurrence illustration represents the total link strength of the corresponding term (sum of co-occurrences of the term with all the other terms) and the width of the arcs represents the number of co-occurrences between a term-term pair. Because of the interrelatedness of many terms with many other terms, the algorithm used in the VOSviewer software [59] suggests eight global clusters of terms that tend to frequently appear in the same documents (illustrated with different colors in Fig. 2). This procedure is different from the LSA because the LSA groups documents based on term commonality whereas a co-occurrence network groups terms (and not documents) based on how frequently they occurred together.

From Fig. 2 it can be seen that there are four very clearly defined global clusters of terms: inventory modeling and control (light blue), traditional optimization problems in OR/MS (green – e.g., *machine scheduling, vehicle routing, traveling salesman, assembly line balancing*), safety issues (blue – e.g., *occupational health and safety, accident causation, risk assessment, analysis and management*), and decision making, decision support, and data analysis tools (yellow – e.g., *data envelopment analysis, artificial intelligence, machine learning, data mining, analytic hierarchy process, multi-criteria decision*).

The other four clusters are constituted by terms that have various links with many other terms outside their own cluster. However, we still can identify some common themes in these clusters: operations management topics (red – e.g., *information systems, knowledge management, quality management, product development*), manufacturing systems topics (grey – e.g., *flexible manufacturing, material handling, automated guided vehicles, discrete-event simulation*), production planning and control (orange), and supply chain-related topics (purple – e.g., *reverse logistics, green and sustainable supply chain, supply chain performance*), in which we find

Table 4
LSA-based topic clusters (ordered by number of reviews).

ID	Cluster name	Content class	# Rev.	Times cited	Highest loading terms
71	Supply chain topics	Object of research	62	5264	supply chain, knowledge management, supply chain systems
53	Resource and machine scheduling	Object of research	46	5344	setup times, scheduling problems, flowshop scheduling, parallel machines, flow shop, survey scheduling, single machine, job shop, setup cost, classification scheme
8	Combinatorial optimization	Methodological	36	2912	combinatorial optimization, optimization problems, assignment problem, quadratic assignment problem, evolutionary algorithms, exact heuristic, data analysis, integer programming, comprehensive survey, genetic algorithms
76	Vehicle routing problem	Object of research	36	4355	vehicle routing, heuristics metaheuristics, classification scheme, combinatorial optimization, exact algorithms, service quality, multiobjective optimization, environmental social, customer satisfaction,
10	Data mining/data analysis	Methodological	34	2883	data mining, multiobjective optimization, knowledge discovery, optimization problems, data analysis, product development, quality improvement, quality management, manufacturing industry, quality control
26	Inventory models	Object of research	34	2328	lead time, setup cost, inventory model, service level, continuous inventory, optimal solution, lost sales, numerical examples, sensitivity analysis, quality improvement
25	Inventory control	Object of research	30	1167	inventory control, optimal policy, optimal order, order quantity, periodic inventory, (s, S), inventory model, inventory level, continuous inventory, lost sales
49	Production planning and control	Object of research	29	2713	planning control, production planning control, production planning, planning scheduling, project scheduling, job shop, small medium, classification scheme, shop floor, supply chain systems
32	Manufacturing systems topics	Object of research	28	1590	manufacturing systems, flexible manufacturing, supply chain systems, next generation, queueing theory, product design, product development, network analysis, advanced manufacturing, design manufacturing
42	Operations management	Object of research	27	2461	operations management, system dynamics, health services, service quality, customer satisfaction, network analysis, operational models, business process, s s
3	Artificial intelligence	Methodological	26	1495	artificial intelligence, feature extraction, deep learning, dynamic programming, monte carlo, knowledgebased systems, support vector, decision theory, supplier selection, multiagent systems
7	Capacity planning/mathematical programming	Object of research	26	1865	capacity planning, mathematical programming, machine scheduling, manufacturing industry, industrial applications, manufacturing companies, structured overview, solution procedures, classification models, flexible manufacturing
13	Decision support	Methodological	26	1287	decision support, decision support systems, intelligent systems, factor analysis, information systems, continuous inventory, classification scheme
68	Supply chain management	Object of research	26	2387	supply chain management, performance measures, supply chain systems, genetic algorithms, competitive advantage, robust optimization, green supply, logistics supply chain
37	Multicriteria decision	Methodological	25	4198	multicriteria decision, multicriteria decision aid, decision analysis, data collection, human behaviour, decision problems, problem structuring, maintenance management, classification scheme, decision support
36	Modeling of manufacturing systems	Methodological	23	1612	discrete event simulation, system design, design operation, case study, manufacturing processes, decision support, design manufacturing, multicriteria decision, decision support systems, supply chain systems
60	Safety culture, climate and performance	Object of research	23	870	safety culture, culture safety, bibliometric analysis, safety climate, construction safety
62	Sensitivity analysis	Methodological	23	2244	sensitivity analysis, monte carlo, performance assessment, lead time, analysis simulation, quality improvement, experimental design, simulation models, inventory model, response surface
15	Facility location	Object of research	22	2517	facility location, facility location models, stochastic dynamic, strategic planning, integer programming
35	Mixed/integer/linear programming	Methodological	22	1634	mixed integer, integer linear, integer programming, design problems, linear programming, process industry, case studies, optimization models, optimization problems, stochastic programming
24	Information technology	Object of research	21	2034	information technology, competitive advantage, data collection, information systems, performance measures, management information, operational performance, systems management, organizational learning, logistics supply chain
43	Organizational learning/problem structuring/construction industry	Object of research	20	943	organizational learning, problem structuring, construction industry, project management, occupational safety, process safety, competitive advantage, soft systems, information technology, accident causation
47	Product development	Object of research	20	1830	product development, product design, development process, design manufacturing, project management, concurrent engineering, manufacturing systems, rapid development, technological innovation, manufacturing industry
31	Machine learning	Methodological	19	1301	machine learning, machine learning algorithms, recommender systems
12	Decision making in multiple topics	Object of research	18	884	decision making, multicriteria decision, data collection, maintenance management, human behaviour, multicriteria decision aid, modelling approaches, decision support, system dynamics, information systems
64	Statistical process control	Methodological	18	2070	control charts, process control, statistical process control, quality control, quality management, manufacturing processes, design process

(*continued on next page*)

Table 4 (*continued*)

6	Business processes/total quality management	Object of research	17	1472	business process, quality management, modelling techniques, total quality management, human behaviour, control charts, flexible manufacturing, data collection, process design, knowledge management
9	Data envelopment analysis	Methodological	17	1444	data envelopment analysis, sustainable supply chain, artificial intelligence
16	Freight transportation	Object of research	17	2270	freight transportation, optimization models, transportation planning, planning problems, tactical operational, strategic tactical operational, transportation systems, global supply, capacity planning, scheduling problems
18	General scheduling problem	Object of research	17	1650	flowshop scheduling, setup times, evolutionary algorithms, quality management, heuristics metaheuristics, data analysis, project scheduling, simulated annealing, bibliometric analysis, setup cost
11	Decision analysis methods	Methodological	16	1379	decision analysis, multicriteria decision, multicriteria decision analysis, problem structuring, decision making, goal programming, organizational learning, decision models, game theory, social sciences
14	Expert systems	Methodological	16	700	expert systems, industrial applications, statistical analysis, computer vision, supplier selection, systems methodology, intelligent systems
21	Health care	Object of research	15	1568	health care, resilience engineering, bibliometric analysis, operations management, health services, genetic algorithms, routing scheduling
23	Information systems	Object of research	15	573	information systems, competitive advantage, multiagent systems, decision making, fuzzy logic, decision support, conceptual framework, resource planning, systems management, technology management
40	Neural networks	Methodological	15	1090	neural networks, artificial neural networks, fuzzy logic, network models, deep learning, combinatorial optimization
58	Risk management	Object of research	15	1287	risk management, development process, risk analysis, risk assessment, supply chain risk, supply chain systems, occupational safety, rapid development, safety systems, health safety
45	Planning problems modeling	Object of research	14	909	planning problems, freight transportation, tactical operational, customer service, customer demand, time windows, optimization models, integer linear, supply chain planning, strategic tactical operational
46	Planning topics	Object of research	14	1106	process planning, planning scheduling, design process, production process, production planning, shop floor, genetic algorithms, manufacturing systems, decision making, manufacturing engineers
61	Safety management	Object of research	14	284	safety management, construction safety, process safety, occupational safety, project management, human error, safety climate, resilience engineering, quality management, safety systems
73	Systems thinking/soft systems/complex systems	Methodological	14	758	systems thinking, sociotechnical systems, accident causation, system safety, soft systems, complexity theory, systems methodology, complex systems, human factors, service quality
17	Fuzzy logic	Methodological	13	1255	fuzzy logic, linear programming, robust optimization, machine learning, particle swarm, mass customization, deep learning, support vector, mathematical programming,
20	Health and safety	Object of research	13	268	health safety, occupational health safety, enterprises smes, performance evaluation, safety climate, network analysis, construction industry, safety performance
34	Material handling	Object of research	13	2007	material handling, design control, automated guided, transportation systems, container terminals, design operation, system design, flexible manufacturing, design problems, decision problems
56	Risk assessment	Object of research	13	660	risk assessment, process industry, risk management, process safety, safety security, risk analysis, modelling approaches, nuclear power, organizational learning, performance assessment
74	Technology management	Object of research	13	458	technology management, strategic management, innovation management, technological change, developing countries, technological innovation, knowledge management, products services, social sciences, product development
59	Robust optimization	Methodological	12	372	robust optimization, decision variables, static dynamic, objective function, mathematical optimization, optimization problems, machine learning, real life, multicriteria decision, revenue management
66	Supply chain and manufacturing systems	Object of research	12	797	supply chain systems, network analysis, manufacturing systems, flexible manufacturing, multiagent systems, sustainable supply chain, product design, production planning, production planning control, complex systems
44	Performance measures	Object of research	11	443	performance measures, logistics supply chain, green supply, factor analysis, supply chain management, supply chain performance, s s, performance indicators, competitive advantage, operational performance
52	Reliability analysis	Object of research	11	393	reliability analysis, human reliability, human error, human behaviour, safety assessment, human factors, complex systems
55	Risk analysis	Object of research	11	256	risk analysis, quantitative risk, case studies, occupational safety, accident causation, risk management, performance assessment, nuclear power, sensitivity analysis, mathematical models
22	Human resource management	Object of research	10	657	human resource management, quality management, logistics supply chain, multiobjective optimization, human resources, data analysis, total quality management, data collection, regression analysis, project management
27	Inventory systems with service level	Object of research	10	190	fill rate, inventory system, base stock, periodic inventory, inventory control, demand distribution, lead time, optimal policy, monte carlo, quality improvement
29	Knowledge management	Object of research	10	734	knowledge management, case study, performance measures, technology management, supply chain, information technology, knowledgebased systems, problem structuring

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Table 4 (*continued*)

