



A structured literature review on the interplay between emerging technologies and COVID-19 – insights and directions to operations fields

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Accepted: 6 May 2021

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Abstract

In recent years, emerging technologies have gained popularity and being implemented in different fields. Thus, critical leading-edge technologies such as artificial intelligence and other related technologies (blockchain, simulation, 3d printing, etc.) are transforming the operations and other traditional fields and proving their value in fighting against unprecedented COVID-19 pandemic outbreaks. However, due to this relation's novelty, little is known about the interplay between emerging technologies and COVID-19 and its implications to operations-related fields. In this vein, we mapped the extant literature on this integration by a structured literature review approach and found essential outcomes. In addition to the literature mapping, this paper's main contributions were identifying literature scarcity on this hot topic by operations-related fields; consequently, our paper emphasizes an urgent call to action. Also, we present a novel framework considering the primary emerging technologies and the operations processes concerning this pandemic outbreak. Also, we provided an exciting research agenda and four propositions derived from the framework, which are collated to operations processes angle. Thus, scholars and practitioners have the opportunity to adapt and advance the framework and empirically investigate and validate the propositions for this and other highly disruptive crisis.

Keywords COVID-19 · Emerging technologies · Artificial intelligence · Structured literature review

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1 Introduction

The COVID-19 pandemic outbreak has caused unparalleled disruptions in practically all fields and organizations' business models (Dubey, Bryde et al., 2020; Ivanov, 2020a; Pan & Zhang, 2020; Queiroz, Ivanov et al., 2020). In consequence, traditional industries like automotive (Forbes, 2020), food supply chain (Butu et al., 2020; Singh et al., 2020), information systems and education (Dwivedi et al., 2020), medical supplies (Manero et al., 2020; Pacheco & Laguna, 2020), hospital operations (Bauer et al., 2020; Marin-Garcia et al., 2020; Mileder et al., 2020), and the transportation sector (Baveja et al., 2020), among others, experimented exceptional disruptions and challenges (Ruel et al., 2021).

In this context, industry practitioners (Deloitte, 2020; McKinsey, 2020) and scholars (Ivanov, 2020b; Remko, 2020; Sarkis et al., 2020; Sodhi et al., 2021) has agreed about the decisive role of technologies in to fight against COVID-19 and other future disruptive events and emergency situations (Amaratunga et al., 2021). More specifically, the emerging technologies (Grover et al., 2020; Queiroz, Fosso Wamba et al., 2020), also known as cutting-edge technologies, refer to a set of disruptive technologies that present fast growth, major impact, and in various cases, radical novelty, but with its potential under development (Akter et al., 2020; Rotolo et al., 2015).

In this vein, organizations and the whole society can benefit from a wide range of disruptive digital technologies (M. Gupta et al., 2021; Spanaki et al., 2021) to face an exceptional event like COVID-19. These include artificial intelligence (Belhadi et al., 2021; Fosso Wamba, Bawack, et al., 2021), blockchain (Dubey, Gunasekaran, Bryde, et al., 2020; Wamba & Queiroz, 2020), big data analytics (Dubey, Gunasekaran, Childe, et al., 2020; Fosso Wamba, Queiroz, et al., 2020), the internet of things (A. Sinha et al., 2019), 5G (Siriwardhana et al., 2020), 3d printing (Belhouideg, 2020), virtual reality (Mao et al., 2020), augmented reality (Sahu et al., 2020), digital twin applications (Ivanov & Dolgui, 2020), as well as the Industry 4.0 applications (Kumar & Singh, 2021; Queiroz, Ivanov et al., 2020).

While the literature exploring COVID-19 in different operations, management, and information systems perspectives have made significant progress (Chesbrough, 2020; Dwivedi et al., 2020; Y. Li et al., 2020; Manero et al., 2020; Queiroz, Ivanov et al., 2020; Remko, 2020; Sarkis, 2020; Sodhi et al., 2021; Ivanov, 2020a, b), there is still a huge gap when we consider a systemization about the role of emerging technologies to fight against this pandemic outbreak, the lessons, insights, and directions for other future emergency situations (Choi, 2021; Ivanov, 2021).

In this line of thought, the literature dealing with the interplay between technologies approaches and COVID-19 shows a lack of a structured integration of key emerging technologies for COVID-19 control (Ivanov, 2020b; S. Kumar et al., 2021; Queiroz, Ivanov et al., 2020). For example, despite the recent, rapid increase in the number of reviews (Chowdhury et al., 2021; Ranjbari et al., 2021; Surabhi & Anders, 2020), most of them are limited to fully explore the integration between emerging technologies and COVID-19 as a primary approach. In this regard, Surabhi and Anders (2020) presented a bibliometric analysis integrating business and management perspectives. Ranjbari et al. (2021) provided a systematic literature review with a focus on the issue of sustainability and COVID-19, and concluded by drawing an agenda considering sustainable development. In the supply chain field, Chowdhury et al. (2021) made a systematic literature review and presented interesting research opportunities on this integration.

In addition, some literature reviews have predominantly focused on only one of these elements (Choi, 2021; Queiroz, Ivanov et al., 2020). For instance, Choi (2021) presented a

well-articulated literature analysis exploring the COVID-19 in the lens of operations management. Queiroz, Ivanov et al., (2020) explored the COVID-19 and other epidemic outbreaks using a structured literature approach and focusing on supply chain-related fields. Katsaliaki et al. (2021) provided a literature review on supply chain disruptions, including the COVID-19, but without any focus on emerging technologies.

