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DIGITAL TRANSFORMATION IN OPERATIONS MANAGEMENT: A BIBLIOMETRIC-BASED SYSTEMATIC REVIEW

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ABSTRACT

Digital transformation undoubtedly has important implications on the discipline of Operations Management. To unveil these effects and interpret the future research directions requires an in-depth review and analysis of the scientific literature on this research area. This study uses a two-stage approach including Systematic Literature Review and bibliometric analysis to draw a broad perspective on the relationship between DT and OM, reveal the thematic evolution of this research area, and inference about potential future research directions. The scope of the analysis includes the articles drawn from the Web of Science and Scopus databases published between 2007 and 2021 in this research area. With the descriptive analysis of 3021 selected articles to the research sample, top articles, authors, countries, journals, and keywords in this research field were determined. Following the descriptive analysis of the data, the co-occurrence analysis of keywords, thematic evolution, and thematic map analysis was conducted using RStudio and VOSviewer.. All bibliometric analyzes were performed using the R Bibliometrix package.

Keywords: *Systematic Literature Review, Operations Management, Digital Transformation, Bibliometric Analysis, Industry 4.0.*

ÜRETİM YÖNETİMİNDE DİJİTAL DÖNÜŞÜM: BİBLİYOMETRİK TEMELLİ SİSTEMATİK BİR İNCELEME

ÖZET

Dijital dönüşümün en çok etkilediği alanlarının başında şüphesiz ki Üretim/İşlemler Yönetimi disiplini gelmektedir. Üretim/İşlemler Yönetimindeki bu etkileri ortaya çıkarmak ve gelecekteki araştırma yönlerini yorumlayabilmek için alandaki bilimsel literatürün derinlemesine incelenmesi ve analiz edilmesi gerekmektedir. Bu çalışmada, dijital dönüşüm ve Üretim/İşlemler Yönetimi arasındaki ilişki hakkında geniş bir perspektif çizmek, bu araştırma alanının tematik evrimini ortaya çıkarmak ve gelecekteki potansiyel araştırma yönleri hakkında çıkarım yapmak için sistematik literatür taraması ve bibliyometrik analizi içeren iki aşamalı bir yaklaşım kullanılmıştır. Analize, 2007-2021 yılları arasında bu araştırma alanında Web of Science (Wos) ve Scopus veri tabanlarında taranan dergilerde yayınlanan makaleler dahil edilmiştir. Araştırma örneklemine seçilen 3021 makalenin tanımlayıcı analizleri ile bu araştırma alanında öne çıkan makaleler, yazarlar, ülkeler, dergiler ve anahtar kelimeler belirlenmiştir. Verilerin tanımlayıcı analizlerinin ardından anahtar kelimelerin birlikte oluşum analizi, tematik evrim ve tematik harita analizi RStudio ve VOSviewer kullanılarak gerçekleştirilmiştir. Tüm bibliyometrik analizler R Bibliometrix paketi kullanılarak yapılmıştır.

Anahtar Kelimeler: *Sistematik Literatür Taraması, Üretim/İşlemler Yönetimi, Dijital Dönüşüm, Bibliyometrik Analiz, Endüstri 4.0.*

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1. Introduction

Recent rapid developments in information and internet technologies have formed the basis of today's industrial understanding, Industry 4.0 (I4.0), and forced companies to transform. These developments and the transformation process inevitably affect Operations Management (OM) discipline that deals with processes in production systems. However, in the literature, I4.0 is often used as synonymous with concepts such as "digital transformation (DT)," "smart manufacturing (SM)," and "fourth industrial revolution," and this leads to confusion about the scope of these concepts (Culot et al., 2020). DT refers to the strategic transformation using digital technologies for business improvement (Caputo et al., 2021). However, beyond the scope of business, DT is also defined more broadly as a continuous process of change driven by technology, affecting society, politics, and social issues (Ebert & Duarte, 2018). The OM discipline founded in the first industrial revolution in the industrial context (Singhal et al., 2007) has evolved until today. All around the world, academics of the OM field work under many different named departments.

OM, which has different definitions in the literature, has changed scope and perspective, depending on many factors, especially market conditions and technological developments. For example, Heizer & Render (2014:4) described OM as "the set of activities that creates value in the form of goods and services by transforming inputs into outputs." In another study, Dhamija & Bag (2020:870) explained OM as "a complex task involving management of procurement, manufacturing, quality, logistics and physical distribution" by focusing on the processes it covers.

DT has been receiving increasing attention in OM research. A systematic and objective analysis approach is needed to evaluate the impacts of DT on OM in-depth in the academic literature and reveal the development and orientation in this research field. The Systematic Literature Review (SLR) is an objective, repeatable method with specific application steps that enable to examine the literature to respond to research questions, to position studies in the literature, to evaluate and analyze the contributions of studies, and to reach clear conclusions (Tranfield et al., 2003; Denyer & Tranfield, 2009). Bibliometric analysis is an analysis that enables to evaluate of the development of a discipline or research area systematically and meta-analytically over a time that is based on statistical measurement, to reveal publication trends and theme changes over time, to identify the most productive authors, institutes, countries, and collaborations between them, and thus to draw a broad perspective of the development of this discipline or research area (Aria & Cuccurullo, 2017).

In the recent literature, there have been studies performing bibliometric analysis on OM and related concepts of DT for different purposes such as to reveal the development and research direction in OM (Fry et al., 2013; Shang et al., 2015; Akmal et al., 2018), to clarify how I4.0 is handled in various disciplines including OM (Ivanov et al., 2021), to clarify the definition and scope of I4.0 (Culot et al., 2020), to analyze the relationship between digitalization and business models (Caputo et al., 2021). Some of these recent studies on OM examined productivity in this field through a specific OM journal (Fry et al., 2013; Akmal et al., 2018; Romero-Silva & Marsillac, 2019; Wang & Sun, 2019), some through more than one OM journal (Agrawal, 2002; Hsieh & Chang, 2009; Shang et al., 2015).

Agrawal (2002) analyzed the productivity of five constituencies he selected from the OM community based on their publications in the three core journals on the OM area. Hsieh & Chang (2009) evaluated the productivity in the OM area by analyzing the publications in 20 OM-related journals indexed in the Web of Science (WoS) during the years 1959-2008. Israel, Hong Kong, and Singapore were the first three countries on the top in the country productivity list, considering the population sizes. In another study, Fry et al. (2013) analyzed studies published in the International Journal of Production Research (IJPR) between 1985 and 2010. They evaluated the productivity of authors, countries, and institutions. Shang et al. (2015) carried out a similar and extended version of Fry et al. (2013)'s study by including 11 well-known OM journals in their analysis.

Akmal et al. (2018) conducted a bibliometric analysis that included the studies published Production Planning & Control (PPC) during 1990-2016. According to their results, service operations research had started to gain attention after 2005, and supply chain management was an increasingly popular research field starting from 2000 in the OM field. In a more recent study, Romero-Silva & Marsillac (2019) analyzed which terms were most used in the title, abstract, and keywords of the studies published in IJPR between 1961 and 2017 by text mining.

In one of the bibliometric studies conducted in DT-related research areas, Ivanov et al. (2021) addressed how I4.0 was analyzed in different disciplines, including OM. They prepared the bibliographic co-occurrence data map based on the data from the Scopus database and made inferences about the research areas for OM in I4.0. Nakayama et al. (2020) evaluated the transformation process from industry 3.0 to I4.0 and developed a framework based on the insights from a bibliometric analysis and interviews with I4.0 experts. Caputo et al. (2021) addressed the digitalization and business models relations in the literature by conducting a bibliometric analysis based on the data from the WoS database during 2010-2019. They categorized the studies addressing this relationship under three clusters based on keyword analysis. Data management and information technology were among the prominent subtopics under DT, one of these clusters. Culot et al. (2020) conducted an SLR and searched for the definitions of I4.0 and the concepts that are often used synonymously in the literature. They aimed to clarify these concepts' common and different characteristics in many aspects such as scope, enabling technologies, and possible outcomes by searching from Scopus until February 2019.

