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Trends and topics in IJPR from 1961 to 2017: a statistical history

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This paper studies the history of the International Journal of Production Research (IJPR) by analysing the topics that have received the most attention in each of the journal's publication years. Text mining exposed for scrutiny the most frequently mentioned and cited terms contained in the titles, abstracts and keywords of IJPR papers. Analyses suggest that the triad of scheduling/optimisation/simulation and supply-chain-related topics have been IJPR's mainstays, but valuable opportunities remain for relevant topics that have not yet been concurrently and frequently studied. Results also show that terms related to sustainability and risk management topics have gained recent relevance. In addition, IJPR appears to complement its modelling technique focus with empirical methodological approaches to provide a well-balanced perspective, since the 'case study' term is common. Finally, a linear relationship is found between the number of papers that have covered certain topics and the number of citations those topics have received, highlighting which topics had fewer or more citations than expected, given the number of papers that covered those topics. IJPR stands as one of the most prestigious and established journals in its field and the results from this study indicate the evolving interests of the field for over half a century.

Keywords: bibliometric analysis; Scopus; text mining; operations management; industrial engineering; operations research

1. Introduction

As the global economy has evolved from an agricultural to an industrial to an informational focus, economic sectors have needed new techniques to better manage firms' value-added operational activities.

In response, the research areas of Management Science and Operations Research (MS&OR), Industrial Systems and Manufacturing Engineering (I&ME), and Operations Management (OM) have produced scientific proposals addressing the changing needs of the economic sectors. Some research areas have covered a range of topics over the years as new interests have appeared, while other topics remain more steadfast.

The 55th issue publication of the International Journal of Production Research (IJPR) serves as a great opportunity to conduct a retrospect of the main research topics covered by this community and assess the maturation of research streams. As one of the most prestigious and long-standing venues to publish research in the MS&OR, I&ME and OM areas (Fry and Donohue 2013), IJPR is a unique scientific source that longitudinally captures this evolution of different research interests, from a purely manufacturing scope to the broader scope of strategic planning and supply chain management.

The aim of this paper is to analyse the research topics covered by IJPR, from its inception to the present, to review the evolution of the MS&OR, I&ME and OM areas. Developing a statistical history of IJPR, by its main topics of interest, provides insights into the relevance, impact and progress of the MS&OR, I&ME and OM communities since 1961. Furthermore, this review will provide information about future research opportunities for both IJPR and the MS&OR, I&ME and OM subject areas.

To attain this goal, this study applies *text mining* (Berry 2004) to the text content of the title, abstract and keywords of every IJPR paper ever published, to identify and analyse the most common topics studied. We believe this novel methodological approach adds enhanced insights to the conclusions of previous studies that utilised solely systematic literature review (SLR) or traditional bibliometric analysis as their methodological approaches.

This paper is organised as follows: Section 2 reviews some studies related to the current paper. Section 3 explains the methodology used in this paper. Section 4 provides study results, and discussion and conclusions are presented in Sections 5 and 6, respectively.

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2. Related studies

Recent studies encompassing the global output of the MS&OR, I&ME and OM areas have been carried out using either a SLR approach or a bibliometric, statistical approach.

For instance, Shang et al. (2015) studied OM-related research output from 1985 to 2010, based on the publications of 11 journals. Since some of the journals selected for that study publish articles that are not directly related to OM, the journal articles were reviewed by two of the paper's authors using information from the title, abstract and keywords. From a total of 14,526 articles, they accumulated OM-field statistics such as the most prolific authors and institutions, and the number of authors per article.

Fry et al. (2015) investigated the internationalisation of OM research using the same data-set used by Shang et al. (2015). Fry et al. (2015) note that, although North America remains the region publishing the most OM articles, other regions have grown in relative importance in the last years, such as Asia, which increased the most from 2006 to 2010.

Tavares Thomé, Scavarda, and Scavarda (2016) proposed a methodology to conduct SLR in OM, and also reviewed other studies that conducted SLR in OM by applying their own proposed methodology. They selected 11 journals for their study and, based on a pre-selected set of their own keywords, the titles, abstracts and authors' keywords were searched in the Journal Citation Reports' Web of Science (WoS) and Scopus databases to identify relevant work. This resulted in a selection of 193 articles for text review. Tavares Thomé, Scavarda, and Scavarda suggest, based on their pre-selected set of keywords, that from 2010 to 2015, six clusters of topics could be identified based on their co-occurrence (i.e. business processes, genetic algorithms, supply chains, general systems, manufacturing systems, manufacturing industries, and capabilities).

Merigó and Yang (2017) reported on the 200 most cited articles in the MS&OR area by considering the top 30 journals in the Operations Research and Management Science category from the WoS, based on their h-index. Similar to Shang et al. (2015), Merigó and Yang also indicate the most influential authors in the MS&OR area based on number of citations.

More directly related to the current study, three recent studies developed a bibliometric analysis of the history of three well-known journals in MS&OR, I&ME and OM.

The first of these studies is by Laengle et al. (2017), who conducted a review of 40 years of publications in the European Journal of Operational Research (EJOR) via the WoS database. Following the path of previous contributions (Shang et al. 2015; Merigó and Yang 2017), they reported the most highly cited articles and authors and provided a bibliometric comparison of EJOR with other journals in the same subject areas, based on public information from the WoS. They also provided a study on the co-occurrence patterns of authors' keywords and the coupling of authors, institutions and countries publishing papers in EJOR. Based on authors' keywords and on the main nodes of the co-occurrence matrix, they suggest that EJOR articles published from 1977 to 2016 can be categorised in the following clusters: scheduling; heuristics and integer programming; supply chain management and inventory; data-envelopment analysis; and simulation.

The second study is by Cancino et al. (2017) who conducted a bibliometric analysis of the history of the Computers & Industrial Engineering journal (CAIE) using the same methodologies as Laengle et al. (2017). Considering the authors' keywords, they identified the following topic clusters published at CAIE: scheduling, genetic algorithms, simulation, statistical process control, data-envelopment analysis, and supply chain management.

Finally, Akmal et al. (2018) conducted a bibliometric analysis of the total research output of the Production Planning & Control journal (PP&C) using the Scopus database. Complementing their report on traditional bibliometric study results (most prolific and cited papers, authors, institutions and countries), they also performed content analysis on the topics covered by the journal. To perform the content analysis, Akmal et al. applied their field expertise to select a set of keywords to be searched within the contents of the title, abstract and keywords. Based on this search, they found the topics of production, supply chain management and performance had received the most attention in PP&C, with the topics of healthcare, services and sustainability trending upwardly in recent years.

As seen from the previous review of relevant studies, bibliometric analysis is a research methodology that has gained recent significance in investigating the impact and contribution of different subject areas and journals (Ellegaard and Wallin 2015). The inclusion of statistical analysis through visualisation tools into the electronic platforms of both WoS and Scopus has further facilitated the ease and interest in conducting bibliometric analysis.

Building on the contributions made by recent bibliometric studies in the areas of MS&OR, I&ME and OM, we provide additional conclusions regarding the areas' most relevant topics and the evolution of those topics, advancing past the results of previous studies that are limited by their identification of relevant topics through the study of keywords' content or use of a pre-selection of keywords searched in the content of the paper (i.e. title, abstract, keywords). To contribute to the discussion, this study applies a text mining approach to uniquely identify the most common IJPR terms for comprehensive topic analysis. This approach is explained in the next section.

3. Methodology

Traditional bibliometric analysis, as seen in Section 2, commonly relies on structured data (i.e. keywords) provided by global research databases, such as WoS and Scopus. Despite the high reliability of structured data, it has limitations regarding the content that can be obtained because it needs to be formatted and included into a predefined structure (Li et al. 2008). Because of this limitation, there has been an increase in techniques that support the analysis of unstructured data (Feldman and Sanger 2006), such as text.

With the objective of expanding the sources that are normally used by bibliometric studies to identify topics covered by a subject area or journal, the current paper uses text mining tools to identify the topics that have received the most attention in the history of IJPR.

The database of Scopus (Elsevier 2018) was used to retrieve bibliographic information on all the papers ever published in IJPR. Information about the Title, Abstract, Author Keywords, Year and Number of Citations was retrieved on 19 March 2018, inclusive from 1961 to 2017. Data from 10,031 papers were retrieved from this period.

Following the retrieval of information, both the 'tm' package (Feinerer, Hornik, and Meyer 2008) for R (The R Foundation 2016) and the VOSviewer software (van Eck and Waltman 2010) were used to process text data and identify the most common terms.

To process text using the 'tm' package, text was converted to lower case, while typical English stop-words, numbers and punctuation were removed. Typical supporting words found in the titles and abstract of the papers, but not related to content topics, were removed from the database after a first trial, and plurals of common words were replaced with their corresponding singular term (see the Appendix for the list of removed and replaced words).

After cleaning the text, term-document matrices (*TDM*) were built for sets of words of size 1, 2, 3, 1–3 and 2–3 using the 'tm' and RWeka package for R (Hornik, Buchta, and Zeileis 2009) to identify the most frequent *ngrams* (or terms of *n* words) in the database. *TDMs* were used to count the number of times that each *ngram* appeared on the title, abstract and keywords of a paper. Furthermore, in order to identify if a certain *ngram* appeared in a document and count the number of papers containing each *ngram*, irrespective of the number of times the *ngram* appeared, binary term-document matrices were built (*bTDM*).

The 55 most frequent *ngrams* of size 1, 2, 3 and 2–3 were selected, respectively, to identify the most relevant topics in the history of IJPR and discover possible trends in different periods of years. In addition, the VOSviewer software was used, as in previous studies (Cancino et al. 2017; Laengle et al. 2017), to analyse the Scopus database without any further processing, to identify the most common keywords found in the period of 2005–2017, since author keywords information was only available for that period (Taylor and Francis Online 2018). Direct results from the VOSviewer and from the *ngram* retrieval exercise were then compared to build a final list of relevant *ngrams* for further *TDM* and *bTDM* processing.

The statistical correlation of the co-occurrences between pairs of *ngrams* was estimated using the Pearson's correlation coefficient (Rodgers and Nicewander 1988) for each pair of *ngrams*. *Ngram* co-occurrences were calculated using the adjacency matrix (*AJM*) of the most common terms, which was calculated in the following manner:

$$AJM = bTDM * bTDM^T \tag{1}$$

being that $bTDM^T$ is the transpose of the *bTDM*.

P-values for the Pearson's correlation coefficient were also estimated to assess the statistical significance of the correlations. Clusters of terms, based on their co-occurrences, were then built using hierarchical clustering with Euclidean distances and the Ward method (Mooi and Sarstedt 2011).

Statistics about the number of papers containing a specific *ngram* per year were then computed by building *bTDMs* for each year of publication. To study the relevance of each term relative to a year, the measurement of number of papers that contained a specific *ngram* was standardised, depending on the year of publication. Similarly, the number of citations received by papers containing a particular *ngram* were counted and further standardised.

Finally, the relationship between the number of papers where an *ngram* appeared and the citations that the papers containing those *ngrams* received was assessed through a simple linear regression model to study the global impact each topic has created, compared to how many papers IJPR published studying each topic.

4. Results

The 55 most frequent *ngrams* of size 1, 2 and 3, stemming from the titles, abstracts and keywords of all 10,031 papers are shown in Table 1. The most frequent terms in the history of IJPR are 'system' and 'model', appearing in around half of IJPR's papers, which aligns with the target audience of the journal, since their main concern is to improve the management of firms' operational activities using models of real systems.

Table 1. Percentage of papers published in IJPR containing a specific *ngram*, n = size of *ngram*.

$n = 1$		$n = 2$		$n = 3$	
ngram	% papers	*ngram*	% papers	*ngram*	% papers
System	44.9	Manufacturing system	12.0	Supply chain management	3.7
Model	43.0	Supply chain	10.5	Flexible manufacturing system	3.2
Problem	38.3	Case study	7.3	Integer linear programming	1.4
Manufacturing	35.1	Scheduling problem	6.8	Cellular manufacturing system	1.2
Process	33.3	Production system	5.9	Mixed integer programming	1.2
Time	32.9	Genetic algorithm	5.2	Mixed integer linear (programming)	1.2
Production	31.2	Production planning	3.7	Statistical process control	1.2
Method	28.4	Flexible manufacturing	3.7	Job shop scheduling	1.1
Study	28.0	Manufacturing process	3.6	Shop scheduling problem	1.1
Performance	28.0	Processing time	3.6	Integer programming model	1.0
Algorithm	22.2	Mathematical model	3.5	Assembly line balancing	1.0
Analysis	21.7	Optimal solution	3.4	Linear programming model	0.9
Design	21.5	Programming model	3.3	Decision support system	0.9
Solution	20.5	Linear programming	3.2	Sequence-dependent setup time	0.8
Machine	18.5	Performance measure	3.2	Discrete event simulation	0.7
Cost	18.5	Assembly line	3.1	Materials handling system	0.7
Control	17.9	Lead time	3.0	Flow shop scheduling	0.7
Product	17.4	Job shop	3.0	Structural equation modelling	0.7
Optimal	17.1	Simulation model	3.0	Particle swarm optimisation	0.7
Order	17.0	Cycle time	2.9	Analytic hierarchy process	0.6
Scheduling	16.5	Mixed integer (programming)	2.8	Line balancing problem	0.6
Case	16.4	Setup time	2.6	Cell formation problem	0.6
Management	16.3	Integer programming	2.6	Material requirements planning	0.6
Data	15.8	Total cost	2.5	Production planning control	0.6
Planning	15.7	Process planning	2.5	Automated guided vehicle	0.6
Simulation	14.7	Control system	2.5	Facility layout problem	0.6
Quality	13.9	Production process	2.4	Data envelopment analysis	0.6
First	13.6	Production line	2.3	Supply chain network	0.6
Total	12.4	Cellular manufacturing	2.3	Supply chain performance	0.6
Supply	12.2	Materials handling	2.3	Supply chain design	0.6
Information	12.2	System performance	2.2	Flow-shop scheduling problem	0.6
Chain	11.9	Computational experiments	2.1	Mixed-model assembly line	0.6
Programming	11.4	Simulated annealing	2.1	Quality function deployment	0.6
Operations	11.4	Numerical examples	2.0	Supply chain system	0.5
Objective	11.4	Heuristic algorithm	2.0	Mixed-integer linear programming	0.5
Products	11.3	Process control	2.0	Storage retrieval system	0.5
Literature	11.1	Product development	2.0	Automated manufacturing system	0.5
Set	11.0	Decision making	1.9	Closed-loop supply chain	0.5
Environment	10.9	Shop scheduling	1.9	Machine scheduling problem	0.5
Decision	10.9	Case studies	1.8	Reconfigurable manufacturing system	0.5
Demand	10.8	Shop floor	1.8	Simulated annealing algorithm	0.5
Application	10.5	Sensitivity analysis	1.8	Mathematical programming model	0.5
Costs	10.4	Production scheduling	1.7	Printed circuit board	0.5
Compared	10.4	Neural network	1.7	Parallel machine scheduling	0.5
Development	10.2	System design	1.7	Theory of constraints	0.5
Applied	10.0	Quality control	1.7	Job-shop scheduling problem	0.5
Computational	9.9	Manufacturing environment	1.7	Response surface methodology	0.5
Example	9.8	Integer linear (programming)	1.6	Shop floor control	0.5
Due	9.8	Product design	1.6	Supply chain risk	0.5
Level	9.8	Production control	1.6	Production planning problem	0.4
Modelling	9.8	Decision support	1.6	Average run length	0.4
Tool	9.8	Cell formation	1.5	Monte carlo simulation	0.4
Heuristic	9.7	Flow shop	1.5	Product life cycle	0.4
Part	9.6	Control charts	1.5	Variable neighbourhood search	0.4
Inventory	9.6	Due date	1.5	Enterprise resource planning	0.4