In order to minimize this gap, our study follows a structured literature review strategy approach (Queiroz, Ivanov et al., 2020) to explore the dynamics of the relationship between emerging technologies in the COVID-19 pandemic outbreak. Thus, the following research questions (RQs) emerge:

RQ1. What is the dynamics used for publications dealing with the interplay between COVID-19 and emerging technologies?

RQ2. What technologies are being used to fight against COVID-19?

RQ3. What are the main lessons about the application of emerging technologies to emergency events such as COVID-19?

Regarding this study's main contributions, we expect to provide a well-articulated systematization about the main emerging technologies and their role in the fight against COVID-19. This study intends to unlock new research streams by presenting a novel categorization and an insightful research agenda to support industry practitioners and scholars in their efforts to understand the contributions and role of key technologies applied in emergency situations.

This paper is organized as follows. Section 2 presents the methodology approach, followed by the analysis of the results in Sect. 3. In sequence, Sect. 4 points out the discussion and implications. Section 5 introduce a novel framework and research directions. Finally, Sect. 6 is dedicated to highlighting the concluding remarks and the main contributions.

2 Methodology approach

Following recent studies (Beydoun et al., 2019; Kapoor et al., 2018; Mishra et al., 2018), we adopted a bibliometric approach to capture the literature's dynamics regarding the interaction between emerging technologies and COVID-19. Bibliometric analysis is considered a robust approach to map a particular field by providing different metrics in order to support a more in-depth comprehension of the topic (Beydoun et al., 2019; Mishra et al., 2018; Nunes & Pereira, 2021). Besides, we applied a structured strategy to manage a research protocol and provide new categorization to the literature (Queiroz, Ivanov et al., 2020). This mixed strategy can be considered a structured literature review by integrating these two literature review techniques (bibliometric and systematic) (Queiroz, Ivanov et al., 2020) (Table 1).

Firstly, we identified the leading and reliable, and trustworthy database to support the search. Thus, we used the Web of Science database (Clarivate Analytics, 2020) as the main source to search. Secondly, in order to organize the amount of data, we adopted two well-known software. For this reason, we employed Biblioshiny (Aria & Cuccurullo, 2017; Queiroz, Ivanov et al., 2020) and VOSviewer (Mishra et al., 2018; Nunes & Pereira, 2021). We selected the keywords by screening on Google Scholar different previous studies exploring COVID-19 and proposing emerging technologies to fight against this pandemic outbreak.

Table 1 Research protocol

Dimension	Description
Keywords	(TS=(“covid-19” OR “Covid19” OR “Covid” OR “coronavirus” OR “Sars-CoV-2” OR “SarsCoV2”) AND TS=(“Internet of things” OR “IoT” OR “artificial intelligence” OR “machine learning” OR “deep learning” OR 5G OR “Serverless Computing” OR blockchain OR Robotics OR Biometrics OR “3D Printing” OR “Additive Manufacturing” OR “Virtual Reality” OR “Augmented Reality” OR Drone OR “Digital twin”))
Timespan	2020
Web of Science databases	SCI-EXPANDED, SSCI, A&HCI, CPCI-S, CPCI-SSH, ESCI
Fields	Title, Abstract, and Keywords
Inclusion criteria	Papers published in the WoS database
Complete information about the article’s data	
Exclusion criteria	Non-English language articles
Incomplete information about the article	
Data extraction and analysis	Biblioshiny and VOSviewer

3 Results analysis

3.1 Main information of the search

By applying the keywords mentioned in the research protocol, we identified 1,297 papers. In sequence, we employed the inclusion and exclusion criteria, which in turn resulted in 1247 papers to analyze. Regarding some basic metrics, the average citations per paper are 3.76. A total of 3,406 keywords were used for 1,247 papers. Also, 6,473 authors appeared in these articles, and only 114 papers were single-authored papers. The average number of authors per document was 5.19. These initial numbers are highlighted in Table 2, and show an interesting interaction and contribution between the authors.

3.2 Sources indicators

In Table 3, we present the top 20 sources based on a number of publications (NP) and total citations (TC). We found the dominance of the journals from the computer fields, medical and medical informatics. In this vein, the first ranked was the *IEEE Access* (NP=57), a multidisciplinary and open access journal, which publishes several papers on the interplay between computer science and engineering. However, when considering the TC, the most ranked journal is the *International Journal of Environmental Research and Public Health* (TC=215), which is focused on the interactions between environmental science and medicine. While these three categories (computer fields, medical and medical informatics) dominate the most relevant sources considering the output and citations, journals from traditional areas like operations management/research, production systems, logistics, supply chain, information systems and business management do not appear in the ranking.

Table 2 Main information

Description	Results
Timespan	2020
Sources (Journals, Books, etc.)	613
Documents	1247
Average citations per documents	3.763
Average citations per year per doc	2.056
<i>Document contents</i>	
Author's Keywords (DE)	3406
<i>Authors</i>	
Authors	6473
Author Appearances	7437
Authors of single-authored documents	108
Authors of multi-authored documents	6365
<i>Authors collaboration</i>	
Single-authored documents	114
Documents per Author	0.193
Authors per Document	5.190

3.3 Authors indicators

To explore the indicators from the authors, Table 4 presents the top 20 ranked authors based on the output of papers. Also, we added the fractional authorship indicator, which computes an individual author's contributions to a group of papers published (Geunes & Su, 2020). The most contributed author was Li (10), followed by Wang (8), Duong (6), and Kumar (6). It is interesting to note that four authors outperformed five papers.