Although there have been studies in the literature that carry out systematic, bibliometric analyzes in the OM-related and DT-related fields, as far as the authors know, there is no study in the literature that comprehensively analyzes the relationship between DT and OM integrated with SLR and bibliometric analyzes. This study aims to fill this gap and reveal the current state of knowledge that has been created in the literature in the relationship between DT and OM, uncover the significant evolving themes in this research area and make inferences about future research directions. For these purposes, this study adopts a methodological approach in which studies relevant to the research area are selected with SLR, and these studies are examined with detailed bibliometric analyzes. WoS and Scopus databases, the most used academic citation databases, have been searched until late June 2021 with the determined keywords related to OM and DT. An extensive OM-related keyword list has been formed to capture the studies carried out under the OM field, which is comprehensive and studied with many different monikers. Terms that can often be used interchangeably with DT in the literature have been included in the DT-related list of keywords.

2. Methodology

This study aims to investigate the scientific literature on the relationship between DT and OM systematically to draw a broad perspective of this research area and find responses to the determined research questions. In line with the aims and scope, a two-stage approach is applied. In the first stage, the studies relevant to the research area have been selected by the SLR method. Afterward, these studies have been examined in depth in the second stage with bibliometric analyses. This study adopted the three-step SLR performed by Strozzi et al. (2017) to identify studies to be included in bibliometric analysis. The steps are: determining the scope of the analysis, locating studies, selecting and evaluating studies. In the bibliometric analysis, descriptive analysis and network analysis have been performed on the selected studies.

2.1. Systematic Literature Review

SLR is a rigorous and systematic approach to reviewing the available literature on a specific research topic (Kitchenham et al., 2009). It is a comprehensive examination of published research studies conducted on a particular subject to identify patterns, trends, and gaps in current knowledge. The purpose of an SLR is to provide an overview of the research's state and identify areas for further study (Núñez-Merino et al., 2020). It involves using a predefined protocol to minimize bias and ensure the selection of relevant studies is transparent. The results of an SLR are used to inform future research and decision-making in a specific field. This review is considered the most rigorous type of literature review and is often required in academic and research settings.

2.1.1. Determining the Scope of the Analysis

Research questions (RQ) that represents the scope and aims of this study:

RQ1. What is the publication trend on the relationship between DT and OM over the years?

RQ2. What is the distribution of publications in the research area by OM subject groups?

RQ3. What is the citation structure of the studies on this research area over the years?

RQ4. What is the distribution of citations in the research area by OM subject groups?

RQ5.Which authors, articles, countries, and journals have contributed the most to the research field?

RQ6. Which keywords have been used most frequently?

RQ7. How has the conceptual structure of studies in this research area evolved till late June 2021?

RQ8. What are the potential future research directions in this research area?

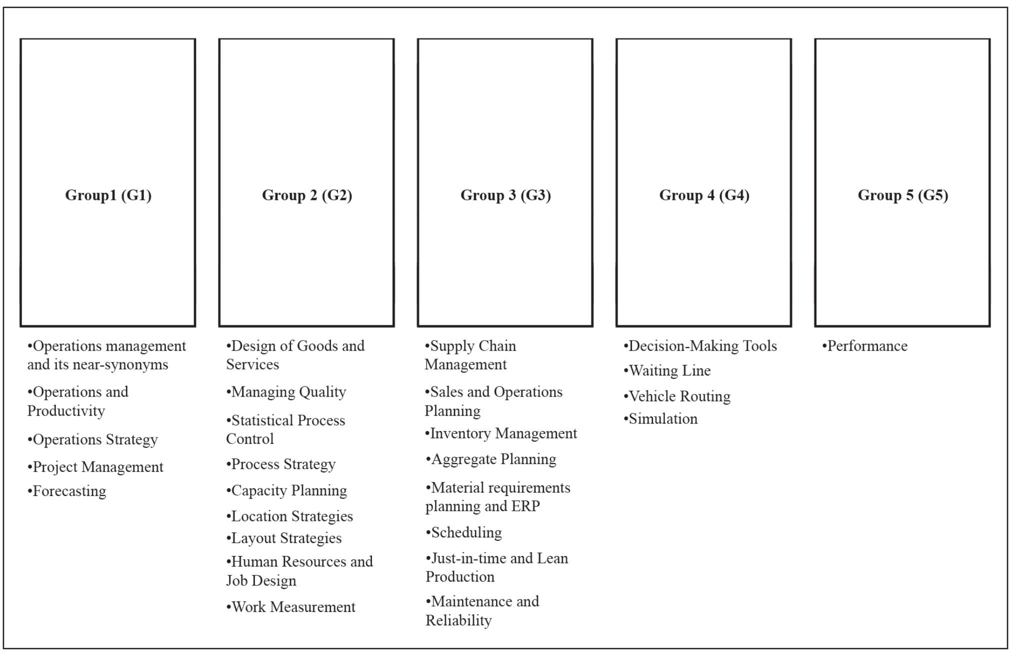
2.1.2. Locating Studies

This step includes locating the studies that match the research questions. A systematic review should consider as many studies as possible of high quality and relevant to research questions. Furthermore, for the effectiveness of the search, search strings should be determined in line with the objectives of the research and reported in detail to provide replicability (Tranfield et al., 2003; Denyer & Tranfield, 2009). Therefore, in fulfilling the requirements of the SLR, it is critical to choose the databases from which the data will be provided and specify the search words and search strings with sufficient scope. In this study, Wos and Scopus, which are frequently used in SLRs related to the OM field and are among the most relevant databases (Núñez-Merino et al., 2020), have been used.

Since this study analyzes the effects of DT in the field of OM, quite comprehensive search words and search strings have been created for OM and DT as two separate sets. In addition, the topics in the books of Heizer & Render (2014), Krajewski et al. (2010), and Russell & Taylor (2019), which are widely used as teaching materials in universities in OM courses, have also been reviewed and common topics have been determined. Then, search terms related to these topics have been included in the OM-related keywords list.

The topics included in the search, given in Figure 1, have been separated into 5 groups based on the sections of the referred textbooks. Since performance is a subject studied in relation to many OM topics, it has been evaluated separately.

Figure 1: OM Subject Groups Included in the Analysis



The search string is arranged so that the located studies include at least one of the words searched for each of the OM and DT sets in their title, abstract, or keywords fields (In WoS, in addition to Author Keywords, Keywords Plus field has also been searched). Search terms in OM and DT sets are given in Figure 2.

Figure 2: Search Terms for OM and DT Sets

OM set

- operations management, production management, manufacturing management, operational management, operation management, enterprise management, acceptance sampling, aggregate planning, capacity, capacity planning, constraint management, decision making, decision-making, design of goods, design of services, distribution, enterprise resource planning, erp, facilities design, facility design, forecasting, hr, human resources, inventory management, jit, job design, just in time, just-in-time, layout, lean, lean operations, lean systems, location strategies, maintenance, managing quality, material requirements planning, mrp, operation planning, operations planning, operations strategy, performance, process strategy, processes and technology, procurement, product design, productivity, project management, quality, quality management, reliability, resource planning, s&op, sales and operations planning, scheduling, scm, service design, simulation, sop, spc, statistical process control, supply chain, supply chain analytics, supply chain design, supply chain integration, supply chain logistic networks, supply chain sustainability, supply-chain analytics, supply-chain management, tps, vehicle routing, waiting line, waiting-line, work measurement

DT set

- digital transformation, digitalization, digitalisation, industr* 4.0, i4.0, i40, fourth industrial revolution, 4th industrial revolution, smart manufacturing, smart factory

2.1.3. Selecting and Evaluating Studies

The initial search was performed in WoS and Scopus in late June 2021, with the determined search words as given in Figure 2. Some restrictions were added to the search to ensure the quality of the studies to be included in the bibliometric analyses. In WoS search, only journals indexed in SCI-EXPANDED, SSCI, and/or ESCI were included. In addition, only articles are written in English (published or Early Access) were considered; Abstract, Data Sheet, Book Chapter, Retracted Publications were removed. These restrictions led to 5590 articles in WoS and 7175 articles in Scopus. Following this, the search was restricted to the categories given in Figure 3 for WoS and Scopus by removing the research areas that are clearly outside the scope of this study. As a result of the research area restriction, 4520 articles in WoS and 6430 in Scopus were identified.

