Proceedings of the 8th Annual World Conference
of the Society for Industrial and Systems Engineering,
Baltimore, MD, USA
October 17-18, 2019

Industry 4.0 in Logistics and Supply Chain Management Using Topic Modeling Method

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Abstract: "Industry 4.0" is a recent concept that focuses on automation, digitalization, and data exchange in industries. Its goal is to achieve a smart factory to reduce lead time and improve productivity in the system. This concept is leading to changes in manufacturing, the supply chain (SC), and logistics. The role of Industry 4.0 in supply chain management (SCM) is a new and critical subject with a need for more research. A few studies have started reviewing the existing works on Industry 4.0; however, they do not focus on its role in SCM. This paper presents a systematic review and synthesis of the current literature on Industry 4.0 in SCM. The goal here is the following: (1) to summarize the existing knowledge on Industry 4.0 in SCM, and (2) to analyze the content of research papers using topic modeling (TM) techniques. Current shortcomings and future research directions are also discussed.

Keywords: Industry 4.0, Supply Chain, Logistic, Internet of Things

1. Introduction and Background

Achieving a modern and agile supply chain (SC) that is efficient, automated, more flexible, and transparent is the goal of most companies. Moreover, a modern SC can work in dynamic systems and can handle high volumes of data, which enables efficient cooperation among all elements in the SC including suppliers, manufacturers, and customers (Yin, Stecke, & Li, 2018) (Barata, Rupino Da Cunha, & Stal, 2017). Industry 4.0 provides a framework that can guide the move from a traditional SC to a modern SC. Industry 4.0 is a strategic approach that focuses on automation, digitalization, interconnection (e.g., via the Internet of Things), information transparency, and decentralized decisions (e.g., autonomous cyber-physical systems) in companies (Barata et al., 2017). This paper reviews the existing literature on modern supply chains, highlights the need for studies to enable a modern SC using Industry 4.0, and identifies future directions to achieve success in this field. This work identifies and reviews current literature on this topic, utilizes text mining techniques to analyze the content of selected papers, and develops conclusions and possibilities for future research.

2. Research Method

The authors conducted a systematic review based on question formulation, locating studies, study selection and evaluation, analysis and synthesis, and reporting and using result. The authors reviewed research trends in the literature from the perspective of a number of studies on Industry 4.0 in supply chain, in logistics, and related subjects, evaluating the context of studies and different methods. They analyzed findings and its impact from other research, which led to two questions: "What are the trends in Industry 4.0 based on the SC?" and what are the current research efforts.

ISBN: 97819384961-7-2

Five keyword phrases were used: Industry 4.0 and Supply Chain, Industry 4.0 and Logistics, Smart Supply Chain, E-Logistics, and E-Supply Chain. The study using Google Scholar included Taylor & Francis, Emerald, Elsevier, IEEE, and Springer, to identify the papers. The search focused on the title, abstract, or keywords. Keywords, database lists, and English language caused some limitation on finding papers in this research. A total of 57 out of 507 papers were selected and included in the analysis; Taylor & Francis (9 out of 123), Emerald (7 out of 56), Elsevier (16 out of 37), IEEE (2 out of 27), Springer (7 out of 211) and 16 papers from other databases (Figure 1).

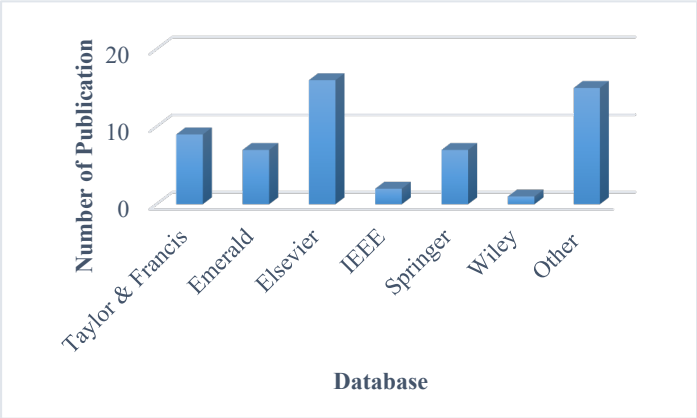

Figure 1. Number of publication based on databases.

The selected papers were categorized based on their meta-data and the research methodology used. The papers were classified accordingly. The human expert analysis is complemented by analyzing the paper content using topic mining techniques. The human expert and topic-mining analyses are used to determine research gaps and recommend future research needs.