3.4 Affiliations information

Considering the outcomes by affiliations (Table 5), the first five of the ranking were Chinese and American institutions. The most productive was *Huazhong University of Science and Technology*, a Chinese university, with 47 papers, followed by the Americans *Icahn School of Medicine at Mount Sinai* (39 papers), *Harvard Medical School* (32 papers), *Stanford University* (27 papers), and again a Chinese institution with *Fudan University* (26 papers). Furthermore, considering the top 20, this behavior is similar, with a few exceptions: the University of Toronto (sixth position), King Saud University (eighth), the University of Milan (eleventh), followed by the University of Oxford (twelfth), and the University of Cambridge (seventeenth).

3.5 Information about countries production

Regarding the countries' papers production (Table 6), the USA (1,047), China (804), India (382), Italy (360), and the United Kingdom (262) rank the top five. In this outlook, only two countries outperformed 500 papers. Moreover, the ranking comprises another North America country (Canada) that achieved great performance. While countries from Asia and Europe reached excellent participation, countries from underrepresented regions did

Table 3 Most relevant sources and impact

Rank	Source	h_index	g_index	m_index	TC	NP	PY_start
1	IEEE Access	6	10	3.0	119	57	2020
2	Journal of Medical Internet Research	5	9	2.5	99	48	2020
3	Chaos Solitons & Fractals	6	10	3.0	134	29	2020
4	PLOS ONE	3	6	1.5	43	25	2020
5	Applied Sciences-Basel	4	5	2.0	33	22	2020
6	International Journal of Pervasive Computing and Communications	2	2		12	22	2020
7	International Journal of Environmental Research and Public Health	5	14	2.5	215	21	2020
8	Applied Intelligence	2	6		37	17	2020
9	Journal of Intelligent & Fuzzy Systems	0	0	0.0	0	13	2020
10	Sustainability	1	1	0.5	6	13	2020
11	Journal of Clinical Medicine	3	4	1.5	21	11	2020
12	IEEE Journal of Biomedical and Health Informatics	1	2	0.5	4	10	2020
13	European Radiology	2	2		12	9	2020
14	Journal of Medical Systems	4	8	2.0	65	9	2020
15	Scientific Reports	1	1	0.5	4	9	2020
16	Sensors	2	3	1.0	12	9	2020
17	CMC-Computers Materials & Continua	2	7	1.0	58	8	2020
18	Computers in Biology and Medicine	5	8	2.5	127	8	2020
19	PEERJ	1	3	0.5	11	8	2020
20	Diabetes & Metabolic Syndrome-Clinical Research & Reviews	5	7	2.5	66	7	2020

Table 4 Most relevant authors

Rank	Authors	Articles	Articles Fractionalized
1	Li L	10	0.74
2	Wang J	8	0.91
3	Duong TQ	6	0.89
4	Kumar S	6	2.45
5	Das R	5	0.66
6	Hossain Ms	5	1.16
7	Kumar A	5	1.86
8	Lee J	5	0.70
9	Li Hf	5	0.69
10	Liu J	5	0.30
11	Peng CZ	5	0.83
12	Pirouz B	5	1.00
13	Sharma A	5	1.39
14	Wang L	5	0.37
15	Wang Yl	5	1.16
16	Ye Rz	5	0.83
17	Zhang Y	5	0.46
18	Zhu Ts	5	0.88
19	Abdulkareem KH	4	0.33
20	Ali S	4	0.56

not appear in the top-10 list. For instance, it should be noticed the stark absence of Central Africa's countries. Surprisingly, a Latin American country, namely Brazil, achieved the eighteenth position.

3.6 Citations per countries

In Table 7, we consider the countries' citations. It can be seen that although China and the USA are practically tied in a number of citations, with 1,129 and 1024, respectively, the performance of the average article citations of China is better. In addition, these two countries were the only ones that outperformed 1,000 citations. The third in the rank, India, raised only 298 citations. On the one hand, China and the USA led the total citations; surprisingly, the average citations were dominated by Mauritius (40.000), Belgium (30.889), and Croatia (15.500). However, it is important to note that a small number of papers can benefit from the average article's citations.

3.7 Top 20 papers based on the number of citations

Table 8 shows the 20 papers most cited, their respective first authors, and the journal. The top-ranked was a systematic review and critical analysis of prediction models for COVID-19. While the second paper did not focalize on any specific utilization of an AI-related

Table 5 Most relevant affiliations

Rank	Affiliations	Articles
1	Huazhong Univ Sci and Technol	47
2	Icahn Sch Med Mt Sinai	39
3	Harvard Med Sch	32
4	Stanford Univ	27
5	Fudan Univ	26
6	Univ Toronto	24
7	Natl Univ Singapore	22
8	King Saud Univ	21
9	Zhejiang Univ	21
10	China Med Univ	19
11	Univ Milan	19
12	Univ Oxford	19
13	Shanghai Jiao Tong Univ	18
14	Univ Hong Kong	18
15	Johns Hopkins Univ	16
16	Michigan State Univ	16
17	Univ Cambridge	16
18	Univ Penn	16
19	Wuhan Univ	16
20	Univ Calif Los Angeles	15

technology, the authors highlight the role of IoT in to fight against COVID-19 and other epidemic outbreaks; in the third most ranked, the authors used machine learning integrated with different approaches to explore the mental's health of the people during COVID-19. In general, papers exploring AI techniques like machine learning, deep learning, deep neural networks, convolutional neural networks, and other data-driven mechanisms were the most popular approaches. Predicting models for diagnosis, psychological treatments, image trials, and health monitoring were the most popular issues explored. Surprisingly, we found an exception outside from the healthcare perspective. A paper exploring COVID-19 from the lens of operations and supply chains (Ivanov, 2020a) achieved the citations' seventh position. The paper focuses on the epidemic outbreaks prediction by a simulation approach, considering the supply chains. Finally, we can see that only six papers exceeded 100 citations.