Articles from the two databases were combined using WoS as the reference database. Duplicate articles were eliminated, and 7339 articles were obtained. In the data set obtained, 463 articles did not have keywords. These 463 articles were searched one by one, and the keywords of 35 articles were found. 428 articles without keywords were removed from the database. Unnecessary HTML entity encodings (““”, “–” etc.) in the database have been removed or changed for better results. English differences in keywords were edited. For example, “digitalisation” has been changed to “digitalization.” In addition, keywords were analyzed and standardized. An example is the standardization of the keywords “INDUSTRY4.0”, “INDUSTRIE 4.0”, “INDUSTRY 4”, “I4.0”, “I40”, “INDUSTRY 40” and “INDUSTRIAL 40” to “INDUSTRY 4.0”. Finally, all the remaining articles’ keywords, titles, and abstracts were gone through. Some articles were found to deal with advanced applications of different fields such as electronics, chemistry, and nuclear. Accordingly, 3890 articles not directly related to the research subject were deleted from the database. After all this data deletion and editing process, there are 3021 articles in the database.

Figure 3: Included Research Areas

WoS Categories	• Engineering Manufacturing; Management; Engineering Electrical Electronic; Engineering Industrial; Computer Science Information Systems; Computer Science Interdisciplinary Applications; Operations Research Management Science; Business; Telecommunications; Environmental Sciences; Green Sustainable Science Technology; Environmental Studies; Automation Control Systems; Materials Science Multidisciplinary; Computer Science Artificial Intelligence; Economics; Computer Science Theory Methods; Information Science Library Science; Engineering Mechanical; Multidisciplinary Sciences; Engineering Environmental; Computer Science Software Engineering; Communication; Computer Science Hardware Architecture; Social Sciences Interdisciplinary; Robotics; Business Finance; Mathematics Interdisciplinary Applications; Computer Science Cybernetics; Mechanics; Transportation; Transportation Science Technology; Mathematics; Statistics Probability
Scopus Categories	• Engineering; Computer Science; Business, Management And Accounting; Social Sciences; Decision Sciences; Environmental Science; Materials Science; Economics, Econometrics And Finance; Energy; Mathematics; Multidisciplinary

2.2. Bibliometric Analysis

This study performs descriptive analysis and network analysis on 3021 selected articles published on the relationship between DT and OM between 2007 and 2021. Descriptive analyzes include the publication and citation structure of the research area, the distribution of publications and citations in the OM subject groups, and publication and citation indicators of the top articles, authors, countries, and journals in the research area, and the most frequently used keywords in the research area. In addition, in the network analysis, co-occurrence and thematic evolution analyses based on the Author's Keywords have been carried out to reveal the current state of knowledge of this research area and reveal the evolution of themes over time in this research area. Bibliometric analyses have been performed using the R Bibliometrix package, Biblioshiny app, and VOSviewer.

3. Bibliometric Analysis Results

3.1. Descriptive Analysis

3.1.1. Overview of the Analysis Data

Table 1 summarizes the general descriptive statistics for the selected studies in the bibliometric analysis. The first article was obtained from 2007 in the search, which was conducted without any time restrictions. Totally, from 2007 to the end of June 2021, there are 3021 articles, 174 of which are Early Access, published in 848 different journals, authored by 8178 scholars. Out of 3021 articles, 187 are single-authored, and 2834 are multi-authored. Co-authors per document, which considers author appearances (3.71), is higher than the authors per document (2.71), which considers an author once, even if that author appears in more than one article. The collaboration index, which is one of the significant indicators of the degree of collaboration among authors, is the rate of a total number of multi-authored articles' authors to a total number of multi-authored articles (Aria & Cuccurullo, 2019). The collaboration index is 2.83, indicating that the number of authors per only the multi-authored articles is 2.83. The average citation per article is 11.53.

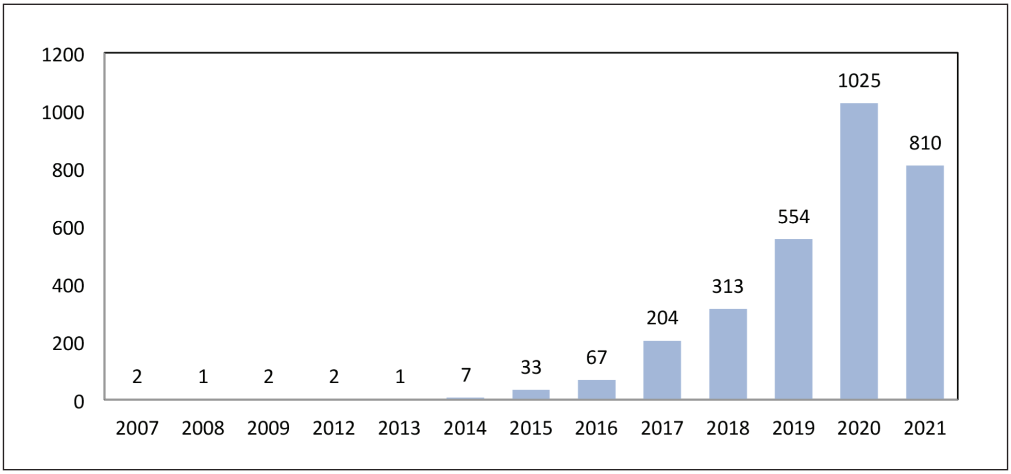
Table 1: Summary of Bibliometric Analysis

Description	Results
Time period	2007-2021
Sources (Journals)	848
Articles	3021
Article	2847
Early Access	174
Number of authors	8178
Total author appearances	11220
Number of authors of single-authored articles	187
Number of authors of multi-authored articles	7991
Number of single-authored articles	194
Number of articles per author	0.369
Number of authors per article	2.71
Number of co-authors per article	3.71
Collaboration index	2.83
Average citations per document	11.53

3.1.2. Annual Basis Publication Trend

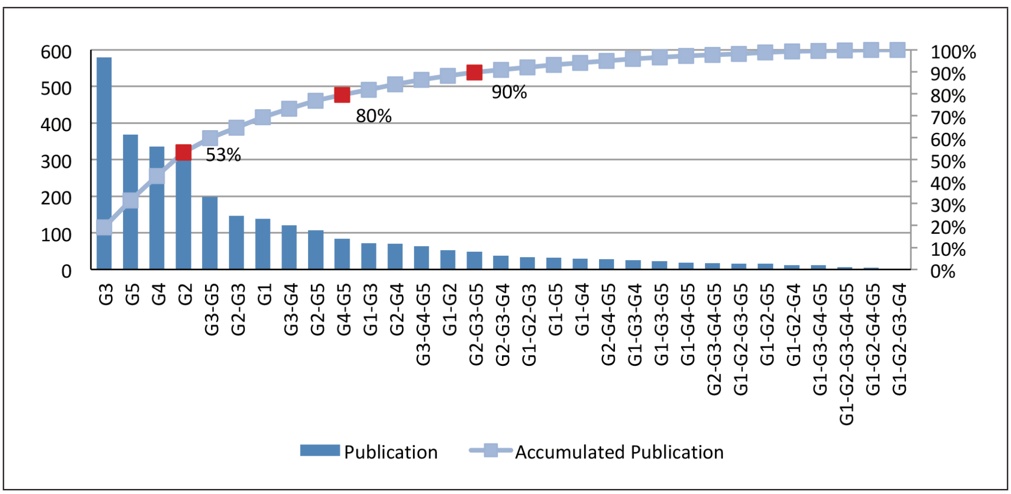
The annual basis distribution of the number of articles on the relationship between DT and OM from 2007 to the end of June 2021 is presented in Figure 4. During 2010-2011, no articles match the search and inclusion criteria. While the annual number of articles in this field was 15 before 2015, there has been a substantial increase in studies since 2015. The number of articles, which was 1025 in 2020, reached 810 in the first six months of 2021. Early access articles have been included in 2021 publications.