38	Nature-inspired metaheuristics	Methodological	10	616	ant colony optimization, particle swarm, complex problems, optimization problems, optimization algorithm, neural networks, monte carlo, engineering applications, discrete optimization, multiobjective optimization
63	Simulation and optimization	Methodological	10	342	simulation optimization, inventory system, inventory management, genetic algorithms, fill rate, evolutionary algorithms, objective function, response surface
67	Supply chain design	Object of research	10	666	supply chain design, global supply, product design, supply chain systems, classification scheme, inventory management, sustainable supply chain, tactical operational, integer programming, flexible manufacturing
4	Assembly line balancing	Object of research	9	1482	assembly line, line balancing, heuristics metaheuristics, experimental design, production process, exact heuristic, comprehensive survey, heuristic solution, objective function, combinatorial optimization
19	Genetic algorithms	Methodological	9	1083	genetic algorithms, production operations management, operations management, system dynamics, service quality, health care, quality management, customer satisfaction, reverse logistics, data collection
39	Network design	Object of research	9	431	network design, design problems, decision variables, supply chain network, linear programming, mixed integer, optimization models, integer linear, global supply
30	Lot sizing	Object of research	8	1122	lot sizing, production planning, flowshop scheduling, comprehensive survey, setup times, scheduling survey, mathematical programming, machine scheduling, classification scheme, quality improvement
41	Occupational safety	Object of research	8	148	occupational safety, construction industry, organizational learning, problem structuring, process safety
50	Project scheduling	Object of research	8	1941	project scheduling, classification scheme, resource constraints, machine scheduling, heuristic algorithms, exact heuristic, project management, software development, scheduling problems, exact heuristic algorithms
54	Revenue management	Object of research	8	812	revenue management, dynamic pricing, conceptual framework, demand distribution, stochastic demand, control problem
65	Supplier selection	Object of research	8	1017	supplier selection, classification framework, expert systems, content analysis, decision models, artificial intelligence, decision problems, experimental design
72	System dynamics	Methodological	8	451	system dynamics, operations management, accident causation, decision making, human factors, genetic algorithms, lead time, empirical studies, sociotechnical systems, complexity theory
5	Big data/data analytics	Methodological	7	546	big data, data analytics, case study, critical analysis, logistics supply chain, classification framework
75	Traveling salesman problem	Object of research	7	535	traveling salesman problem, optimization problems, linear programming, genetic algorithms, empirical evidence, heuristic algorithms, comparative analysis, exact algorithms, integer linear, survey classification
2	Analytic hierarchy process	Methodological	6	2040	analytic hierarchy process, operations management, network analysis, case study, robust optimization, process design
57	Risk in the primary sector	Object of research	6	128	nuclear power, power plants, probabilistic risk assessment, united states, s s, performance assessment, safety assessment, risk assessment, sensitivity analysis, software development
69	Supply chain network	Object of research	6	1397	supply chain network, network design, green supply, environmental social, design problems, sustainable development, mathematical models, industrial applications, facility location models, linear programming
70	Supply chain risk management	Object of research	6	1276	supply chain risk, risk management, supply chain systems, quantitative risk, development process, risk analysis, mathematical models, network analysis, decision models,
48	Product life cycle	Object of research	5	457	life cycle, product lifecycle, concurrent engineering
51	Recommender systems	Object of research	5	393	recommender systems, machine learning, social networks, classification scheme, complex problems, scheduling problems, information systems, decision making, deep learning, support vector
1	Accident causation	Object of research	4	201	accident causation, system safety, system design, fault tree, safety issues, control problem, probabilistic risk assessment, health safety, accident prevention, nuclear power
28	Job shop topics	Object of research	4	142	flexible manufacturing, survey classification, resource constraints, flowshop scheduling, setup times, classification scheme, supply chain systems, linear programming, project scheduling, material handling
33	Mass customization	Object of research	4	814	mass customization, empirical studies, production systems, products services, fuzzy logic

many topics associated with optimization of strategic and tactical decisions via mathematical programming in supply chain management, e.g., *facility location*, *network design*, and *supply chain planning*.

Fig. 2 also helps to illustrate which terms are "central" and which terms are on the boundaries of the field, i.e. the terms that are well integrated into the field by being associated with many others or terms that are studied mainly in isolation and only have a tangential relationship with other terms. For instance, many terms associated with safety (blue cluster) are rarely related with other terms outside their cluster, whereas terms such as *supply chain*, *manufacturing systems*, *production planning*, and *decision making* are all associated with many other terms in different clusters and are centrally located, suggesting their relevance for the whole field. The reader is referred to the supplementary material of this paper for the two files containing the full information needed to build Fig. 2 using VOSviewer [35]. The data used to build all figures in this document is also provided in the supplementary material.

Since a single document classified in a cluster might be associated with both an object of research and a methodology, which could be hiding some insights from the analysis, we included Fig. 3 to show a different analysis where more than one term (from the CTL of the review database), either methodological or topical, can be counted per single document. In Fig. 3 we analyze the interests that authors have had in different topics by plotting the z-score

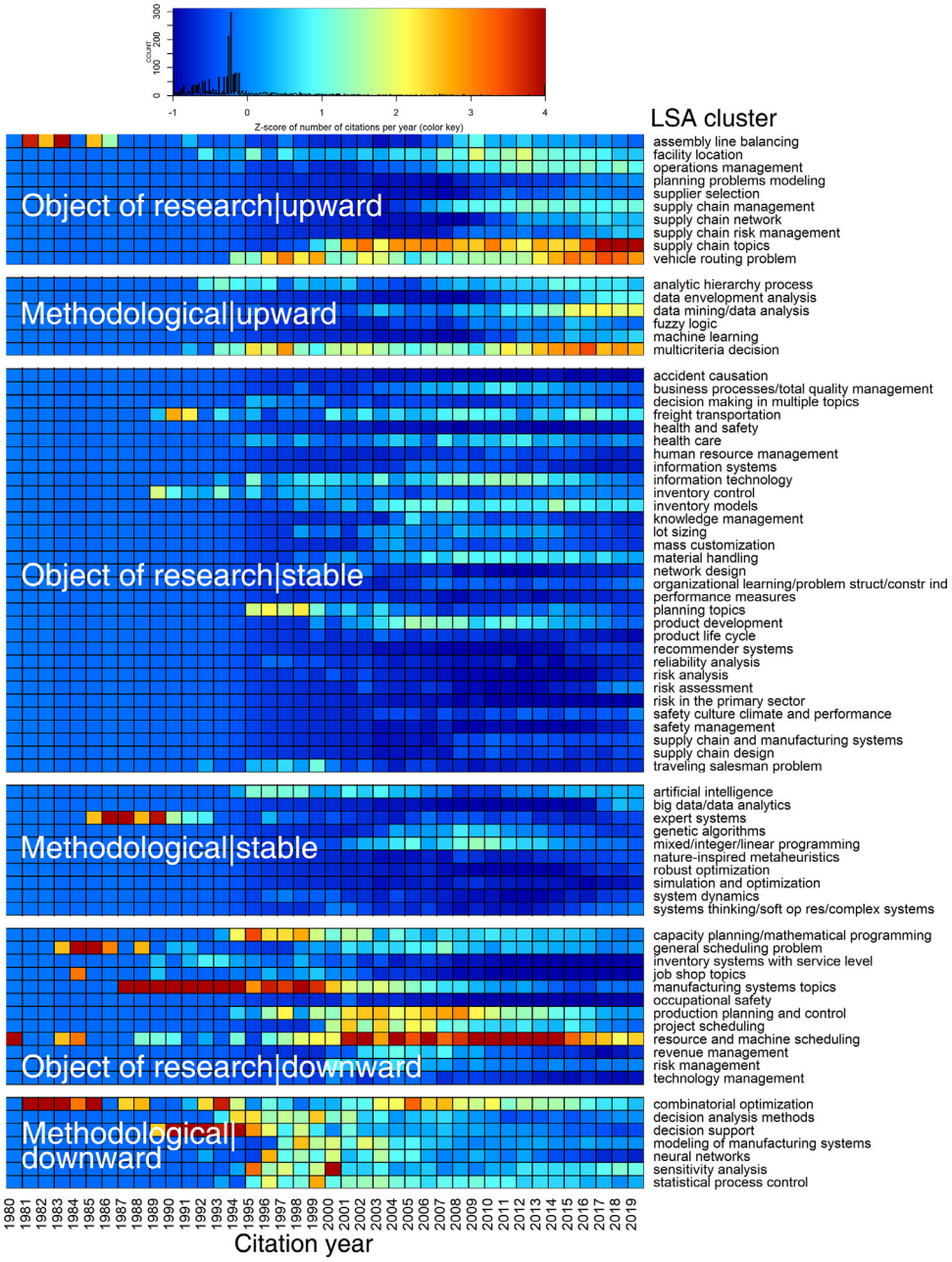


Fig. 1. Citations per year to the review papers for each LSA cluster (note that all z-scores below -1 are represented by the same color).

per year of the number of papers in which a specific term was found (note: we do not include the citations as in Fig. 1 because it is not a straightforward analysis to count citations over multiple terms that might appear in the same document). Fig. 3 illustrates the evolution of author interests in some topics by showing the terms with upward, stable and downward trends in the last 20 years. Similar to Fig. 1, a term trend in Fig. 3 was estimated by calculating the slope of the linear regression between publication year and z-score of the number of occurrences of a term and then standardizing the resulting values of the term slopes. The threshold values of standardized slopes to identify upward, stable and downward trends per term were the same as in Fig. 1.

Because of the simpler terms that are used in Fig. 3, we can identify new insights. For instance, the number of papers containing terms such as *healthcare, human* (from, e.g., human factors, human resources), *maintenance, resilience*, and *simulation* has been increasing in recent years. Furthermore, while the trend regarding the number of citations to reviews included in risk and safety-related clusters is not upwards (see Fig. 1), the trend in the number of papers containing the words *risk* and *safety* actually is. So, there does not seem to be a straightforward relationship between the number of papers published on one topic and its impact (citations). We discuss this topic in Section 6.1.