3.8 Keywords frequency—authors versus keywords plus

In Table 9, we provide the most frequent keywords. On the left side, we have the keywords given by the authors, and on the right side, the keywords plus, which were not provided by the authors (found by an algorithm approach). Considering the authors' side, it is clear that the keywords used in the search (protocol) were the top-ranked “covid-19”, “machine learning”, “artificial intelligence”, “deep learning”, “coronavirus”, etc. In addition, words that denote important operations supported by technologies like “telemedicine”, “prediction”, and “classification”, appear in this list. Finally, other cutting-technologies like “internet of things”, “3d printing”, and “big data”, also were protagonists.

Table 6 Country scientific production

Rank	Country	Frequency
1	USA	1047
2	China	804
3	India	382
4	Italy	360
5	United Kingdom	262
6	Canada	152
7	Spain	127
8	South Korea	126
9	Germany	117
10	Australia	96
11	France	80
12	Saudi Arabia	80
13	Singapore	74
14	Turkey	72
15	Iran	71
16	Egypt	65
17	Pakistan	60
18	Brazil	59
19	Netherlands	49
20	Vietnam	43

Table 7 Most cited countries

Rank	Country	Total Citations	Average Article Citations
1	China	1129	6.103
2	USA	1024	4.016
3	India	298	2.463
4	Belgium	278	30.889
5	Canada	277	6.756
6	Italy	208	3.200
7	United Kingdom	200	2.564
8	Germany	181	7.870
9	Turkey	159	6.360
10	Greece	96	7.385
11	Iran	77	5.133
12	Korea	62	1.676
13	Netherlands	58	7.250
14	Australia	47	1.424
15	Brazil	43	2.867
16	Mauritius	40	40.000
17	Qatar	40	10.000
18	Egypt	39	1.696
19	Spain	38	1.086
20	Croatia	31	15.500

Regarding the keywords plus, the term “prediction” appeared in the top three, suggesting one of the main features and concerns that the emerging technologies could improve. Also, influential keywords that participated in the author’s keywords, like “classification” and “artificial-intelligence”, populates the top ten. Furthermore, other keywords emerged and reinforce the needs for the usage of leading-edge technologies to fight against epidemic outbreaks. The keywords were “model”, “impact”, “diagnosis”, “risk”, “management”, and “design”.

3.9 Treemap dynamics

To finalize the analysis of the keywords dynamics, in Fig. 1 we present a TreeMap taking into account the abstracts. The size rectangle denotes the frequency of the term. In this vein, “covid”, “patients”, “data”, “pandemic”, and “learning”, were the most frequent topics. Regarding the emerging technologies outlook, we recognize that related topics like “data”, “learning”, “models”, “machine”, “methods”, “system”, “artificial”, “deep”, “accuracy”, “analysis”, “ai”, “detection”, “intelligence”, achieved good participation. Therefore, it bolsters the suggestion that emerging technologies play an essential role to tackle epidemic outbreaks and other emergency situations.



Fig. 1 TreeMap based on abstracts

Table 8 Most global cited documents

Rank	First author and Journal	Paper	DOI	Total Citations
1	Wynants L, 2020, <i>Bmj-Brit Med J</i>	Prediction models for diagnosis and prognosis of covid-19: systematic review and critical appraisal	10.1136/bmj.m1328	250
2	Peeri NC, 2020, <i>Int J Epidemiol</i>	The SARS, MERS and novel coronavirus (COVID-19) epidemics, the newest and biggest global health threats: what lessons have we learned?	10.1093/ije/dyaa033	231
3	Li SJ, 2020, <i>Int J Erv Res Pub He</i>	The Impact of COVID-19 Epidemic Declaration on Psychological Consequences: A Study on Active Weibo Users	10.3390/ijerph17062032	168
4	Yang ZF, 2020, <i>J Thorac Dis</i>	Modified SEIR and AI prediction of the epidemics trend of COVID-19 in China under public health interventions	10.21037/jtd.2020.02.64	148
5	Li L, 2020, <i>Radiology</i>	Using Artificial Intelligence to Detect COVID-19 and Community-acquired Pneumonia Based on Pulmonary CT: Evaluation of the Diagnostic Accuracy	10.1148/radiol.202000905	116
6	Li DS, 2020, <i>Korean J Radiol</i>	False-Negative Results of Real-Time Reverse-Transcriptase Polymerase Chain Reaction for Severe Acute Respiratory Syndrome Coronavirus 2: Role of Deep-Learning-Based CT Diagnosis and Insights from Two Cases	10.3348/kjr.2020.0146	115
7	Ivanov D, 2020, <i>Transport Res E-Log</i>	Predicting the impacts of epidemic outbreaks on global supply chains: A simulation-based analysis on the coronavirus outbreak (COVID-19/SARS-CoV-2) case	10.1016/j.tre.2020.101922	97
8	Ton AT, 2020, <i>Mol Inform</i>	Rapid Identification of Potential Inhibitors of SARS-CoV-2 Main Protease by Deep Docking of 1.3 Billion Compounds	10.1002/minf.202000028	88
9	Ozturk T, 2020, <i>Comput Biol Med</i>	Automated detection of COVID-19 cases using deep neural networks with X-ray images	10.1016/j.cmbiomed.2020.103792	71
10	Shen B, 2020, <i>Cell</i>	Proteomic and Metabolomic Characterization of COVID-19 Patient Sera	10.1016/j.cell.2020.05.032	70

Table 8 (continued)