3. Review of Research Trends

Based on this research, the publications distribution is from 2014 to 2017. There is a significant growth in the research on Industry 4.0 in supply chain until 2017. Because the last selected papers were published in July 2018, this year's data is inconclusive. Elsevier had the highest number of publications (16), followed by Taylor and Francis with 9. This indicates that Industry 4.0 in supply chain is a priority topic and covered by outstanding publishers. Germany is a pioneer in this research area. From research methods implemented in prior research, 28 of the papers involve content analysis of Industry 4.0 in the SC, which indicates a lack of other research methods such as surveys, interviews, case studies, literature reviews, modeling, etc.

4. Content Analysis

Based on the literature, whether or not conceptual Industry 4.0 is more important than technical Industry 4.0 in the supply chain is an open question. Hence, the authors decided to analyze the content of the papers and classify them into 3 dimensions: exploratory vs. confirmatory, qualitative vs. quantitative, management level vs. process/technology level. In the exploratory cluster, the review focused on how Industry 4.0 can be implemented within the company's supply chain. The confirmatory cluster uses quantitative methods to analyze or provide an implementation model. Quantitative studies measure variables with some precision using numeric scales and analysis. Qualitative studies are based on direct observation of behavior, or on transcripts of unstructured interviews with experts. Management-level papers propose an approach to support companies in understanding the needed organizational changes to reach a respective supply chain system. In contrast, process/technology-level papers focus on improving the process and implementation of concepts and frameworks of Industry 4.0 within company systems. Some of the papers in this research are similar review papers but with different content and they do not belong to the management level vs. process /technology level. Hence, those paper were not considered.

ISBN: 97819384961-7-2

4.1. Management Level vs. Process /Technology Level

Some papers that were classified as management level proposed a framework. In the conceptual realm, Industry 4.0 was selected as an innovation in logistics and the SC. Researchers believe that Industry 4.0 must use cyber CPSs, IoT, IOS, smart factory, and big data, in the development of logistics. The impact of new digital technology and process improvement was explained (Yin et al., 2018). Several research proposed theoretical frameworks to evaluate Industry 4.0 and its implementation in logistics and supply chains. Jayaram proposed an enterprise model for a global supply chain with support for IoT and Industry 4.0. Strandhagen et al. designed a framework related to logistics, and business operations and models. Ivanov et al. identified business, information, engineering, and analytics perspectives on digitalization and SC risk. Man and Strandhagen proposed how Industry 4.0 can be used to create sustainable business models .

4.2. Process/Technical Level

Some papers discuss dynamic models in Industry 4.0, which involve processes that work with real-time data. Ivanov et al. designed an algorithm for short-term supply chain scheduling in smart factories. Sokolov et al. developed a model for dynamic scheduling of services for Industry 4.0 supply networks. Dunke et al. studied impact of digitalization on Industry 4.0 and SC planning, and how online optimization copes with real-time challenges. Some papers, such as Dweekat et al. presented a framework for an IOT SC performance measurement, and validated it using real-world examples. Avventuroso et al. offered a digital factory framework focused on data management. Another paper proposed a framework that identified a correlation between supply chain risks and Industry 4.0.

Premm and Kim used a multi-agent model for logistics modeling based on Industry 4.0. In a similar paper, a framework was built for a digital supply chain integration in multi-stakeholder environments based on blockchain and Industry 4.0 principles. Chhetri et al. discussed combinations of different components of a manufacturing SC and Industry 4.0. Armengaud et al. investigated the impacts of Industry 4.0 for an automotive supply chain on its production lifecycle. The benefits of Industry 4.0 and digitalization were evaluated and analyzed by several researchers, and the impacts of Industry 4.0 on the procurement function was explored by Glas and Kleemann. A validated mobile model of an application of a supply chain model based on Industry 4.0 was shown by Ignacio et al.. Another study discusses the role of Industry 4.0 for digitized procurement in SC using radio frequency identification.

4.3. Further Discussion on Content Analysis

The number of papers in management level and process/technical level are equal. By delving more deeply into them, it was found that just 4% of the management-level papers are quantitative and confirmatory, i.e. are in conceptual part of management. 57% of the technical papers are quantitative and explain findings based on analysis or case studies. There is a lack of research in the technical and analytical areas for implementing Industry 4.0. This study found that the number of exploratory papers is more than the number of confirmatory papers at the technical level. It can be stated that research is in the early stages, and further exploration is still needed.

