Proceedings of the First Australian International Conference on Industrial Engineering and Operations Management, Sydney, Australia, December 20-21, 2022

The Use of Scheduling in the COVID-19 Pandemic: A Systematic Literature Review

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Abstract

Between 2020 and 2022, an extensive number of papers about the COVID-19 pandemic have been developed to help authorities in the decision-making process to tackle the pandemic. One of the key functions to achieving a timely response to all the activities is scheduling. Therefore, this paper presents a literature review of all the research regarding scheduling and the COVID-19 outbreak. The search was conducted in SCOPUS and snowballing, gathering a total of 323 papers. A systematic review was conducted, and 43 articles were included. This literature review is classified into five sections: vaccines, testing, developed tools, healthcare scheduling, and others. It was found that the scheduling function is mainly concentrated on designing vaccination strategies. The discussion section provides insights from the literature, including descriptive analysis, used methods, and implemented models.

Keywords
Scheduling, Vaccine Allocation, COVID-19, Vaccination and Literature Review.

1. Introduction
The COVID-19 pandemic impacted almost every single area of human life, not only hitting the healthcare system but bringing out a global ripple effect where livelihood, economy, and supply chains were highly compromised (Olivares-Aguila & Vital-Soto 2021). Therefore, governments started implementing different policies to control the spread of the virus and have relied on vaccination campaigns as the best strategy to fight the pandemic.

Implementing optimal strategies that allow a better performance of the vaccine administration is necessary to guarantee the correct allocation of different resources. Scheduling allows allocating scarce resources to activities to optimize one or more performance measures (Pinedo 2005). In the vaccine supply chain (VSC), many different stages make vaccine administration possible. With the help of different techniques, scheduling has been a crucial element in the success of this supply chain. This situation has encouraged researchers from different areas to contribute with models, simulations, and solutions that can help to predict a better allocation of scarce resources.

This paper presents several research works that include scheduling in the VSC. Additionally, scheduling has been implemented in similar areas like testing and healthcare scheduling which are also included in the literature review. The scope of this literature review presents the following preliminary search (Figure 1), which was generated with the complete initial database using VOSviewer (www.vosviewer.com, accessed on 3 June 2022). In Figure 1, two main clusters can be appreciated. The green group (A) presents an epidemiological perspective, whereas the red group (B) depicts an optimization approach. This paper focuses on this last cluster, where some keywords such as vaccine allocation, policy, and mathematical model are highlighted. Within this context, this paper intends to provide an answer to the following research questions:

1. How has scheduling been used in the distribution of vaccines?
2. How has scheduling been used to tackle the COVID-19 pandemic?

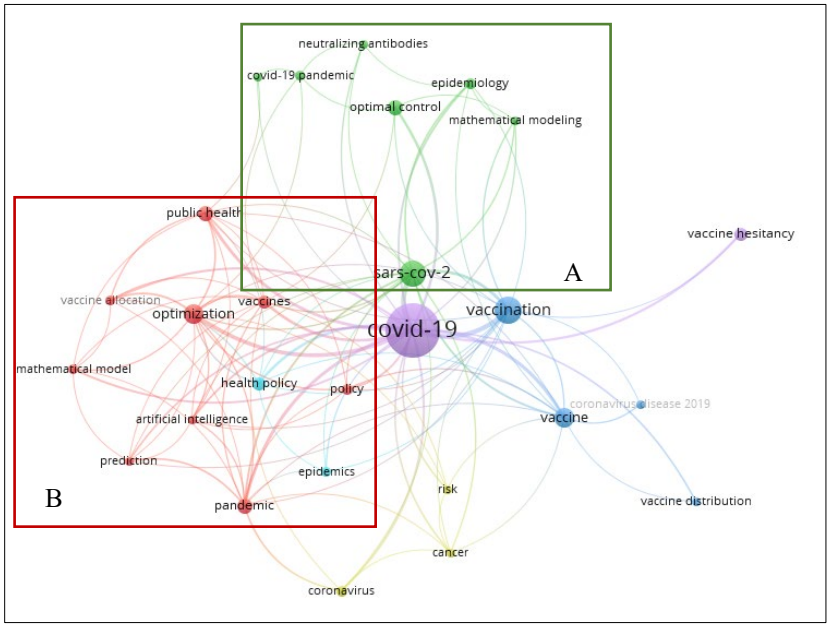

Figure 1. Initial VOS visualization.

The structure of this literature review is as follows: In chapter 2, the methodology is described. Chapter 3 classifies the literature regarding scheduling and its implications for alleviating the current pandemic. Next, chapter 4 presents the discussions and future work, where an author's table and graphical results of the literature review are described. Finally, chapter 5 brings out the conclusions of this literature review.

2. Methodology

The search was conducted using SCOPUS database to identify relevant articles. The literature search was performed using the combination of the following keywords (immunization OR vaccin*) AND (covid OR sars-cov-2) AND (polic* OR schedul*) AND optimiz*) in the title, abstract, or keywords. Wildcards (*) were employed to obtain papers having different spelling variations. Moreover, additional critical articles were searched and added by reference snowballing. The search process led to 323 papers. Then, the title, abstracts, keywords, and conclusions were read to verify whether they fit the scope of this research.