Rank	First author and Journal	Paper	DOI	Total Citations
11	Yan L, 2020, Nat Mach Intell	An interpretable mortality prediction model for COVID-19 patients	10.1038/s42256-020-0180-7	66
12	Apostolopoulos ID, 2020, Phys Eng Sci Med	Covid-19: automatic detection from X-ray images utilizing transfer learning with convolutional neural networks	10.1007/s13246-020-00,865-4	65
13	Jiang XG, 2020, Cmc-Comput Mater Con	Towards an Artificial Intelligence Framework for Data-Driven Prediction of Coronavirus Clinical Severity	10.32604/cmc.2020.010691	54
14	Vigneswaran Y, 2020, J Gastrointest Surg	What Is the Appropriate Use of Laparoscopy over Open Procedures in the Current COVID-19 Climate?	10.1007/s11605-020-04,592-9	49
15	Mccall B, 2020, Lancet Digit Health	COVID-19 and artificial intelligence: protecting health-care workers and curbing the spread	10.1016/S2589-7500(20)30,054-6	49
16	Mei XY, 2020, Nat Med	Artificial intelligence-enabled rapid diagnosis of patients with COVID-19	10.1038/s41591-020-0931-3	44
17	Ciotti M, 2020, Crit Rev CI Lab Sci	The COVID-19 pandemic	10.1080/10408363.2020.1783198	42
18	Santosh KC, 2020, J Med Syst-a	AI-Driven Tools for Coronavirus Outbreak: Need of Active Learning and Cross-Population Train/Test Models on Multitudinal/Multimodal Data	10.1007/s10916-020-01,562-1	42
19	Allam Z, 2020, Healthcare-Basel	On the Coronavirus (COVID-19) Outbreak and the Smart City Network: Universal Data Sharing Standards Coupled with Artificial Intelligence (AI) to Benefit Urban Health Monitoring and Management	10.3390/healthcare8010046	40
20	Eccleston C, 2020, Pain	Managing patients with chronic pain during the COVID-19 outbreak: considerations for the rapid introduction of remotely supported (eHealth) pain management services	10.1097/j.pain.0000000000001885	38

Table 9 Most frequent words

Rank	Author's keywords	Occurrences	Keywords plus	Occurrences
1	covid-19	677	pneumonia	51
2	machine learning	181	coronavirus	50
3	artificial intelligence	157	prediction	37
4	deep learning	141	china	35
5	coronavirus	134	internet	33
6	sars-cov-2	113	health	32
7	pandemic	81	wuhan	32
8	computed tomography	40	classification	31
9	pneumonia	39	artificial-intelligence	30
10	learning	38	system	30
11	internet of things	37	disease	27
12	telemedicine	36	model	27
13	lung	31	impact	25
14	3d printing	30	outbreak	25
15	big data	30	covid-19	24
16	prediction	26	diagnosis	24
17	classification	24	risk	23
18	diseases	24	management	22
19	intelligence	24	sars	22
20	artificial	22	design	21

3.10 Cluster analysis

We performed a cluster analysis to explore the topic's similarities characteristics (Hosseini & Ivanov, 2020; Kafeza et al., 2020). In order to ensure reliability and replicability, Table 10 highlights the protocol adopted. Thus, we found six interesting clusters (Fig. 2).

In this respect, cluster one (red) is a mixed cluster, with emerging technologies (AI, augmented reality, big data, blockchain, IoT, robotics, simulation, virtual reality, etc.), operations medical approaches (contact tracing, digital health, telehealth), and business management (framework, innovation, management). Cluster 2 (green), is governed by deep learning and other AI approaches (convolutional neural network, neural network) applied mainly in the diagnosis process, diseases, image segmentation, recognition, segmentation,

Table 10 Cluster protocol

Type of analysis	Co-occurrence
Unit of analysis	All keywords
Counting type	Full counting
Minimum number of occurrences of a keyword	9
Meet the threshold	123

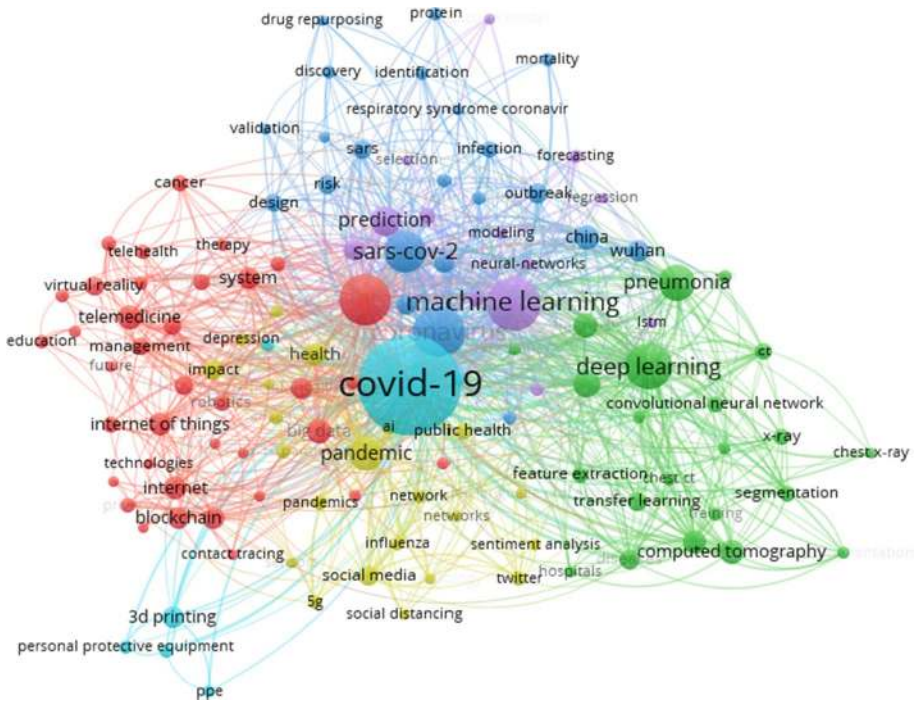


Fig. 2 Cluster analysis

x-ray, etc. Cluster 3 (dark blue) is dedicated to sars-cov-2 dynamics (identification, infection, mortality, outbreak, etc.). In sequence, cluster 4 (yellow) concentrates on social network approaches (networks, sentiment analysis, social media, Twitter, etc.) and other technology approaches (AI, natural language processing, 5G) to support the evolution of the pandemic outbreak. Next, cluster 5 (purple) is concentrated on technical aspects of the technologies (algorithm, forecasting, machine learning, model, neural networks, prediction, long short-term memory (LSTM), etc.). Lastly, cluster 6 (light blue) is focused on equipment supply (3d printing/additive manufacturing, personal protective equipment, etc.).