One result that shows opposite trends in citations and number of reviews is the result regarding the term/cluster *operations management*. In this regard, while we can see that the citations to reviews classified in the *operations management* cluster have been steadily increasing since 2000 (Fig. 1), Fig. 3 shows that the relative number of reviews per year that contain the term *operations management* has been decreasing for the same period. Zooming in at the data, this does not entail that the number of reviews containing the term *operations management* has decreased (in fact, 2018

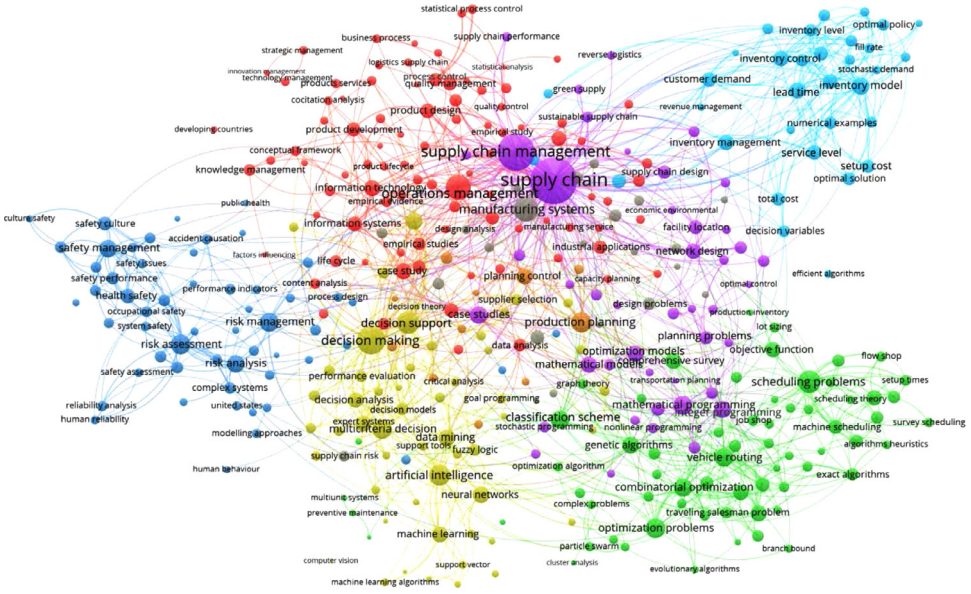


Fig. 2. Co-occurrence network of high-loading terms in OR/MS review papers.

was the year with the highest number of reviews containing this term – 9) but that the share of papers containing this term has been decreasing. The reader is referred to the supplementary material to access the data on term occurrence per year used to build Fig. 3.

5. Influence of OR/MS reviews in other subject areas

In addition to studying which are the core topics of OR/MS, we wanted to investigate what has been the influence of OR/MS in other fields, and which of the OR/MS-related topics have had the most impact outside OR/MS. To attain this objective, we searched for all the research papers (either reviews or regular articles) published between 2010 and 2019 (up until November 19th) that have cited one of the 1744 review papers included in our analysis.

Fig. 4 illustrates the percentage of papers published in an aggregated subject area e.g., the Engineering area contains branches such as Industrial, Manufacturing, and Mechanical Engineering, that have cited any of the papers in REV (database of review papers). The main percentage numbers shown in Fig. 4 represent the proportion of papers that have cited OR/MS reviews per subject area, out of the total number of citations that OR/MS reviews received; whereas the numbers in the parenthesis in Fig. 4 depict the proportion of papers that have cited OR/MS reviews in each subject area, out of the whole set of papers published in a subject area between 2010 and 2019. In this regard, since Engineering is the subject area with the biggest number of papers published between 2010 and 2019 overall, it is also the area with the highest number of papers citing OR/MS papers, followed by OR/MS, Computer Science, and Business & Economics. However, the influence of OR/MS on the area of Engineering seems to be minimal as only 2% (shown in the parenthesis in Fig. 4) of all the papers published in that field between 2010 and 2019 have cited OR/MS reviews. Something similar happens with Computer Science as it is also a big field that has cited many OR/MS reviews but without being highly influenced by this field (only 3% of all the papers published in that field have cited OR/MS reviews). The subject area that seems to have a big interaction and overlap with OR/MS is the area of Business & Economics since it represents both a big proportion of the citations received by OR/MS reviews and a big proportion of the papers from that field cite OR/MS reviews (23%).

On the other hand, subject areas such as Transportation, Information Science & Library Science, and Geography are areas in which the proportion of the total papers published in that field citing OR/MS reviews is higher than the proportion of the total cites received by OR/MS reviews, suggesting that, while these areas are not as big and influential, they have been influenced by the OR/MS field. The area of Public Administration is a special case of this phenomenon because it only represents 1% of all the citations received by OR/MS reviews but a total of 16% of their papers published between 2010 and 2019 are citing OR/MS reviews, suggesting that Public Administration might be highly influenced by the OR/MS field. It is worth noting that the data regarding the number of papers published between 2010 and 2019 from all subject areas were also obtained from the WoS database.

Fig. 4 also suggests the relevance of OR/MS for very different areas of research, such as Environmental Sciences & Ecology, Telecommunications, Chemistry, Mechanics, Geology, Psychology, and Agriculture. It should be noted that the sum of the percentages in Fig. 4 does not add to 100% because some journals might be classified in more than one subject area in WoS, which results in one document being counted more than once.

To assess which OR/MS topics have had the most relevance in other subject areas, we used the CTL (concise term list) of the CITE database (papers published between 2010 and 2019 citing OR/MS reviews) to find which terms have been used more frequently by papers published in different subject areas. Thus, Fig. 5 shows, via a color-coded heatmap, the standardized number of papers by subject area which were found to include a highly-occurring term. From Fig. 5 it is clear that a big proportion of studies that cite OR/MS papers are concerned with *optimization* since this term appeared frequently in the majority of subject areas included in CITE. Other terms with high relevance for all subject areas are *decision making, fuzzy, risk, safety, scheduling, sensitivity analysis, simulation, supply chain*, and *uncertainty*.

Additional terms with high relevance in various subject areas were *china* in Geology, Meteorology and Atmospheric Sciences, and Public Administration; *data envelopment analysis* and *energy efficiency* in Energy and Fuels, and Thermodynamics; *innovation* in Business and Economics, Information Science and Library Science, and Public Administration; *multi-criteria decision* in Electrochemistry and Water Resources; *resilience* in Meteorology and Atmo-

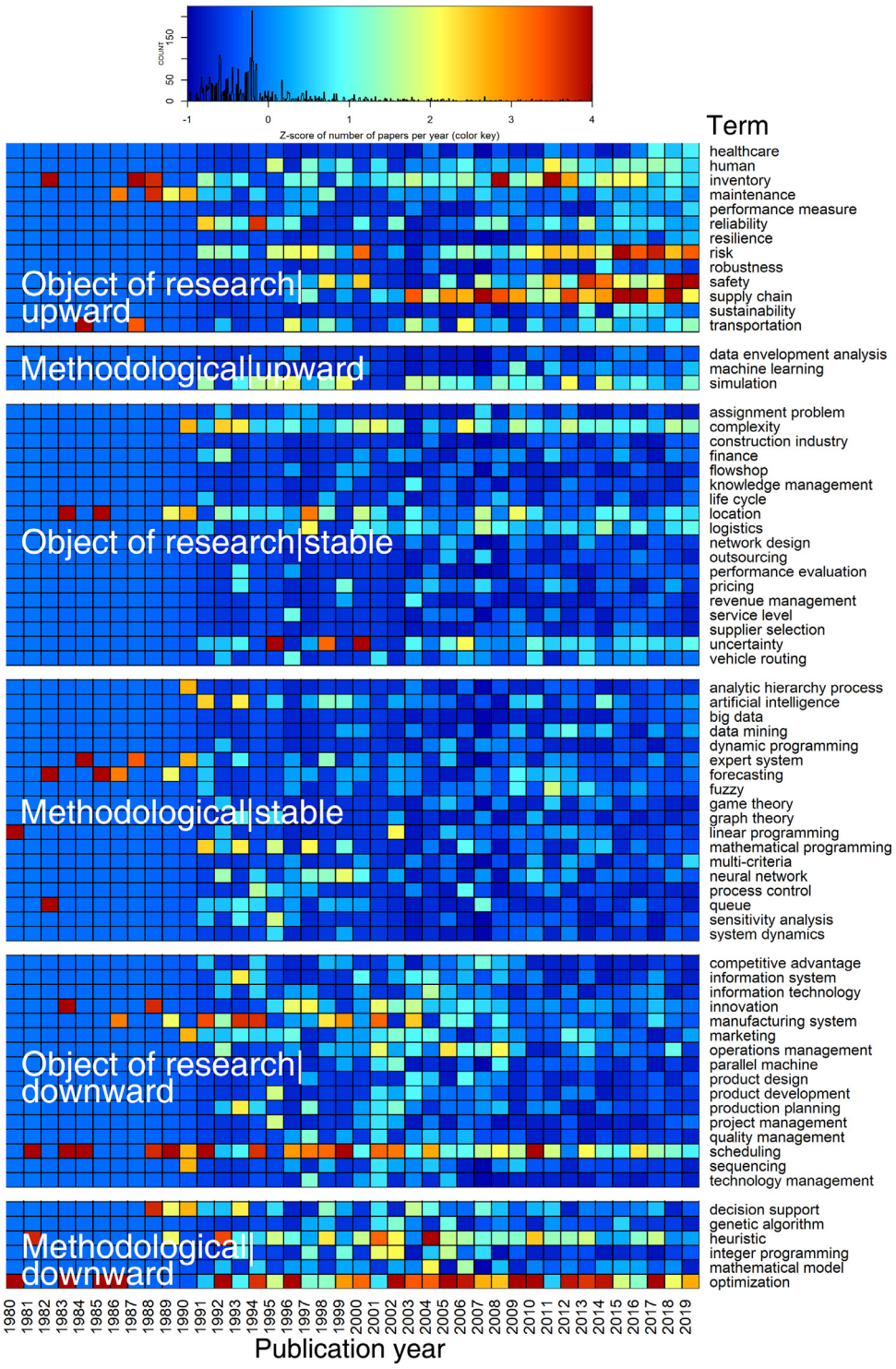


Fig. 3. Papers per year containing a specified term (note that all z-scores below -1 are represented by the same color).

spheric Sciences, Psychology, and Water Resources; *sustainability* in Environmental Sciences and Ecology, Public Administration, and Science and Technology – Other Topics; and *useful life* in Electrochemistry and Instruments and Instrumentation.

Noteworthy associations between some terms and particular research areas are *decision support* in Agriculture; *neural network* in Chemistry; *big data, information systems, knowledge management*, and *learning effect* in Information Science and Library Science; *reliability* in Nuclear Science and Technology; *TOPSIS* in Materials Science; *polynomial chaos* in Physics; and *big data* and *sustainable development* in Public Administration.