Figure 4: Annual Basis Publication Trend



The distributions of publications on the relationship between DT and OM among the considered OM subject groups are depicted in Figure 5. Suppose any search word related to the subjects under a subject group is included in the studies' abstract, title or keywords. In that case, that study is classified under that OM subject group. Studies containing search words from more than one group are expressed by putting "–" between group names. For example, Figure 5 indicates that about 20% of publications only address topics under G3.

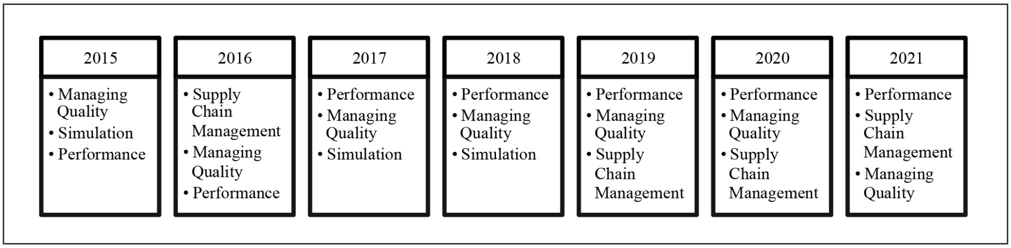
Figure 5: Distribution of Publications among OM Subject Groups



The most studied subjects in this group are Supply Chain Management, Maintenance and Reliability, Just-in-time and Lean Production, Scheduling, respectively. On the other hand, while S&OP has been studied in a single article, Aggregate Planning has not been mentioned in the abstract, title, and keyword sections of any study in the analysis set. After G3, the most addressed subject group is G5, namely performance. The remarkable point here is that the performance is often studied alone and integrates with other OM subject groups. G4 and G2, respectively, follow G3 and G5. Studies that address these OM subject groups without interacting with other subject groups constitute 53% of the data set. Then, the topics under G3 and G5 groups are discussed together in most articles. 6 articles study five OM subject groups in an integrated manner. One of these articles was published in 2019, 2 in 2020, and 3 in 2021.

OM subjects with the highest TP since 2015, when the number of articles started to increase significantly, are presented in Figure 6.

Figure 6: OM Subjects with the Highest TP



In the last 5 years and mid-2021, Performance and Managing Quality have always been among the top 3 OM subjects with the highest TP. Supply Chain Management has been on the list for the last 3 years, 4 times in total, and Simulation has been on the list 3 times.

3.1.3. Annual Basis Citation Structures of Articles

The annual basis citation structures of the articles on the relationship between DT and OM are demonstrated in Table 2, with the total publications number (TP), the total citations number (TC), Citations per Paper (CPP), and TC per year (TCY) indicators. CPP is calculated by dividing TC by TP.

Table 2: Annual Citation Structures of Articles

Year	TP	TC	CPP	TCY	Year	TP	TC	CPP	TCY
2007	2	19	9.50	1.27	2016	67	3316	49.49	552.67
2008	1	33	33.00	2.36	2017	204	7578	37.15	1515.60
2009	2	41	20.50	3.15	2018	313	8542	27.29	2135.50
2012	2	359	179.50	35.90	2019	554	7073	12.77	2357.67
2013	1	15	15.00	1.67	2020	1025	5503	5.37	2751.50
2014	7	323	46.14	40.38	2021	810	1258	1.55	1258.00
2015	33	777	23.55	111.00					

According to the CPP, the most productive year was 2012 (179.50), followed by 2016 (49.49). Articles included in the analysis from studies published in 2012, Davis *et al*. (2012) and Dougherty & Dunne (2012), have received high citations, 294 and 65, respectively. Significantly, the study of Davis et al. (2012) is one of the important articles that is frequently cited by the studies addressing many topics such as SM and its-related concepts, manufacturing process, manufacturing management system, and enabling technologies, in many fields, including manufacturing engineering, robotics, computer science, and automation control systems.

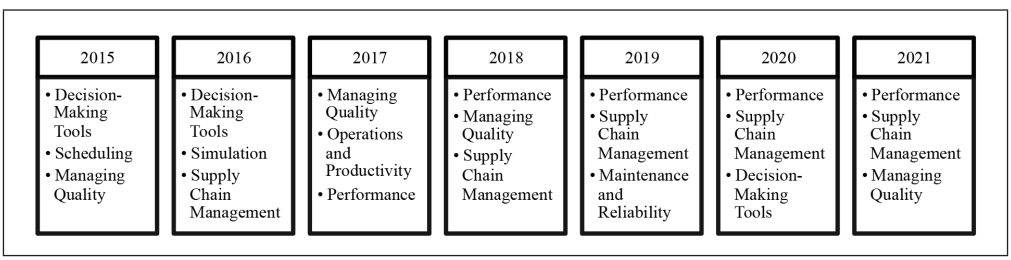
There is a continuous increase in the citations of articles published in the field of DT-OM on TCY basis. However, since the analysis period covers the period until mid-2021, it would not be relevant to interpret TCY for 2021. The citation structure of articles on OM subject groups is given in Table 3. The first group with the highest TC among all OM subject groups is G3 by far. G4, G5, and G2 follow it. In terms of CPP, the most productive group is G1-G2. G1-G3-G5 and G1-G5 follow it. Even though G3 has the highest TC, it is ranked 7th on the basis of CPP.

Table 3: Citation Structures of Articles on OM Subject Groups

OM Subject Group	TC	CPP	Rank by TC	Rank by CPP
G3	7935	13.7047	1	7
G4	4733	14.0863	2	6
G5	3887	10.5625	3	14
G2	3002	9.23692	4	21
G3-G5	2007	1 0.1364	5	15
G1-G2	1415	26.6981	6	1
G3-G4	1315	10.9583	7	11
G1	1314	9.45324	8	20
G2-G3	1185	8.06122	9	22
G1-G3	1068	14.8333	10	5

OM subjects with the highest TC since 2015, when the number of articles started to increase significantly, is presented in Figure 7.

Figure 7: OM Subjects with the Highest TC



In the last 5 years, "Performance" has always been among the top 3 subjects with the highest TC. Similarly, "Supply Chain Management" and "Managing Quality" have been at the top 3 list in most years. In addition, although "Maintenance and Reliability" are at the top 3 only in 2019, it draws attention that has received a significant amount of TC, especially since 2018.

3.1.4. Top-Publishing Authors

The top 10 authors who contributed by publishing the highest number of articles on the relationship between DT and OM from 2007 to the end of June 2021 are presented in Table 4. The authors' names are included as abbreviations in the data set retrieved from Wos and Scopus. This situation causes authors with the same last name and also name starting with the same initial to appear as the same authors. In the literature, many studies performed author analyzes without correcting this error. The author names of the studies were updated one by one using Google scholar to conduct the author analysis properly. Table 4 shows these authors' contributions with the indicators of TP, TC, CPP, h-index, Publication Year (PY) start, and yearly distribution of citations derived from the Biblioshiny app. A researcher's h-index, one of the important impact indicators, refers to a researcher's number of papers (h) cited at least (h) times (Hirsch, 2005; Barnes, 2017).