4 Discussion and implications

Following the main aim of this study, regarding the investigation of the relationship between emerging technologies and COVID-19 by the lens of operations-related fields, our structured literature review revealed interesting behavior. Firstly, considering one year of time horizon, we found 1,247 papers, and 6,473 authors; this is an impressive output. The papers resulting from a collaboration between several authors suggest an interesting effort between authors and countries to provide insights against this pandemic. Thus, resulting in a good average citation per article (3.763).

Given the journals' performance, while journals from the computer, medical, and medical informatics fields dominate the top 20 journals from production and operations management fields do not appear in the ranking. Thus, it can be seen as an alert for these fields

to engage the community on this topic. From the author's productivity side, four authors exceeded five papers — Li (10), Wang (8), Duong (6), and Kumar (6). Regarding the most productive institutions, China and the USA dominate the list. The same behavior was found in most cited countries' analysis. However, taking into account the average article citations, other countries appear more ranked (Mauritius, Belgium, and Croatia). It could be seen that due to a large number of papers from the USA and China, the average citation is minimized.

Regarding the performance of the top-cited papers, we found that machine learning, deep learning, deep neural networks, convolutional neural networks, and data-driven were the most popular techniques (Apostolopoulos & Mpesiana, 2020; Jiang et al., 2020; D. Li et al., 2020; Wynants et al., 2020; Yan et al., 2020). Although these techniques were predominantly applied in healthcare-related themes, we found an outlier representing the production and operations management field. A paper investigating the dynamics of the epidemic outbreaks on supply chains (Ivanov, 2020a), supported by the simulation approach, ranked in the seventh position.

The keywords analysis revealed interesting behavior in the literature. By comparing the authors versus keywords plus, we found similarities and some different words. From the author's lens, besides the popularity of the words used in our search (machine learning, artificial intelligence, deep learning, etc.), no keywords concerning a direct connection to operations and production management fields were found. Considering the keywords plus, the ranking was dominated by related-pandemic words. Furthermore, "prediction" appeared in both rankings, showing the need to use some emerging technologies to improve the response and the operations as a whole.

In order to explore other perspectives from the dynamics of the word, we performed a TreeMap analysis based on the abstracts. While we found that AI-related technologies reached good participation in the frequency, words that evidence a direct application to the production and operations management were scarce. However, it is important to note that there was an indirect connection of the keywords when it considered the angle from healthcare operations. For instance, "data", "learning", "models", "methods", "system", "artificial", "accuracy", "analysis", "detection", etc.

In relation to the cluster analysis, we found six clusters. The first, although being miscellaneous, it was dominated by emerging technologies that are related to AI (virtual reality, augmented reality, blockchain, big data, IoT, robotics, simulation, etc.), that are used to support operations medical approaches (contact tracing, digital health, telehealth). We found that cluster 2 was focused on deep learning and other AI approaches (convolutional neural network, neural network) to operations related to diagnosis, recognition diseases, etc. While cluster 3 did not present any production and operations perspective, cluster 4 emphasized social networks and other technologies like 5G to follow the evolution of the pandemic. Finally, cluster 5 emphasized the technical approaches (i.e., algorithms) of the emerging technologies, and cluster 6 concentrated on medical supply using technologies (i.e., 3d printing).

4.1 Theoretical implications

Our results unveiled intriguing behavior regarding the dynamics of the interplay between emerging technologies and COVID-19. Firstly, while journals from the computer, medical and medical informatics literature were protagonists in exploring emerging technologies

(Hao-Chih et al., 2020; Jiang et al., 2020; McCall, 2020; Ozturk et al., 2020), there is a huge gap concerning journals from production and operations-related fields, regarding the output's perspective. In this vein, an exception was Ivanov (2020a), with his paper "Predicting the impacts of epidemic outbreaks on global supply chains: A simulation-based analysis on the coronavirus outbreak (COVID-19/SARS-CoV-2) case", published on *Transportation Research Part E*. Thus, it suggests a more engagement by the scholars and journals of these fields to advance on this hot topic, increasing the output and the influence of the papers published.

From the emerging technologies angle, AI technologies like machine learning and deep learning were the most common approaches (D. Li et al., 2020; S. Li et al., 2020) but mainly applied to diagnosis, telemedicine, and prediction on hospital's operations. Other disruptive technologies like blockchain, virtual reality, 5G, 3d printing, big data, simulation, and IoT were found less frequent than the aforementioned AI technologies, but all can be integrated with AI technologies in order to leverage the power of the solutions to fight against epidemic outbreaks. Surprisingly, words related to "serverless computing", "biometrics", "drone", and "digital twin" did not appear in the keywords or cluster analysis. Thus, it suggests that these topics are embroidery in this perspective (AI and COVID-19), mainly regarding the production and operations fields.

Furthermore, in Sect. 5, we provide valuable research directions considering different and the most adherent operations approaches and organizational theories that can be used to explore the interplay between emerging technologies, COVID-19 and other emergency situations.