6. Research opportunities for future OR/MS reviews

6.1. Relevance of topics

The most straightforward way to discover research opportunities for future review papers is to analyze the latest year of pub-

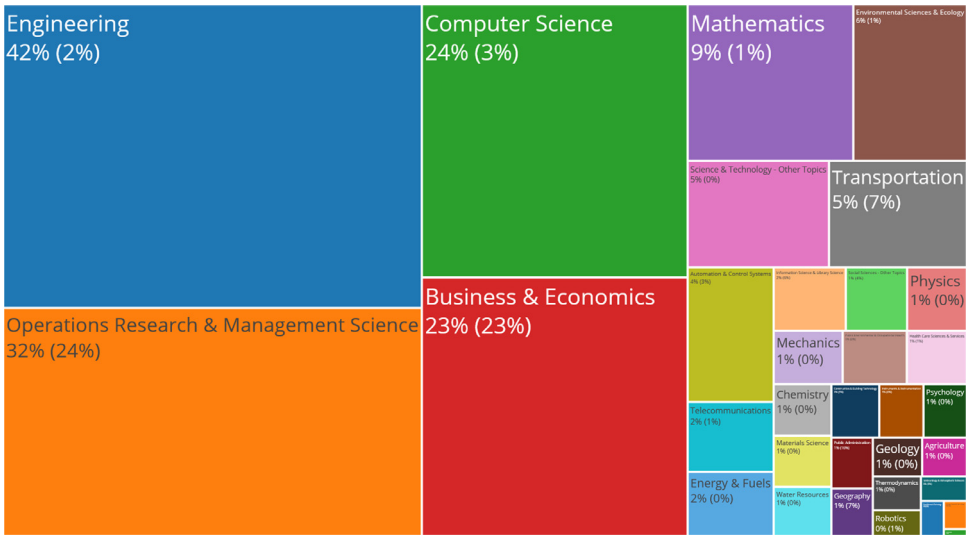


Fig. 4. Percentage of citing papers per WoS subject area between 2010 and 2019 out of all citations to OR/MS reviews (in parenthesis: percentage of all the papers in the subject area citing OR/MS reviews).

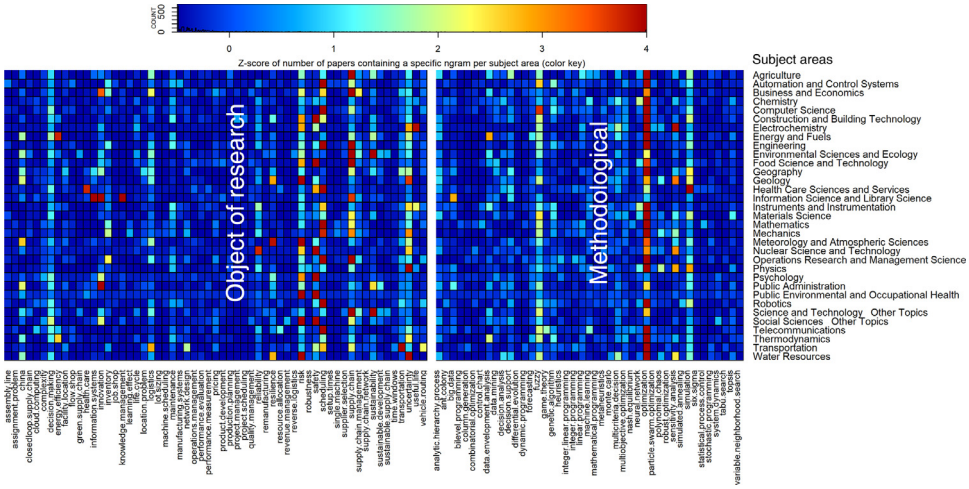
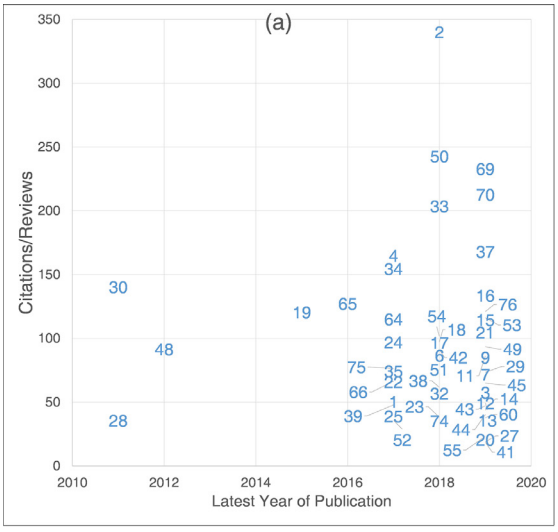


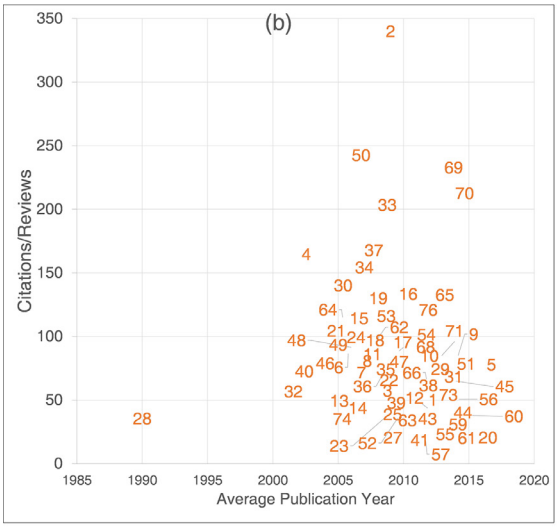
Fig. 5. Heatmap of the standardized number of papers per subject area containing a specific term (note that all z-scores below -0.5 are represented by the same color).

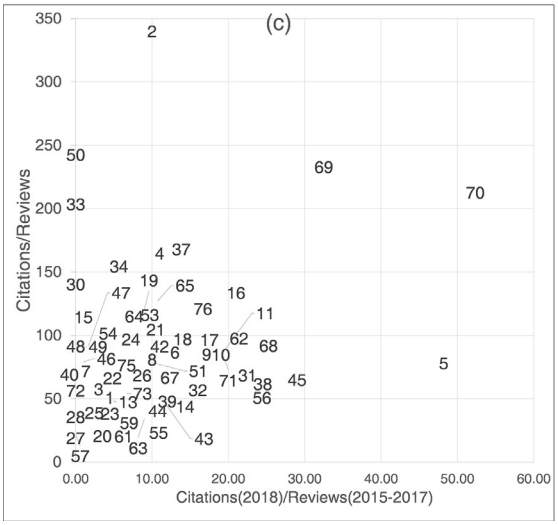
lication of a review paper for each topical cluster and select the cluster with the oldest publication year (see Fig. 6 (a)). For instance, the last review paper on lot-sizing in our database was published in 2011, which suggests that a more updated review on lot-sizing would be an interesting paper. However, since the latest year of publication of a review on certain topics could be a result of the current relevance of a topic and not an indication of future research opportunities, i.e. the topic has lost its relevance, we also needed to gauge the relevance of the topics with other measurements, such as overall and recent citations. To conduct this analysis, we first calculated the global impact of the clusters by dividing the sum of citations of the reviews included in each cluster by the total number of reviews in each cluster (Citations/Reviews). This measurement gauges the overall impact (based on citations) of a topic without any regard for temporality. Thus, if we only take into account the latest publication year we would conclude that the cluster of *job shop topics* (cluster 28) has potential for new reviews as the latest review classified into that cluster was published in 2011. However, if we compare the latest publication year against the Citations/Reviews of the same cluster (Fig. 6 (a)), the conclusion is that it might not be worthwhile to conduct a literature review regarding this topic as its overall impact is minimal, i.e. it has a small number of average citations per review.

To further assess the relevance of the clusters, we then calculated the average publication year per cluster as well as a 2018 impact factor of sorts for each cluster [38]. The average publication year per cluster shows how recent the consolidation of each cluster has been by providing data on the average publication year of the clusters (see Fig. 6 (b)). The clusters of *big data analytics, health and safety, safety culture climate and performance, safety management, recommender systems, supply chain risk management, performance measures, risk assessment, data envelopment analysis*, *robust optimization*, and *planning problems modeling* all have average publication years higher or equal than 2014 (the last 5 full years), showing their recent emergence. However, when plotted against Citations/Reviews (Fig. 6 (b)) we can see that papers classified in the clusters of *health and safety, safety culture climate and performance*, *safety management, performance measures*, and *robust optimization* have had little impact in terms of citations. This could be caused by the lack of relevance of these topics but also because the interest in these topics has only peaked in recent years, leaving little time to make a significant impact in terms of citations.

Thus, to uncover the most recent impact of topical clusters, we calculated a 2018 impact factor [38] of sorts for each cluster by dividing the citations that reviews published between 2015 and 2017 received in 2018 by the sum of reviews published between







LSA cluster

1 accident causation
2 analytic hierarchy process
3 artificial intelligence
4 assembly line balancing
5 big data/data analytics
6 business processes/total quality management
7 capacity planning/mathematical programming
8 combinatorial optimization
9 data envelopment analysis
10 data mining/data analysis
11 decision analysis methods
12 decision making in multiple topics
13 decision support
14 expert systems
15 facility location
16 freight transportation
17 fuzzy logic
18 general scheduling problem
19 genetic algorithms
20 health and safety
21 health care
22 human resource management
23 information systems
24 information technology
25 inventory control
26 inventory models
27 inventory systems with service level
28 job shop topics
29 knowledge management
30 lot sizing
31 machine learning
32 manufacturing systems topics
33 mass customization
34 material handling
35 mixed/integer/linear programming
36 modeling of manufacturing systems
37 multicriteria decision
38 nature-inspired metaheuristics
39 network design
40 neural networks
41 occupational safety
42 operations management
43 organizational learning/problem struct/constr ind
44 performance measures
45 planning problems modeling
46 planning topics
47 product development
48 product life cycle
49 production planning and control
50 project scheduling
51 recommender systems
52 reliability analysis
53 resource and machine scheduling
54 revenue management
55 risk analysis
56 risk assessment
57 risk in the primary sector
58 risk management
59 robust optimization
60 safety culture, climate and performance
61 safety management
62 sensitivity analysis
63 simulation and optimization
64 statistical process control
65 supplier selection
66 supply chain and manufacturing syst
67 supply chain design
68 supply chain management
69 supply chain network
70 supply chain risk management
71 supply chain topics
72 system dynamics
73 systems thinking/soft syst/complex syst
74 technology management
75 traveling salesman problem
76 vehicle routing problem

Fig. 6. Relevance analysis of LSA clusters of review papers.

