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Lean simulations in production and operations management – a systematic literature review and bibliometric analysis

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Abstract

Purpose – Recently, much research about the effects of simulation on an organization's operational performance and efficiency has been carried out. But still, there is a need for lean-based simulations rather than just modelling the system. However, these studies still lack systematization. Consequently, the purpose of this paper is to systematize the literature on lean simulations in the area of production and operations management.

Design/methodology/approach – A systematic analysis was performed on 93 articles extracted from the Clarivate Analytics Web of Science (WoS) Core Collection database. The analysis was limited to only articles that come under the "Engineering industrial," "Engineering Manufacturing" and "Operations Research and Management" subject category in WoS Core Collection database. Later, a bibliometric analysis was integrated with the literature review for deeper literature categorization.

Findings – A bibliometric analysis displayed the relevance of selected literature (keywords, authors and sources). The systematic literature review helped to clarify each clusters' content and purpose.

Research limitations/implications – This study portrays the gaps in the lean simulation integration methods and techniques through a detailed systematic and bibliometric review.

Practical implications – Lean managers can get various insights and ideas on implementing lean and simulation integration methods in real-time process improvement scenarios.

Social implications – This study demonstrates the best future recommendations for lean based modelling for both consumers and organizations that shall address the social and economic issues.

Originality/value – To the best of the authors' knowledge, minimal attention has been paid to systematizing the literature on lean simulation in industrial, manufacturing and operations management. This study contributes to close this gap.

Keywords Production, Operations management, Optimization, Manufacturing, Modelling, Simulation

Paper type Literature review

Introduction

Lean experts are trying to persuade managers to take advantage of the possible benefits of lead-time reduction and inaccurate inventory levels but struggled to do so using traditional approaches. A variety of barriers that are experienced in the process sectors make lean adoption less desirable if there are discrete manufacturing operations involved (Abdulmalek

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and Rajgopal, 2007). To address this problem, simulation modelling was needed as an effective method for pre-and post-scenario quantification (Abideen and Mohamad, 2019). The simulation was also used to assess performance. In some special cases, concepts such as data-driven simulations can lend a helping hand to even non-experts (Tannock *et al.*, 2007). The impact created by the intuitive bond between the human and the computer is very strong because of the development of advanced computer interfaces that immerse the practitioners in experimental simulation, creating a virtual simulation model in areas such as manufacturing, rapid prototyping and engineering (Mujber *et al.*, 2004). For more than a decade, it has proved itself to be one of the most useful tools for manufacturing system design and analysis (Mujber *et al.*, 2004).

Studies based on simulation modelling have been applied to improve quality and shorten the time-to-market scenarios. But still, this approach is not being tapped in all industrial sectors. Strategic operations and simulation techniques seem to be closely intertwined but still, reasons for non-adoption have to be explored that could change top management's perspective (McLean and Leong, 2001). Various simulation techniques such as spreadsheet simulation, system dynamics (SD), discrete event simulation (DES) and business games were invented to answer the managerial questions posted by different problems (Kleijnen, 2005). These tools are capable of assisting in creating a digital factory for various production operations (Abideen and Mohamad, 2020). Furthermore, the product and process planning for different levels of production seem to be easily optimized to great extent by discrete event modelling and simulation technique that can portray three-dimensional motion visuals for virtual models and interestingly a dynamic simulation that displays output variations over a defined timeline (Kuhn, 2006).

The National Aeronautics and Space Administration (NASA) has implemented computational models and simulations for their Digital Astronaut Project to avoid unanticipated novel operational conditions and possible performance risks in space that could lead to traumatic results. However, stringent validity and credibility assessment procedures are ensured to confirm the positive mitigation of the simulation tool to avoid risk and thereby strengthening countermeasure procedures (Mulugeta *et al.*, 2015).

Techniques such as SD are directly applied to solve probabilistic models (Poornikoo and Qureshi, 2019). It has also been applied in policy and decision-making in national defense and homeland security, public health, logistics and commercial management applications (Cioffi-Revilla, 2017). Recent studies have shown that DES have been used as an optimization tool in maintenance domain (Alrabghi and Tiwari, 2015). Besides, it has also addressed problems related to supply chain disruptions (Burggraef *et al.*, 2019). It was an absolute necessity to go through and systematize these lean simulation-based studies. Hence, this study aimed to portray the systematic literature review and bibliometric analysis of a collection of high-impact articles retrieved from the Web of Science (WoS) Core Collection database of the studies related to production, manufacturing and operations research and management focusing on simulation-integrated lean approaches. This paper projects the overview of past lean-integrated simulation studies, the methodology of the review undertaken, a bibliometric analysis of the data set, systematic review results, lean simulation framework, research gaps and insights from the study.

Overview of lean simulations

The advent of lean is the result of growing challenges in achieving operational efficiency and process improvement. Especially, in the areas of inventory control practices and complicated work-in-process atmospheres (Meade *et al.*, 2006). Web-based lean office simulation games were designed by Kuriger *et al.* (2010) to train the office personnel in creating awareness and knowledge in one-piece flow technology, workload balancing, error-proofing, quality management and pull-production and also analyze results under several performance metrics. In some cases, energy and material efficiencies are not sufficient; hence, the need for economic efficiency arises. Lean and simulations can be a proven combination to predict and plan the overall economic performance of an organization (Greinacher *et al.*, 2015). Furthermore, there combination was used by Doğan and Unutulmaz (2016) to render value stream maps of both states to assess the quality and efficiency levels of the physical and rehabilitation department of health care. The major purpose of lean and simulation analysis share the same objective: to design and improve processes in a better fashion. It has become more popular among both public and private organizations. Other problems with multiple conflicting objectives in a system can be tackled using optimization (Uriarte *et al.*, 2015).

Simulation is a best-suited complementary tool for integrating with value stream mapping (VSM) technique (Abideen and Mohamad, 2020). It enables us to visualize a production line under excessive stocks and buffers and simple concept such as first-in-first-out can be applied to avoid bottlenecks. Nowadays, virtual production lines are modeled and simulated to study the output data without implementing the whole set-up in real-time. Lean tools such as kanban and VSM integrated with simulation shall give the best results for strong optimal managerial decision-making (Andrade *et al.*, 2016).

The impact of other techniques such as radio-frequency identification (RFID) in a lean production environment can be empirically visualized through simulations and some aspects of the latest simulation software come with built-in parameters to display this result (Chongwatpol and Sharda, 2013). Furthermore, the efficiency of product and process routing operations in the area of operations research that was previously traditionally addressed by mathematical modelling can now be solved with simulation-based optimization (Villarreal *et al.*, 2016). Moreover, this also improves the service level with the help of tools such as DES. To prove this right, Robinson *et al.* (2012) developed a “SimLean” approach that explores potential complementary roles of DES and lean in a health care under theoretical and empirical perspective to improve stakeholder engagement (Robinson *et al.*, 2012). At present more advanced features are available to integrate management and operations research through hybrid modelling and simulation (Gu and Kunc, 2019).

Method

Systematic reviews are essential to summarize the empirical evidence related to technology or method that help in suggesting feasibilities for further investigation in the same area. Sometimes, it can also be used to contradict or support a hypothesis. First, a proper justifiable need for the review needs to be identified along with a protocol to select, study and extract information from the data set and later take efforts to synthesize the data and report the overall review in a proper manner (Kitchenham, 2004). Hence, the studies related to lean simulation in the production, manufacturing and operations management domain were systematically reviewed to gain some corroborative implications from the bibliometric analysis and results.