4.2 Practical implications

Regarding the practical and managerial implications, our study highlights that managers and practitioners should consider the adoption of AI-related technologies to improve their operations, independently of the segment of the organization (Dwivedi et al., 2019). For instance, machine learning, deep learning, and data-driven are powerful approaches to improve the prediction's capabilities of the organizations and, consequently, develop strategies to anticipate, respond, and improve their operations during and after complex crisis such as COVID-19. Moreover, other leading-edge technologies like blockchain, 5G, 3d printing and IoT, represent opportunities to managers integrate into their operations in order to improve the traceability of the goods, as well as replace some of the essential equipment by employing 3d printing.

Besides, as we consider that it is not trivial to integrate various emerging technologies under a holistic framework as an attempt to better inform practitioners, the next section proposes a framework that highlights key emerging technologies and their usage level, as well as some activities that could be supported by them in relation to emergency situations. Furthermore, the digital twin approach (Ivanov & Dolgui, 2020) appears as another valuable approach to combining different technologies in the same framework for the same purpose.

5 Framework and research directions

Based on the findings and the lack of literature, in this section, we provide a novel framework (Fig. 3) considering the interplay between AI, complex emergency situations like COVID-19, and the integration with production and operations-related fields. The framework has four AI perspectives.

First, the “Emerging technologies relative mature level”, which is related to technologies that are already being used in different COVID-19 operations through the organization’s network. In this category, machine learning, deep learning and big data analytics have been used to improve the predictions/forecasting regarding diagnosis, thus supporting the optimization of the resources planning (Allam & Jones, 2020; Jiang et al., 2020; D. Li et al., 2020; S. Li et al., 2020).

The second category is the “Emerging technologies early use level”, which is about the technologies required at the first stage of operations focused on COVID-19. For example, of the use of simulation techniques (Ivanov, 2020a) contributes to improving on supply chain, thereby enhancing the effectiveness of the achieved responses. This is particularly true with 3d printing, the use of which enables a quick replacement of critical medical supplies (Manero et al., 2020).

The third category is compounded by “Emerging technologies awareness level”, that is, technologies with a high potential to support operations in pandemic and other types of crisis, but managers and practitioners are still gaining knowledge about its applications in operations. This category has emerging technologies like digital twin (Ivanov, 2020a), 5G (Allam & Jones, 2020), among others.

The “Emerging technologies operations processes view” forms the last category. It encompasses the main operations that are enabled by the AI (emerging)-related technologies. Hence, we point out that with the use of the technologies from the aforementioned categories, processes related to contact tracing, telemedicine/telehealth, diagnosis, recognition, drug repurposing, forecasting, and production of critical supplies, can be significantly improved.

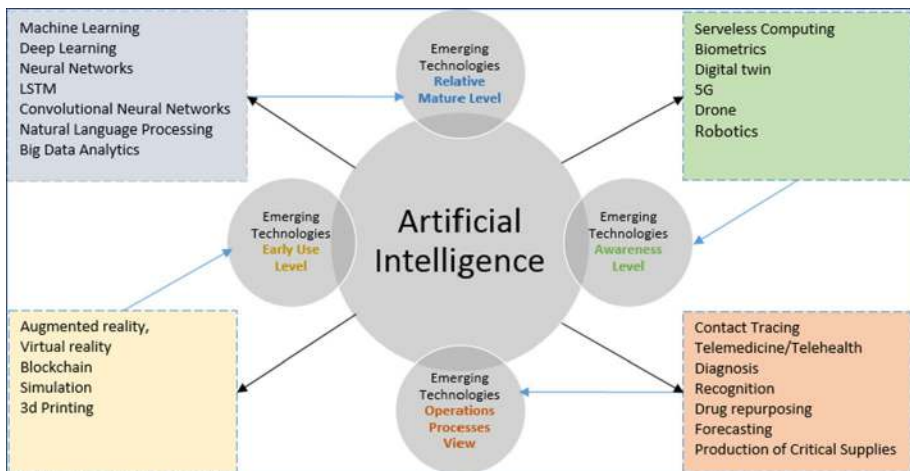


Fig. 3 Emerging technologies framework

Table 11 Future research directions supported by key organizational theories and OR/OM approaches

Research gaps and future research opportunities	Key organizational theories	Key operations approach	Suggested literature on operations and related fields
To explore how AI can support organizations and their SC in order to develop operations capability to fight against highly disruptive environments	Dynamic capabilities theory (Teecce & Pisano, 1994; Teece et al., 1997)	Simulation techniques for modeling the organizations and their SC with a view to adequate operations and resources monitoring during complex events	Ivanov (2020b); Mitreğa & Choi, (2021)
To explore how digital transformation has been supporting the creation of resources capabilities during and after disruptive events	Resource-based view (RBV) (Barney, 1991, 2001; Wernerfelt, 1984)	Structural equation modeling for understanding the digital capabilities that exert more influence and contribution to the management of emergency situations	El Baz & Ruel (2021); Nandi et al.(2020)
To investigate how emerging technologies can support operations management according to the emergency situation (evolution) stage	Contingency theory (Lawrence & Lorsch, 1967; Van de Ven et al., 2013)	Fuzzy and AI models to explore different strategies to respond to the crisis	Hassan & Abbasi(2021); A. Kumar, Man-gla, et al. (2021); Kumar, Xu, et al.(2021)
To explore the reconfiguration of SCs enabled by emerging technologies	Resilience theory (RT) (Duchek, 2019; Home, 1997)	Development of digital twin to support the decision-making process in the context of SC reconfiguration and viability	Ivanov (2020b); Remko (2020)
To explore vaccine distribution blockchain	Organizational information processing theory (OIPT) (Burns & Wholey, 1993; Galbraith, 1974)	Exploration of vaccine distribution models using blockchain to minimize the uncertainty and instability of the SC behavior	Benzidia et al. (2021); P. Sinha et al. (2021); Yu et al. (2021)
To explore the organizations and the SC operations adaptation behavior supported by emerging technologies	Complexity theory and Complex adaptive systems (Burnes, 2005; Holland John, 2006)	Big data analytics and AI to enable models to understand critical activities, vulnerabilities, and responses planning in the SC	Angeli & Montefusco (2020); Guo et al.
To explore how the organizations and their SC reconfigure their structures supported by emerging technologies	Institutional theory (DiMaggio & Powell, 1983)	Digital twins and AI approaches to understand and improve the reconfiguration processes of the organization's operations	Hwang & Höllner (2020); Ivanov & Dol-gui (2020); Karpen & Conduit (2020)
To explore how organizations share their digital capabilities to improve their response and resilience in the SC	Social network theory (Freeman, 1978; Granovetter, 1973)	AI and social networks models to understand critical relationships weak, and strength nodes in the SC	Bassett et al. (2021); Santosh et al. (2021)