Table 4: Citation Structure of Top 10 Authors

Author	TP	TC	CPP	h_ index	PY start	Yearly distribution of citations						
						2015	2016	2017	2018	2019	2020	2021
ZHONG Ray	16	1368	85.50	9	2015	214	16	1074		19	39	6
TAO Fei	15	1022	68.13	9	2017			328	458	194	42	
TORTORELLA Guilherme	14	446	31.86	8	2018				150	198	54	44
WAN Jiafu	14	1149	82.07	9	2016		514	409	172	35	15	4
HUANG George	13	490	37.69	7	2015	214	16	201	14	14	30	1
LI Di	12	1147	95.58	9	2016		514	446	171		15	1
GARZA-REYES Jose	11	242	22.00	6	2019					113	108	21
WUEST Thorsten	11	420	38.18	6	2016		245		30	108	37	
RAUCH Erwin	10	131	13.10	7	2017			56		20	54	1
XU Xun	10	975	97.50	7	2017			895		24	51	5

The author at the top of the list is ZHONG Ray, with 16 articles. ZHONG Ray, who has started publishing in this field in 2015, has got 1368 citations and the author's h-index is 9. TAO is second on the list with 15 articles. TORTORELLA Guilherme is the most cited author, with 44 citations in the first half of 2021.

3.1.5. Most Cited Articles

The author, title, journal, and TCY of the most cited ten articles are presented in Table 5. Zhong et al. (2017)'s article published in the "Engineering" journal has the highest TC and the highest TCY among all articles, with 796 TC and 159.20 TCY. Kang et al. (2016)'s article is the second on the list regarding TC and TCY.

Table 5: Most Cited 5 Articles

Authors	Title	Journal	TC	TCY
Zhong et al. (2017)	Intelligent manufacturing in the context of industry 4.0: a review	Engineering	796	159.20
Kang et al. (2016)	Smart manufacturing: Past research, present findings, and future directions	International Journal of Precision Engineering and Manufacturing - Green Technology	548	91.33
Wang S. et al. (2016)	Towards smart factory for industry 4.0: a self-organized multi-agent system with big data based feedback and coordination	Computer Networks	453	75.50
Hofmann & Rüsch (2017)	Industry 4.0 and the current status as well as future prospects on logistics	Computers in Industry	426	85.20
Wang J. et al. (2018)	Deep learning for smart manufacturing: Methods and applications	Journal of Manufacturing Systems	318	79.50

3.1.6. Publication and Citation Structures of Top Countries

Corresponding authors from 81 countries contributed by producing articles on the relationship between DT and OM. The number of countries with at least one citation is 74. The TC, TP, and CPP indicators of the top 10 countries with the highest TC are presented in Table 6.

Table 6: Publication and Citation Structures of the Most Cited 10 Countries

Country	TC	TP	CPP	Rank by TC	Rank by TP	Rank by CPP
China	6795	383	17.74	1	1	10
Usa	3273	184	17.79	2	3	9
Italy	2954	263	11.23	3	2	24
Germany	2671	174	15.35	4	4	15
Brazil	1414	86	16.44	5	9	13
Korea	1344	141	9.53	6	6	26
United Kingdom	1325	143	9.27	7	5	27
India	1206	133	9.07	8	7	28
Spain	1139	130	8.76	9	8	31
New Zealand	1026	13	78.92	10	38	1

China, which has the highest TC (6795) during the analysis period, also contributed the most articles (383). The USA, Italy, Germany, and Brazil have the most TP. China, the USA, Italy, Germany, and Brazil are in the top five in the ranking by TC. However, none of them are in the top five in terms of CPP. In the CPP-based ranking, New Zealand ranked first, Ghana (TP=1, TC=71, CPP=71) second, Switzerland third, Malta (TP=1, TC=35, CPP=35) fourth, and Iran (TP=8, TC=259, CPP=32.38) fifth.

3.1.7. Leading Journals

The data set of this study consists of 3021 articles published in 848 different journals. Table 7 shows the 10 most productive journals ranked by TC received during the analysis period. The top five leading journals published in the research field in terms of TC are IJPR (TC=2881), Procedia Manufacturing (TC=1525), IEEE Access (TC=1524), Computers in Industry (TC=1360), and International Journal of Production Economics (TC=1181). Among the leading journals with the top ten TC, the five ones with the highest TP are IEEE Access (TP=90), Sustainability (TP=89), International Journal of Advanced Manufacturing Technology (TP=80), IJPR (TP=70), and IEEE Transactions on Industrial Informatics (TP=68). The journals with the highest CPP on the list are Engineering (CPP=128), IJPR (CPP=41.16), International Journal of Production Economics (CPP=36.91), Procedia Manufacturing (CPP=34.66), and Computers in Industry (CPP= 26.67). IJPR (h-index =25) and Procedia Manufacturing (h-index =20) are the journals with the highest h-index.

Table 7: Most Productive 10 Journals Ranked by Total Citation

Journal Title	TP	TC	CPP	h-index	Citation (yearly) distribution of articles							
					<2015	2015	2016	2017	2018	2019	2020	2021
International Journal of Production Research	70	2881	41.16	25			209	487	958	494	686	47
Procedia Manufacturing	44	1525	34.66	20		7	4	1514				
IEEE Access	90	1524	16.93	17			78	625	468	194	156	3
Computers in Industry	51	1360	26.67	17			295	500	111	339	109	6
International Journal of Production Economics	32	1181	36.91	15		214		70	221	283	359	34
IEEE Transactions on Industrial Informatics	68	1177	17.31	17			18	217	460	299	144	39
Journal of Manufacturing Systems	49	913	18.63	14				108	601	25	103	76
Engineering	7	896	128.00	6				845		46	5	
Sustainability	89	850	9.55	15				58	391	187	198	16
International Journal of Advanced Manufacturing Technology	80	848	10.60	17			8	101	384	265	84	6

3.1.8. Most Frequent Keywords

In this study, keyword analysis has been conducted based on the keywords collected from the Author's Keywords of the articles included in the analysis. There are 7338 different keywords in the Author's Keywords of 3021 articles in the dataset. The ten most frequently used keywords are presented in Table 8, I4.0 (1706), "internet of things (IoT)" (381), SM (363), "cyber-physical systems (CPS)" (248), "digitalization" (217) and "smart factory (SF)" (217) are in the top 5 of the list. DT is among the ten most frequently used keywords with 148 occurrences.

Table 8: Most Frequent 10 Keywords

Keyword	Occurrences
Industry 4 0	1706
Internet of things	381
Smart manufacturing	363
Cyber-physical systems	248
Digitalization	217
Smart factory	217
Digital twin	165
Big data	145
Industrial internet of things	145
Digital transformation	141

3.2. Network Analysis

3.2.1. Co-Occurrence Analysis of Keywords

In order to analyze the research patterns on the relationship between DT and OM, a co-occurrence analysis of keywords has been performed on VOSviewer software. The co-occurrence network presented in Figure 8 has included keywords mentioned at least 25 times in the Author Keywords sections of the articles in the entire dataset. Co-occurrence analysis of keywords resulted in six main clusters.

The frequencies of the keywords determine the size of the circles representing the keywords in the network. The largest cluster is red (Cluster 1) and contains 16 keywords. The green (Cluster 2), dark blue (Cluster 3), yellow (Cluster 4), purple (Cluster 5), and light blue (Cluster 6) clusters contain 13, 9, 9, 7, and 2 keywords, respectively. Keywords under all clusters are listed in Figure 9.