Search for the articles was strictly restricted within the Clarivate Analytics WoS Core Collection database. The number of journal sources relevant to lean simulations was mainly indexed in WoS than in the Scopus database, this is another major reason for selecting WoS for searching the articles. The very first step was to identify the relevant research studies on lean-integrated simulation studies in the production, manufacturing and operations domain. Second, articles of other subject areas are excluded except “Engineering Industrial,” “Engineering Manufacturing” and “Operations Research and Management.” Later, the articles were classified according to their attributes (purpose of study, study method, technique implemented, software tool used and implications) to ease the systematic review process. Finally, a bibliometric analysis was done considering various co-occurrences and various bibliographic coupling criteria to find out the strength of relevance among keywords, sources and authors in the area of lean simulation within the selected data set to summarize the main results. Finally, a conceptual framework was developed to describe the gaps in the current body of knowledge regarding the feasibilities of future work in lean-assisted simulations. According to Díaz-García *et al.* (2015), the Scopus database has wider data coverage but WoS database has stricter methodological criteria for database coverage and according to Falagas *et al.* (2008), the WoS database offers the high-impact scientific collection of data that is most reliable, updated and suitable for systematic and bibliometric analysis. And WoS has a large database that includes articles published in reputable journals over time with weekly updates of recently published articles and excludes papers written in non-scientific predatory journals and magazines. Figure 1 shows the methodology adapted for the study.

After several iterations to define a broad research query, the final search was based on the steps given below.

Topic (lean simulations) or topic (lean simulation)

Timespan: 2000–2019. Indexes: Science Citation Index Expanded, Social Sciences Citation Index, Arts & Humanities Citation Index, Conference Proceedings Citation Index-Science, Conference Proceedings Citation Index-Social Science & Humanities, Book Citation Index-Science, Book Citation Index-Social Sciences & Humanities and Emerging Sources Citation Index.

In the WoS search page, the title search box was used to initiate the search process and the "Lean Simulations" or "Lean Simulation" was typed in the search box instead of "Lean" and "Simulation" separately to get rid of articles from other irrelevant subject areas that are not related to the required study and then topic search criteria were selected to elaborate the

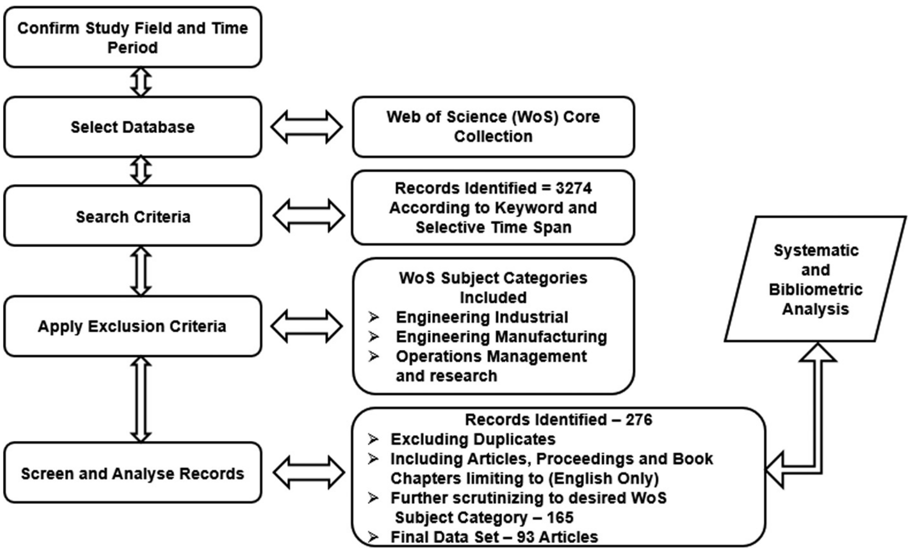

Figure 1. Methodology, adapted from (Álvarez-García *et al.*, 2018)

search dimension. Over 3,724 entries were generated as preliminary data set. A 19-year cross-section (2000–2019) was considered as the timespan. The search was limited to "Engineering Industrial," "Engineering Manufacturing" and "Operations Management and Research" under the WoS subject criteria as previously stated above in this section. The result showed three conference proceedings and one book chapter which was also included in this study. After all these processes, the final search ended with 93 articles. The topic search criterion was not selected as the number of articles that appeared goes beyond 30,000 which was very difficult to scrutinize.

A critical thorough reading of these articles was done to get an overview of how lean simulations support the production and manufacturing operations domains under various constructs and constraints. Subsequently, the authors observed the quantitative evolution of literature and projected them with suitable tables and figures that would add more value to the systematic review. The final stage was to perform a bibliometric analysis using VOSviewer 1.6.5, a software that is used for manuscript aggregations following a standard aggregation mechanism and bibliographic coupling (Waltman *et al.*, 2010). Usually, a bibliographic coupling happens when two authors cite a common author in their references or a keyword that has been used or shared by different articles. According to Waltman *et al.* (2010), the distance between the items portrays the relatedness of those terms. The smaller the distance, the stronger is the association between them. And cluster analysis highlights the knowledge-based diversity in a well-structured way.

The whole bunch of articles is fed into the software as a windows tab delaminated format. Later, the suitable parameters are set within the software to generate the desired bibliometric graphs consisting of a different set of nodes related to their respective clusters assigned by the software. The parameters are set to get a maximum number of co-occurrences and connections in the bibliometric graph. If a set of articles or keywords or documents are in the same cluster, it means they are closely related to their shared references. The results are shown in the form of circular nodes. Nodes which are bigger show that they have extensively been studied and nodes closest to each other show that they

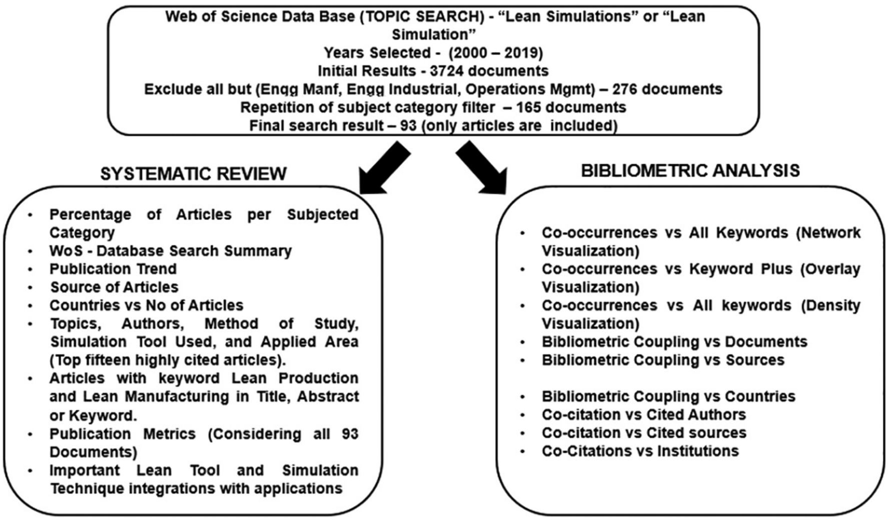

Figure 2.
Schematic of systematic and bibliometric review map

are closely related. Researchers can identify the most influential parameters in terms of research metrics (Van Eck *et al.*, 2010). Figure 2 displays the overall outline of the review.

Bibliometric network analysis

Scientific knowledge can be projected visually in a deductive way in the form of the bibliometric map after the application of a few quantitative methods. This gives a direct overview of influential relationships in the body of knowledge (Van Eck and Waltman, 2009). To study a large variety of bibliometric networks, visualization proves to be an indispensable approach. Networks of relations between authors, co-citation, journals and co-occurrence relations between keywords shall give more implications and understanding to the new researchers to find the gap in the body of knowledge. Researchers are most interested in studying co-citation, bibliographic coupling, keyword co-occurrence and co-authorship networks. These networks are made up of nodes and edges where nodes denote publications, sources or keywords, and edges indicate the relationship and also the strength of the relation between the corresponding nodes (Van Eck and Waltman, 2014). In the event of calculating bibliometric indicators, two methods are incorporated to solve the problem. The most well-known approaches are the full-counting and fractional counting method (Aksnes *et al.*, 2012). An article co-authored by three persons is assigned to each author with a full weight of one in the full-counting method. But in fractional counting method, the published document is allotted to each author with one-third of the fractional weight (Perianes-Rodriguez *et al.*, 2016).

Bibliographic coupling is completely different from the concept of co-citation. Two papers are bibliographically coupled if a third article is cited by the previous two articles. In other words, the bibliographic coupling is nothing but the overlapping density in the reference lists of publications. Though it was not popular in the earlier days, it has become an effective method to study the work done by various literature and their relationship with the work done by their predecessors (Boyack and Klavans, 2010). Usually, three popular approaches were used for visualizing the bibliometric network: timeline-based approach, distance-based approach and graph-based approach. The distance between the nodes represents the relatedness between the two in a distance-based approach. Smaller the distance, larger is the relatedness, which is also known as multidimensional scaling (Borg and Groenen, 2003).