Interestingly, the term 'control' (18% of papers) has appeared more frequently than the terms 'management', 'scheduling' and 'planning', illustrating how the topic of control is a founding principle of the field.

Results from Table 1 also suggest that IJPR has continuously focused on performance issues, as the *ngrams* of 'performance measure', 'total cost' and 'cycle time' appear regularly, as do the terms 'algorithm', 'simulation' and 'programming'. All of these terms are directly associated with methodologies used to improve model performance. Despite a focus on modelling, the term 'case study' is also common, suggesting that IJPR supports empirical methodological approaches. Addressing production environments, the terms 'flexible manufacturing', 'job shop', 'assembly line' and 'cellular manufacturing' occurred most often.

Furthermore, the interest of the community in an enterprise-wide scope can be seen in the frequency of occurrence of the *ngrams* associated with the different steps of a product value-chain (Al-Mudimigh, Zairi, and Ahmed 2004), such as 'supply chain management', 'process planning' and 'product development'.

4.1. Interests throughout the years

To assess the importance of different topics in different periods of time, the number of papers containing a specific *ngram* and the number of citations received by those papers were calculated according to the papers' year of publication. This built a list of the 40 most frequent *ngrams* of size 2 or 3, depending on the paper's year of publication. *Ngrams* of size 1 were not considered in this specific analysis as they tended to lack useful contextual information to identify general topics of interest.

Table 2 shows the evolution of the topics from one decade to the next by presenting the 40 most frequent 2 or 3 size *ngrams* per decade. The change from a purely industrial and manufacturing focus in the initial publication years to a supply chain and optimisation focus in the latter years can be clearly seen in Table 2. For instance, manufacturing-related *ngrams* such as, 'surface finish', 'production rate', 'cutting speed' and 'tool life', were prevalent in the 1961–1979 period while the 80's produced papers focused on traditional industrial and manufacturing engineering topics, such as, 'production control', 'quality control', 'material requirements planning', 'lot size', 'inventory control' and 'layout problem'. Specific terms of interest in the 90's were 'flexible manufacturing system', 'neural network', 'cellular manufacturing system', 'cell formation', 'automated guided (vehicle)', 'dispatching rules' and 'expert system'.

Note the terms marked with an asterisk (*) in Table 2 to identify *ngrams* associated with a specific period, as these *ngrams* only appear in the associated period and do not appear in the list of the most frequent *ngrams* for all publication years (see first column of Table 2).

Papers published in IJPR changed in overall focus from 2000 to 2009 as *ngrams* not predominantly manufacturing-related, such as 'supply chain' and 'product development', became prevalent for the first time. The ascendancy of supply chain and mathematical programming becomes evident when analysing the most frequent emerging terms (as *ngrams*) for 2010–2017. 'Supply chain management', 'genetic algorithm', 'optimisation model' and 'integer linear programming' all gained relevance in this period. The term 'operations management' gained relevance in 2017, as well as the issue of risk, reflected by *ngrams* such as 'risk management' and 'supply chain risk'.

For a list of emerging terms in 2017 not found in other tables, refer to Table A1 in the Appendix, where the currently popular terms 'data mining', 'sustainable manufacturing', '(product) life cycle', 'healthcare' and 'multi-objective optimisation' can be found. Furthermore, the increase in the number of papers including terms such as 'multi-objective optimisation', 'data envelopment analysis' and 'analytic hierarchy process' in recent years also reflect current community concern for problems with multiple (and possibly conflicting) goals.

In addition, the database of Scopus and the software VOSviewer were used to identify the 50 most relevant author keywords from 2005 to 2017 (see Appendix, Table A2) to include more recently relevant topics in the analysis. The most frequent keywords/topics found by the VOSviewer software, that were not originally included in the list of 50 most frequent *ngrams* of $n = 2$ or 3 stemming from the direct text mining exercise, were then added to a final list of terms. Moreover, similar *ngrams* representing the same topic were joined in one single term to produce more compact results (see Table A3 in the Appendix for a list of all the *ngrams* that were considered for aggregating statistics into a single term/topic). This resulted in a list of 58 terms (considered in all figures) that were used to analyse the progression of topics' interest throughout the history of IJPR.

Note that if more than one *ngram* was considered for the same term and appeared in the same document, e.g. 'manufacturing system' and 'production system' were considered as the single term 'manufacturing system', the statistical aggregation only counted one document as having either *ngram*.

Figure 1 shows this progression by means of a heatmap representing the number of papers containing a specific *ngram* in each year. Red colours in Figure 1 represent a high number of papers containing a specific *ngram*, while blue colours represent a low number of papers. Colour intensity reflects more extreme values.

Table 2. Percentage of papers per period containing a specific *ngram, n = 2 or 3*.

ngram	All years	*ngram*	1961–1979	*ngram*	1980–1989	*ngram*	1990–1999	*ngram*	2000–2009	*ngram*	2010–2017	*ngram*	2017
Manufacturing system	12.0	Production system	4.2	Manufacturing system	10.5	Manufacturing system	17.4	Manufacturing system	14.0	Supply chain	21.3	Supply chain	25.0
Supply chain	10.5	Scheduling problem	3.9	Production system	8.0	Flexible manufacturing	7.1	Supply chain	9.0	Case study	11.2	Case study	11.6
Case study	7.3	Mathematical model	3.2	Flexible manufacturing	6.7	Flexible manufacturing system	6.2	Case study	8.0	Scheduling problem	10.3	Manufacturing system	10.3
Scheduling problem	6.8	Service time*	3.2	Simulation model	5.7	Cellular manufacturing	5.7	Genetic algorithm	7.7	Manufacturing system	10.0	Supply chain management	9.6
Production system	5.9	Assembly line	2.9	Flexible manufacturing system	5.6	Production system	5.6	Production system	5.5	Genetic algorithm	7.4	Scheduling problem	8.2
Genetic algorithm	5.2	Cycle time	2.9	Control system	4.4	Scheduling problem	5.6	Manufacturing process	5.3	Supply chain management	7.3	Linear programming	7.8
Production planning	3.7	Control system	2.6	Job shop	4.0	Materials handling	4.5	Scheduling problem	4.9	Production system	6.2	Mixed integer (programming)	7.7
Flexible manufacturing	3.7	Production scheduling*	2.4	Lead time	3.5	Job shop	4.4	Production planning	4.4	Programming model	5.6	Production system	7.4
Supply chain management	3.7	Surface finish*	2.4	Processing time	3.4	Performance measure	4.1	Process planning	4.1	Linear programming	5.4	Programming model	6.0
Manufacturing process	3.6	Case study	2.3	Production planning	3.3	Processing time	3.8	Flexible manufacturing	3.7	Mixed integer (programming)	5.3	Computational experiments	5.4
Processing time	3.6	Production rate*	2.1	Mathematical model	3.2	Process planning	3.7	Performance measure	3.7	Mathematical model	4.6	Production planning	5.3
Mathematical model	3.5	Cutting speed*	2.1	Scheduling problem	3.1	Cell formation*	3.6	Processing time	3.5	Production planning	4.4	Integer programming	5.3
Optimal solution	3.4	Production line	2.0	Assembly line	3.1	Simulation model	3.4	Supply chain management	3.5	Optimal solution	4.4	Genetic algorithm	5.2
Programming model	3.3	Cutting tool*	2.0	Production process	3.1	Setup time	3.3	Flexible manufacturing system	3.3	Processing time	4.0	Mathematical model	5.2
Linear programming	3.2	Surface roughness*	1.8	Numerical example*	3.0	Control system	3.1	Optimal solution	3.3	Manufacturing process	4.0	Integer linear (programming)*	5.0
Flexible manufacturing system	3.2	Tool life*	1.8	Production line	2.8	Neural network*	3.1	Cycle time	3.2	Assembly line	3.8	Processing time	4.9
Performance measure	3.2	Speed feed*	1.8	Production rate*	2.6	Optimal solution	3.0	Product development	3.2	Lead time	3.7	Numerical experiments*	4.9
Assembly line	3.1	Simulation model	1.7	Linear programming	2.6	Heuristic algorithm	3.0	Lead time	3.1	Integer programming	3.6	Mixed integer linear (programming)*	4.6
Lead time	3.0	Quality control*	1.7	Production control*	2.5	Cellular manufacturing system*	3.0	Simulation model	3.0	Computational experiments	3.5	Integer linear programming*	4.4

Job shop	3.0	Production control*	1.7	Inventory system*	2.5	Production line	3.0	Manufacturing environment*	3.0	Total cost	3.5	Optimal solution	4.1
Simulation model	3.0	Manufacturing system	1.5	Assembly system*	2.3	Case study	2.9	Process control	2.9	Integer linear (programming)*	3.3	Performance measure	4.0
Cycle time	2.9	Processing time	1.5	Quality control*	2.2	Mathematical model	2.8	Simulated annealing	2.9	Minimise total (objective)*	3.3	Risk management*	3.7
Mixed integer	2.8	Job shop	1.5	Optimal solution	2.2	Assembly line	2.8	Control system	2.7	Performance measure	3.2	Minimise total (objective)*	3.5
Setup time	2.6	Total cost	1.5	Lot size*	2.1	System performance	2.7	Neural network*	2.6	Cycle time	3.2	Sensitivity analysis*	3.5
Integer programming	2.6	Numerical example*	1.5	Case study	2.0	Manufacturing environment*	2.5	Mathematical model	2.6	Numerical experiments*	3.2	Assembly line	3.4
Total cost	2.5	Sequencing problem*	1.5	Inventory control*	2.0	Production planning	2.5	Job shop	2.5	Setup time	3.1	Optimisation model*	3.4
Process planning	2.5	Cutting conditions*	1.5	Lot sizing*	2.0	Automated guided (vehicle)*	2.4	Assembly line	2.5	Optimisation model*	3.1	Mixed integer programming*	3.4
Control system	2.5	Depth cut*	1.5	Cycle time	1.9	Cycle time	2.4	Cellular manufacturing	2.4	Optimisation problem*	3.0	Manufacturing process	3.2
Production process	2.4	Production planning	1.4	Computer simulation*	1.9	Integer programming	2.4	Product design*	2.4	Shop scheduling	3.0	Production process	3.2
Production line	2.3	Optimal solution	1.4	Process planning	1.8	Simulated annealing	2.3	Integer programming	2.4	Integer linear programming*	2.9	Operations management*	3.2
Materials handling	2.3	Decision making*	1.4	Layout problem*	1.8	Manufacturing process	2.3	System design*	2.3	Production process	2.9	Total cost	3.1
Cellular manufacturing	2.2	Inventory control*	1.4	Setup time	1.8	Neural networks*	2.3	Programming model	2.3	Sensitivity analysis*	2.9	Flow shop*	3.1
System performance	2.2	Computer simulation*	1.4	Total cost	1.7	System design*	2.2	Shop floor*	2.3	Flow shop*	2.7	Case studies*	3.1
Computational experiments	2.1	Feed rate*	1.4	Manufacturing process	1.7	Lead time	2.2	Computational experiments	2.3	Mixed integer linear (programming)*	2.7	Lead time	2.9
Simulated annealing	2.1	Minimum cost*	1.4	Line balancing*	1.7	Total cost	2.2	Setup time	2.2	Job shop	2.6	Decision support*	2.9
Numerical examples	2.0	Production process	1.2	Planning system*	1.7	Programming model	2.2	Case studies*	2.2	Numerical examples	2.6	Heuristic algorithm	2.9
Heuristic algorithm	2.0	Dynamic programming*	1.2	Material requirements planning*	1.7	Dispatching rules*	2.1	Production process	2.1	Case studies*	2.6	Shop scheduling	2.8
Process control	2.0	Inventory model*	1.2	Decision making*	1.6	Expert system*	2.1	Linear programming	2.1	System performance	2.6	Parallel machine*	2.8
Product development	1.9	Job-shop scheduling*	1.2	Numerical examples	1.6	Production process	2.1	Materials handling	2.0	Decision support*	2.5	Literature review*	2.8
Shop scheduling	1.9	Cutting tools*	1.2	Materials handling	1.6	Simulation study*	2.1	Production line	2.0	Product development	2.4	Supply chain risk*	2.8
Total papers per period	10031		660		945		1887		2790		3749		679

**ngrams* with particular relevance for each period as they are not included in the top 40 *ngrams* when considering all years.