Figure 8: Author Keywords Co-Occurrence Network of DT-OM Articles

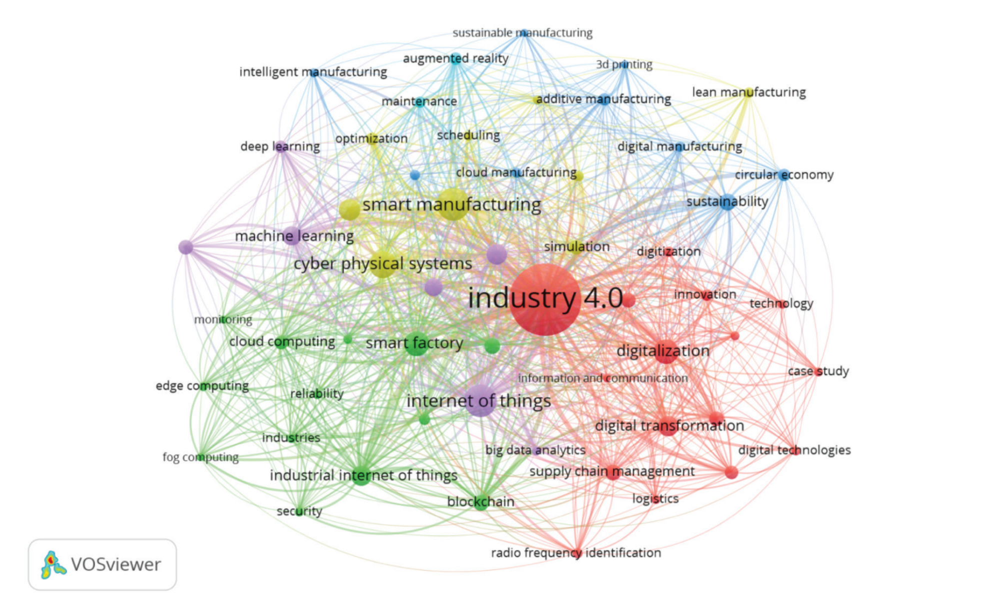


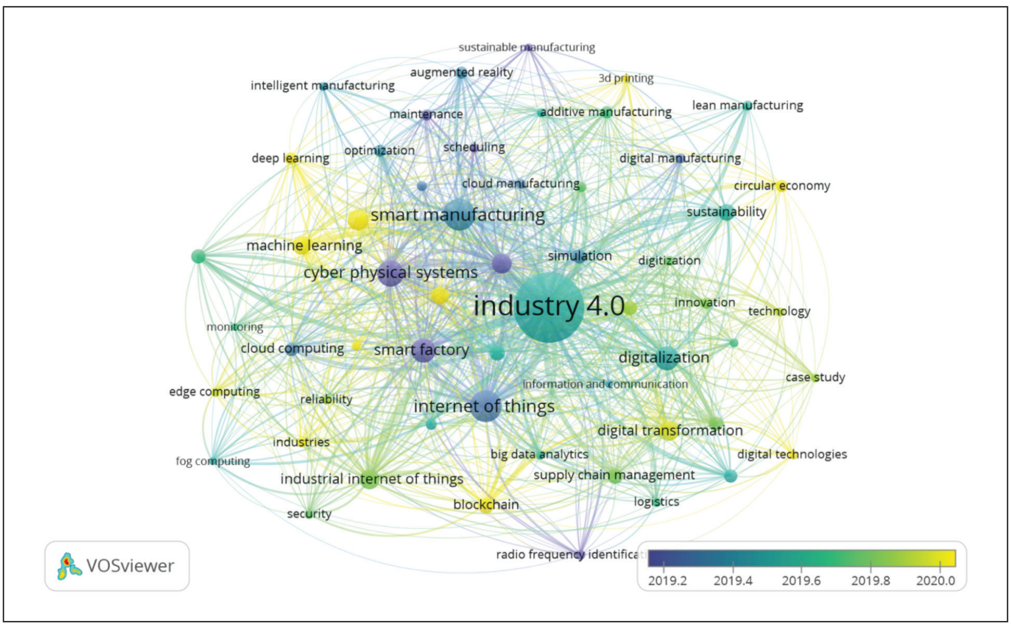
Figure 9: Clusters Resulted from the Co-Occurrences Analysis of Keywords

Cluster 1	Cluster 2	Cluster 3	Cluster 4	Cluster 5	Cluster 6
•case study	•automation	•3d printing	•cyber physical systems	•big data	•augmented reality
•digital technologies	•blockchain	•additive manufacturing	•data analytics	•big data analytics	•maintenance
•digital transformation	•cloud computing	•circular economy	•decision making	•deep learning	
•digitalization	•edge computing	•cloud manufacturing	•digital twin	•internet of things	
•digitization	•fog computing	•digital manufacturing	•lean manufacturing	•machine learning	
•fourth industrial evolution	•industrial internet of things	•intelligent manufacturing	•optimization	•predictive maintenance	
•industry 4.0	•industries	•manufacturing systems	•scheduling		
•information and communication technology	•manufacturing	•sustainability	•simulation		
•innovation	•monitoring	•sustainable manufacturing	•smart manufacturing		
•logistics	•production				
•performance	•reliability				
•radio frequency identification	•security				
•small and medium enterprises	•smart factory				
•supply chain					
•supply chain management					
•technology					

Cluster 1, led by I4.0, addresses the effects of digitalization, digital technologies, and I4.0 on supply chain management. The use of cloud computing, edge computing, and fog computing for the industrial internet of things (IIoT) data demand and impacts of blockchain on the security of these computing paradigms in the context of smart factories have been examined by the studies included in cluster 2. Cluster 3 has been formed by focusing on the effects of I4.0 technologies on sustainable manufacturing. Cluster 4 is grouped on simulation applications to create a digital twin to optimize processes and schedule tasks in manufacturing systems; Cluster 5, on the other hand, is grouped on predictive maintenance applications with machine learning and deep learning, based on the IoT data. The last and the smallest cluster, Cluster 5, focuses on the maintenance applications of augmented reality.

In the overlay visualization network shown in Figure 10, the co-occurrence of keywords that occur at least 25 times is colored on a time basis. The average publication years of the articles using these keywords range from 2018.21 (radio frequency identification) to 2020.50 (industries). At the beginning of 2019, the most studied keywords were CPS, "big data," SF. The keywords with the average publication year mid-2019 are I4.0, SM, "digitalization," "sustainability," "lean manufacturing," and "fog computing." The most recently studied keywords are "machine learning," "deep learning," DT, "blockchain," "edge computing," and "industries."

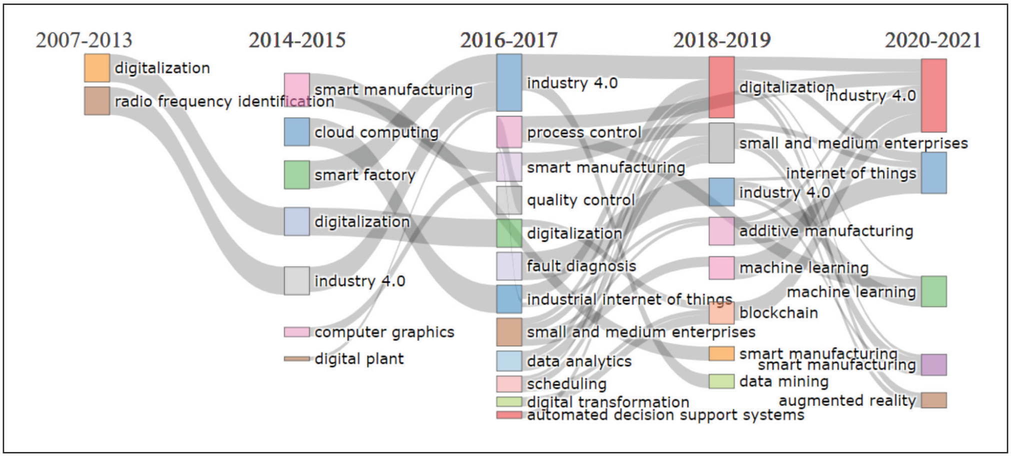
Figure 10: Overlay Visualization of Author Keywords Co-Occurrence Network of DT-OM Articles



3.2.2. Thematic Evolution

Thematic evolution and thematic map analyses have been performed with R Biblioshiny app to visually reveal the evolution of the articles published on the relationship between DT and OM over time and provide insight for future studies in this field. The thematic evolution shown in Figure 11 has been created based on the Author's Keywords, using 2013, 2015, 2017, and 2019 as the cutting points. Moreover, for each time slice between the cutting points, thematic maps have been created to reveal the positions of the themes on the development of the DT-OM field. In thematic maps, themes are classified using two parameters, density and centrality, and mapped in four quadrants: motor, niche, emerging or declining, and basic themes (Callon et al. 1991; Cobo et al., 2011). Thematic maps have been used in many studies to reveal the current status and direction of research themes and visualize the maturity and cohesion of research themes (Hosseini et al., 2021).