Software – VOSviewer

A distance-based visualization technique is adopted in VOSviewer. Nodes are visible and edges are avoided to gain more details on the factor of relatedness between the nodes. VOSviewer is a powerful application to visualize large networks with some special text-mining features that portray strong bibliographic graphical networks.

Benefits in integrating systematic and bibliometric review

The integration of systematic review and bibliometric results can give birth to a new form of systematic mapping study that has the capability of delivering recommendations for further research gaps based on the taxonomic and analytic exploration and later assist in structuring the results through co-occurrence, co-citation and bibliometric graphs (Fellnhofer, 2019). More methodologies like this are needed in finding out the influence of scientific quality, research disclosures and journal characteristics through a systematic review. A combination of systematic and bibliometric meta-analyses can prove beneficial in studying complex iterations and interactions (Ruano *et al.*, 2018).

Results

The very first result output generated is the distribution of research papers according to the WoS subject category. Figure 3 shows all three categories selected during the article search for this study and the percentage denotes the volume of articles that are categorized out of 93 selected articles.

In the number of articles published according to individual publishers, Elsevier tops the list followed by Taylor & Francis and Springer. DAAM International Vienna has the same number of publications as Springer publisher as shown in Table 1.

In a publication trend shown in Figure 4, the years 2009, 2014, 2015 and 2017 clocks the highest value with eight publications each covering 34% of the total publications, but there is a gradual loss seen in the number of publications since 2017. Researchers should take this note seriously and find out the possible reason for this condition. Lean simulations still have greater scope to be applied to the service and supply chain sectors (Frazzon *et al.*, 2017; Rossini and Portioli Staudacher, 2015).

Figures 5 and 6 show the number of publications per journal source and country, respectively. "*International Journal of Production Research*" tops the list with 36 articles followed by "*International Journal of Production Economics*" with 13 articles out of total 93, and USA, England, India, Germany and Taiwan are the countries that are leading in the number of publications related to this area.

Table 2 below portrays the research work undertaken and the area of applications for the top 15 most highly cited papers from the selected data set and Table 3 shows the list of articles that are divided according to the keywords "lean production" and "lean

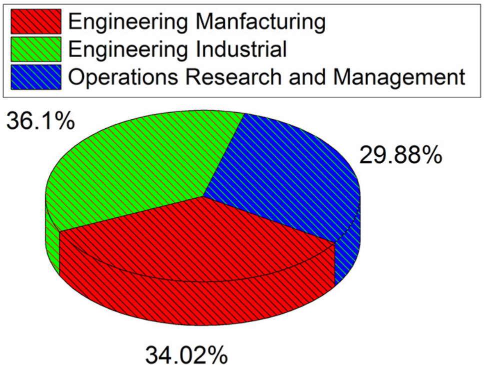

Figure 3. Percentage of articles vs subjected category

Table 1. Database search summary

Publisher	No. of articles
Taylor & Francis	49
Elsevier	20
DAAM International Vienna	6
Springer	5
University of Cincinnati (Industrial Engineering)	4
Omniascience, Society of Manufacturing Engineers	2
Blackwell-Wiley , Kluwer Academic Publisher, Institute of Industrial Engineers, World Scientific Publishing and Co, University Polytechnica Katalunya	1

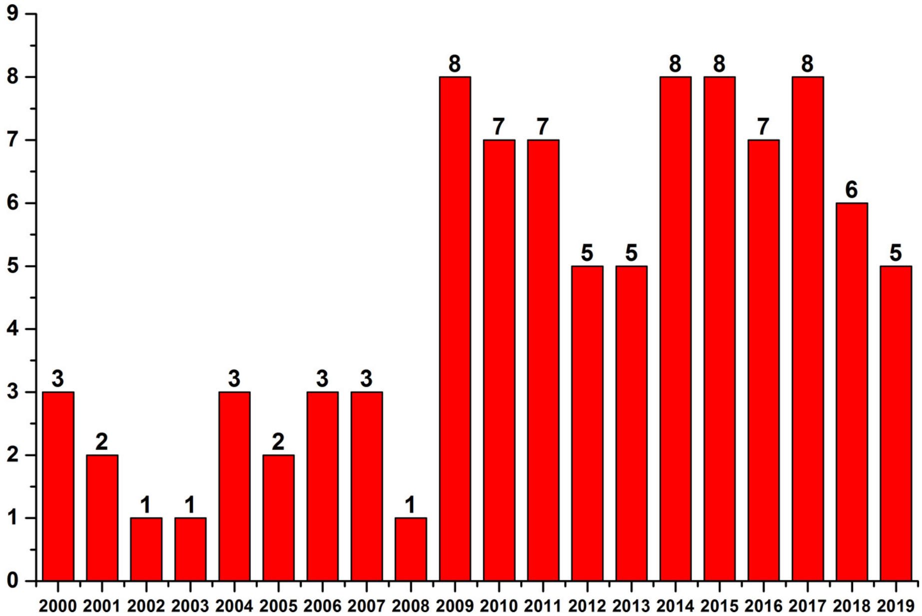

Figure 4.
Publication trend

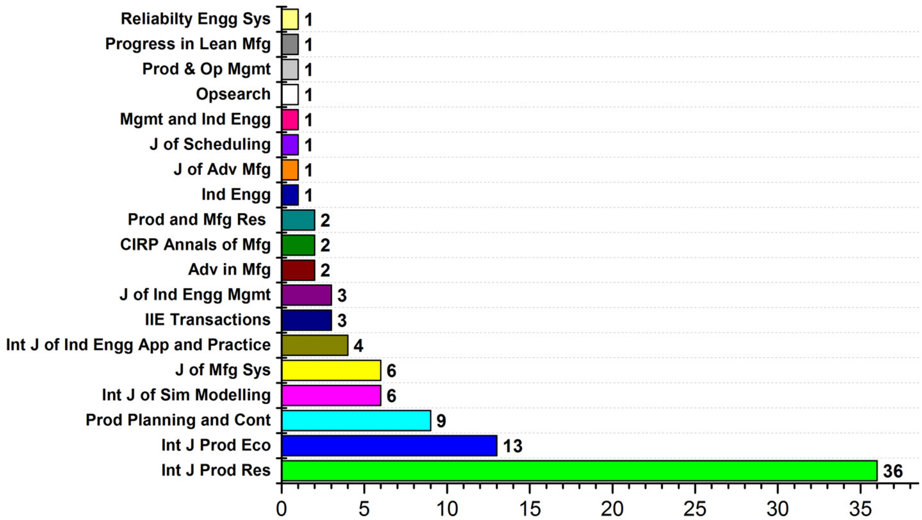

Figure 5.
Source of articles published

manufacturing." The title, abstract and keywords of all the articles were screened to complete this process.

The publication metrics are essential to understand the impact of this selected area of study in the current body of knowledge. Table 4 displays a few important publication metrics retrieved from the data set. The process of calculation of these metric values has been discussed further.