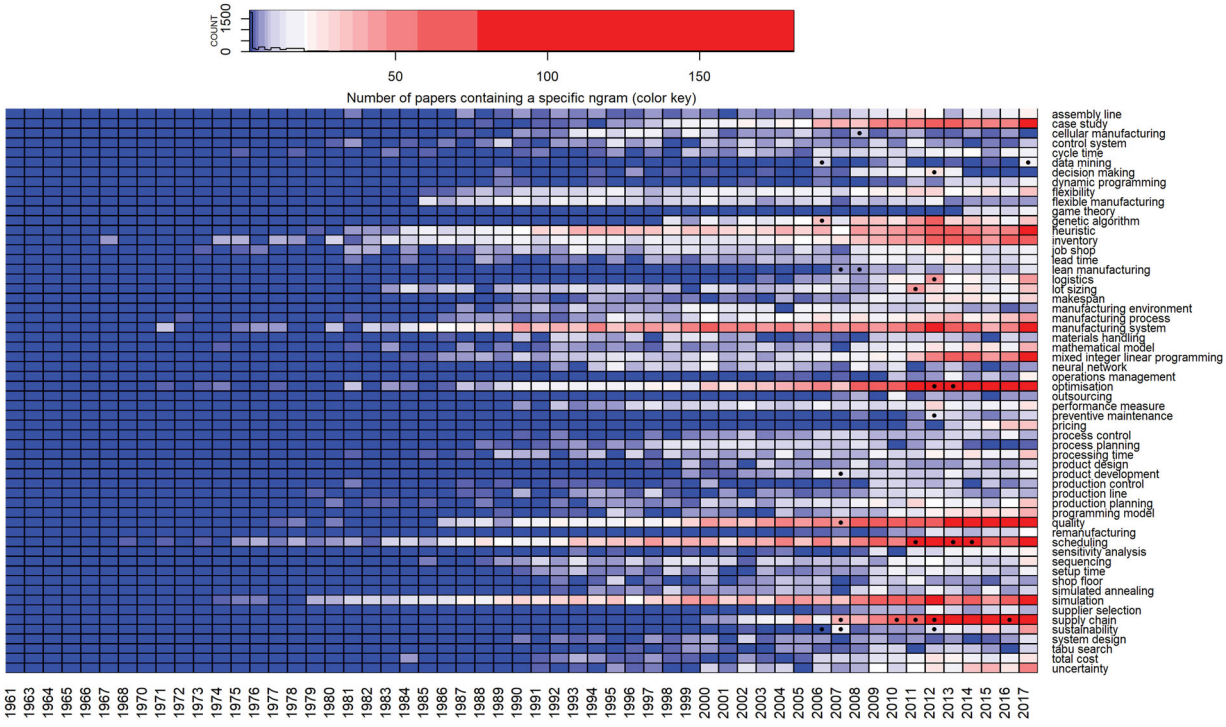

Figure 1. *Heatmap* representing the number of papers containing a specific topic; • marks a special issue in that year, related to a term.

Since the frequency of occurrence for some *ngrams* in specific years can stem from a special issue publication, information about the special issues published since 2004 (data from previous years was not available) was collected and included as supplementary information in Figure 1 (see Appendix, Table A4 for a full list of special issues), based on an internet consult by the authors of the current study (Taylor and Francis Online 2018).

Figure 1 clearly shows the shift in focus from traditional manufacturing and industrial engineering topics, in the early days of IJPR, to a focus on supply chain and optimisation topics in the most recent decade. Figure 1 also suggests that scheduling has been one of the most steadfast topics in IJPR, exhibiting consistent frequency over time. Although the term 'simulation' has not appeared as frequently as 'scheduling' over time, it has consistently appeared as a highly mentioned *ngram* since IJPR's first year of publication and has gained even more relevance since 2012. While the topic of inventory has exhibited consistent interest over time, it received significant relative attention from 1974 to 1986; whereas 'optimisation' has gained relevance since 2009, as have the associated terms 'genetic algorithm', 'heuristic' and 'mixed integer linear programming'.

Some terms have received significant attention for short periods of time. For example, the *ngram* 'flexible manufacturing' had a frequency burst from 1985 to 1994, 'cellular manufacturing' from 1993 to 2000 and the term 'decision making' appeared regularly from 2008 to 2012.

Akin to Figure 1, Figure 2 presents a heatmap of citations received by papers containing a particular *ngram*, depending on the year of publication. As in Figure 1, red represents an *ngram* that received a high number of citations in that year, whereas blue represents a low number of citations, and colour intensity reflects more extreme values.

To illustrate, papers published in 1974, 1975, 1977 and 1983 received a significant number of citations from studies that included the term 'inventory'; while papers focused on 'scheduling' published from 1993–1997 were highly cited, as were papers containing the *ngrams* 'flexible manufacturing' and 'cellular manufacturing' in 1985 and 1986. On the other hand, the bulk of citations for papers published more recently (2005, 2007, 2009–2017) has been received by papers concerned with supply chain topics. Remarkably, papers published in 2007 containing the *ngram* 'supply chain', are also highly cited, concurring with the special issue publication 'Knowledge and Information Technology Management in Supply Chain Integration'.

Overall, Figure 3 shows that the terms 'supply chain', 'manufacturing system', 'optimisation', 'scheduling', and 'simulation' received the most citations, followed by 'inventory' and 'case study'.

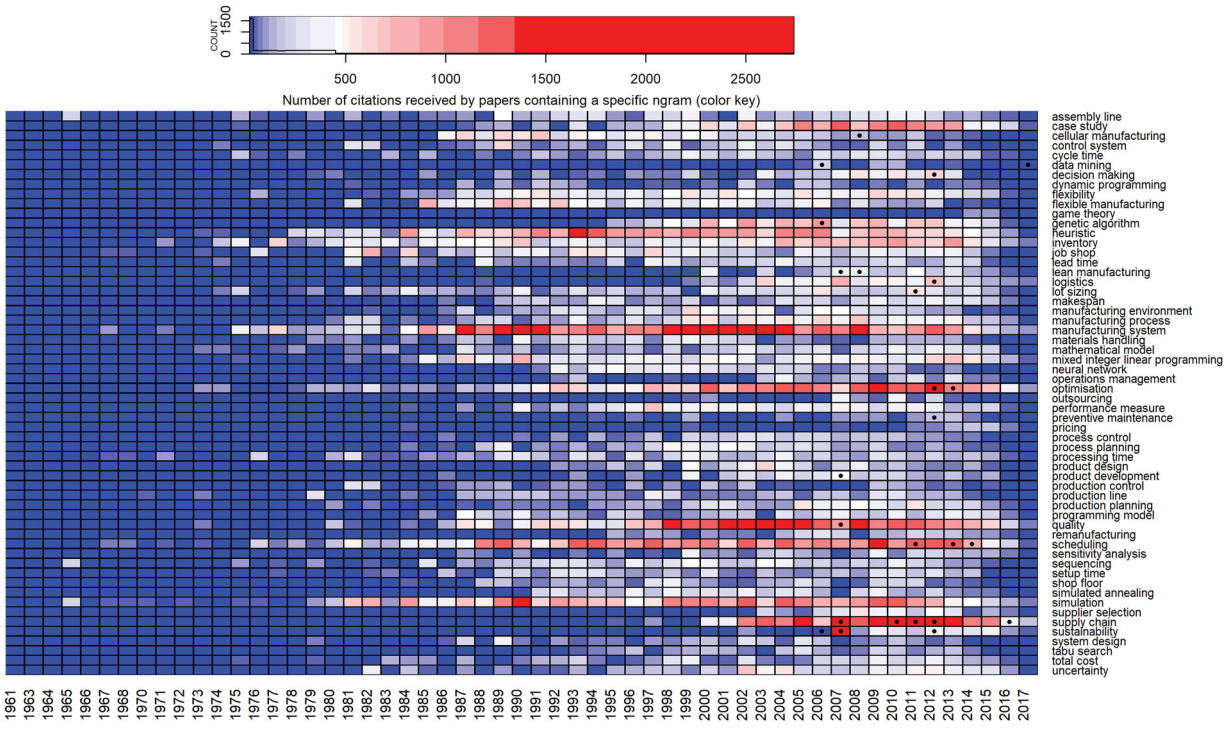

Figure 2. *Heatmap* representing the number of citations received by a paper containing a specific topic; • marks a special issue in that year, related to a term.

For additional insights, refer to Figures A1 and A2 in the Appendix for an illustration of the resemblance among years according to these 58 terms that were most commonly mentioned and cited, respectively, per year via a standardised heatmap with the corresponding dendrogram clustering similar years using hierarchical cluster analysis.

4.2. Ngram co-occurrence

A topic worth investigating is how some topics have been studied jointly in the IJPR. The analysis of this issue can help identify 'global topics' by clustering various terms and support the identification of future research opportunities. To investigate this topic, the number of papers where pairs of *ngrams* (included in the list of 58 terms) appeared in the same paper were counted and used to estimate the statistical correlation of the co-occurrence between pairs of *ngrams*.

Figure 3 shows the Pearson's correlation coefficient (r) of the topic co-occurrence matrix by colour-coding the values of r. It also shows whether r per each pair of topics was found to be statistically significant (p-value ≤ 0.05). Note that shorter *ngrams* contained in the same long term, e.g. 'flexible manufacturing' and 'manufacturing system' are both contained in 'flexible manufacturing system', do have highly statistical significant co-occurrence coefficients.

In addition to the obvious relationships between similar *ngrams* or between traditional highly related topics, e.g. 'scheduling' with 'job shop', 'makespan' and 'heuristic' or 'logistics' with 'supply chain', Figure 3 shows seven main topic clusters: (a) quality; (b) general OM topics; (c) inventory management; (d) supply chain; (e) modelling and design of manufacturing and control systems; (f) scheduling; and (g) optimisation.

Furthermore, Figure 3 also identifies general correlations among different clusters. For instance, clusters (f) and (g) are highly intertwined since scheduling topics are generally related to optimisation techniques. Similarly, cluster (e) topics appeared regularly with topics of clusters (f) and (g). Terms related with inventory management in cluster (c) have a high degree of correlation with select topics of cluster (d), which focuses on supply chain issues. Figure 3 also suggests that the individual topics of 'optimisation' 'mixed integer linear programming' and 'simulation' are highly correlated with a wide range of topics across all clusters, except for cluster (a), which is related to quality.

In contrast, some clusters show limited relationships with other clusters through low frequency of occurrence among their terms. For example, topics in clusters (d) and (e) show a statistically significant lack of correlation (dark blue colours). Similarly, terms related to supply chain topics (cluster (d)) show a low correlation with topics in cluster (f).

Correlating specific modelling techniques to general topics, Figure 3 shows that game theory appears to be exclusively applied to supply chain and operations management topics, while optimisation-focused methods, such as mixed integer

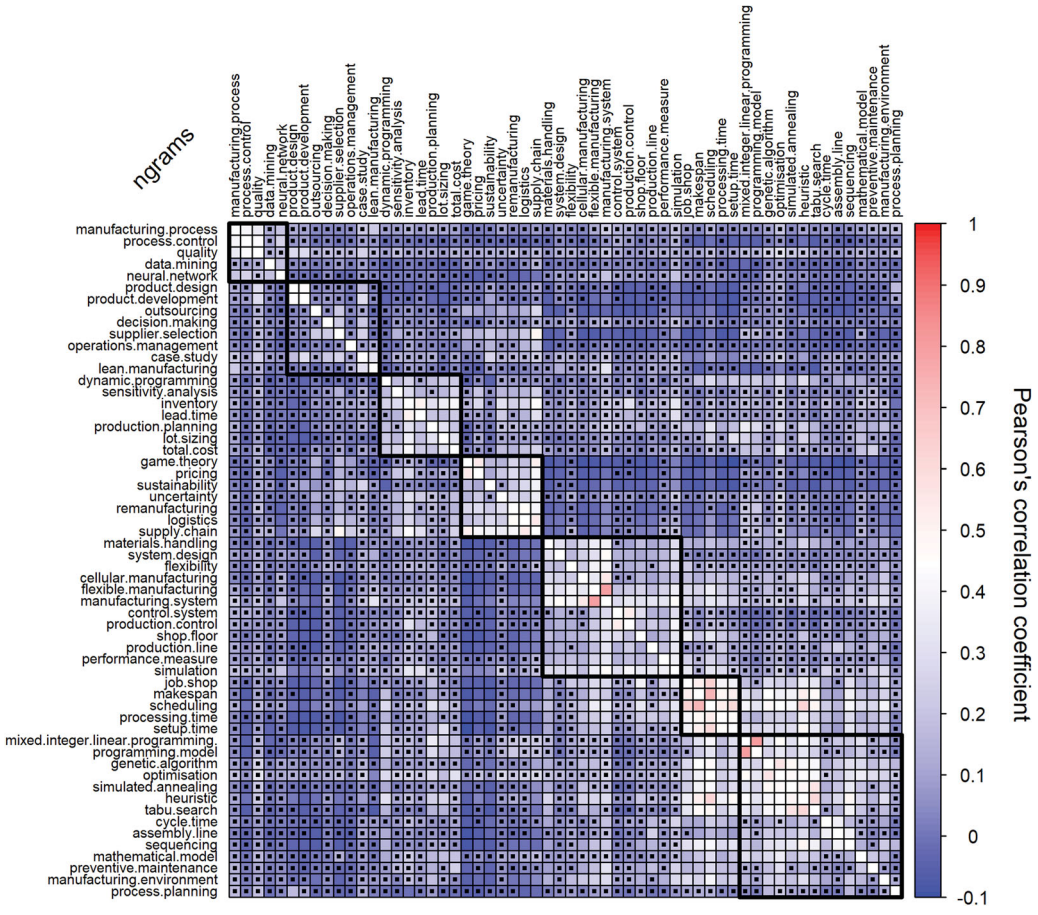

Figure 3. Topic co-occurrence correlation plot (■ represents a non-significant r, i.e. p-value > 0.05).

linear programming, simulated annealing, tabu search, genetic algorithms and dynamic programming, are all correlated with topics in different clusters, with the exception of clusters (b) and (d).