Table 11 (continued)

Research gaps and future research opportunities	Key organizational theories	Key operations approach	Suggested literature on operations and related fields
To explore the challenges and main issues concerning the integration of the emerging technologies	Organizational change management (Appelbaum et al., 2012; By, 2005)	To identify the main issues related to emerging technologies (Fig. 3), and integration during and after disruptive events (i.e., privacy, security and organizational change), as well as the impacts on operations management	Allam & Jones(2021); Baptista et al. (2020); Fletcher & Griffiths (2020); Lee & Trimi(2021); Papagiannidis et al. (2020)

In order to better scrutinize this framework and provide valuable research directions, we derived four intriguing propositions that could be empirically investigated.

- Proposition 1* ‘Emerging technologies relative mature level’ is positively associated with the operations’ agility during and after a prolonged emergency situation.
- Proposition 2* ‘Emerging technologies early use level’ is positively associated with the operations adaptability during and after a prolonged emergency situation.
- Proposition 3* ‘Emerging technologies awareness level’ can positively or negatively affect the operations performance during and after a prolonged emergency situation.
- Proposition 4* ‘Emerging technologies operations processes view’ is positively associated with the organization’s capabilities in using different technologies to support their operations during and after a prolonged emergency situation.

5.1 Research agenda for COVID-19 and emerging technologies

Based on S. Gupta et al. (2019) and Queiroz, Ivanov et al., (2020a), this section shows the emergence of integrative research directions in relation to emerging technologies, COVID-19 and key theories. Besides, it examines the integration challenges, privacy, security and organizational change management issues with regard to the application of these emerging technologies (Hensmans, 2021; Wilson, 2020). In this vein, in Table 11 we report important research gaps concerning emerging technologies and digital transformation in the COVID-19 outlook. Moreover, in order to support scholars and practitioners, we suggest classic organizational theories, key operations approaches, and some recent literature on operations and related fields.

5.2 Limitations

This study harbors a number of limitations. The first is related to the unprecedented characteristics of the COVID-19 pandemic outbreak, which leads to some natural delays in some fields, with possible impacts on the journals’ output concerning this topic. As a result, the search on the databases can also be affected. This is why we could not be able to obtain papers from important journals in due time. This negative impact can be upset if scholars and practitioners further use AI and big data techniques to monitor the literature on the interplay between emerging technologies and COVID-19. The second limitation derives from the fact that the keywords used for the search may not have considered some potential papers (Mishra et al., 2018), for one reason or the other. We suggest future literature reviews on this topic to expand the keywords to use in the databases. The third limitation comes from our using only the Web of Science database to perform the search, as multiple sources of data would have inevitably led to more convincing results. By combining the Web of Science database with other databases including Scopus, future research will definitely fill such a gap. The various research avenues outlined from these limitations, coupled with the proposed framework and its propositions, represent a significant opportunity to advance the literature, especially as regards the production and operations-related fields. Furthermore, managers and practitioners are henceforth offered the opportunity to explore our framework in order to better grasp how emerging technologies get integrated with their firms’ operations.

6 Concluding remarks and contributions

In this study, we explored the interplay between emerging technologies and COVID-19 by means of a structured literature review, taking into account the operations-related fields. Thus, our findings showed that cutting-edge AI technologies like machine learning and deep learning are the most popular approaches to support operations in this pandemic outbreak, but that other related technologies—like big data analytics, blockchain, simulation, AR/VR, 3d printing, etc.—are also increasingly since the outbreak of COVID-19. Findings also indicate that a group of leading-edge technologies (i.e., digital twin, 5G, drones, etc.) remain at their infancy stage when it comes to interventions or applications in emergency situations. Similarly, it appears that all these technologies, together with more others, are mainly used in operations related to contact tracing, telemedicine, diagnosis, drug repurposing, forecasting, etc.

In terms of contributions, this study appears as one of the first papers that have mapped the literature exploring key emerging technologies in the COVID-19 outlook. Secondly, we found that traditional journals featured very few papers dealing with the production and operations fields. This therefore reinforces the need for scholars and practitioners to call for action so that this gap be filled. Thirdly, we provided a novel framework that synthesizes the main emerging technologies that can be used in the context of a huge epidemic outbreak. Fourthly, the four propositions derived from the framework can be a rich avenue for scholars and practitioners to investigate and empirically validate the role of emerging technologies in emergency situations. Lastly, we suggest other exciting future research directions supported by key organizational theories and OR/OM approaches.

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