2015 and 2017: Citations(2018)/Reviews(2015-2017). The comparison between the global impact (Citations/Reviews) and the most recent impact (Citations(2018)/Reviews(2015-2017)) for each cluster is shown in Fig. 6 (c). Fig. 6 (c) suggests that reviews classified in the clusters of *health and safety, safety culture climate and performance, safety management*, and *robust optimization* have not had a high impact in the most recent years, even though there have been many recent reviews on those topics (high average publication year). On the other hand, clusters such as *big data analytics, planning problems modeling, supply chain risk management, nature-*

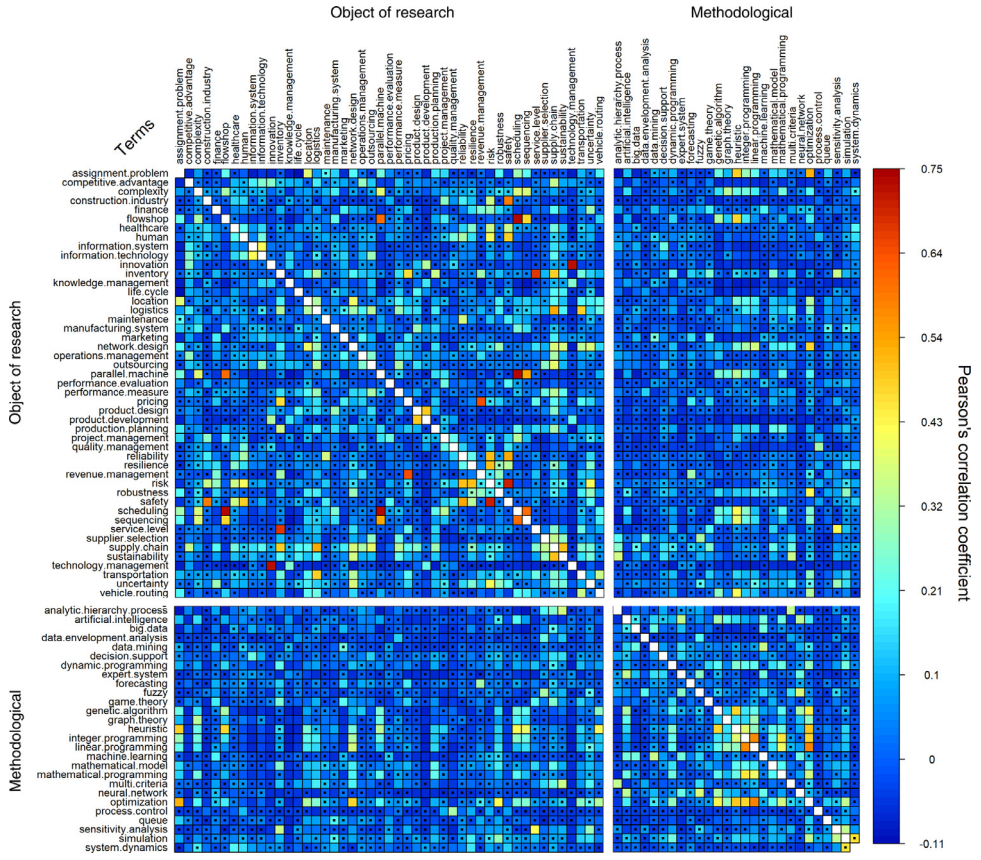


Fig. 7. Term-term correlation plot for review papers (■ represents a non-significant Pearson's correlation coefficient, i.e. p-value > 0.05).

inspired metaheuristics, and *risk assessment*, despite their moderate ratio of Citation/Reviews, have had a high impact in recent years, suggesting continuing opportunities for impactful and relevant research on these topics.

6.2. Research gaps in combined reviewed topics

Several topics have been subject to a significant number of reviews and the maturation of the OR/MS field is such that there are many reviews on the combined use of different methods to study particular topics. Examples of the latter are artificial intelligence in scheduling [92,93] and big data in supply chains [80,94], and the combination of methods to solve a particular issue, e.g., data mining with optimization [95,96] and simulation with optimization [97–99]. There are still subjects that have not been studied jointly with such attention that these can result in a sizeable sample of literature review papers. By studying the correlation between terms, suggestions can be made regarding the topics that have not been commonly concurrently studied in order to suggest future research opportunities. To study this issue, we present an analysis of term-term correlations in Fig. 7. A darker-blue hue in Fig. 7 represents a low Pearson's correlation coefficient [100], suggesting a lack of concurrent research between related topics in the matrix, and opportunities for future OR/MS research. We used the concise terms list (CTL) for this analysis to have a short list of terms consolidating many concepts and to have an easier visual inspection of the term-term correlation plot. It is worth noting that many terms included in the CTL regarding REV can be found in papers that have been classified in related LSA clusters (e.g., *sequencing* and *scheduling* in the cluster of job shop topics – see Fig. A2 in the Appendix) or are eminently contained in one of the clusters (*risk* in the clusters of risk analysis, risk assessment, and risk management), which explains why this concise list covers almost 84% of the reviews.

Some of the non-correlated terms in review papers are terms that do not have an ontological association between them, e.g., *life cycle* with *assignment problem* or *product development* with *vehicle routing* (see supplementary material for the Pearson's correlation coefficients between terms as well as the coefficients' p-values). However, from Fig. 7 we can identify some opportunities for future research given current gaps between methodologies and objects of research, or between two different methodologies or two different objects of research. For instance, *artificial intelligence* for *pricing*; *big data* for *forecasting* and for *sequencing* job arrivals in *parallel machines* and *flowshop* environments; the *competitive advantage* gained by using *expert systems*; *forecasting* for *maintenance*; *data mining* in *healthcare*; the *human* (factor) in *scheduling*; *risk* (assessment) in *logistics, outsourcing*, and *supplier selection*; the effects of good *maintenance* policies on *sustainability* and *supply chain* performance; *expert systems* and *big data* for *transportation* topics; and *reliability* considerations in *vehicle routing*.

Overall, terms related to the topic of inventory control and management (*inventory, logistics, service level)* have not had enough co-occurrences with terms associated with job shop sequencing (*flowshop, parallel machine, sequencing, scheduling*) suggesting a research gap on those combined problems, e.g., the effects of using dispatching rules, such as the shortest processing time (SPT) rule [101], in reducing stockouts of certain components/products. Furthermore, terms associated with optimization methods (*dynamic programming, genetic algorithm, integer programming*, *optimization*) have a lack of correlation with terms associated with practical decision support, such as *decision support, expert systems*, and *information systems*, suggesting a lack of consideration about practical implementation topics of optimization approaches.

Table 5
Emerging author keywords based on their average publication year.

Term	# Reviews	Average publication year
Deep learning	6	2018.33
Industry 4.0	7	2018.29
Sociotechnical systems	7	2017.43
Feature extraction	6	2017.33
Big data	10	2017.30
Data analytics	6	2017.17
Performance indicators	8	2016.88
Social networks	7	2016.86
Predictive models	6	2016.83
Process safety	8	2016.63
Green supply	6	2016.50
Thematic analysis	6	2016.50
Environmental (and) social	9	2016.44
Structured overview	6	2016.33
Resilience engineering	7	2016.29
Bibliometric analysis	15	2016.27
Intelligent systems	9	2016.22
Occupational health safety	12	2016.17
Advanced manufacturing	7	2016.14
Sustainable supply chain	7	2016.14
Construction safety	8	2016.13
Public health	6	2016.00
Transportation systems	6	2016.00

Fig. 7 also shows that the warmer (i.e., redder) the color is, the more terms are eminently associated with each other. Terms associated with each other are, e.g., *risk* with *safety* and *resilience, safety* with *construction industry, innovation* with *technology management, logistics* with *sustainability*, and *pricing* with *inventory*. From Fig. 7 we can also see that the terms of *supply chain, logistics*, and *simulation* are related to many other terms, suggesting their overall relevance to OR/MS research.

6.3. Emerging topics in OR/MS and related research areas

To discover the emerging topics in OR/MS in the last decade, we looked at the frequency of occurrence of terms included in the list of 378 high-loading terms (from the LSA) in REV with an average publication year higher or equal than 2016. Table 5 shows that keywords associated with emerging industrial and technological aspects (*Industry 4.0, socio-technical systems, advanced manufacturing*), sustainability issues (*green supply, environmental (and) social, resilience engineering, sustainable supply chain*) and data analytics (*deep learning, big data, data analytics, social networks, predictive models*, *bibliometric analysis*) all have received considerable attention in recent years.

Similarly, we searched for emerging terms in CITE (the database of papers citing OR/MS reviews) by looking for terms that have not been listed previously (Fig. 4, Tables 4 and 5) to extract information about recent relevant topics from outside OR/MS. Three general themes seem prevalent from this analysis presented in Table 6: topics related to the mitigation of climate change (e.g., *circular economy*, *carbon emission, environmental efficiency, food waste, eco-efficiency, green manufacturing*), current technological trends (e.g., *smart cities, 3D printing, microgrid, digital twin*) and emerging logistics issues (e.g., *heterogeneous fleet, reverse supply chain, supply disruption, truck scheduling, green logistics*, *maritime industry, blood supply chain*).

Interestingly, terms such as *China* and *India* appeared very frequently in CITE (see Fig. 4 and Table 6), suggesting also the emergence of those two countries as topics that are subject of study and not only as countries with emerging scientific outputs [102].

7. Discussion

7.1. The past and current state of OR/MS

Examining the results from Section 4 (specifically Table 4) we can see that, as expected, traditional OR/MS methods and application areas summarized in Table 2 have been steadfast topics in the field and remain very relevant. Review papers dealing with resource and machine scheduling, vehicle routing, combinatorial optimization, production planning and control, facility location, and inventory modeling were highly cited in the last decade (see Fig. 1).

Results from Section 4 also show that the predictions that multiple authors gave regarding which will be the next influential topics in OR/MS (also summarized in Table 2) were fulfilled, as the topics of artificial intelligence, business analytics (data mining and big data analytics), problem structuring methods, revenue management, and risk management were found to be relevant topic clusters by the LSA. In particular, the data analytics movement, as it was called by Ranyard et al. [12], and the issues related to risk (management, assessment, and analysis) have been established as fundamental and currently very relevant (see Fig. 6 (c)) topics of study in OR/MS. As a side note, it is of course not possible to identify whether these predictions may have been self-fulfilling prophecies or not. However, we can conclude that our data support the predictions of previous authors by finding that these topics/methods are indeed a fundamental part of the OR/MS domain.

Further inspection of the results shows that "supply chain management" has become one of the core objects of research (if not the core object of research) in OR/MS since supply chain issues have been the subject of many review papers. Furthermore, reviews dealing with supply chain-related topics have been cited continuously and heavily during the most recent decade, and even in the last two years. This suggests that "supply chain management" is at the center of the OR/MS domain, particularly as it is also heavily related to many other topics studied in the field (see, e.g., Figs. 2 and 7).

The need to model and understand ever-increasingly complex real problems by OR/MS scholars, responding to a call from early researchers in the field [9,11,20,103], seems to have resulted in the emergence and full consolidation of topics dealing with complex aspects of reality, such as multi-criteria decision making, and of methods trying to provide decision support for ill-defined problems, e.g., data envelopment analysis, analytic hierarchy process, fuzzy logic, and even machine learning. This trend has been also suggested by previous studies concerned with the output of OR/MS journals [22,24,26,41,43].

An analysis of papers citing OR/MS reviews showed that OR/MS has influenced many subject areas outside traditionally OR/MS-associated areas (Engineering, Computer Science and Business & Economics [32]). In fact, it could be said that some areas, e.g., Environmental Sciences and Ecology, Science and Technology – Other Topics, Transportation, Automation and Control Systems, Telecommunications, Energy and Fuels, Information Science and Library Science, and, particularly, Public Administration, have developed a high interrelation with the OR/MS domain as they have constantly cited OR/MS research in the last decade. Moreover, we found that core topics in OR/MS such as optimization, scheduling, simulation, and supply chain have a big influence in many other subject areas; whereas some other topics (mainly related to metaheuristics) are exclusively used by OR/MS. Most notably, the concept of uncertainty, which the CONDOR authors suggested in 1988 [60] to have a big impact on future research, is one of the concepts that OR/MS shares interest with many other research fields.