It should be noted that, because some of the *ngrams* that were included in Figure 3 appeared only since 2005 (from the VOSviewer analysis using author keywords), there was not enough information to determine statistically significant correlations for some of the *ngrams*, as reflected by the number of black squares inside the correlation plot. Despite this, the number of papers studying combined topics (two or more terms) in recent years is significantly higher than the number of papers studying combined topics in previous years (see, e.g. the comparison between plots (a) and (d) in Figure A3 in the Appendix).

To further illustrate topic correlations, Figure 4 presents the term correlations as a network of terms, using the same software as in previous studies (Cancino et al. 2017; Laengle et al. 2017). The size of the nodes in Figure 4 represents the frequency of occurrence of one term and the width of the links represents the relative frequency of co-occurrence for a pair of terms. This exercise confirmed four topic clusters (represented by different colours): supply chain and quality management, scheduling-optimisation, inventory management, and modelling and analysis of different manufacturing systems. These four clusters are comparable to the seven clusters previously identified in Figure 3 but do not exhibit the two small clusters of quality and general OM topics or separated clusters of scheduling and optimisation.

Figure 4 also shows the remarkable centrality of the terms 'optimisation' and 'simulation', as they are highly interrelated with many other topics such as 'supply chain'. It also shows how the triad of terms 'scheduling', 'optimisation' and 'simulation' constitute the core of IJPR authors' interests. Refer to Figure A4 in the Appendix for a more detailed view of the relations between nodal terms in each cluster and different topics.

4.3. Overall impact of topics

While the frequency of occurrence of a particular *ngram* shows that the topic has received interest from the field, the number of citations show the overall impact a particular topic has had on the field. Thus, in order to investigate whether a very

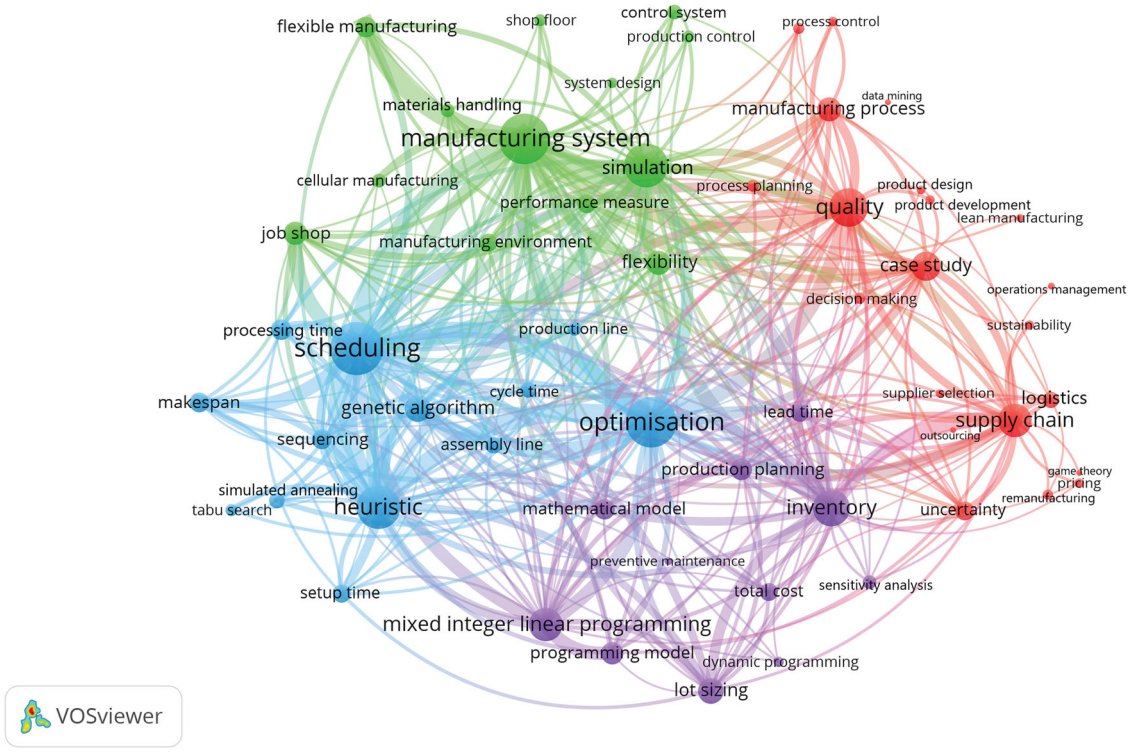

Figure 4. Topic co-occurrence represented as a network.

frequently occurring *ngram* results in a relatively high number of cites, we used linear regression to study the relationship between the number of papers (referred as *papers* in the model) and the number of citations (*cites*) of each *ngram*.

Results from the linear regression showed a highly statistical significant adjustment of the model (p-value < 0.001) with the following linear equation:

$$\text{cites} = 19.88\,\text{papers} + 227.78 \tag{2}$$

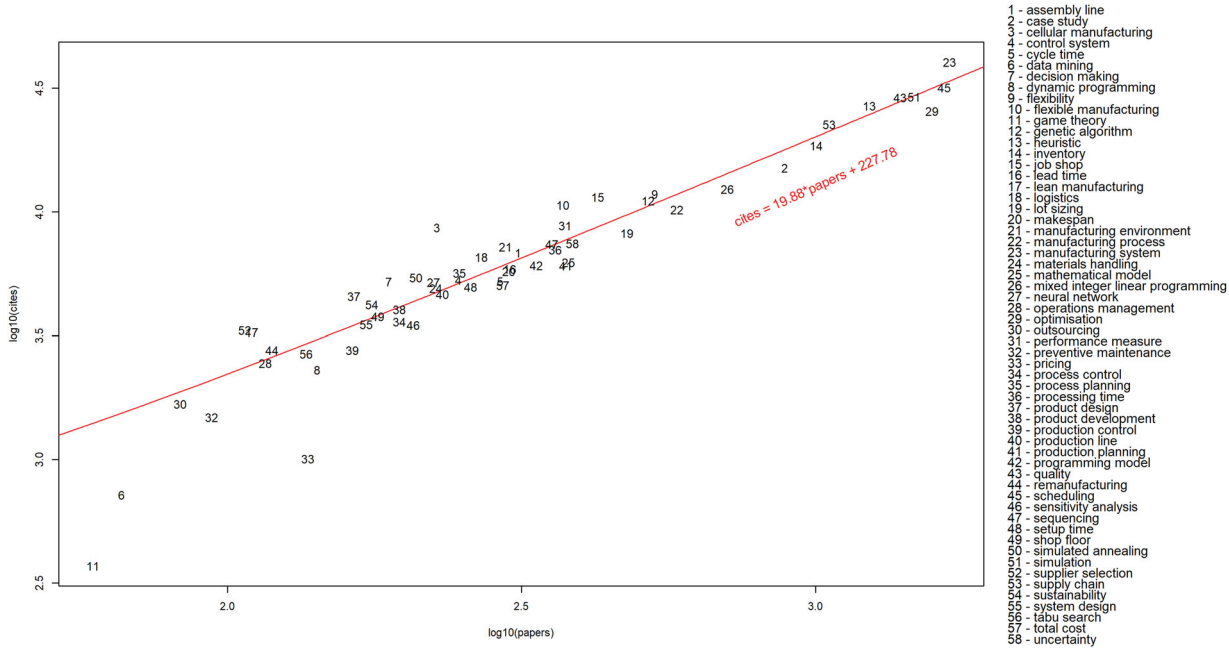

Figure 5. Impact of topic according to number of citations (*cites*) vs. number of papers (*papers*) containing the term.

Table 3. Forty most cited papers published in IJPR overall and 10 most cited papers published in IJPR between 2010 and 2017.

#	First author	Title	Year	Cites	*Ngrams*
1	Blackstone J.H.	A state-of-the-art survey of dispatching rules for manufacturing job shop operations	1982	651	Job shop; simulation
2	King J.R.	Machine-component grouping in production flow analysis: An approach using a rank order clustering algorithm	1980	618	
3	Spearman M.L.	CONWIP: A pull alternative to kanban	1990	617	Manufacturing system; simulation
4	Goyal S.K.	An integrated inventory model for a single supplier-single customer problem	1977	594	Inventory
5	Sugimori Y.	Toyota production system and kanban system materialisation of just-in-time and respect-for-human system	1977	583	Manufacturing system
6	King J.R.	Machine-component group formation in group technology: Review and extension	1982	553	
7	Wemmerlöv U.	Cellular manufacturing in the U.S. industry: A survey of users	1989	455	Cellular manufacturing; control system
8	Kusiak A.	The generalised group technology concept	1987	422	Mixed integer linear programming; programming model; quality
9	Ghosh S.	A comprehensive literature review and analysis of the design, balancing and scheduling of assembly systems	1989	384	Assembly line; scheduling; system design
10	Egbelu P.J.	Characterization of automatic guided vehicle dispatching rules	1984	377	Heuristic; job shop; simulation
11	Asiedu Y.	Product life cycle cost analysis: State of the art review	1998	353	Quality
12	Chandrasekharan M.P.	An ideal seed non hierarchical clustering algorithm for cellular manufacturing	1986	350	Cellular manufacturing
13	Meade L.M.	Analyzing organisational project alternatives for agile manufacturing processes: An analytical network approach	1999	342	Manufacturing process
14	Zhu Q.	The moderating effects of institutional pressures on emergent green supply chain practices and performance	2007	336	Supply chain; sustainability
15	Chandrasekharan M.P.	Zodiac – an algorithm for concurrent formation of part-families and machine-cells	1987	322	
16	Gunasekaran A.	Agile manufacturing: Enablers and an implementation framework	1998	320	Control system; manufacturing system; process planning; quality; shop floor
17	Chen I.J.	Understanding supply chain management: Critical research and a theoretical framework	2004	318	Logistics; operations management; supply chain
18	De Toni A.	Manufacturing flexibility: A literature review	1998	296	Flexibility
19	Alting L.	Computer aided process planning: The state-of-the-art survey	1989	296	Process planning
20	Hill R.M.	The optimal production and shipment policy for the single-vendor single-buyer integrated production-inventory problem	1999	291	Optimisation; total cost
21	Gunasekaran A.	Performance measures and metrics in logistics and supply chain management: A review of recent literature (1995–2004) for research and applications	2007	288	Logistics; outsourcing; performance measure; supply chain
22	Stecke K.E.	Loading and control policies for a flexible manufacturing system	1981	285	Flexible manufacturing; job shop; manufacturing system; scheduling; simulation
23	Chan F.T.S.	Global supplier selection: A fuzzy-AHP approach	2008	280	Decision making; quality; supplier selection; supply chain
24	Chandrasekharan M.P.	Modroc: An extension of rank order clustering for group technology	1986	273	
25	Carrie A.S.	Numerical taxonomy applied to group technology and plant layout	1973	271	

(*Continued*).

Table 3. Continued.

#	First author	Title	Year	Cites	*Ngrams*
26	Huang G.Q.	The impacts of sharing production information on supply chain dynamics: A review of the literature	2003	268	Supply chain
27	Suresh Kumar C.	Grouping efficacy: A quantitative criterion for goodness of block diagonal forms of binary matrices in group technology	1990	268	Manufacturing system
28	Rajagopalan R.	Design of cellular production systems a graph-theoretic approach	1975	253	Manufacturing system
29	Boctor F.F.	A linear formulation of the machine-part cell formation problem	1991	252	Cellular manufacturing; manufacturing system; simulated annealing
30	Waghodekar P.H.	Machine-component cell formation in group technology: Mace	1984	252	Heuristic
31	Buzacott J.A.	Automatic transfer lines with buffer stocks	1967	250	
32	Mason-Jones R.	Lean, agile or leagile? Matching your supply chain to the marketplace	2000	246	Case study; lean manufacturing; supply chain
33	Lambert A.J.D.	Disassembly sequencing: A survey	2003	240	Logistics; sequencing; uncertainty
34	Huang Y.	Deadlock prevention policy based on Petri nets and siphons	2001	237	Flexible manufacturing; manufacturing system; mixed integer linear programming
35	Uzsoy R.	Scheduling a single batch processing machine with non-identical job sizes	1994	237	Heuristic; makespan; scheduling
36	Kimura O.	Design and analysis of pull system, a method of multistage production control	1981	235	Control system; inventory; lead time; lot sizing; manufacturing process; production control; simulation
37	Towill D.R.	Dynamic analysis of an inventory and order based production control system	1982	231	Control system; inventory; manufacturing process; optimisation; production control; uncertainty
38	Krikke H.	Concurrent product and closed-loop supply chain design with an application to refrigerators	2003	230	Logistics; product design; quality; supply chain
39	Misra R.B.	Optimum production lot size model for a system with deteriorating inventory	1975	230	Inventory; lot sizing
40	Wemmerlöv U.	Cellular manufacturing at 46 user plants: Implementation experiences and performance improvements	1997	224	Cellular manufacturing; lead time; quality
A1	Bhamra R.	Resilience: The concept, a literature review and future directions	2011	165	Operations management; uncertainty
A2	Xu L.D.	Information architecture for supply chain quality management	2011	148	Quality; supply chain
A3	Petrovic V.	Additive layered manufacturing: Sectors of industrial application shown through case studies	2011	141	Case study
A4	Zhu Q.	Examining the effects of green supply chain management practices and their mediations on performance improvements	2012	134	Supply chain
A5	Arzu Akyuz G.	Supply chain performance measurement: A literature review	2010	125	Flexibility; performance measure; supply chain
A6	Jaber M.Y.	Supply chain coordination with emissions reduction incentives	2013	109	Inventory; manufacturing process; operations management; supply chain
A7	Akçcal E.	Quantitative models for inventory and production planning in closedloop supply chains	2011	100	Heuristic; inventory; lean manufacturing; optimisation; production planning; remanufacturing; supply chain
A8	Wu D.D.	Enterprise risk management: A DEA VaR approach in vendor selection	2010	99	Decision making; supply chain
A9	Cao M.	Supply chain collaboration: Conceptualisation and instrument development	2010	93	Supply chain; uncertainty
A10	Hollos D.	Does sustainable supplier cooperation affect performance? Examining implications for the triple bottom line	2012	91	Supply chain; sustainability

*List of most cited papers between 2010 and 2017 are numbered with the character 'A', e.g. 'A1'.