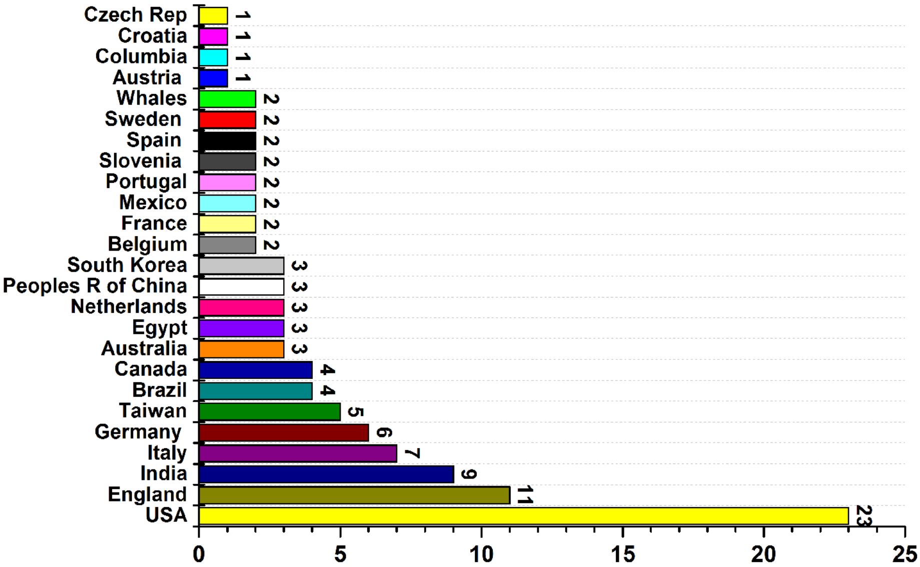

Figure 6.
Countries vs no of articles

Publication metrics

These publication metrics give useful information to other researchers who are working in the same area to get an idea of the impact and scope of this area that could be considered for future collaborations. Citations per paper are the ratio of total citations to the total papers and the citations per year is the ratio of total citations to the number of years since the first paper. The value of citation per author is derived by dividing all citations for each article by the number of researchers and the sum of resulting citations that relate to the single-authored equivalent number of citations for the selected author. The value of papers per author is achieved by dividing each publication by the number of researchers and sum the fractional author counts that relate to a single-authored equivalent number of articles for the selected author. Authors per paper are the value obtained when we add up all the number of authors involved in publication for a given selected author divided by the number of papers. H-index shows the number of citations per individual paper and the cumulative of this as a whole. G-index is derived by calculating the distribution of citation received by an author's publication as this metric looks at the overall record and allows highly cited papers to bolster low-cited papers. *hI* denotes an individual *h*-index and it is acquired by normalizing the number of citations for each publication for each article by dividing the citations number by the number of authors for that paper. *hI* annual shows the high-performing individuals at different career stages (Harzing, 2010). Table 5 shows the lean and simulation or modelling integrations and collaborations that have taken place in the past nine years.

Conceptual framework for lean-assisted simulation

A framework is proposed by the authors on lean simulation integrations in production, manufacturing and operations research and management after a detailed literature review. The studies show that there is a significant scope still yet to be explored and widened to

Author	Research work	Area or scenario of application	No. of citations
Abdulmalek and Rajgopal (2007)	Application of lean was assessed in a steel process industry. VSM was adopted to identify opportunities and later coupled with a simulation model to simulate production lead-time and work-in-process inventory level for before and after scenarios	Process sector (steel mill)	314
Vonderembse *et al.* (2006)	A framework was developed after a case study and literature study to categorize supply chains according to product life cycle and characteristics in the context of lean	Supply chain (discrete product manufacturing firm)	172
Kang and Gershwin (2005)	A lean-based analytical and simulation model was developed to avoid stock loss that is undetected by the information system that leads to inventory inaccuracy and severe out-of-stock situations	Automated inventory management in production	148
Detty and Yingling (2000)	Lean-based modelling and simulation was done to assist in production assemble operations	Lean production shop floor	99
Holweg and Bicheno (2002)	Simulation model developed to describe supply chain dynamics and model possible improvements to adapt techniques such as "Lean Logistics Game" check on "Bullwhip" effect	Automotive steel supply chain	98
Marodin and Saurin (2013)	Detailed literature study on lean production (1996–2012)	Lean production	76
Martorell *et al.* (2004)	Development of lean genetic algorithm to achieve reliability, availability and maintainability in industrial equipment safety-related systems	Industrial safety	70
Lian and van Landeghem (2007)	A new VSM paradigm that can be adapted for use in simulation was designed to study especially push and pull system	VSM paradigm/lean manufacturing	69
Prince and Kay (2003)	Development of virtual group concept was done to apply in cellular manufacturing layout and test lean and agile concepts and its effects on production flow	Virtual production	68
Vinodh and Chintha (2011)	Leanness index in manufacturing firm was assessed using multi-grade fuzzy approach and a leanness measurement model was designed based on that technique	Lean simulation using fuzzy approach	61
Diaz-Elsayed *et al.* (2013)	Both lean and green strategies were incorporated into a manufacturing system and simulated to see reduction in production cost for individual parts	Automotive part production	53
Vinodh and Balaji (2011)	Level of leanness is assessed in a manufacturing organization based on a lean measurement model using computerized decision support system and fuzzy logic	Manufacturing	46
Brintrup *et al.* (2010)	RFID and lean simulations system to identify cost-effective opportunities for its use	Consumer goods manufacturing	41
Pool *et al.* (2011)	Analyzing lean in semi-process to discrete production transitions under demand-driven cycling scheduling	Automotive process industry	40
Huettmeir *et al.* (2009)	Simulation model was developed to address challenges in production scheduling and raw material reordering to execute (Heijunka) – to control the variability of the job arrival sequence to permit higher-capacity utilization in an automobile engine manufacturing	Automotive part manufacturing (engine)	34

Table 2.
Topics, authors, method of study, simulation tool used and applied area (top 15 highly cited articles)

improve various performance metrics in production and manufacturing. Figure 7 is a conceptual framework developed to show the trend and procedure of lean and simulation integration used as a strong tool for organizational performance. This framework also indicates that the present simulation software tools must inculcate direct parametric variables that could quantify a lean tool or a lean procedure empirically in terms of simulated graphs. A separate window panel for inserting the desired performance metrics or lean benchmarks covering the scope of the given system under study is an absolute necessity (Abideen and Mohamad, 2020).

Bibliometric analysis

The data set is downloaded in the form of a windows tab-delaminated format, which is recognizable by the software VOSviewer. All 93 articles were included in the data sets and the bibliometric simulation is run under certain specific criteria selected by the authors and each type demanded the corresponding unit of analysis. Detailed information on this is shown in Table 6.

Lean production	Lean manufacturing
Allwood and Lee (2004), Croci *et al.* (2000), Deif and ElMaraghy (2014), Detty and Yingling (2000), Huettmeir *et al.* (2009), Hwang and Katayama (2010), Jimenez *et al.* (2012), Lolli *et al.* (2016), Marodin and Saurin (2013), Saurin *et al.* (2013), Torkabadi and Mayorga (2018) and Yang *et al.* (2015)	Abdulmalek and Rajgopal (2007), Askin and Krishnan (2009), Darlington *et al.* (2015), Deif (2012), Deif and ElMaraghy (2014), Detty and Yingling (2000), Ben Fredj-Ben Alaya (2016), Gopinath and Freiheit (2012), Gracanin *et al.* (2013), Huang and Liu (2005), Hunter (2001), Kumar and Parameshwaran (2018), Lian and van Landeghem (2007), Lucherini and Rapaccini (2017), McDonald *et al.* (2009), Meade *et al.* (2006), Mehrsai *et al.* (2014), Ozelkan and Galambosi (2009), Stadnicka and Litwin (2017), Susilawati *et al.* (2015), Thomas *et al.* (2018), Trebuna *et al.* (2019), De Vin and Jacobsson (2017), Vinodh and Balaji (2011), Vinodh and Chintha (2011) and Vinodh and Dhakshinamoorthy (2018)

Table 3. Articles with keyword lean production and lean manufacturing in title, abstract or keyword

Metrics	Value
Publication years	(2000–2019)
Total citations	2,169
Cites per year	114.16
Cites per paper	23.32
Cites per author	901.17
Paper per author	38.52
h-index	24
g-index	44
hI, norm	14
hI, annual	0.74

Table 4. Publication metrics (considering all 93 documents)