Interestingly, the suggestions of the CONDOR report for future avenues of research regarding methodological aspects of OR, even

Table 6
Emerging terms in papers citing OR/MS reviews.

Term	# docs.	Term	# docs.
India	194	Failure mode and effects analysis	58
Electric vehicle	129	Agent-based model	58
Polynomial chaos expansion	128	Imperfect maintenance	56
Small medium-sized enterprises	121	Fuzzy inference system	55
Carbon emission	119	Eco-efficiency	53
Gamma process	106	Truck scheduling	52
Circular economy	105	Supply disruption	51
CO_2 emissions	95	Cognitive mapping	45
Service innovation	92	Smart cities	44
Order allocation	76	Online reviews	43
Food industry	75	Scenario analysis	42
Environmental efficiency	74	Sustainable supplier selection	41
Grey relational analysis	73	Social commerce	40
Panel data	72	Microgrid	40
Financial crisis	72	Information quality	39
Surrogate model	69	Educational data mining	39
Undesirable outputs	69	Data quality	38
Reverse supply chain	69	Green manufacturing	36
Fuel consumption	62	Dempster-Shafer evidence theory	35
Lean six sigma	60	Maritime industry	33
Greenhouse gas emissions	60	Food waste	32
Green logistics	60	Blood supply chain	31
Heterogeneous fleet	59	Convolutional neural network	30
Predictive maintenance	59	Cloud model	27
Hesitant fuzzy linguistic	58	Sharing economy	24
3D printing	58	Digital twin	17

though they were made in 1988, are still very relevant today as many of those research topics/methods appeared frequently in the list of high-loading terms, e.g., non-linear and multi-objective programming, robust optimization, stochastic programming, simulation, and decision support. Possibly the only topic that seemed relevant for the authors of CONDOR at that time that does not appear as relevant today is the topic of expert systems. This term may have lost importance during the last 10 years, as shown by the significant decrease in citations for this cluster (see Fig. 1). A possible explanation for this could be that the general term *expert system* has been substituted by a wide range of terms associated with more specific methodologies, e.g., *artificial intelligence, neural networks*, and *machine learning* (see Fig. 2).

7.2. OR/MS bibliography of structured review papers

After conducting the text mining analysis of OR/MS literature review papers, we found that there were several terms frequently associated with literature reviews providing a structured analysis of the literature: *benchmark, bibliometric analysis, classification framework, classification scheme, conceptual framework, conceptual model, content analysis, meta-analysis, systematic literature review*, and *taxonomy*. Because literature reviews providing this type of structured analysis are very helpful for practitioners and researchers of any research topic, we built a summary table of literature review papers (Table C1) where we identify the type of structured analysis done in the paper and the LSA cluster of the document in question. This summary table can be used as a bibliography of literature review papers on the core topics of OR/MS.

To cover more content, we also provide a complementary summary table of the structured literature reviews containing both a term included in the concise term list and a term frequently found in structured literature reviews, as papers containing some highly relevant terms for some clusters were not always included in the associated clusters (see Fig. A2 in the Appendix). Thus, in the second table (Table C2), any review that contains a specific combination of terms, e.g., *risk* and *taxonomy*, will be shown, irrespective of the relevance of the review for a specific topic. We provide these summary tables as a digital companion document to this paper.

7.3. The future of OR/MS reviews

There are some suggestions for future research from the CONDOR report that have not yet been fulfilled but that we believe would be very interesting to study. For instance, stakeholders adaptation to lack of performance, the trade-off between modeling effort and modeling accuracy, transient behavior of systems, and production and distribution decisions under real-time information, which is a very relevant topic considering the business environment of the future (a sentiment shared also by Sodhi and Tang [18]) in which cyber-physical systems will be more present in daily operations, e.g., Trucking 4.0 [104] and Industry 4.0 [105].

Furthermore, based on the emerging topics found from recent OR/MS studies and citing articles (Tables 5 and 6), it can be suggested that new technologies associated with the manufacturing sector, e.g., Industry 4.0, 3D printing, digital twins, as well as sustainability issues will be on the center of debate in the next decade. Text mining from different subject areas also showed that OR/MS journals and researchers have yet to consider topics very relevant for the mitigation of climate change. Particularly striking is the fact that terms such as *circular economy, carbon emissions* or *food waste*, which already have a consolidated output in other

fields (see, e.g., [106–108]), have barely received any attention from OR/MS reviews, as they are critical regarding the sustainability efforts of society. In this regard, Sodhi and Tang [18] suggested that efforts such as reverse logistics, which is a current trending area of research within OR/MS along with sustainable supply chains, supply chain coordination, green supply chain, and closed-loop supply chain, could help in the sustainability efforts of supply chains.

Results from Fig. 6 suggest that the topics of *lot-sizing* and *supplier selection* could be very relevant topics to write updated reviews since the last review on the topics (included in our database) were published in 2011 and 2016, respectively, and the global impact of these topics in terms of Citations/Reviews is very high (in comparison with other clusters). Overall, it could be said that the list of topics in Table 4 constitute the mature and consolidated topics in OR/MS, whereas the lists in Tables 5 and 6 and the analysis presented in Fig. 6 could be used as a guideline of potential topics which could be subject of future and impactful literature reviews. Furthermore, as we mentioned in Section 6.2, Fig. 7 can be used to identify areas of opportunity for future reviews by locating topics that have not yet been reviewed jointly and have relevance for the field, e.g., artificial intelligence for pricing, big data for forecasting, data mining in healthcare, risk assessment in logistics, and reliability considerations in vehicle routing.

As a global conclusion, it could be said that the concept of supply chain is the core current notion within OR/MS as many reviews have been focused on supply chain topics and reviews classified in the clusters of *supply chain management, supply chain network* and *supply chain risk management* have had a high number of citations in the last 10 years. In addition, beyond the total output dedicated to each topic, review papers on *analytic hierarchy process* have been the most influential in the field, as their average citations per review have been the highest of all topics. Similarly, reviews classified in the clusters of *project scheduling, supply chain network, supply chain risk management*, and *mass customization* have all had a big impact in the field.

Has OR/MS become too broad in its scope as some authors have mentioned? Based on our results, we observed that OR/MS has indeed integrated many methodologies into its pool of decision-making tools, effectively turning this area of expertise into a multidisciplinary field. However, the main application areas of OR/MS continue to be the same as in the past (e.g., outlined by the CONDOR report), with some very interesting additions, e.g., revenue management, risk management, and portfolio selection. Optimization is still at the core of the overall influence of OR/MS, as shown by our results regarding the citations OR/MS reviews received from other fields and previous empirical evidence [12]. Additionally, our analysis from Figs. 2 and 7 suggests that business analytics (with terms such as *data mining* and *big data*), artificial intelligence (and the term *machine learning*), and risk considerations have been incorporated into the core content of OR/MS as they are related with many other topics in the field. On the other hand, we found that there are in fact some topics that have yet to build ties with the core contents of OR/MS as they have normally been studied in isolation, e.g., safety topics, technology management, and innovation, and thus, one should ask whether they should be included as part of the OR/MS field. Some other terms such as *deep learning, particle swarm optimization, statistical process control* or *lot-sizing* have also a limited connection with many topics in the field. However, since they are very tightly related to core topics in the field (deep learning and particle swarm optimization with artificial intelligence, statistical process control with quality control, and lot sizing with scheduling), we cannot say that they are dispersing the field, even though they only cover a narrow topic (see [20] for a discussion on topics with a high degree of focus).

It is worth noting that since data collection was completed in November 2019, our data is not able to show the very latest trends in research and the world. For instance, 2020 brought us the COVID-19 pandemic which has significantly affected the daily operations of businesses, pushing them to adapt to new circumstances [109]. While our data is not showing this, there are huge opportunities for future research in the OR/MS field regarding this topic, as can be attested by the multiple recent efforts to better understand the impact of COVID-19 in supply chains [110–113] and proposing ways to overcome its impacts [114–116].

7.4. Comparison with bibliometric studies

Since this study used text mining tools to analyze topical patterns in OR/MS its results provide new insights compared with bibliometric studies. The use of LSA enabled us to assess the impact that various topics have had throughout the years (see Figs. 1 and 6). The classification of papers into topical clusters with common objects of research and methodologies allowed us to combine the results of different terms and keywords into one single topic. Thus, by using LSA we were able to identify 76 main topical clusters and to assess the impact of those clusters by accumulating the total citations for each cluster. This result goes beyond previous results that exclusively relied on author keyword identification to study the output publication patterns (see, e.g., [22,24,26,43]) and not the citation patterns. Moreover, while some studies have used text mining to uncover the patterns of the OM field [39] and particular journals [27,28,41], they only studied the output patterns in terms of the number of publications and not the citation patterns or any other analysis to identify future research opportunities (see Section 6).

With the concise list of terms contained in literature reviews resulting from the identification of frequent terms, we were also able to assess how certain methodologies have been used to study different objects of research and, more important, which topics have yet to be studied concurrently (see Fig. 7). In this regard, our results are the first results to purposely highlight the lack of co-occurrence among terms found in review papers (e.g., *artificial intelligence* for *pricing*; *big data* for *forecasting* and *sequencing*), extending the results of previous bibliometric studies regarding author keyword co-occurrence. Similarly, using a concise list of terms of papers citing OR/MS reviews we were able to assess how OR/MS has influenced different fields of research (e.g., *decision support* in Agriculture; *neural network* in Chemistry; and *reliability* in Nuclear Science and Technology). These results provide complementary information to the results of Pilkington and Meredith [32,33], who studied how different research areas associated with OM influence each other and how knowledge is transmitted from journal to journal.

Furthermore, as text mining facilitated identifying the most frequent methodological terms contained in structured literature reviews, e.g., *benchmark, meta-analysis, taxonomy*, we provided the reader with two summary tables of structured literature reviews in different topics, a one of a kind result that can be a starting reference source for doctorate students and practitioners. This reference table can also be used to identify future opportunities to conduct structured literature reviews with a specific methodological focus for some topics. For instance, even though we identified that the cluster of *analytic hierarchy process* has the highest number of citations per review, we did not find any literature review providing a taxonomy associated with this term.

Since we considered all journals classified in the subject area of Operations Research and Management Science in WoS, our results consolidate previous findings of studies covering only single journal output [22–25,42,43] and studies considering a sample of journals [39,40]. What previous studies have found to be the central topics for specific journals, e.g., data envelopment analysis, heuristics, inventory, scheduling, simulation, and supply chain

management for the European Journal of Operational Research [22], the International Journal of Production Research [41] and Omega-International Journal of Management Science [43], we have found to also be true for the broad OR/MS field by using text mining analysis techniques. This suggests that, apart from the new results stemming from the text mining of titles, abstracts, and keywords, we were able to confirm results from previous studies and extend them from selected journals to the broader OR/MS domain.