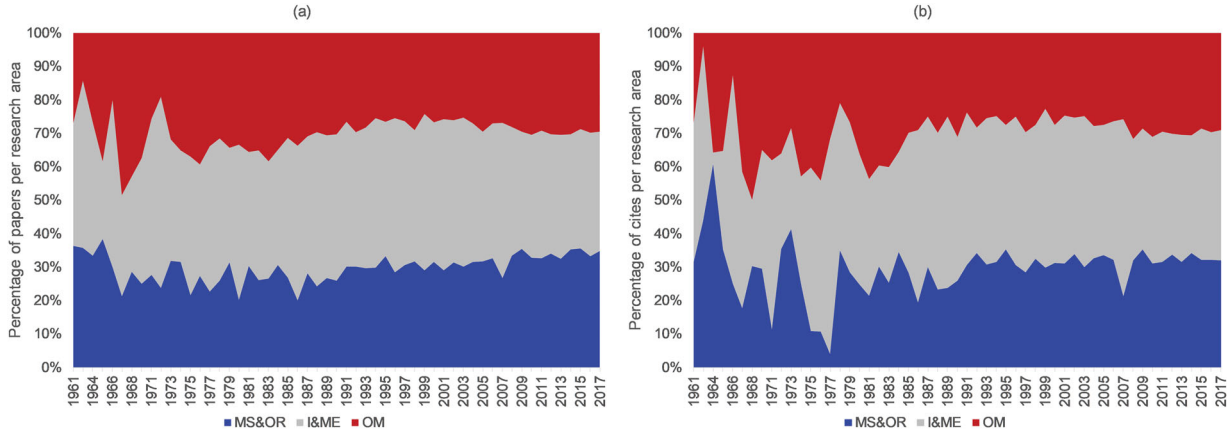

Figure 6. Percentage of papers (a) and citations (b) per general subject area, considering the 58 terms.

suggesting that the number of citations are, in fact, related to the number of papers that contain a specific term included in this list of 58.

Furthermore, Equation (2) was used as a threshold value to evaluate if a specific term has had more impact than expected by comparing its actual number of citations against the estimate resulting from Equation (2). Figure 5 plots Equation (2) as well as the actual values of number of citations and number of papers per term to evaluate the impact of each term. All points located above the linear regression line in Figure 5 received more citations than expected, whereas all points located below that line received fewer citations than expected.

Figure 5 suggests that terms such as 'cellular manufacturing', 'flexible manufacturing', 'job shop', 'lean manufacturing' and 'supplier selection' received significantly more citations than expected; whereas terms such as 'data mining', 'game theory', 'preventive maintenance' and 'pricing' received fewer citations than expected, possibly since some have appeared more recently.

Figure 5 also suggests that highly frequent terms, such as 'manufacturing system', 'optimisation', 'quality', 'scheduling', 'simulation', and 'supply chain' all performed as expected in terms of âĄănumber of citations.

Similar to previous studies (Cancino et al. 2017; Laengle et al. 2017; Merigó and Yang 2017) and to a recently published list by IJPR ('IJPR Papers Cited at Least 55 Times in Scopus' 2017), Table 3 shows the 40 most cited papers in Scopus in the history of IJPR, as well as the 10 most cited papers in the last 8 years (2010–2017) in order to further assess the global impact of different topics published in IJPR. From Table 3 it can be concluded that the most influential papers in IJPR have been concerned with either production management and control techniques, e.g. dispatching rules, CONWIP and Kanban, or with group technology topics, which, interestingly, did not appear as one of the most common terms (although the term 'cellular manufacturing', related with this topic, was found frequently).

On the other hand, the most cited papers in the current decade are mostly related with the topic of supply chain, including the topics of supply chain management and supply chain collaboration/coordination/cooperation. It is worth noting that the most influential paper of the last 8 years is a literature review paper on *resilience*.

Finally, to assess the evolution of interests in the global subject areas of MS&OR, I&ME and OM, the 58 terms were classified into one of these three groups (a list of terms and their classifications can be found in Table A3 in the Appendix). In this regard, Figure 6(a) shows that I&ME topics have comprised the bulk of publications in IJPR in all its history, whereas MS&OR and OM subjects have retained a significant presence. Figure 6(a) also suggests that the percentage of papers studying MS&OR topics has been steadily increasing since 2000 and that the percentage OM-related papers increased in the 2000s decade but stabilised in the current decade.

Figure 6(b), on the other hand, illustrates that, while the area of MS&OR has steadily increased its share in number of papers since 2000, it has received a somewhat constant share of citations since 2010, at the same time that OM topics have increased their citation share since 2008. From Figure 6(b) it also can be seen that I&ME topics have steadily represented around 40% of all citations in IJPR.

5. Discussion

Motivated by the publication of IJPR's 55th volume and by previous bibliometric studies of other journals, the current study applied text mining to explore the most frequent and influential topics in the history of IJPR. Study results show how the

topics of inventory management, scheduling, simulation, and supply chain management as well as manufacturing system modelling have been the backbone topics of IJPR.

The frequency of terms such as 'model', 'manufacturing system' and 'production system' and the percentage of highly frequent terms related to the I&ME area (see Figure 6(a)) confirm IJPR's tradition of publishing high quality research concerned with the *design, monitoring and management of production and logistics systems* (Dolgui 2017). Moreover, the sheer number of papers concerned with group technology included in IJPR's most cited works (see Table 3) and the high proportion of citations including 'cellular manufacturing' (see Figure 5) suggests that IJPR has been a fundamental reference source for cellular and flexible manufacturing and corresponds to the journal's aim of relaying technological innovations in the field.

In the same vein, IJPR has been a crucial driver in the study of control-theoretic techniques (Vieira, Herrmann, and Lin 2003), such as CONWIP, Drum-Buffer-Rope (Jodlbauer and Huber 2008), and order release and dispatching rules (Lu, Huang, and Yang 2011) for managing dynamic and stochastic production environments. While these techniques are generally considered to be well-studied, they can also be applied in novel service situations such as health care or preventative maintenance.

More recently, IJPR has also been an influential journal in the evolution of supply chain management. This is particularly visible for 'supply chain coordination/cooperation', which emerged as a result of recent directives from the production research community to conduct more interdisciplinary and empirical research, and is represented by the increasing number of papers concurrently studying two or more topics – see Figure A3 in the Appendix.

Comparing IJPR's most relevant topics with the most relevant topics of EJOR (Laengle et al. 2017) and CAIE (Cancino et al. 2017) via the network of co-occurrences (Figure 4), it can be concluded that supply chain and scheduling have been essential for the subject areas of MS&OR and I&ME, since these two area clusters have appeared for all three journals. On the other hand, clusters covering subjects related with general OM topics and, particularly, modelling and design of manufacturing and control systems, shown in Figure 3, are exclusive to IJPR.

Perhaps because of its more industrial scope, IJPR authors have also been interested in other topics, such as product design and development, flexible manufacturing, materials handling, and assembly lines. In addition, reflecting a well-balanced portfolio, IJPR has also published a significant proportion of papers including the 'case study' term, suggesting that the scope of IJPR is empirical, experimental and theoretical. Comparing the results of the current study and the research focused on PP&C interests (Akmal et al. 2018) shows that both IJPR and PP&C routinely address the topics of production and supply chain management and performance. Recent papers in both journals also suggest that the topics of healthcare and sustainability have been gaining relevance (see Table A1 in the Appendix).

These overall results suggest that IJPR is highly aligned with the OM field and the topics receiving the most interest from the field, as results from Tavares Thomé, Scavarda, and Scavarda (2016) show. For instance, IJPR and OM share a common interest in genetic algorithms, supply chains and manufacturing systems. On the other hand, the current study suggests that the main difference between the topics covered by OM studies and the topics studied by IJPR is the examination of inter-firm relationships and their competition in different markets and industries through the investigation of manufacturing strategy, organisation and capabilities, e.g. resource-based theory (Hitt, Xu, and Carnes 2016) and contingency theory (Romero-Silva, Santos, and Hurtado 2018).

5.1. Future IJPR research opportunities

IJPR has been a cornerstone in the development of research in MS&OR and I&ME since it is a principal reference for topics related to supply chain, optimisation, scheduling and simulation. Yet many relevant areas and opportunities for future research remain available for exploitation.

For instance, since one of IJPR's aims is to publish research concerned with 'manufacturing strategy, policy formulation and evaluation' (Taylor and Francis Online 2018), there seems to be great potential for future research focused on inter-firm collaboration and competition via manufacturing strategy, organisation and capabilities (see, e.g. Adebanjo, Teh, and Ahmed 2018; Sarmiento, Whelan, and Thürer 2018) to find better balance between strategic, tactical and operational decisions (Meredith and Pilkington 2018). Despite this, IJPR's most frequent and recent topics remain more focused on operational contexts rather than strategic ones.

In addition, Figure 3 can be used to identify future research opportunities in jointly studying topics that have not previously received concurrent attention but could provide new research insights and expand IJPR's multidisciplinary focus (Akkermans and Van Wassenhove 2013). For example, the majority of terms in the cluster of scheduling have not concurrently appeared with the term 'pricing' (see, e.g. Öner-Közen and Minner 2017) nor with many other terms associated with the modelling and design of manufacturing and control systems cluster. In this regard, there is a recent call for papers for a

special issue in 'New consideration of pricing in supply chain', showing that the IJPR editorial team has also identified this opportunity.

Moreover, Figure 3 shows a dearth of research concurrently addressing 'data mining' (or data modelling – Kim et al. 2017) and topics in the cluster of scheduling, suggesting valuable future research topics combining data mining (and by extension machine learning) and scheduling (see, e.g. Li and Olafsson 2005; Choudhary, Harding, and Tiwari 2009; Zheng et al. 2015; Srinivas and Ravindran 2018). The objective of a recent call for papers for the special issue in 'Artificial Intelligence in Manufacturing and Logistics Systems: Algorithms, Applications, and Case Studies' by IJPR clearly intends to exploit this research opportunity.

Since current environmental challenges in the manufacturing and service sectors have been the focus of worldwide discussion, 'sustainability' and the circular economy are also relevant (O'Brien 2013). Thus, addressing research which combines 'sustainability' with 'scheduling' (see Giret, Trentesaux, and Prabhu 2015 for a review of these topics), the use of 'flexible manufacturing' for 'remanufacturing' efforts, and its implications on 'production line' and 'manufacturing system' modelling and performance, could provide significant contributions to efficient resource usage.

Another promising research topic is the issue of manufacturing in developed (high-cost) economies (Srai and Ané 2016). Studying the implications of 'outsourcing' decisions (Dolgui and Proth 2013) on 'production planning' and 'scheduling' tasks could produce interesting insights. Examining how different production system configurations could increase customer-responsiveness capabilities (Kim, Suresh, and Kocabasoglu-Hillmer 2013; Schonberger and Brown 2017) and reduce the need of 'outsourcing' practices by increasing manufacturing flexibility could also shed light on the implications and competitive advantages of manufacturing in high-cost environments.

More research opportunities can also arise from 'case studies' addressing scheduling problems (see, e.g. Fuchigami and Rangel 2017) and other topics, since the number of papers using this methodological approach is insufficient to find statistically significant correlation coefficients, despite that 'case study' is the third most common *ngram* of size 2. Another interesting study topic could be the impact of 'preventive maintenance' on the overall performance of supply chain operations (see, e.g. Li 2014; Simões, Gomes, and Yasin 2016; Diallo et al. 2017) and sustainability, as there is a dearth of concurrent studies with these terms.

Since some *ngrams* have not appeared as frequently as others, no statistical significance was found in their correlation coefficients with other *ngrams*, e.g. 'data mining', 'lean manufacturing', 'operations management', 'quality', '(statistical) process control' and 'uncertainty'; thus, more papers containing these terms would be needed to determine if *ngrams* like these are related with other terms. For instance, the correlation of the topics of 'quality' and 'lean manufacturing' with 'sustainability' has no statistical significance in the current state, but could shed light on the effects that different manufacturing strategy options have on the sustainability of a firm (see, e.g. Ivanov, Das, and Choi 2018).

5.2. Methodological considerations for bibliometric studies in MS&OR, I&ME and OM areas

The current study has progressed bibliometric analysis in the fields of MS&OR, I&ME and OM by applying a text mining technique to identify the most common IJPR terms for comprehensive topic analysis. This technique contrasts with previous studies (Cancino et al. 2017; Laengle et al. 2017; Merigó and Yang 2017) which exclusively studied the content of author keywords or were limited to searching only a pre-selected set of keywords, based on the expertise of the studies' authors (Tavares Thomé, Scavarda, and Scavarda 2016; Akmal et al. 2018).