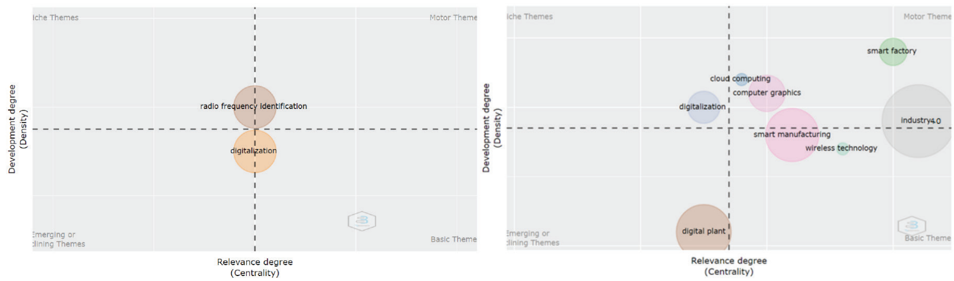
Figure 11: Thematic Evolution on DT in OM Research Field



In the 2007-2013 period, there are eight studies in total in the dataset of this study. Caulkin et al. (2007) and Santolaria et al. (2009) have used digitalization, and Zhang et al. (2008) and Petracca et al. (2013) have mentioned radio frequency identification in the Author's Keywords section of their studies. Caulkin et al. (2007) handled the problem of packing particles in columns with digital techniques, Santolaria et al. (2009) addressed digitalization in the calibration process for measuring machines.

SM, "cloud computing," SF, "digitalization," I4.0, "computer graphics," and "digital plant" have emerged as new themes between 2014 and 2015 when studies on the relationship between DT and OM have started to increase. Figure 12 demonstrates the thematic map of the 2007-2013 and 2014-2015 time slices.

Figure 12: Thematic Maps of DT in OM Research Field over the 2007-2013 and 2014-2015 Time Slices



2007-2013 2014-2015

Between 2014-2015, SF, “computer graphics,” and “cloud computing” are motor themes, also a large part of I4.0 and a part of SM are in the field of motor themes. This situation indicates that these themes have driven this field in this time slice. On the other hand, the “digitalization” theme in the niche theme quadrant indicates that digitalization has been developed in this time slice but isolated from other themes. “digital plant” is the only emerging theme in this time slice.

SM and I4.0, first developed as a theme in the DT-OM field in 2014-2015, remain research themes in all subsequent periods in this field. Another important theme, “digitalization,” has continued to be a theme in the field from 2007 to 2020-2021. In 2014-2015, SM was addressed in articles dealing with topics such as the use of big data and big data technologies in production (O’donovan et al., 2015), maintenance in an SM environment (Lao et al., 2015), standardization for enabling technologies in an SM environment (Helu et al., 2015), and development a testbed for sustainable manufacturing in the context of SM (Lee et al., 2015).

During 2014-2015, digitalization mainly studied on the topics of digitization on the product design process (Henfridsson et al., 2014), the effects of digitalization on productivity and employment growth (Evangelista et al., 2014), and plant simulation in a digital factory (Hovanec et al., 2015). Another important theme, I4.0, was studied in various studies in 2014-2015. For example, Prause (2015) studied sustainable business model structures required for I4.0, Yue et al. (2015) addressed the effects of industrial CPS and cloud technologies on the manufacturing environment, Agarwal & Brem (2015) provided case studies on the use of enabling technologies of I4.0, Maier et al. (2015) addressed the problem of information asymmetries in supply networks with I4.0 enabling technologies.

In the next time slice between 2016 and 2017, new keyword themes have been developed, including “process control,” “quality control,” “fault diagnosis,” IIoT, “small and medium enterprises,” “data analytics,” “scheduling,” DT, and “automated decision support systems.” In the 2016-2017 time period, the themes that have driven the field are IIoT, DT, “data analytics,” “security,” “quality control,” “flexible manufacturing,” and “process planning.” I4.0, which was closer to being a motor theme between 2014-2015, is clearly among the basic themes in the 2016-2017 time slice. This result means that the I4.0 theme has significant external ties with other themes and is essential for the development of the literature in the field. However, its internal ties are not sufficiently developed during this time slice. The development of the SM theme has followed a similar course. “digitalization,” which was a niche theme in 2016-2017, has become a basic theme in this time period. “fault diagnosis,” “scheduling,” “process control,” “small and medium enterprises” are other basic themes of this time period.

Between 2016 and 2017, studies have been carried out on the IIoT and DT, which are among the prominent motor themes of this period in the manufacturing environment. Barreto et al. (2017) discussed the effects of the IIoT in logistics, and Kiel et al. (2017) addressed its effects on sustainable value creation. Civerchia et al. (2017) studied the monitoring of industrial machines via IIoT devices and their use in predictive maintenance applications, while Lee et al. (2017) developed an IIoT based cloud platform for the smart production environment. Küsters et al. (2017) explained the DT process through a factory case. In another study, Schlüter & Sommerhoff (2017) focused on the impacts of DT on quality management. Apart from the manufacturing context, Pal (2016) addressed DT in meta-data production, Kettunen & Laanti (2017) discussed future software organizations considering the effects of DT.

The keyword themes “additive manufacturing,” “machine learning, “blockchain,” “data mining” have been first developed between 2018-2019. Figure 13 shows the thematic map of the 2016-2017 and 2018-2019 time slices.

Figure 13: Thematic Maps of DT in OM Research Field over the 2016-2017 and 2018-2019 Time Slices

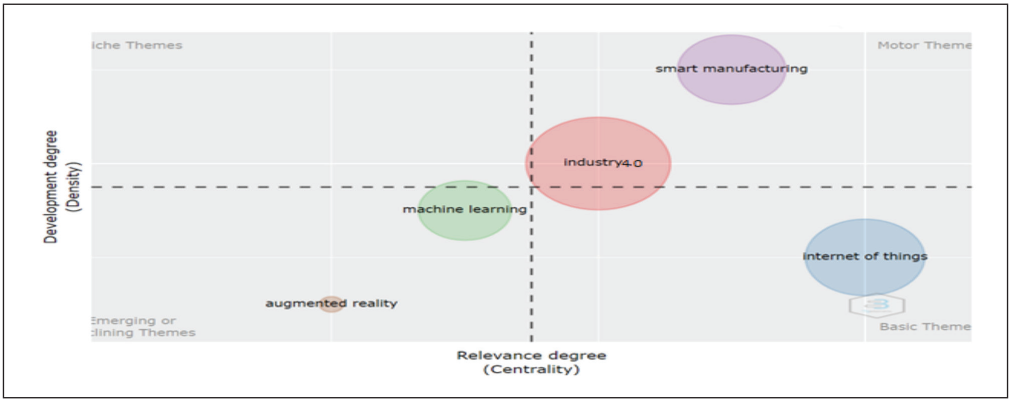
In the 2018-2019 time slice, I4.0, SM, and “digitalization” maintained their positions in the 2016-2017 time slice. In this time slice, “industrial automation” applications took place as the motor theme of the DT-OM field. Also, the “machine learning” theme is located in the middle of the motor and basic theme quadrants.

Among the studies examining industrial automation systems, Bizubac et al. (2018) studied the effects of I4.0 on ERP operations in the context of industrial automation. Brodny & Tutak (2019) addressed the industrial automation systems’ impacts on the utilization of mining machines. Machine learning has received a great deal of attention in the OM field between 2018 and 2019 and has been studied in a wide variety of areas such as predictive maintenance (Zenisek et al., 2019; Yang et al., 2019), inventory classification (Lolli et al., 2019), anomaly detection (Maamar & Benahmed, 2019; García, 2019), and quality control (Peres et al., 2019).

The blockchain theme, which first appeared in this time slice, is located in the basic theme quadrant close to the motor theme quadrant. In this period, studies on blockchain have focused on the effects of blockchain on supply chain ripple effects (Ivanov et al., 2019), trust issues among supply chain partners (Longo et al., 2019), reduction of carbon emissions (Fu et al., 2018), improvement in energy productivity (Mohamed et al., 2019), cognitive manufacturing processes (Chung et al., 2019), and improvement in information security (Cardoso et al., 2019).