Author	Lean simulation/modelling integration methods	Application
Trebuna *et al.* (2019)	VSM + Technomatix Plant Simulation tool	Production flow improvement in discrete event industry 4.0 environment
Stadnicka and Litwin (2019)	VSM + SD simulation software (Vensim)	To eliminate waste in inventory levels in work-in-process and production levels in an automobile industry
Lin and Yang (2018)	Load leveling (smooth flow) + artificial fish swarm algorithm	Production flow analysis
Vinodh and Dhakshinamoorthy (2018)	Lean + partial least square and structural equation modelling (SEM)	Health-care operations management
Torkabadi and Mayorga (2018)	Just in Time (JIT) + fuzzy logic algorithm	Multi-stage assembly line (automobile electro-mechanical part manufacturing)
Kumar and Parameshwaran (2018)	VSM + Fuzzy assisted quality function deployment and fuzzy failure modes and effects analysis	Waste elimination in (people, equipment and material) in manufacturing industries
Gjeldum *et al.* (2017)	Lean + supply chain spread sheet simulator	Studying bullwhip effect in manufacturing industries
Lolli *et al.* (2016)	Kanban + multi-scenario simulation	Production warehouse
Aqlan *et al.* (2014)	Lean + bow-tie analysis and optimization techniques	To quantify and mitigate supply chain risks in server manufacturing industry
Nguyen (2015)	Kaizen and 5S + Crystal Ball software	Sustainability in small and medium-sized enterprises
Sarkar *et al.* (2015)	six-sigma + queuing theory	Reduction of productivity cost in textile manufacturing industry
Herakovic *et al.* (2014)	Push – pull system + virtual game	Eliminate motivational and communication problems in new production environment for better competitiveness
Zuting *et al.* (2014)	VSM + DES	Reduce vehicle routing time in steel warehouse supply chain
Belay *et al.* (2014)	Lean set based concurrent engineering + SD	Lead time reduction in cost in new product development
Schmidtke *et al.* (2014)	VSM + DES	Lead time reduction in exhaust gas purification catalyst production process
ElMaraghy and Deif (2014)	Lean cell + SD	Comparative cost analysis in production leveling stage
Gracanin *et al.* (2013)	VSM + cost time profiler simulation systems	Reducing cost in job-shop scheduling
Bortolotti *et al.* (2013)	JIT + SEM	Operational efficiency and performance improvement through JIT
Vinodh and Balaji (2011)	Lean assessment model + fuzzy logic-assisted decision-support system	Cost reduction in modular switches manufacturing
Pool *et al.* (2011)	Pull system + DES	Demand-driven product flow in automobile industry
Wadhwa *et al.* (2010)	Lean supply chain + DES (Arena)	Information transparency in multi-product multi-echelon supply chain
Koulouriotis *et al.* (2010)	Kanban systems + genetic algorithm	Optimization of part assembly process simulation systems
Hwang and Katayama (2010)	Lean + priority based multi chromosome algorithm (PCM)	Production assembly line modelling

Table 5.
Important lean tool and simulation techniques integrations with applications (latest first)

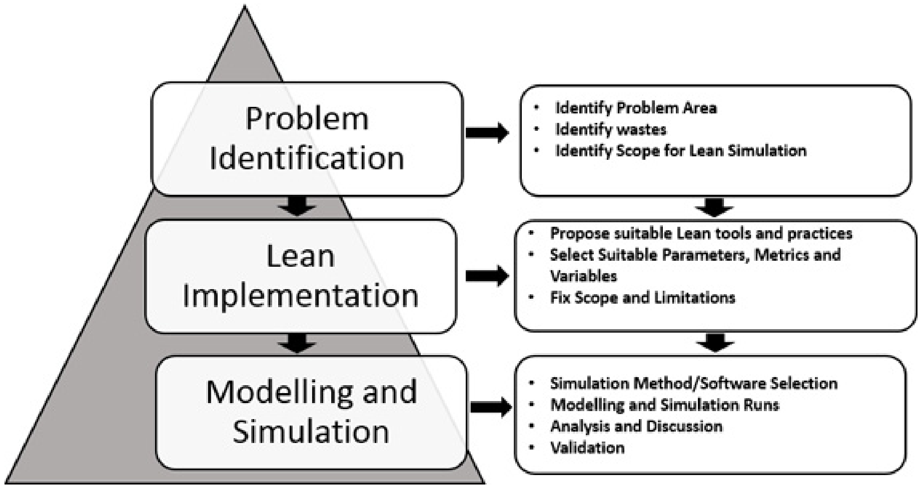

Figure 7. Conceptual framework for lean simulation

Type of analysis	Unit of analysis	Criteria applied
Co-occurrences	Keywords plus	Minimum number of occurrences – 2 60/221
Co-occurrences	All keywords (network and density view)	Minimum no of occurrences of a keyword – 2 97/510
Co-citation	Journal sources	Minimum number of documents of a source – 2 11/18
Co-citation	Cited sources	Minimum number of citations of a source – 15 26/1424
Co-citation	Cited authors	Minimum number of citation of an author – 10
Bibliographic coupling	Documents	Minimum number of citation of one document – 0 86/93
Bibliographic coupling	Sources	Minimum number of documents of a source – 2 11/18
Bibliographic coupling	Countries	Minimum docs per country – 2 21/45
Bibliographic coupling	Institutions	Minimum number of documents per institution is – 1 132/140

Table 6. Type and unit of analysis

All-keyword and keyword-plus co-occurrence network and overlay visualizations

The keywords in the article refer to and reflect the concerned research topic. The keyword co-occurrence network is studied to study the core topic distribution and reveal the certain relationship between each other, as just the frequency of the keywords may not be able to assist in that aspect. The closer they are to each other in the bibliographic map, the stronger is their relevance and interaction with each other to form a cluster (Van Eck *et al.*, 2010). The density distribution maps of keyword co-occurrence networks can help identify the most popular research topics and research trends over time. A co-occurrence network of all the keywords is given in Figure 8. Simulation is used as a keyword more than others in the list followed by lean manufacturing, performance, implementation, benefits and lean production.

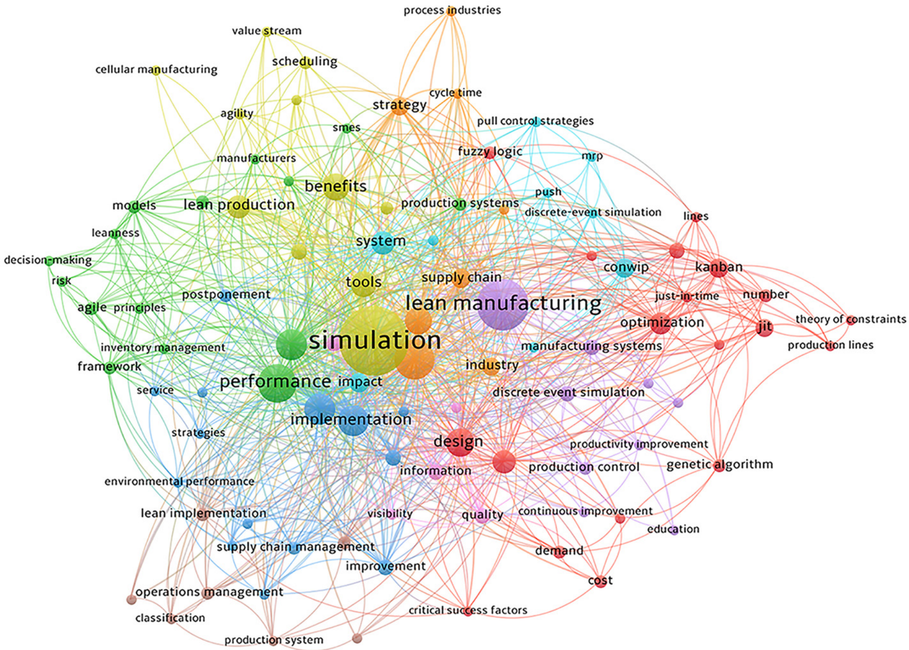

Figure 8.
Co-occurrences vs all keywords (network visualization)

In overlay visualization, the color of a node shows a certain property of the node. For example, nodes are journals and the color indicates the number of times a journal has been cited. But in this current analysis, the number of times a keyword that has been used and other keywords nearest to the previous one show the strength of relevance. Another type of visualization is the density visualization in which the colors indicate how nodes are distributed in the two-dimensional space underlying the visualization and identify dense areas in which most of the nodes are located close to each other (Van Eck *et al.*, 2010). The software extracts the keywords from the title and abstract of a publication. The number of co-occurrences of two keywords is the number of publications in which both keywords occur together in the title, abstract or keyword list. Figures 9 and 10 show the co-occurrences of keyword plus (overlay visualization) and co-occurrences of all-keywords (density visualization).