Although these previous studies provided valuable conclusions, such as the most commonly cited papers, authors and institutions, and commonly cited networks of institutions and authors, we believe that they were constrained by using a single technological tool. This study, by using two methodological approaches, provides the reader with a new set of conclusions, e.g. the most common terms per year, the most cited terms per year of publication, and a correlation matrix of the co-occurrences between pairs of terms.

With the emergence of various bibliometric software tools (Schildt and Mattsson 2006; Jacsó 2009; van Eck and Waltman 2010; Cobo et al. 2011; Jacsó 2012) and bibliographic databases in the last years, bibliometric analysis has never been more widely accessible. Today's modern software tools facilitate users' ability to perform bibliometric analysis with publicly available software and databases; therefore, future bibliometric studies will need to provide the field with much deeper analyses than those typically provided by these tools.

To assist in this endeavour, the following methodological considerations are suggested based on the experience of conducting the current study:

i Author keywords provide the most condensed and relevant information, which *ngrams* of size one generally lack.
ii Author keywords depend on the correct identification of relevant terms by the authors of each study, which could limit the results of studies that exclusively depend on them as a source of information.

iii Bibliometric studies that also include content found in the titles, abstracts and, if possible, the main text of the papers, would expand the conclusions of the bibliometric exercise.

iv More than one text mining technique or software should be used to identify and confirm different potential relevant terms.

v Although text mining is a very powerful tool, in its current state, it still has some drawbacks. For instance, as a tool that aggregates terms without further intelligence by depending on simple data processing methods such as removal of punctuation, sentences are not partitioned, which creates senseless *ngrams* of size $n > 2$ (e.g. 'production control production', 'control production control', 'scheduling scheduling algorithm'). Thus, authors should remove senseless *ngrams* manually before presenting text mining results.

vi Similarly, further intelligent automatic analysis is required to eliminate redundant *ngrams*, e.g. 'production control' and 'control production', 'supply chain management' and 'management supply chain'; and replace American spelling with British spelling, e.g. 'optimization' with 'optimisation'.

vii In addition to bibliometric analysis, text mining can be a complementary methodology for SLR studies as it can add a statistically representative point of view to the qualitative analysis of this type of studies.

viii While software such as VOSviewer provides the user with the ability to build useful illustrations of correlation networks (see Figure 4), bibliometric studies that also provide the reader with traditional statistical analyses can develop more robust, statistically significant conclusions about the relationships between different factors associated with scientific output, e.g. topics, authors, institutions, countries, journals, and even methodological approaches.

ix Future studies focused on bibliometric analysis could also *mine* other sources of information, e.g. Google Trends (Vaughan and Romero-Frías 2014) and Twitter (Ke, Ahn, and Sugimoto 2017), to assess and compare the impact and interests that different topics have received in fields other than solely academic. Similarly, to study how the academic and industrial sector interact to create innovative methodologies and technologies, future research could use patent data, e.g. using tech mining (Cunningham, Porter, and Newman 2006) and trade journals/magazines databases, e.g. through the EBSCO's Business Source Complete database (see, e.g. Chircu et al. 2016), to investigate the correlation between developing topic interests in academy and industry.

5.3. Limitations of the study

Since the current study used text mining as the main methodology to produce its results, its main limitations are inherently associated with its methodological approach. Points v. and vi. in the previous subsection describe the main limitations of using text mining in this context.

In addition, results from this study are limited by the database that was used since full texts were not included in the analysis and authors' keywords information was only available since 2005. Similarly, this study is limited by including only academic sources without considering other sources of information where interests in different topics could be discovered (see point ix. in the previous subsection).

Finally, limiting the study to IJPR's completed years of publication excluded information about the current running year (2018 at the time of writing), where topics such as Industry 4.0 and Smart Manufacturing have been rapidly gaining steam (see, e.g. Liao et al. 2017; Kusiak 2018; Moeuf et al. 2018; Yin, Stecke, and Li 2018). Since IJPR is at the vanguard of these topics, this study was unable to capture some very recent emerging topics.

6. Conclusions

This study investigated the interest that different topics have received throughout IJPR's history. By identifying the frequency of occurrence and the number of citations of different terms since the inception of IJPR, this paper also provided a longitudinal review of the evolution of the subject areas of MS&OR, I&ME and OM, since IJPR can be seen as a representative outlet of these fields.

Results from the current and previous studies suggest that the topics of scheduling and supply chain management have been the cornerstone of these fields and that they are evolving towards a more sustainable, economical and sociological scope, beyond a typical manufacturing focus. This study also provided statistical evidence of the topics that have been the most commonly jointly studied and relevant topics that can provide future research opportunities by being concurrently investigated.

Finally, this paper presented several methodological considerations for future bibliometric analysis studies in the field.

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Supplementary material

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References

Adebanjo, Dotun, Pei-Lee Teh, and Pervaiz K. Ahmed. 2018. "The Impact of Supply Chain Relationships and Integration on Innovative Capabilities and Manufacturing Performance: The Perspective of Rapidly Developing Countries." *International Journal of Production Research* 56 (4): 1708–1721. doi:10.1080/00207543.2017.1366083.

Akkermans, Henk A., and Luk N. Van Wassenhove. 2013. "Searching for the Grey Swans: The Next 50 Years of Production Research." *International Journal of Production Research* 51 (23–24): 6746–6755. doi:10.1080/00207543.2013.849827.

Akmal, Adeel, Nataliya Podgorodnichenko, Richard Greatbanks, and André M. M. Everett. 2018. "Bibliometric Analysis of Production Planning and Control (1990–2016)." *Production Planning & Control* 29 (4): 333–351. doi:10.1080/09537287.2018.1429030.

Al-Mudimigh, Abdullah S., Mohamed Zairi, and Abdel Moneim M. Ahmed. 2004. "Extending the Concept of Supply Chain: The Effective Management of Value Chains." *International Journal of Production Economics* 87 (3): 309–320. doi:10.1016/j.ijpe.2003.08.004.

Berry, Michael W. 2004. *Survey of Text Mining*. 1st ed. New York, NY: Springer-Verlag. doi:10.1007/978-1-4757-4305-0.

Cancino, Christian, José M. M. Merigó, Freddy Coronado, Yasser Dessouky, and Mohamed Dessouky. 2017. "Forty Years of Computers & Industrial Engineering: A Bibliometric Analysis." *Computers & Industrial Engineering* 113: 614–629. doi:10.1016/j.cie.2017.08.033.

Chircu, Alina, Nikita Kononchuk, Gang Li, Yi Qi, and Euthemia Stavrulaki. 2016. "Business Analytics and Supply Chain and Operations Management–A Text Mining-Based Literature Review." In *Proceedings for the Northeast Region Decision Sciences Institute*, 1–24. Alexandria, VA: Decision Sciences Institute.

Choudhary, A. K., J. A. Harding, and M. K. Tiwari. 2009. "Data Mining in Manufacturing: A Review Based on the Kind of Knowledge." *Journal of Intelligent Manufacturing* 20 (5): 501–521. doi:10.1007/s10845-008-0145-x.

Cobo, M. J., A. G. López-Herrera, E. Herrera-Viedma, and F. Herrera. 2011. "Science Mapping Software Tools: Review, Analysis, and Cooperative Study among Tools." *Journal of the American Society for Information Science and Technology* 62 (7): 1382–1402. doi:10.1002/asi.21525.

Cunningham, Scott W., Alan L. Porter, and Nils C. Newman. 2006. "Special Issue on Tech Mining." *Technological Forecasting and Social Change* 73 (8): 915–922. doi:10.1016/j.techfore.2006.06.004.

Diallo, Claver, Uday Venkatadri, Abdelhakim Khatab, and Sriram Bhakthavatchalam. 2017. "State of the Art Review of Quality, Reliability and Maintenance Issues in Closed-Loop Supply Chains with Remanufacturing." *International Journal of Production Research* 55 (5): 1277–1296. doi:10.1080/00207543.2016.1200152.

Dolgui, Alexandre. 2017. "55th Anniversary of Production Research." *International Journal of Production Research* 55 (1): 1–2. doi:10.1080/00207543.2016.1261649.

Dolgui, Alexandre, and Jean-Marie Proth. 2013. "Outsourcing: Definitions and Analysis." *International Journal of Production Research* 51 (23–24): 6769–6777. doi:10.1080/00207543.2013.855338.

Ellegaard, Ole, and Johan A. A. Wallin. 2015. "The Bibliometric Analysis of Scholarly Production: How Great is the Impact?" *Scientometrics* 105 (3): 1809–1831. doi:10.1007/s11192-015-1645-z.

Elsevier, B. V. 2018. "Scopus." www.scopus.com.

Feinerer, Ingo, Kurt Hornik, and David Meyer. 2008. "Text Mining Infrastructure in R." *Journal of Statistical Software, Articles* 25 (5): 1–54. doi:10.18637/jss.v025.i05.

Feldman, Ronen, and James Sanger. 2006. *Text Mining Handbook: Advanced Approaches in Analyzing Unstructured Data*. New York, NY: Cambridge University Press.

Fry, Timothy D., and Joan M. Donohue. 2013. "Outlets for Operations Management Research: A DEA Assessment of Journal Quality and Rankings." *International Journal of Production Research* 51 (23–24): 7501–7526. doi:10.1080/00207543.2013.783245.

Fry, Timothy D., Joan M. Donohue, Brooke A. Saladin, and Guangzhi Shang. 2015. "The Internationalisation of Operations Management Research." *International Journal of Production Research* 53 (16): 4857–4887. doi:10.1080/00207543.2014.998792.

Fuchigami, Helio Yochihiro, and Socorro Rangel. 2017. "A Survey of Case Studies in Production Scheduling: Analysis and Perspectives." *Journal of Computational Science*. doi:10.1016/j.jocs.2017.06.004.

Giret, Adriana, Damien Trentesaux, and Vittal Prabhu. 2015. "Sustainability in Manufacturing Operations Scheduling: A State of the Art Review." *Journal of Manufacturing Systems* 37: 126–140. doi:10.1016/j.jmsy.2015.08.002.

Hitt, Michael A., Kai Xu, and Christina Matz Carnes. 2016. "Resource Based Theory in Operations Management Research." *Journal of Operations Management* 41: 77–94. doi:10.1016/j.jom.2015.11.002.

Hornik, Kurt, Christian Buchta, and Achim Zeileis. 2009. "Open-Source Machine Learning: R Meets Weka." *Computational Statistics* 24 (2): 225–232. doi:10.1007/s00180-008-0119-7.

"IJPR Papers Cited at Least 55 Times in Scopus." 2017. *International Journal of Production Research*. https://www.tandf.co.uk//journals/pdf/55th-Anniversary-IJPR-citations.pdf.

Ivanov, Dmitry, Ajay Das, and Tsan-Ming Choi. 2018. "New Flexibility Drivers for Manufacturing, Supply Chain and Service Operations." *International Journal of Production Research* 0 (0): 1–10. doi:10.1080/00207543.2018.1457813.

Jacsó, Péter. 2009. "Calculating the H-index and Other Bibliometric and Scientometric Indicators from Google Scholar with the Publish or Perish Software." *Online Information Review* 33 (6): 1189–1200. doi:10.1108/14684520911011070.

Jacsó, Péter. 2012. "Google Scholar Metrics for Publications: The Software and Content Features of a New Open Access Bibliometric Service." *Online Information Review* 36 (4): 604–619. doi:10.1108/14684521211254121.

Jodlbauer, H., and A. Huber. 2008. "Service-Level Performance of MRP, Kanban, CONWIP and DBR Due to Parameter Stability and Environmental Robustness." *International Journal of Production Research* 46 (8): 2179–2195. doi:10.1080/00207540600609297.

Ke, Qing, Yong-Yeol Ahn, and Cassidy R. Sugimoto. 2017. "A Systematic Identification and Analysis of Scientists on Twitter." *PLOS ONE* 12 (4): 1–17. doi:10.1371/journal.pone.0175368.

Kim, Byeong Soo, Bong Gu Kang, Seon Han Choi, and Tag Gon Kim. 2017. "Data Modeling Versus Simulation Modeling in the Big Data Era: Case Study of a Greenhouse Control System." *SIMULATION* 93 (7): 579–594. doi:10.1177/0037549717692866.

Kim, Minkyun, Nallan C. Suresh, and Canan Kocabasoglu-Hillmer. 2013. "An Impact of Manufacturing Flexibility and Technological Dimensions of Manufacturing Strategy on Improving Supply Chain Responsiveness: Business Environment Perspective." *International Journal of Production Research* 51 (18): 5597–5611. doi:10.1080/00207543.2013.790569.

Kusiak, Andrew. 2018. "Smart Manufacturing." *International Journal of Production Research* 56 (1–2): 1–10. doi:10.1080/00207543.2017.1351644.

Laengle, Sigifredo, José M. M. Merigó, Jaime Miranda, Roman Słowiński, Immanuel Bomze, Emanuele Borgonovo, Robert G. G. Dyson, José Fernando Fernando Oliveira, and Ruud Teunter. 2017. "Forty Years of the European Journal of Operational Research: A Bibliometric Overview." *European Journal of Operational Research* 262 (3): 803–816. doi:10.1016/j.ejor.2017.04.027.

Li, Shoude. 2014. "Optimal Control of Production-Maintenance System with Deteriorating Items, Emission Tax and Pollution R&D Investment." *International Journal of Production Research* 52 (6): 1787–1807. doi:10.1080/00207543.2013.848486.

Li, Xiaonan, and Sigurdur Olafsson. 2005. "Discovering Dispatching Rules Using Data Mining." *Journal of Scheduling* 8 (6): 515–527. doi:10.1007/s10951-005-4781-0.

Li, Guoliang, Beng Chin Ooi, Jianhua Feng, Jianyong Wang, and Lizhu Zhou. 2008. "EASE: An Effective 3-in-1 Keyword Search Method for Unstructured, Semi-Structured and Structured Data." In *Proceedings of the 2008 ACM SIGMOD International Conference on Management of Data*, 903–914. SIGMOD '08. New York, NY: ACM. doi:10.1145/1376616.1376706.