In the 2020-2021 time slice, there are five themes, as seen in Figure 14. The motor themes that guided the DT-OM field in this time period have been SM and I4.0. In addition, the "machine learning" theme, which was between the motor and basic theme quadrants in the 2018-2019 time period, was included in the emerging/declining theme quadrant in the 2020-2021 period due to the decrease in its relevance degrees. However, there was no significant change in its development degree.

Figure 14: Thematic maps of DT in OM research field over 2020-2021



"augmented reality" has been an emerging theme in the 2020-2021 time slice. This result indicates that studies on augmented reality may increase in the future and trigger new trends in the research field. IoT has been included as a theme for the first time in the 2020-2021 time slice as a basic theme. It has been studied in many studies with many other themes. As a result of this interaction, even though its internal ties are not sufficiently developed, external ties are significantly developed. In this time slice, IoT has been studied in the context of many topics in the field of DT-OM, including the applications of I4.0 on quality (Viriyasitavat et al., 2020; Yadav et al., 2020), supply chain (Esmaeilian et al., 2020; Fatorachian & Kazemi, 2021), maintenance and reliability (Navas et al., 2020; Yu et al., 2020), production planning (Oluyisola et al., 2020), ERP systems (Tsai et al., 2020).

4. Conclusions

Inevitably, the DT imposed by the production understanding of our age has affected the OM discipline, which is related to all sub-processes of production. The idea that the scientific literature examining the relationship between OM and DT is an important indicator for understanding these effects and their evolution over time constitutes the motivation of this study. This study uses a two-stage approach including SLR and bibliometric analysis to draw a broad perspective on the relationship between DT and OM, reveal the thematic evolution in this research area, and infer potential future research directions. This study's data set comprises articles retrieved from Wos and Scopus, which are among the most comprehensive databases for the OM field, by using an extensive keyword list about OM and DT, without any time restrictions. Removing articles with missing sections and filtering articles by content and quality resulted in the final dataset containing 3021 articles. The final dataset was analyzed to find responses to the RQs determined in line with the scope and purpose of the study.

Descriptive analysis indicates an increasing publication trend in this research area since 2015. DT has been mostly studied in Performance, Managing Quality, Supply Chain Management, Maintenance and Reliability, and Simulation topics of OM, respectively. On the other hand, “aggregate planning,” “waiting line,” and “waiting-line” have not been mentioned in the abstract, title, and keyword sections of any study in the analysis set. TCR of articles published in the DT-OM field, without publication in 2021, indicates a steady increase over the analysis period. In the articles in the DT-OM field, Performance, Supply Chain Management, and Managing Quality have been the most consistently cited OM topics in recent years.

The most prolific author is ZHONG Ray (Ray Y. Zhong). The most cited article in this field is “Intelligent Manufacturing in the Context of Industry 4.0: A Review”, of which Ray Y. Zhong is the corresponding author. According to the corresponding author-based analyses, China, Italy, and the USA produce the most articles. China, the USA, and Italy are in the top three in terms of total citations. The IJPR, Procedia Manufacturing, and IEEE Access are in the top three for total citation. The most frequently used keyword in the Author's Keywords of articles in the final data set is I4.0 by far. This keyword is followed by IoT, SM, CPS, digitalization,” and SF, which have similar frequencies.

The conceptual structure of the DT-OM research area has been examined by creating co-occurrence networks of the Author's Keywords and conducting thematic evolution and thematic map analyses based on those keywords. In the co-occurrence network analysis, six main clusters were determined, led by I4.0, SF, “sustainability,” SM, and IoT. The two largest clusters are Cluster 1 and Cluster 4, with the highest total occurrence of the keywords they contain. In these clusters, applications of digital technologies in I4.0 and SCM and simulation-based digital twin creation of manufacturing systems have been discussed.

In the overlay visualization of co-occurrence network, among the keywords in these clusters, the most used keyword in the articles published in the DT-OM research field in mid-2018 was “radio frequency distribution,” in early 2019 CPS, “big data,” and SF. While the most mentioned keywords in mid-2019 were I4.0, SM, “digitalization,” “sustainability,” “lean manufacturing,” and “fog computing,” the most recently studied keywords are “machine learning,” “deep learning,” DT, “blockchain,” “edge computing” and “industries.”

The thematic evolution of the research area has been analyzed in five time periods: 2007-2013, 2014-2015, 2016-2017, 2018-2019, and 2020-2021. SM and I4.0 have always been the themes contributing the most to the literature in the research area, starting from 2014-2015. Many studies have studied these keywords with a wide variety of keywords. For this reason, although they have been the basic theme in some periods, they have been the motor themes of the field in the most recent period, 2020-2021. Digitalization has been an important theme from 2014 to 2019.

In 2016-2017, which is one of the richest periods in terms of the number of themes and the development of the research field, the IIoT and DT are two of the most prominent motor themes. Furthermore, process planning and control, quality control, and scheduling, which are important OM subjects, have also been among this period's motor and basic themes.

Blockchain, an important basic theme in 2018-2019, has been analyzed in many aspects. In addition, machine learning has become a theme in the two most recent periods, 2018-2019 and 2019-2021. In the last two time slices, 2018-2019 and 2020-2021, data mining and augmented reality have been emerging themes, respectively.

5. Potential Future Research Directions

Projections of potential future study topics in DT-OM research have been made based on the thematic map analysis for 2020-2021, distribution of OM topics in articles published during 2020-2021, and a 2021 trend topic analysis with the R Biblioshiny app. According to the thematic map of DT in the OM research field over 2020-2021, "augmented reality" has been an emerging theme in this period. This result indicates that studies on augmented reality may increase in the future and trigger new trends in the research field.

The most studied OM topics of DT in 2021 are Performance, Supply Chain Management, Managing Quality, Maintenance and Reliability, Decision-Making Tools, and Simulation. It is projected that DT will address these areas with this intensity. On the other hand, the topics where search words are not included in the abstract, title, and keyword of any article in the data set in 2021 are Operations Strategy, Process Strategy, Statistical Process Control, Aggregate Planning, Sales and Operations Planning, Location Strategies, Work Measurement, Waiting Line and Vehicle Routing. This situation indicates that DT has research gaps in these OM topics.

The trending topics of 2021 are "industries", "3d printing", "reinforcement learning", "feature extraction" and "computer architecture". Articles published in 2021 or Early Access mentioning these keywords have been reviewed. Based on the studies addressing current trend topics and the findings of the thematic analysis, the topics and the related research areas that are projected to be studied in the DT-OM field in the near future are presented in Table 9.

Table 9: Topics and Research Areas Projected to be Studied in the DT-OM Field

Topic	Research Area
Reinforcement learning	Applications of reinforcement learning to improve resilience in production control and supply chain management
Feature extraction	Applications of deep learning methods for feature extraction, feature recognition, feature selection, fault detection, and quality prediction problems
Computer architectures	Creation of IoT based platforms and computer architectures to enable scheduling of tasks for such a purpose of reducing energy consumption, continuity of data transmission from manufacturing in cyber-physical manufacturing systems
Cybersecurity	Development of models for cybersecurity with different objectives such as determining the cybersecurity maturity level of a system and determining the optimum cybersecurity investments portfolio for a system
Sustainability and resilience of manufacturing systems and supply chains	Enhancement of sustainability and resilience of the manufacturing systems and supply chains, for example, by creating digital twins to ensure that risks in the system are identified and proactively addressed
Augmented reality	Design of augmented reality assisted systems and making industrial applications in human-intensive processes like maintenance and quality inspection
Dynamic capabilities	Analysis of the effects of DT on companies' OM-related processes from the dynamic capabilities view

Conflict of Interest

The authors declare that they have no conflict of interest.

Contribution Statement

The authors contributed to this study equally.

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