Finally, using our database of review papers from 1956 to mid-2019 we were able to contrast our results with the results from Liao et al. [26] bibliometric study, which also considered all the journals classified in the OR/MS category in WoS. In this regard, our results are in line with Liao et al.'s results suggesting that the topics associated with decision analysis (analytic hierarchy process, multi-criteria decision, fuzzy logic/sets), non-linear programming (data envelopment analysis, neural networks, evolutionary algorithms) and with supply chain and logistics (supply chain management, supplier selection, vehicle routing, scheduling) are both highly cited, as they are included in the ESI database of highly-cited papers, and have a high output. Our results also agree with Liao et al. as we found that data science papers are trending upwards in the most recent years.

Despite the agreements, we also found some contrasting results to those of Liao et al. Our results suggested that, contrary to what Liao et al. said, papers classified in the clusters of *supply chain management, vehicle routing*, and *data envelopment analysis* have actually increased in both publication output and citations received, showing their current relevance. Moreover, our results regarding recent topic impact (see Fig. 6 (c)) showed additional trending and very relevant topics from those suggested by Liao et al. by identifying clusters with the most citations received in 2018, namely, *supply chain risk management*, *supply chain network, planning problems modeling*, and *freight transportation*.

7.5. Methodological considerations on text mining

The previous section summarizes the fact that text mining analysis can produce very interesting results, additional to what can be obtained by bibliometric analysis. Bibliometric analysis of topics has been mainly based on the identification of frequent author keywords and keyword co-occurrence analysis to provide an overview of the output of journals and fields of research. While this method based on author keywords produces quick and relevant results due to its implementation in bibliometric software [35,37] and the condensed topical content of keywords, it leaves a significant amount of information out of the analysis, particularly regarding methodological aspects. For this reason, we recommend incorporating text mining as a complementary tool for bibliometric analysis of topics, in addition to keyword analysis, despite the fact that it involves a significant investment of time.

Furthermore, only relying on output analysis of author keywords, which the majority of previous bibliometric studies on OR/MS have done, and not also on citation analysis for the identification of topic trends could result in a limited analysis of trends and wrong conclusions. For instance, looking only at the output patterns of clusters would have led us to conclude that the relevance of the topic of *safety culture, climate and performance* was increasing in the latest years because the number of reviews on that topic has been increasing since 2017 (see Table 4 and Fig. A1); however, when we studied the number of citations received by the papers classified in that cluster in the most recent years, we found that the number of recent citations for that topic is very low (see Figs. 1 and 6), showing the current lack of impact of this stream of research. Thus, as it is tradition with bibliometric analysis regarding journals, institutions, and authors, citation counts associated with topics/keywords should also be considered to have a wider picture of the state of the field.

Regarding text mining methods, we think that various text mining analyses should be carried out to capture different aspects of a research field, instead of relying on a single method. In the current study, latent semantic analysis helped us to summarize the field in mutually exclusive clusters of documents by condensing into a singular dimension a wide variety of dispersed terms referring to the same topic (both methodological and object-of-research-oriented), allowing us to make a straightforward analysis of the evolution of OR/MS in terms of output and citations.

On the other hand, text mining of highly frequent terms provided additional insight into the state of OR/MS by identifying the occurrence of simple terms and helping to analyze correlations (or lack thereof) between terms and other terms and subject areas. This simple text mining uncovered the relevance of very specific terms. For instance, while LSA classified a number of reviews with a common topic into the freight transportation cluster (e.g., papers on optimized shared mobility [117], collaborative urban transportation [118], cross-docking [119] and container terminal operations [120]), the simple text mining of terms allowed us to identify that the term *logistics*, which is highly associated with freight transportation (see Fig. A2 in the Appendix), occurred in many papers where the term *outsourcing* was also present (Fig. 7) (see, e.g., [121–124]). Moreover, since LSA relied on text mining of terms with more than one word to include some contextual meaning, we used simple term analysis to uncover the relevance of some objects of research and methodologies that could be summarized in one-word terms, such as, *forecasting, marketing*, *pricing, queue, risk, safety*, and *simulation*. In this manner, we were able to identify general topic interrelationships since this simple technique was able to find more than one term in a single document. We refer the reader to the paper of Romero-Silva and Marsillac [41] for more technical considerations regarding the use of text mining in bibliometric analysis.

7.6. Limitations of the study

Despite the advantages of using text mining techniques to reduce the dimensionality of such a considerable amount of information and convert it into a relevant analysis, there are some limitations that are inherently associated with this approach. The first limitation is that the approach that was used in this study depends on finding terms with high frequencies and, based on a high co-occurrence of these frequencies, relationships are found to build clusters based on latent semantic analysis. This means that, as less frequent terms are not as visible, very recent trends are more difficult to pick.

Thus, much of the analysis was based on the assumption that a high occurrence term frequency was equivalent to a high topic relevance, as most of the bibliometric studies have done [22–24,41]. This assumption allowed us to base our analysis on the actual content of the database. The alternative to this option would have been to pre-select a set of terms that some experts deemed as core topics in OR/MS, like previous authors have done (see, e.g., [6,27]), and then limit our analysis to this set of terms. However, we feel that the frequency approach was more suitable for our study's objective because we aimed to make a comprehensive exploration of the topics that have been covered by OR/MS. Furthermore, the text mining extraction and clustering methods used in this study still needed experts' input to identify non-relevant terms and to synthesize the content of the clusters, i.e. naming the clusters. Similarly, as we needed to find a compromise between data completeness and ease of analysis, we needed to select thresholds to include only relevant information, as previous studies have done [28,40,84].

Notwithstanding the limitations, we think that this study provides a very interesting view of the past and current state of the OR/MS field and that it has found a good compromise between summarizing a significantly high amount of information and not losing much of the richness of the content contained in the database of OR/MS review papers. This was attained by using a variety of approaches to text mining (two-, three-, and four-word text extraction, latent semantic analysis, term list consolidation) and by building clear illustrations that enable conducting simpler analyses. The use of two-, three- and four-word terms included in the titles, abstracts, and author keywords also provided the analyses with contextual information about topics and methods, which is something that lacks in previous studies that tend to focus on one-word terms.

8. Conclusion

This paper studied the evolution of OR/MS through the most frequently studied topics in literature review papers. Text mining techniques were used to discover which are the most consolidated topics in the field and how often they have been the subject of reviews and citations throughout the years.

Results from this study suggest that supply chain management has come to be one of the core and most reviewed objects of research in OR/MS, whereas review papers on analytic hierarchy process have been the most influential. Most recently (2015-2017), review papers on supply chain risk management and big data analytics have had the highest impact in the field, showing the main current trends in the field. Text mining of papers citing OR/MS literature reviews suggested that OR/MS has had an influence in a wide variety of subject areas, outside the traditional areas of influence from OR/MS, and that optimization continues to be one of the most highly influential methodologies of OR/MS. Results from this study furthermore showed that topics associated with the mitigation of climate change (circular economy, carbon emissions, food waste, eco-efficiency, green manufacturing) and current technological trends (additive manufacturing, cloud computing, smart cities, microgrid, digital twin), which are being currently studied by other subject areas, have yet to catch the interest of the OR/MS community.

Finally, we provided the reader with two summary tables of review papers that have developed a structured analysis regarding different topics, such as benchmarks, classification schemes, and taxonomies, to serve as an overview of the state-of-the-art in OR/MS. All things considered, this study provides a summary of core concepts and studies in OR/MS, emerging topics in the field, and future research opportunities.

Supplementary materials

Supplementary material associated with this article can be found, in the online version, at doi:10.1016/j.omega.2020.102388.

Appendix

Search strings

Literature review papers:

(SU=Operations Research & Management Science AND (TS=review OR TS=survey OR TS=literature OR TS=overview OR TS=bibilograph* OR TS=state-of-the-art OR TS="state of the art" OR TS=histor* OR TS=bibliometr*) NOT TS="online review*" NOT TS="data collected" NOT TS="structural equation" NOT TS="survey data" NOT TS="consumer review*" NOT TS="customer review*" NOT TS="product review*") *AND* LANGUAGE: (English) *AND*DOCUMENT TYPES: (Review)

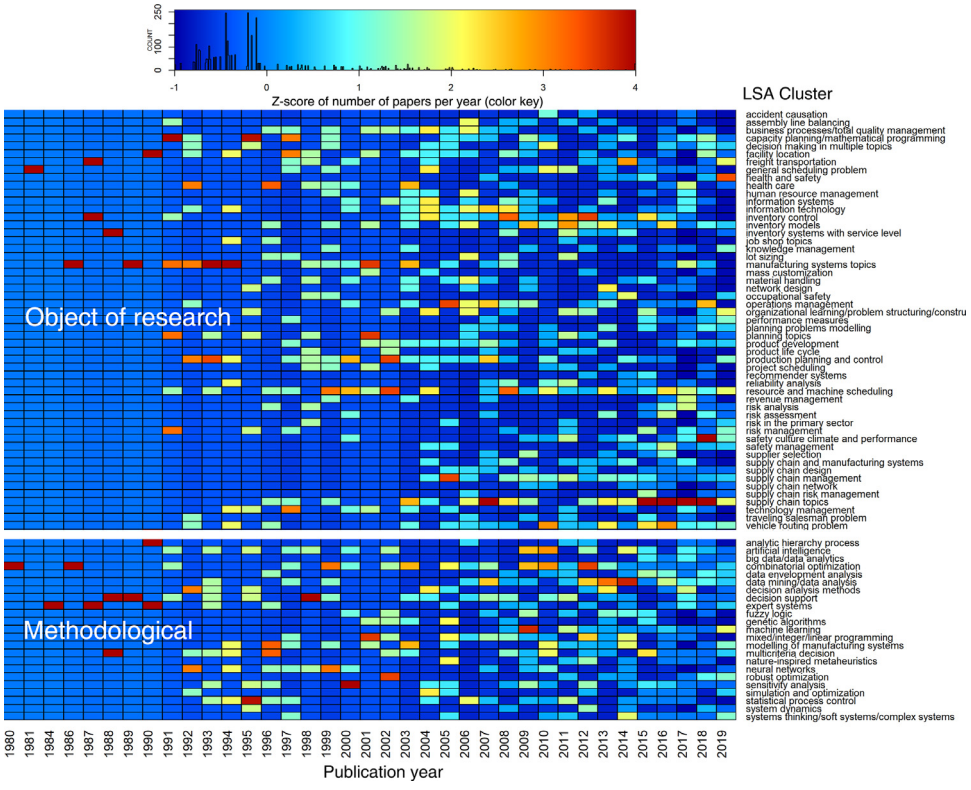


Fig. A1. Number of review papers per year for each LSA cluster.

Table A1
Review papers per journal included in this study.