5. Content Analysis Using Topic Modeling (TM)

TM is a type of unsupervised machine learning technique that uses clustering to derive latent variables or hidden structures of words in documents. TM was used to cluster abstracts of the reviewed papers for this research. One method for TM to discover the hidden thematic structure in a large dataset is to apply matrix factorization methods, such as independent component analysis, singular value decomposition, or non-negative matrix factorization (NMF). NMF generates a matrix with a positive component that produces better results for topic modeling compared to other methods. Therefore, it was decided to use the NMF method. The output of the NMF method contains the term weight for each of the K topics and the documents membership weights. Parameter selection is applied to evaluate the different NMF topics and to select a useful value for the number of topics. For topic coherence, a minimum of 2 and a maximum of 10 were chosen for K (i.e., the number of topics for parameter selection). To build a word-embedding model, the Stanford Natural Language Processing (NLP) dataset is used. The highest mean coherence (0.5030) is achieved with three topics (clusters) based on the top five terms (Figure 2). The name that best identifies each topic, its top 5 terms and an explanation is given below.

Topic 01 (manufacturing): manufacturing, production, industry, product, systems: Papers assigned to this topic generally discuss the integration of smart manufacturing systems and production systems, how to implement Industry 4.0 in these systems, and the effects of Industry 4.0 on them.

ISBN: 97819384961-7-2

Topic 02 (supply chain): supply, chain, scm, risk, management: This topic includes papers that explain Industry 4.0 and its impact on SCM as well as the effect of integrated SCM on the IoT and digitalization technology. There is also an attempt to determine if there is any risk to control it.

Topic 03 (logistics): logistics, industry, information, business, solutions: The selected papers in this topic indicate that Industry 4.0 is changing in industries, logistics and their business. Some of the researchers introduced Industry 4.0 as solutions for process improvement in their system.

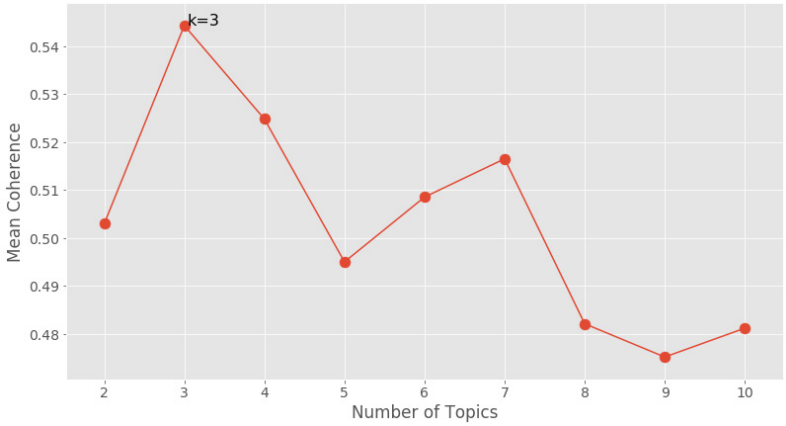

Figure 2. Number of topics based on coherence.

6. Discussion, Conclusions and Future Work

To highlight the trends, advances, and gaps in research on Industry 4.0 in the supply chain, a systematic literature review, and analysis was conducted. The content of the selected papers was analyzed in two ways: based on the authors' opinions, and based on the topic modeling that lead to identifying research gaps. Based on the technical part of this literature review point, there is a large gap, which needs more technical papers to explain the processes and technical implementations. About 50% of the technical papers identified a type of framework to integrate Industry 4.0 into a specific supply chain. However, these studies could not come up with a generalizable framework for an Industry 4.0-based supply chain that could be used as an implementation guideline by companies (firms). Also, there is a lack of studies in the quantitative area, suggesting that there is not enough research based on analytical results and proves the lack of technical know-how in this area.

In general, Industry 4.0 is seen as a concept that has an important role in modern supply chain. Findings from this study prove that by using Industry 4.0, human interaction can be reduced and productivity can be increased in companies. Evidence from this study shows that there is a lack of research in Industry 4.0 and the supply chain, which needs further investigation and can be an important topic for future research. However, the limited number of experts in the area of Industry 4.0 is a factor that limits research and discussion about this subject and prevents its expansion. The gap in this field of study indicates that a comprehensive solid document is lacking. It is suggested that a set of guidelines be written by experts in this area to serve as a dependable reference and guidelines for factories when starting and developing this new concept. There is also opportunities for further research with narrower concentration on identified factory roles in Industry 4.0 in the supply chain. Furthermore, this subject is very applicable to real-time problems. For future work, they suggest a topic such as "The Role of Industry 4.0 in the Supply Chain Using a Dynamic Problem Approach."

In conclusion, the implementation of Industry 4.0 is complex and challenging. The authors recommend more case study research to show where and when factories should start using Industry 4.0 in their SC and how they can develop it in their companies. Furthermore, more case studies need to evaluate the advantages and disadvantages of Industry 4.0 implementation and its cost for other company experiences.

ISBN: 97819384961-7-2

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ISBN: 97819384961-7-2