Liao, Yongxin, Fernando Deschamps, Eduardo de Freitas Rocha Loures, and Luiz Felipe Pierin Ramos. 2017. "Past, Present and Future of Industry 4.0 - a Systematic Literature Review and Research Agenda Proposal." *International Journal of Production Research* 55 (12): 3609–3629. doi:10.1080/00207543.2017.1308576.

Lu, H. L., George Q. Huang, and H. D. Yang. 2011. "Integrating Order Review/Release and Dispatching Rules for Assembly Job Shop Scheduling Using a Simulation Approach." *International Journal of Production Research* 49 (3): 647–669. doi:10.1080/00207540903524490.

Meredith, Jack R., and Alan Pilkington. 2018. "Assessing the Exchange of Knowledge between Operations Management and Other Fields: Some Challenges and Opportunities." *Journal of Operations Management* 60: 47–53. doi:10.1016/j.jom.2018.05.004.

Merigó, José M. M., and Jian-Bo Yang. 2017. "A Bibliometric Analysis of Operations Research and Management Science." *Omega* 73: 37–48. doi:10.1016/j.omega.2016.12.004.

Moeuf, Alexandre, Robert Pellerin, Samir Lamouri, Simon Tamayo-Giraldo, and Rodolphe Barbaray. 2018. "The Industrial Management of SMEs in the Era of Industry 4.0." *International Journal of Production Research* 56 (3): 1118–1136. doi:10.1080/00207543.2017.1372647.

Mooi, E., and M. Sarstedt. 2011. "Cluster Analysis." In *A Concise Guide to Market Research. The Process, Data, and Methods Using IBM SPSS Statistics*, edited by E. Mooi, and M. Sarstedt, 237–284. New York: Springer. doi:10.1007/978-3-642-12541-6.

O'Brien, Christopher. 2013. "Fifty Years of Shifting Paradigms." *International Journal of Production Research* 51 (23–24): 6740–6745. doi:10.1080/00207543.2013.852267.

Öner-Közen, Miray, and Stefan Minner. 2017. "Dynamic Pricing, Leadtime Quotation and Due Date Based Priority Dispatching." *International Journal of Production Research* 0 (0): 1–13. doi:10.1080/00207543.2017.1397791.

The R Foundation. 2016. "The R Project for Statistical Computing".

Rodgers, Joseph Lee, and W. Alan Nicewander. 1988. "Thirteen Ways to Look at the Correlation Coefficient." *The American Statistician* 42 (1): 59–66. doi:10.1080/00031305.1988.10475524.

Romero-Silva, Rodrigo, Javier Santos, and Margarita Hurtado. 2018. "A Note on Defining Organisational Systems for Contingency Theory in OM." *Production Planning & Control: The Management of Operations*. doi:10.1080/09537287.2018.1535146.

Sarmiento, Roberto, Garvan Whelan, and Matthias Thürer. 2018. "A Note on 'Beyond the Trade-off and Cumulative Capabilities Models: Alternative Models of Operations Strategy." *International Journal of Production Research* 1–8. doi:10.1080/00207543.2018.1428773.

Schildt, Henri A., and Juha T. Mattsson. 2006. "A Dense Network Sub-Grouping Algorithm for Co-Citation Analysis and its Implementation in the Software Tool Sitkis." *Scientometrics* 67 (1): 143–163. doi:10.1007/s11192-006-0054-8.

Schonberger, Richard J., and Karen A. Brown. 2017. "Missing Link in Competitive Manufacturing Research and Practice: Customer-Responsive Concurrent Production." *Journal of Operations Management* 49-51: 83–87. doi:10.1016/j.jom.2016.12.006.

Shang, Guangzhi, Brooke Saladin, Tim Fry, and Joan Donohue. 2015. "Twenty-Six Years of Operations Management Research (1985–2010): Authorship Patterns and Research Constituents in Eleven Top Rated Journals." *International Journal of Production Research* 53 (20): 6161–6197. doi:10.1080/00207543.2015.1037935.

Simões, Jorge M., Carlos F. Gomes, and Mahmoud M. Yasin. 2016. "Changing Role of Maintenance in Business Organisations: Measurement Versus Strategic Orientation." *International Journal of Production Research* 54 (11): 3329–3346. doi:10.1080/00207543.2015.1106611.

Srai, Jagjit Singh, and Camille Ané. 2016. "Institutional and Strategic Operations Perspectives on Manufacturing Reshoring." *International Journal of Production Research* 54 (23): 7193–7211. doi:10.1080/00207543.2016.1193247.

Srinivas, Sharan, and A. Ravi Ravindran. 2018. "Optimizing Outpatient Appointment System Using Machine Learning Algorithms and Scheduling Rules: A Prescriptive Analytics Framework." *Expert Systems with Applications* 102: 245–261. doi:10.1016/j.eswa.2018.02.022.

Tavares Thomé, Antônio Márcio, Luiz Felipe Scavarda, and Annibal José Scavarda. 2016. "Conducting Systematic Literature Review in Operations Management." *Production Planning & Control* 27 (5): 408–420. doi:10.1080/09537287.2015.1129464.

Taylor and Francis Online. 2018. "International Journal of Production Research Web Page." https://www.tandfonline.com/toc/tprs20/current.

van Eck, Nees Jan, and Ludo Waltman. 2010. "Software Survey: VOSviewer, a Computer Program for Bibliometric Mapping." *Scientometrics* 84 (2): 523–538. doi:10.1007/s11192-009-0146-3.

Vaughan, Liwen, and Esteban Romero-Frías. 2014. "Web Search Volume as a Predictor of Academic Fame: An Exploration of Google Trends." *Journal of the Association for Information Science and Technology* 65 (4): 707–720. doi:10.1002/asi.23016.

Vieira, Guilherme E., Jeffrey W. Herrmann, and Edward Lin. 2003. "Rescheduling Manufacturing Systems: A Framework of Strategies, Policies, and Methods." *Journal of Scheduling* 6 (1): 39–62. doi:10.1023/A:1022235519958.

Yin, Yong, Kathryn E. Stecke, and Dongni Li. 2018. "The Evolution of Production Systems from Industry 2.0 Through Industry 4.0." *International Journal of Production Research* 56 (1–2): 848–861. doi:10.1080/00207543.2017.1403664.

Zheng, Bichen, Jinghe Zhang, Sang Won Yoon, Sarah S. Lam, Mohammad Khasawneh, and Srikanth Poranki. 2015. "Predictive Modeling of Hospital Readmissions Using Metaheuristics and Data Mining." *Expert Systems with Applications* 42 (20): 7110–7120. doi:10.1016/j.eswa.2015.04.066.

Appendix

List of words removed from the database due to their frequency of occurrence and lack of relevance: *abstract, abstract available, also, approach, available, based, can, considered, copyright, developed, different, francis, given, group, however, important, indicate, informa, international journal of production research, limited, llc, ltd, may, new, number, one, paper, presented, presents, proposed, research, reserved, results, rights, rights reserved, several, show, taylor, three, trading, two, uk, uk limited, use, used, using, various, well, work*.

List of replaced plurals: *supply chains, algorithms, systems, measures, times, models, problems, processes, lines, methods, machines and solutions*.

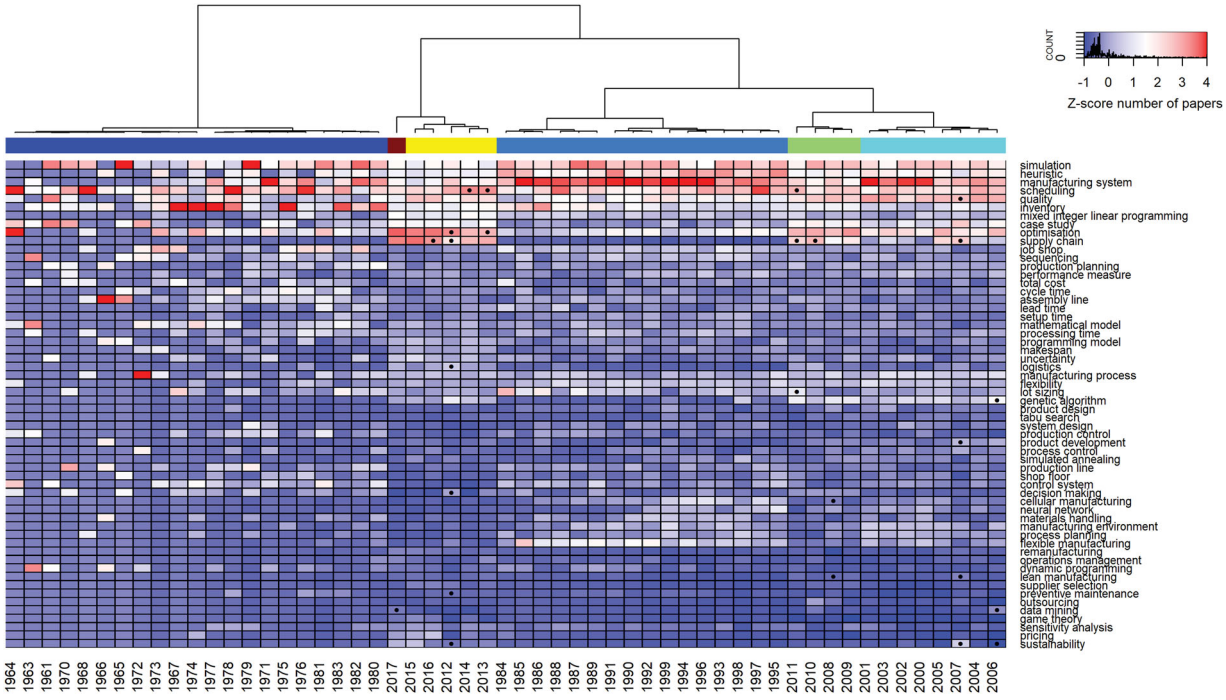

Figure A1. *Heatmap* representing the standardised number of papers per year containing a specific topic with clusters of years built depending on common terms; • marks a special issue appearing that year, related to a term.

Table A1. List of emerging topics in 2017 not found in Tables 1 and 2.

ngram	% of 2017 papers
Data mining	2.7
Dynamic programming	2.5
Supply chain design	2.5
Sustainable manufacturing	2.5
Search algorithm	2.4
Due date	2.4
Managerial insights	2.4
Service level	2.4
Game theory	2.4
(Supply) chain risk management	2.4
Local search	2.2
(Product) life cycle	2.2
Health care	2.2
Support system	2.1
Multi-objective optimisation	1.9

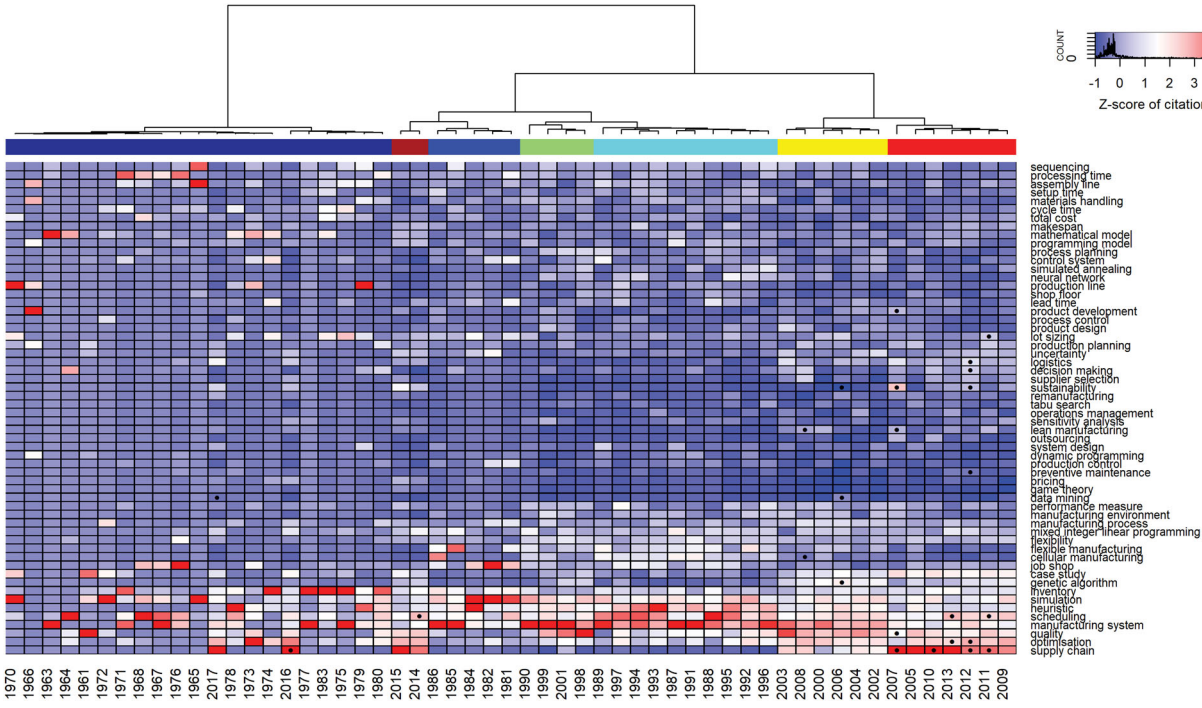

Figure A2. *Heatmap* representing the standardised number of citations received by a paper containing a specific topic with clusters of years built depending on common terms; • marks a special issue in that year, related to a term.

Table A2. Most common author keywords found using VOS viewer software.