Journal Name	Abbreviation	# reviews
4OR-A Quarterly Journal of Operations Research	4OR-Q J OPER RES	7
Advances In Operations Research	ADV OPER RES	0
Annals of Operations Research	ANN OPER RES	37
Applied Stochastic Models In Business and Industry	APPL STOCH MODEL BUS	1
Asia-Pacific Journal of Operational Research	ASIA PAC J OPER RES	4
Brazilian Journal of Operations & Production Management	BRAZ J OPER PROD MANAGE	0
Central European Journal of Operations Research	CENT EUR J OPER RES	1
Computers Environment and Urban Systems	COMPUT ENVIRON URBAN	13
Computer Integrated Manufacturing Systems	COMPUT INTEG MANUF SYST	7
Computers & Operations Research	COMPUT OPER RES	43
Computational Optimization and Applications	COMPUT OPTIM APPL	1
Concurrent Engineering-Research and Applications	CONCURRENT ENG-RES A	7
Criminal Justice Studies	CRIMINAL JUST STUD	0
Decision Support Systems	DECIS SUPPORT SYST	28
Discrete Event Dynamic Systems-Theory and Applications	DISCRETE EVENT DYN S	1
Discrete Optimization	DISCRETE OPTIM	0
Engineering Economist	ENG ECON	0
Engineering Optimization	ENG OPTIMIZ	2
Euro Journal On Computational Optimization	EUR J COMPUT OPTIM	0
European Journal of Industrial Engineering	EUR J IND ENG	6
European Journal of Operational Research	EUR J OPER RES	408
Expert Systems With Applications	EXPERT SYST APPL	131
Flexible Services and Manufacturing Journal	FLEX SERV MANUF J	3
Fuzzy Optimization and Decision Making	FUZZY OPTIM DECIS MA	4
Ieee Systems Journal	IEEE SYST J	8
Iie Transactions	IIE TRANS	17
Iise Transactions	IISE TRANS	2
Ima Journal of Management Mathematics	IMA J MANAG MATH	5
Infor	INFOR	8
Information and Decision Technologies	INFOR AND DECI TECH	2
Informs Journal On Computing	INFORMS J COMPUT	7
International Journal of Computer Integrated Manufacturing	INT J COMPUT INTEG M	27
International Journal of Flexible Manufacturing Systems	INT J FLEX MANUF SYST	2
International Journal of Information Technology & Decision Making	INT J INF TECH DECIS	3
International Journal of Knowledge and Systems Science	INT J KNOWLEDGE SYST SCI	0
International Journal of Management Science and Engineering Management	INT J MANAGE SCI ENG MANAGE	0
International Journal of Production Economics	INT J PROD ECON	80
International Journal of Production Research	INT J PROD RES	107
International Journal of Systems Science	INT J SYST SCI	12
International Journal of Technology Management	INT J TECHNOL MANAGE	22
International Transactions In Operational Research	INT T OPER RES	8
Interfaces	INTERFACES	17
Interpersonal Development	INTERP DEVELOP	2
Journal of Decision Systems	J DECI SYST	0
Journal of Global Optimization	J GLOBAL OPTIM	4
Journal of Industrial and Management Optimization	J IND MANAG OPTIM	3
Journal of Manufacturing Systems	J MANUF SYST	29
Journal of Operations Management	J OPER MANAG	25
Journal of The Operational Research Society	J OPER RES SOC	43
Journal of The Operations Research Society of China	J OPER RES SOC CHINA	0
Journal of Optimization Theory and Applications	J OPTIMIZ THEORY APP	6
Journal of Quality Technology	J QUAL TECHNOL	12
Journal of Scheduling	J SCHEDULING	4
Journal of Simulation	J SIMUL	5
Journal of Systems Engineering	J SYST ENG	1
Journal of Systems Engineering and Electronics	J SYST ENG ELECTRON	1
Journal of Systems Science and Systems Engineering	J SYST SCI SYST ENG	0
Large Scale Systems In Information and Decision Technologies	LARG SCL SYS INFOR DECI TECH	6
Logistics and Transportation Review	LOG TRANSP REVIEW	2
M&Som-Manufacturing & Service Operations Management	M&SOM-MANUF SERV OP	2
Maintenance Management International	MAINT MANAG INT	1
Management Services In Government	MANAG SERV GOV	2
Management Science	MANAGE SCI	31
Mathematical Methods of Operations Research	MATH METHOD OPER RES	1
Mathematics of Operations Research	MATH OPER RES	2
Mathematical Programming	MATH PROGRAM	1
Mathematical Programming Computation	MATH PROGRAM COMPUT	0
Mathematical Programming Study	MATH PROGRAM STUDY	1
Memetic Computing	MEMET COMPUT	1
Military Operations Research	MIL OPER RES	2
Naval Research Logistics	NAV RES LOG	8

(*continued on next page*)

Table A1 (*continued*)

Naval Research Logistics Quarterly	NAV RES LOG QTLY	2
Networks & Spatial Economics	NET SPATIAL ECON	0
Networks	NETWORKS	8
New Zealand Operational Research	NEW ZEALAND OPER RES	3
Numerical Algebra Control and Optimization	NUM ALGEBRA CONT OPTIM	0
Omega-International Journal of Management Science	OMEGA-INT J MANAGE S	68
Operations Research	OPER RES	32
Operations Research and Decisions	OPER RES DECI	0
Operations Research Letters	OPER RES LETT	4
Operations Research Perspectives	OPER RES PERSP	0
Operational Research Quarterly	OPER RES QTLY	4
Operational Research	OPER RES-GER	3
Opsearch	OPSEARCH	0
Optimal Control Applications & Methods	OPTIM CONTR APPL MET	2
Optimization and Engineering	OPTIM ENG	5
Optimization Letters	OPTIM LETT	4
Optimization Methods & Software	OPTIM METHODS SOFT	0
Optimization	OPTIMIZATION	1
Or Spectrum	OR SPECTRUM	15
Proceedings of The Institution of Mechanical Engineers Part O-Journal of Risk and Reliability	P I MECH ENG O-J RIS	5
Pacific Journal of Optimization	PACIFIC J OPTIM	0
Probability In The Engineering and Informational Sciences	PROBAB ENG INFORM SC	2
Production and Operations Management	PROD OPER MANAG	20
Production Planning & Control	PROD PLAN CONTROL	25
Quality Progress	QUAL PROG	1
Quality and Reliability Engineering International	QUAL RELIAB ENG INT	22
Quality Technology and Quantitative Management	QUAL TECHNOL QUANT M	1
Queueing Systems	QUEUEING SYST	3
Rairo-Operations Research	RAIRO-OPER RES	2
Rairo-Recherche Operationnelle-Operations Research	RAIRO-RECH OPER	2
Reliability Engineering & System Safety	RELIAB ENG SYST SAFE	65
Safety Science	SAFETY SCI	136
Socio-Economic Planning Sciences	SOCIO-ECON PLAN SCI	9
Sort-Statistics and Operations Research Transactions	SORT-STAT OPER RES T	2
Studies In Informatics and Control	STUD INFORM CONTROL	3
Systems & Control Letters	SYST CONTR LETT	0
Systems Engineering	SYSTEMS ENG	2
Technovation	TECHNOVATION	28
Top	TOP	5
Transportation Research Part B-Methodological	TRANSPORT RES B-METH	12
Transportation Research Part E-Logistics and Transportation Review	TRANSPORT RES E-LOG	9
Transportation Science	TRANSPORT SCI	13

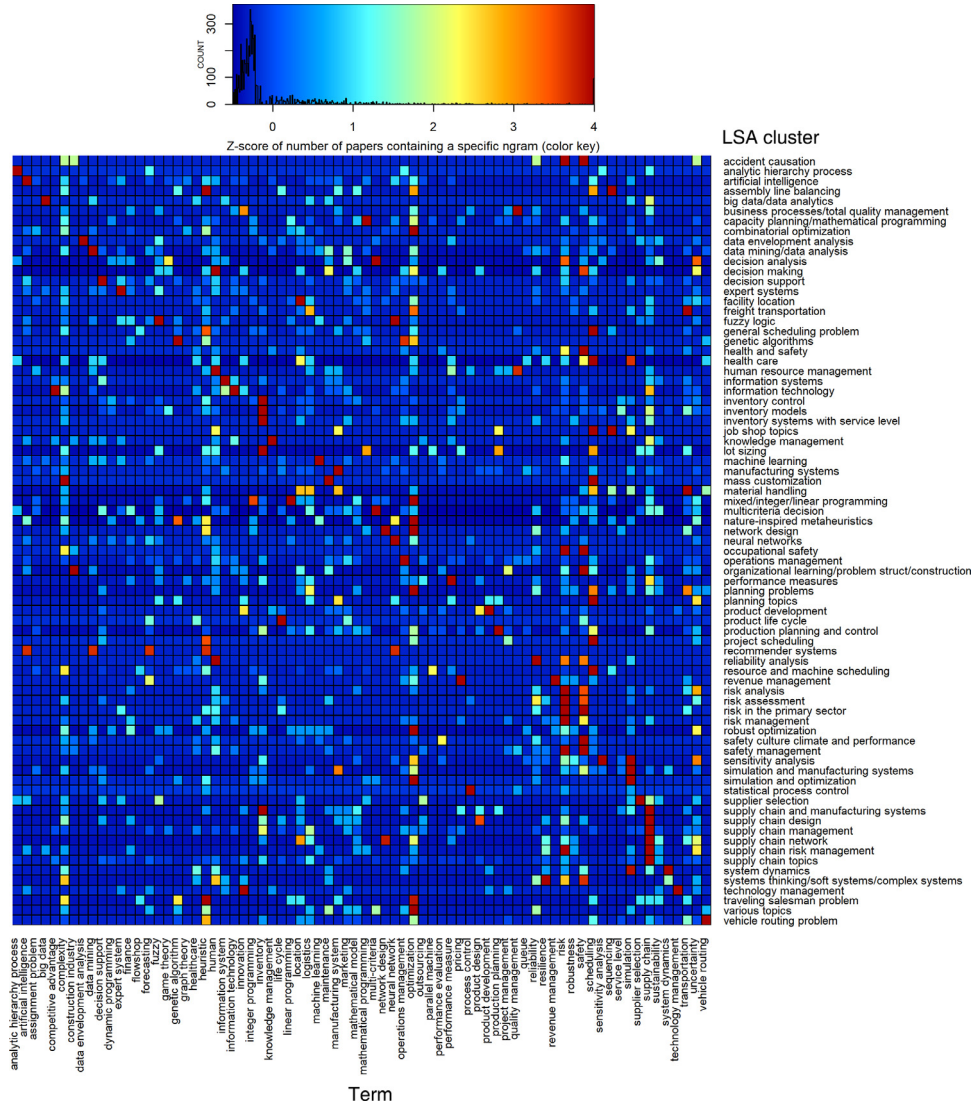


Fig. A2. Heatmap of the number of standardized number of papers per REV cluster in which a specific term was found.

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