Keyword co-occurrence density distribution

In density visualization, each node in the co-occurrence network has a color that depends on the density of items at that point. The nodal weight (density) is increased if the number of neighboring nodes and weights of neighboring nodes is quite large (Waltman *et al.*, 2010). The keywords which are farther from each other and smaller in size give the literature gap between the topic areas with respect to those keywords. A density visualization network of all keywords is shown in Figure 10.

Bibliometric analysis – full-counting method

Each circle given below in Figure 11 represents an article. Large circular nodes with an article name assigned denote that it has more citations compared to others and small

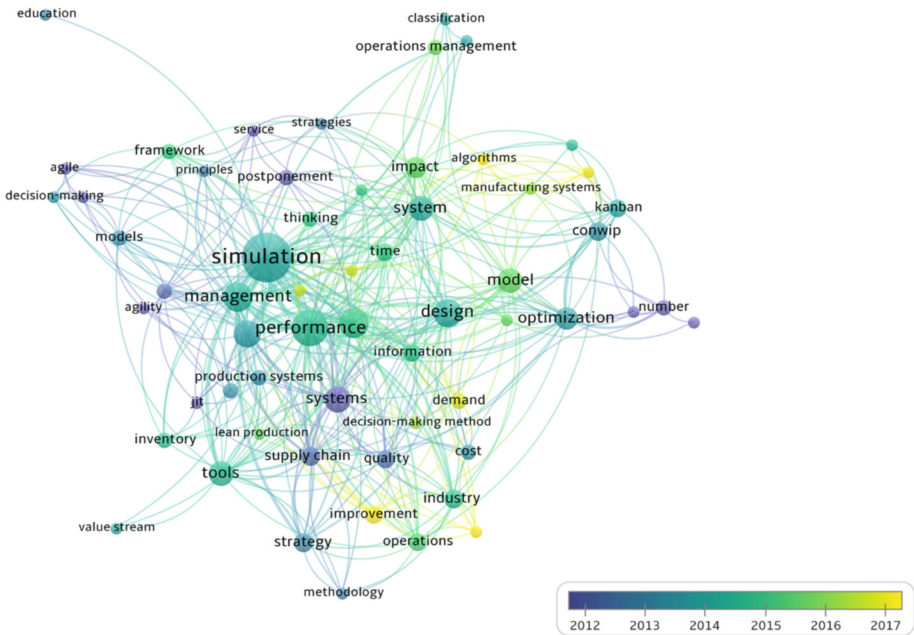

Figure 9.
Co-occurrences vs keyword plus (overlay visualization)

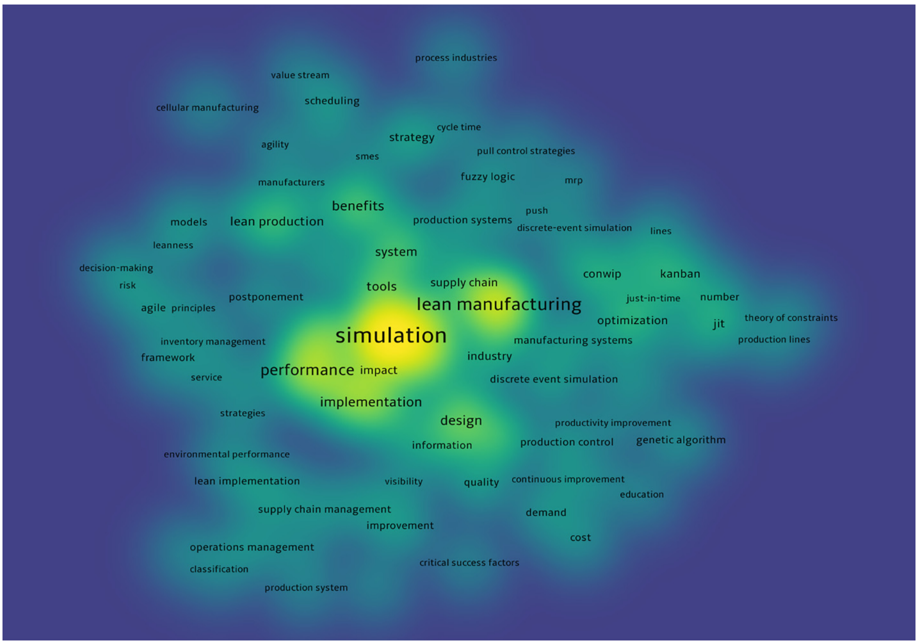

Figure 10.
Co-occurrences vs all keywords (density visualization)

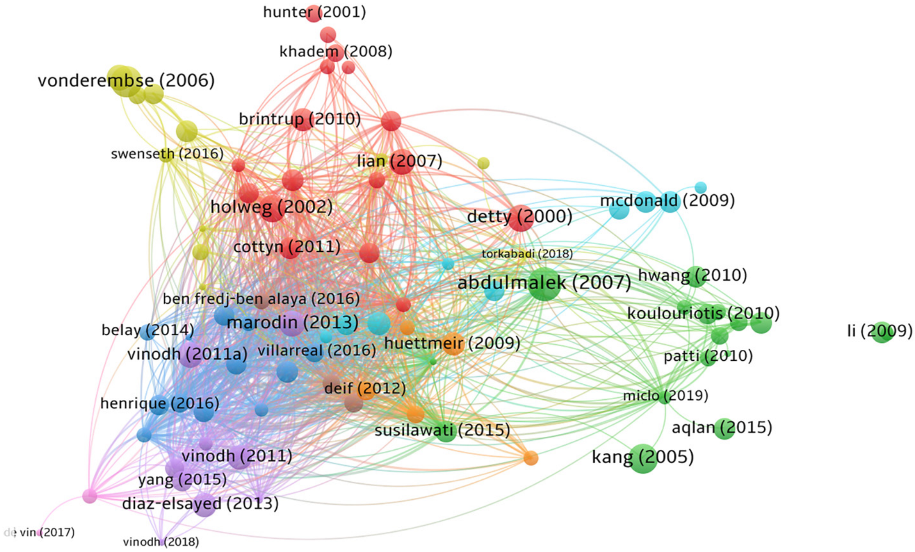

Figure 11.
Bibliometric coupling vs documents

circular nodes represent fewer citations. In general, the closer the two documents are located to each other in the visualization, the stronger they are related to each other based on the bibliographic coupling. Which means, authors of those particular documents who are situated close to each other tend to cite the same publications, while documents that are located far away have not referred to each other. And the same colors also indicate clusters of documents that are relatively firmly related to each other. Furthermore, in Figures 12 and 13, a bibliographic coupling network shows the interactions between the journal sources and countries, respectively.

Co-citation vs author: network visualizations

Co-citation networks show how researchers, research institutions or journal sources are linked to each other based on the number of articles they have authored jointly. The size of a circular node reflects the number of publications of the corresponding author, journal or organization as shown in Figure 14. Similarly, the distance between two nodes approximately indicates the strength of the co-authorship link between the corresponding authors, journal sources and institutions. So, closer the two circles, the stronger are the co-authorship links between them. In general, according to Strozzi *et al.* (2014), in a co-citation network, the nodes are the articles (authors) and the links between them are the citation.