#	Keyword	#	Keyword
1	Assembly line balancing	26	Optimisation
2	Case study	27	Optimisation
3	Cellular manufacturing	28	Outsourcing
4	Data mining	29	Performance analysis
5	Dynamic programming	30	Performance measures
6	Flexibility	31	Preventive maintenance
7	Fuzzy logic	32	Pricing
8	Game theory	33	Production control
9	Genetic algorithm	34	Production planning
10	Genetic algorithms	35	Quality
11	Heuristic	36	Quality management
12	Integer programming	37	Remanufacturing
13	Inventory	38	Reverse logistics
14	Inventory control	39	Scheduling
15	Inventory management	40	Sequencing
16	Lean manufacturing	41	Simulated annealing
17	Logistics	42	Simulation
18	Lot sizing	43	Statistical process control
19	Makespan	44	Supplier selection
20	Manufacturing	45	Supply chain
21	Manufacturing systems	46	Supply chain design
22	Mixed integer linear programming	47	Supply chain management
23	Modelling	48	Sustainability
24	Multi-objective optimisation	49	Tabu search
25	Operations management	50	Uncertainty

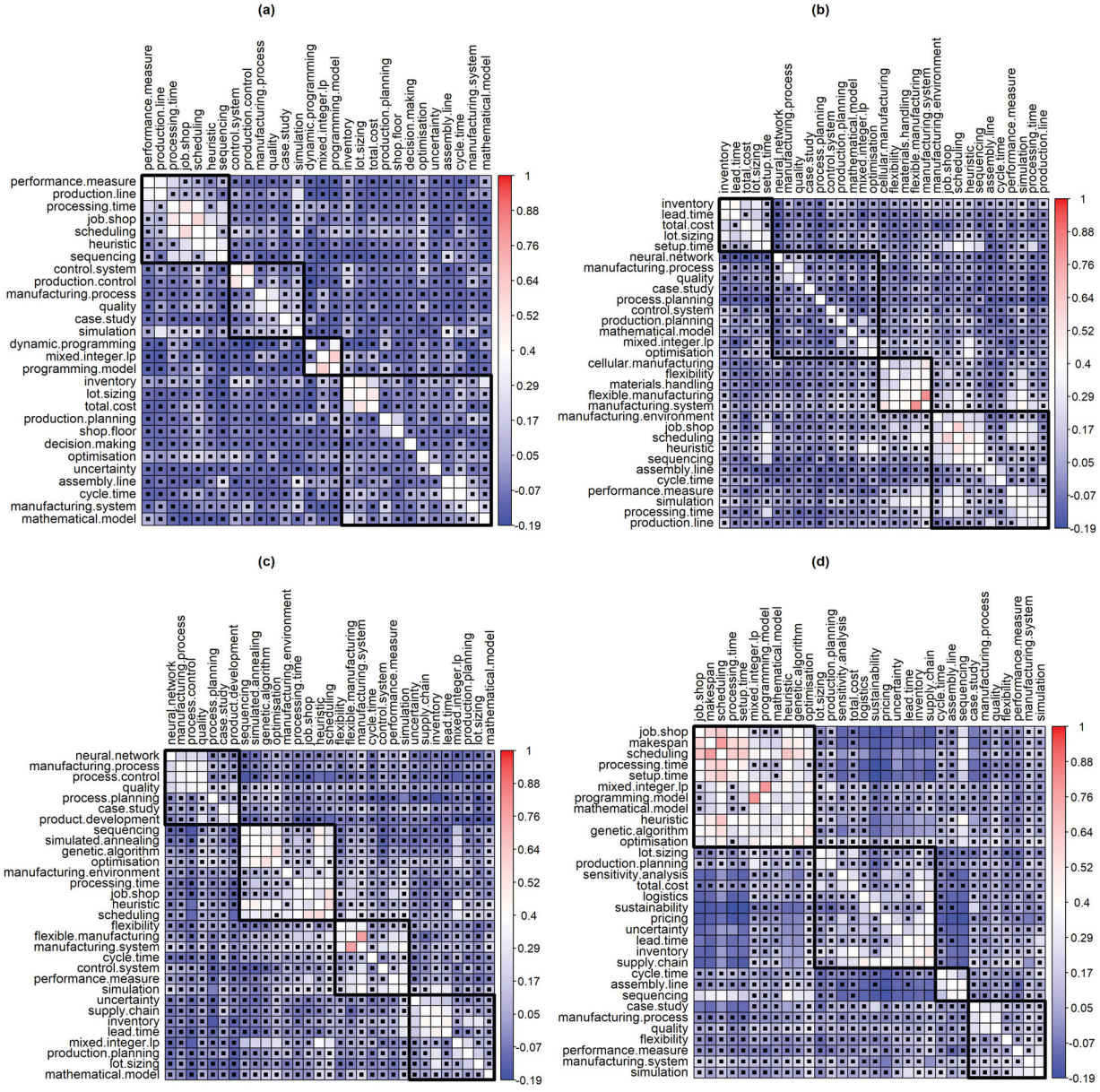

Figure A3. Evolution of co-occurrence among topics considering periods (a) 1961–1979, (b) 1980–1999, (c) 2000–2009, and (d) 2010–2017 for topics with at least 1% of all occurrences among the list of 58 topics.

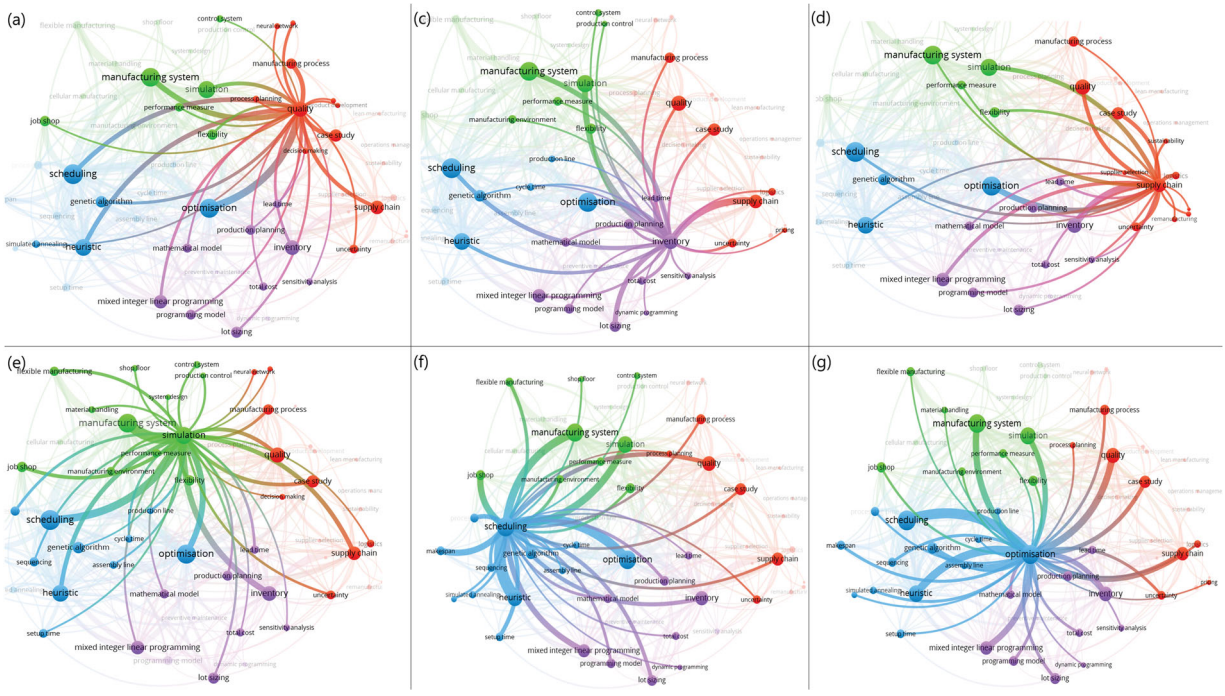

Figure A4. Links for relevant terms of clusters (a), (c), (d), (e), (f) and (g).

Table A3. Final list of terms and their constituting *ngrams* and pertinent subject areas.

Topic or *ngram*	Subject area	*ngrams* considered
Assembly line	I&ME	
Case study	OM	Case studies + case study
Cellular manufacturing	I&ME	
Control system	I&ME	
Cycle time	I&ME	
Data mining	MS&OR	
Decision making	MS&OR	
Dynamic programming	MS&OR	
Flexibility	OM	
Flexible manufacturing	I&ME	
Game theory	MS&OR	
Genetic algorithm	MS&OR	
Heuristic	MS&OR	Heuristic + heuristics
Inventory	OM	Inventories + inventory
Job shop	I&ME	Job shop + job shops + jobshops
Lead time	OM	
Lean manufacturing	OM	Lean manufacturing + lean production
Logistics	OM	
Lot sizing	I&ME	Lot size + lot sizes + lot sizing + lotsizing + lotsizing problem
Makespan	MS&OR	
Manufacturing environment	OM	Manufacturing environment + production environment + manufacturing environments
Manufacturing process	I&ME	Manufacturing process + production process
Manufacturing system	I&ME	Manufacturing system + production system
Materials handling	I&ME	
Mathematical model	MS&OR	Mathematical model + mathematical modelling
Mixed integer linear programming	MS&OR	Integer programming + linear programming + mixed integer + mixedinteger
Neural network	MS&OR	Neural network + neural networks
Operations management	OM	
Optimisation	MS&OR	Optimal solution + optimisation + optimization
Outsourcing	OM	
Performance measure	OM	Performance measure + performance measurement
Preventive maintenance	I&ME	
Pricing	OM	
Process control	I&ME	
Process planning	I&ME	
Processing time	I&ME	
Product design	I&ME	
Product development	OM	
Production control	I&ME	
Production line	I&ME	
Production planning	I&ME	
Programming model	MS&OR	
Quality	I&ME	
Remanufacturing	OM	Remanufactured + remanufacturing
Scheduling	I&ME	
Sensitivity analysis	MS&OR	Sensitivity analyses + sensitivity analysis
Sequencing	I&ME	
Setup time	I&ME	
Shop floor	I&ME	
Simulated annealing	MS&OR	
Simulation	MS&OR	
Supplier selection	OM	
Supply chain	OM	
Sustainability	OM	Sustainable + sustainability
System design	I&ME	
Tabu search	MS&OR	
Total cost	MS&OR	Total cost + total costs
Uncertainty	MS&OR	

Table A4. List of special issues.

Year	Issue	Title	Identified keywords
2017	17	Using big data to make better decisions in the digital economy	Big data; digital economy
2016	23	Distributed Manufacturing to Enhance Productivity	Distributed manufacturing; productivity
2016	21	Continuous Improvement in Manufacturing and Service Systems	Continuous improvement
2016	1	Supply Chain Dynamics Control and Disruption Management	Supply chain; disruption management
2015	24	Operations Research in Healthcare	Healthcare; operations research
2015	21	Green Manufacturing	Green manufacturing
2014	13	New Developments in Scheduling and Manufacturing	Scheduling
2013	23–24	50th Volume Anniversary	
2013	9	Optimisation approaches for distributed scheduling problems	Distributed scheduling; optimisation
2013	7	Knowledge management and supporting tools for collaborative networks	Knowledge management; collaborative networks
2012	21	Selected Papers from the 21st International Conference on Production Research	
2012	17	Research and applications of AHP/ANP and MCDA for decision making in manufacturing	Decision making
2012	13	Optimisation methods in production maintenance and logistics	Maintenance; optimisation
2012	9	Industrial logistics systems: theory and applications	Logistics
2012	5	Sustainable supply chain management and reverse logistics	Sustainability; supply chain
2012	1	Applications of computational intelligence for design and operations decisions in manufacturing	Intelligent manufacturing
2011	18	Creating resilient SMEs	Resiliency
2011	14	Selected papers from the 20th International Conference of Production Research	
2011	9	Lot sizing and scheduling: new models and solution approaches to address industrial extensions	Lot sizing; scheduling
2011	5	Multi-agent and holonic techniques for manufacturing systems: technologies and applications	Multi-agent
2011	1	Quality coordination and assurance in global supply chains	Supply chain
2010	9	RFID Technology and Applications in Production and Supply Chain Management	Supply chain; rfid
2010	2	Modelling and Analysis of Outsourcing Decisions in Global Supply Chains	Supply chain
2009	17	Virtual Enterprises: Coalition Formation in Collaborative Networks	Virtual enterprises; collaborative networks
2009	8	Selected Papers from the 19th International Conference on Production	
2009	2	Cutting Edge Production Research of the French Community	
2008	23	Effective Decision Support for Lean and Six Sigma Methodologies	Lean manufacturing; six sigma
2008	19	Computational Engineering in Systems Applications	Computational engineering
2008	9	Enabling Technologies and Frameworks for Collaborative Intelligent Manufacturing	Collaborative networks; intelligent manufacturing
2008	5	Enhancing Performance in Industrial Collaborative Networks–a Selection of Papers from the PROVE'06 Conference	Collaborative networks
2008	2	Selected papers from the 2nd Group Technology/Cellular Manufacturing World Symposium	Cellular manufacturing
2007	23	Quality Engineering	Quality
2007	18–19	Sustainable Design and Manufacture	Sustainability
2007	16	The Toyota Production System: Thirty Years of Research and beyond	Lean manufacturing

(*Continued*).

Table A4. Continued.

Year	Issue	Title	Identified keywords
2007	11	Knowledge and Information Technology Management in supply chain integration	Knowledge management; supply chain
2007	7	Enabling Technologies and Frameworks for New Product Development: A selection of papers from ICMR2005	Product development
2007	3	Recent Developments in Modelling and Analysis of Semiconductor Manufacturing	Semiconductor
2006	22	Advances in Evolutionary Computation for Design and Manufacturing Problems	Genetic algorithms
2006	18–19	Selected papers from the 18th ICPR – 'The networked enterprise: a challenge for a sustainable development'	Sustainability
2006	14	Data Mining and Applications in Engineering Design Manufacturing and Logistics	Data mining
2005	20	Special Issue: Enterprise Management	Enterprise management
2004	14	Special Issue: Reactive systems modelling	Reactive systems