Co-citation – journal sources network visualization

Circular nodes in Figure 15 denote the number of citations a journal has received. Closeness depicts the strong relatedness and nodes that are farther away from each other portray minimal co-citation scenarios. Journals such as "*International Journal of Production Economics*" and "*International Journal of Production Research*" are strongly related and have achieved most citations followed by "*Production Planning and Control*," "*International Journal of Simulation Modelling*," "*Journal of Manufacturing Systems*" and "*Journal of*

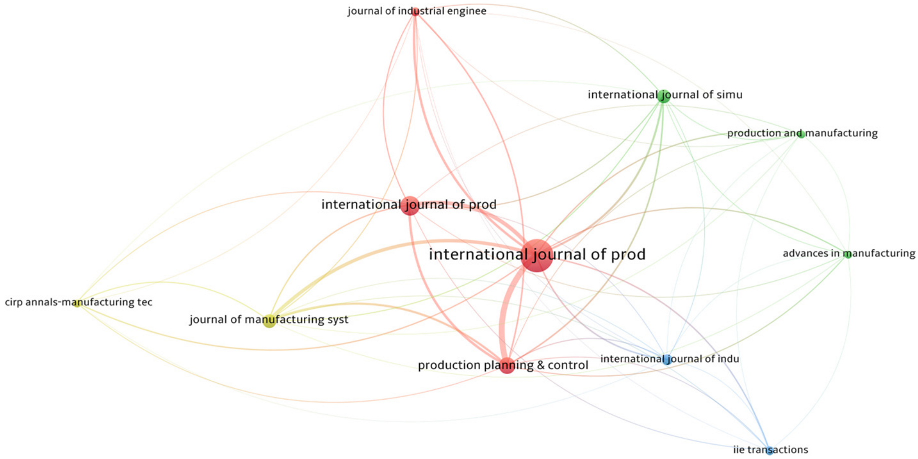

Figure 12.
Bibliometric coupling vs sources

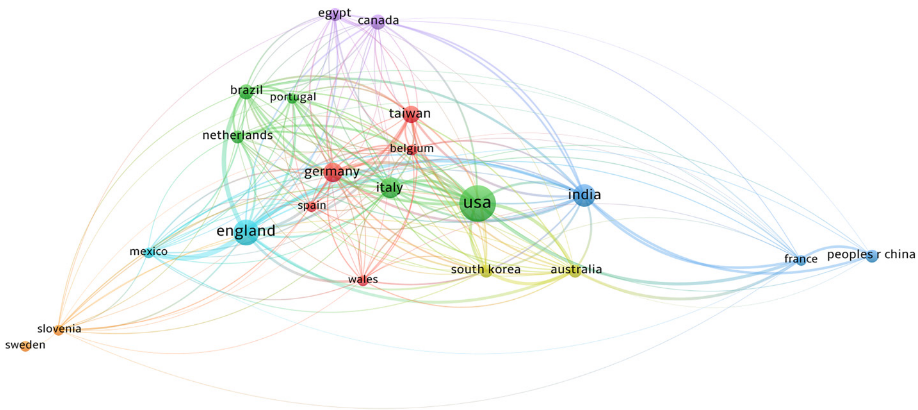

Figure 13.
Bibliometric coupling vs countries

Operations Management." Figure 16 projects the same principle but shows the closeness and association (co-citation) strengths between various institutions around the world.

Research gaps and implications

After a detailed study on the keyword clusters, strong implications were obtained on various research gaps and proposals for future research endeavors. A co-occurrence network diagram of a keyword cluster projects the keywords in different colors with interconnected patterns. As discussed earlier in this paper, the closer they are located, the greater is the relevance with each other and vice versa. The bibliographic coupling of the "keyword plus" network was generated in the software and then considered to build Table 7 to visualize strong research gaps and future research scopes. The co-occurrence diagram is shown previously in Figure 9 as an overlay visualization format.

A detailed study on the individual clusters and the distance between the clusters projects various research gaps and opportunities. The circular nodes of keywords such as lean

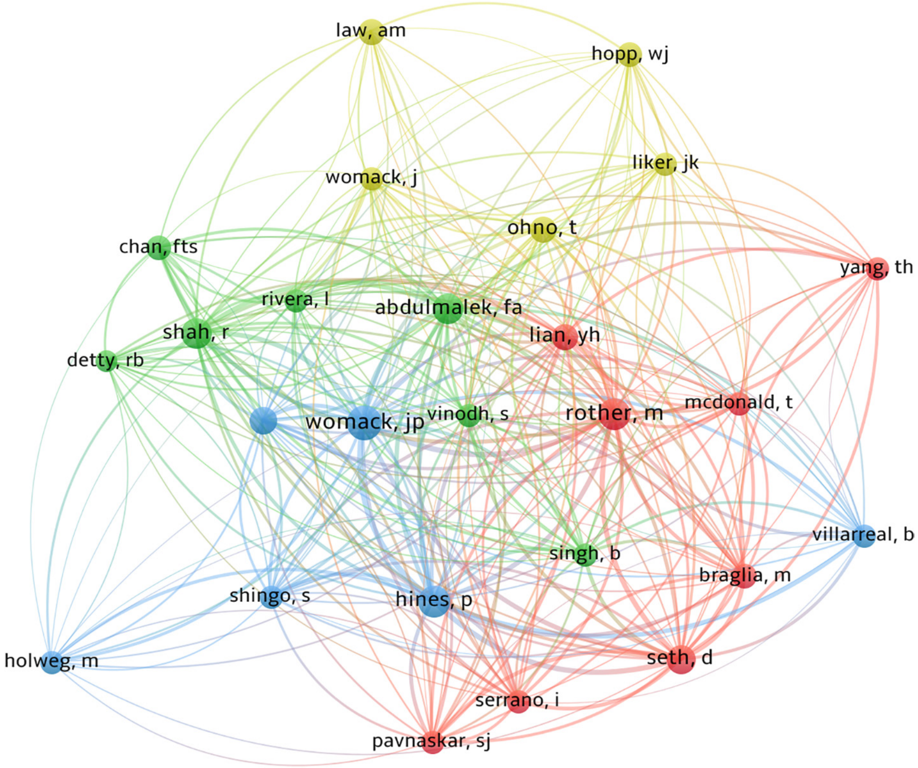

Figure 14.
Co-citation vs cited authors

production, production systems and industry are considerably small in cluster one. Similarly, other lean strategies and tools have not been integrated with simulation techniques, which is evident from the other clusters. Keywords that are highlighted in italic text in Table 7 have larger circular nodes as shown in Figure 9. Hence topic areas related to small nodes should be studied further extensively and nodes that are farther apart can be linked, coupled and integrated to address hybrid problems.

Insights from bibliometric analysis and research gaps

The nodal positions, connections and close relevance from the bibliometric results give a better projection that showcases few justifiable research gaps. Usually, researchers ponder and put a huge effort and try to criticize the drawbacks of other research outcomes to bolster their claim for strengthening their research gaps. Insightful research gaps are derived by deeply analyzing Table 7 and Figures 8 and 9, which are given in Figure 17. This result directly suggests the possible research combinations recommended to the researchers to improve lean-based simulation studies in production and operation research. Each keyword in Figure 17 has a feasible research gap and research scope toward the others as directed by the arrows.

Many insights were derived from Table 7 which was constructed using Figure 9. The impact of risks, decision-making, service and strategies from cluster 2 (green) on the lean production in cluster 1 (red) can still be extensively studied. This can be extended further to

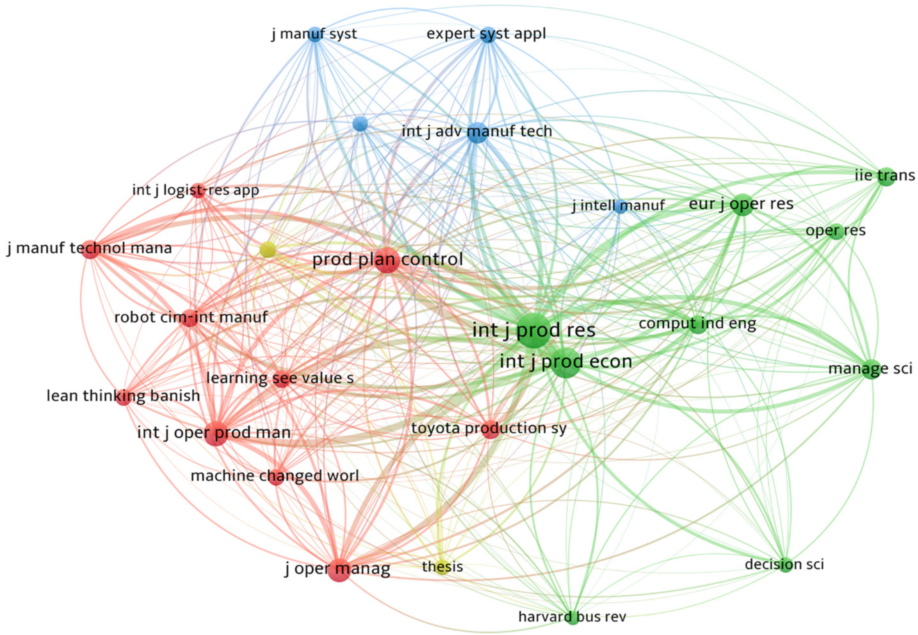

Figure 15.
Co-citation vs cited sources

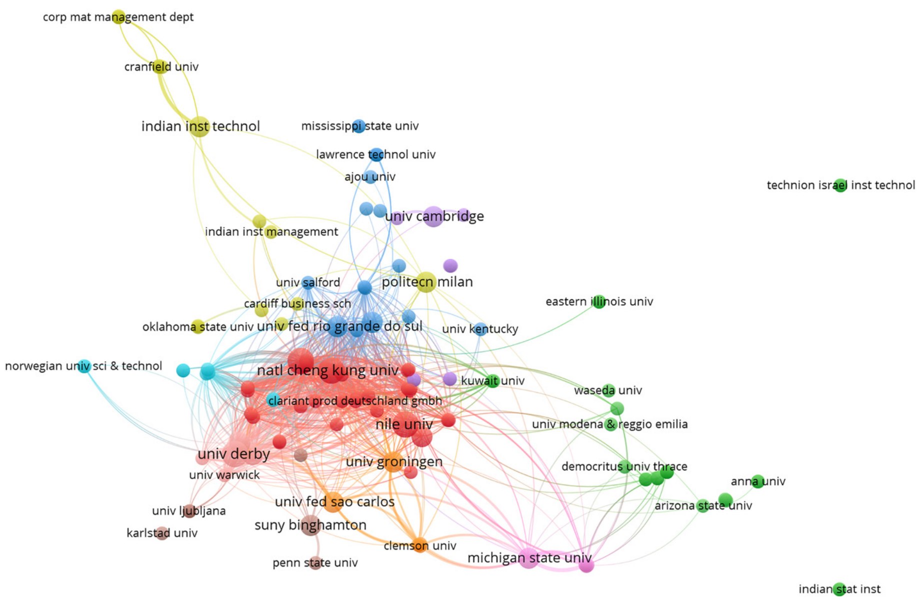

Figure 16.
Co-citations vs institutions

Table 7.
Individual clusters and related keywords

Cluster 1 (Red)	Cluster 2 (Green)	Cluster 3 (Blue)	Cluster 4 (Light green)	Cluster 5 (Violet)	Cluster 6 (Light blue)	Cluster 7 (Orange)
(1) *Benefits*	1. Agile	1. Algorithms	1. Industry	1. Cost	1. Classification	1. Impact
(2) *Implementation*	2. Agility	2. Conwip	2. Methodology	2. Critical success factors	2. Education	2. Information
(3) Industry	3. Decision-making	3. Discrete-event-simulations	3. Operations	3. Decision-making methods	3. Operations management	3. Uncertainty
(4) Lean Production	4. Framework	4. Kanban	4. *Performance*	4. Demand	4. Production system	
(5) Manufacturers	5. *Management*	5. Lines	5. Strategy	5. *Design*	5. *Simulation*	
(6) Organization	6. Models	6. Manufacturing systems	6. Supply chain	6. Improvement		
(7) Production systems	7. Postponement	7. Model	7. *Systems*	7. Quality		
(8) Sector	8. Principles	8. Number	8. *Tools*			
(9) Selection	9. Risks	9. Optimization	9. Value stream			
(10) System	10. Service	10. Production lines				
(11) Thinking	11. Strategies	11. Pull control strategies				
(12) Time	12. Toyota Production System					

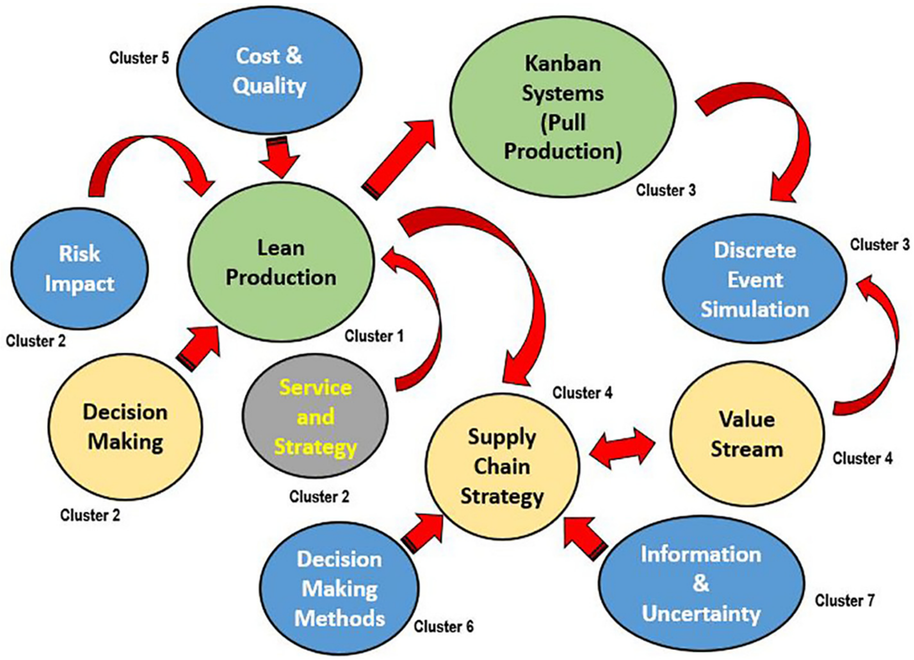

Figure 17. Feasible research gaps and research scope to improve lean simulations

evaluate the impact of kanban (pull production) from cluster 3 (blue) on the production system assisted by a DES technique. The fourth cluster (light green) shows that supply chain-based VSM is left unattended as previous studies have only focused on core production shop floor operations (Abideen and Mohamad, 2020). Other parameters such as cost and quality factors from cluster 5 (violet) need the utmost attention. Finally, the decision-making construct from cluster 5 (violet) could be profited by filling up all these research gaps in various production systems (cluster 5 [light blue]). The final cluster (orange) has information, impact and uncertainty which can be considered as the objective or driving parameter for the above-mentioned areas. The gaps can be filled within a cluster or between the clusters as the nodes which are smaller and farther apart denotes areas with lesser studies and areas that are unconnected or unintegrated.

Conclusion

Quantifiable evidence is very much needed to convince managers to adopt lean. As it is difficult to evaluate the future state map, a non-conventional lean approach is needed that is more viable. A static lean tool such as VSM cannot give exact values of inventories at different levels of the system (Abideen and Mohamad, 2019). Simulation is a best-suited complementary tool to quantify the gains and project dynamic performance statistics and also considering organizational details at the same time. Based on this study, it was evident that lean strategies and simulation can be merged to gain the best results. Efforts are being taken to integrate lean strategies and tools with a suitable simulation modelling approach to quantify them for better decision-making on production flow. The static value stream maps are converted into a dynamic visual prototype to test future states. Moreover, some simulation-based software are user-friendly and replace complex fuzzy and genetic algorithms.

Future scope for lean simulations

Different software systems are built based on a common simulation fundamental rubrics as its backbone. Exhaustive studies have been carried out focusing on the integration of lean and DES, notably in core manufacturing processes. However, there is a huge scope for other combinations such as agent-based modeling, SD or a combination of one or two approaches (multi-method modeling) to be combined with lean-based dynamic models that could prove beneficial in improving process performance. Instead of just core manufacturing processes, areas in industries such as education, utilities, information technology, tourism, security and agriculture have yet to be investigated from the perspective of lean simulation. Besides, more and more research is still needed on the application of lean simulations in maintenance and downstream supply chains such as warehouses and logistics (Abideen and Mohamad, 2020). Another big problem faced by the simulation software technology is that it is not able to calculate the evidential significance and direct empirical value of leanness when various lean methods and procedures are used. Thereby, the authors propose a new notion called "Lean Simulations" which has not been strongly reported, defined, studied and analyzed in the supply chain and service sectors. Lean simulation is the capability of the simulation tool or technique to empirically quantify different lean tools or lean procedures suggested to the system and also keeping the dynamic visualizations intact. Authors also propose that the lean constructs should be planned, constructed and implemented as separate process blocks in the future software system so that researchers or managers can use them as one of the parameters and variables at the modeling stage to help measure the magnitude of the lean effect on the enterprise at different stages.

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