Figure 2. Articles selection methodology

After this stage, a total of 50 papers were chosen and deeply analyzed. From the selected 50 papers, a total of 48 papers were deeply reviewed, and 5 were discarded due to their lack of correlation with the research scope. Finally, 43 papers were classified and included in the literature review. Figure 2 depicts the methodology employed.

3. Literature Review Classification

Firstly, four categories inspired by the Vaccine Supply Chain (VSC) are proposed to classify the literature: 1) Vaccine allocation, 2) Storage and distribution of vaccines, 3) Vaccine administration and post-vaccine administration, and 4) Records and analysis. The study was limited to these categories, as the other stages of the VSC are outside the scope

of this research. Additionally, four more classifications are introduced to discuss where scheduling has been used to tackle the COVID-19 pandemic: Testing, Healthcare scheduling, Developed tools, and Others.

3.1 Vaccine Allocation

Limited Vaccines: Several studies investigating the supply of vaccines have been carried out with the constraint of a limited number of available vaccines. According to Książek et al. (2022), the key to successfully fighting a pandemic relies on finding the equilibrium between the vaccine distribution schedule and the available supplies caused by limited production capacity. For instance, Rao and Brandeau (2021) developed a susceptible-infectious-removed (SIR) model and considered the optimal allocation of a limited supply of vaccines proposing four allocation objectives: minimize new infections, mortality, life years lost, or quality-adjusted life years lost due to death. Rao and Brandeau (2021) also examined an allocation problem with a limited supply of vaccines for controlling an infectious disease to minimize the adequate reproduction number.

Sy et al. (2021) developed a linear programming model and a nonlinear programming model to find the optimal allocation of COVID-19 vaccines that minimize fatalities and transmission, respectively. Both apply to scenarios where the vaccine supply is limited, with different types of vaccines and various degrees of efficacy. Furthermore, two nonlinear mathematical models to gain insight into the optimal vaccination strategy were proposed by González-Parra et al. (2022). In that work, one of the studied scenarios is with a fixed number of vaccines. Moreover, the problem of distributing protective actions (e.g., vaccines) and the formulation of two mixed-integer programs were presented and solved by Książek et al. (2022), focusing on the distribution of protective actions with a herd immunity threshold aiming to be maximized in the situation of limited availability of resources.

Vaccine Uncertainty: There is not much research about unlimited supplies available because it is common to have limited stock at the beginning of an outbreak. Calafiore et al. (2022) are, to our knowledge, the first to propose a dynamic planning vaccination campaign with an uncertain number of supplies. The proposed framework seeks to maximize vaccination coverage, considering the different levels of immunization obtained with partial and complete vaccination.

Additionally, Foderaro et al. (2022) presented the problem of devising a vaccination plan that guarantees the shortest vaccination time to as many people as possible in a scenario of uncertain vaccine deliveries. This problem considered the constraint of ensuring the administration of a booster after a tight time interval. That work aims to minimize the vaccination time, which could lead to resource needs wildly fluctuating over time. Results proposed a daily vaccination plan suggesting how many initial doses and boosters could be administered daily.

Timeslot in Between Doses with Limited Vaccines: Most current vaccine prioritization schedules consist of two doses. However, the logistics of a two-dose vaccination campaign are challenging, especially in the context of limited vaccine supply and shelf-life (Matrajt et al. 2021). This category will discuss the related work to timeslots between doses to ensure the objectives are accomplished.

Moghadas et al. (2021) developed an agent-based model of COVID-19 transmission to compare the impact of two vaccination strategies. The results showed that a delay of at least nine weeks for Moderna vaccines could maximize vaccination program effectiveness. Moreover, Ferreira et al. (2022) proposed a Susceptible, Exposed, Infectious, Removed (SEIR) model that includes a two-dose vaccination schedule with a between-doses delay. The model evaluates the best time windows between first and second doses for individuals in the context of a limited vaccine supply. Furthermore, Matrajt et al. (2021) proposed an optimal allocation strategy with one and two doses of vaccine under different degrees of viral transmission using a mathematical model and optimization algorithms.

3.2 Storage and Distribution of Vaccines

There are two segments in the VSC in low- and middle-income countries, according to Kaufmann et al. (2011): (1) the segments that provide vaccines to the receiving country and (2) the segment that distributes the vaccines within the receiving country (domestic distribution). For instance, in 2020, Europe accounted for 76% of global vaccine production, followed by North America at 13%, Asia at 8%, and the rest at another 3% (McCarthy 2020). As expected, developed countries are the ones that export vaccines all around the globe in the context of a pandemic. In this category, we classify the research work that implements scheduling to solve problems during the distribution of vaccines from one country to another and the vaccine allocation at a domestic level.

National and Regional Distribution: Garg et al. (2021) proposed a model to determine an optimal distribution strategy at a state level with limited vaccine availability and developed an AHP-based multi-purpose distribution model to ensure optimal vaccine distribution. On the other hand, Emu et al. (2021) developed a clustering-based solution to select optimal distribution centers and a constraint satisfaction problem to distribute vaccines optimally. In this work, priority, and distance were stated to determine the optimal number of clusters into which the region can be divided to effectively distribute the vaccines across the chosen area.

Furthermore, Roy et al. (2021) presented a time-varying linear optimization-based approach and incorporated epidemiological factors, such as population density, susceptible count and infected ratio, and transportation costs, to distribute vaccines among zones. The authors showed that the proposed approach allocates vaccines optimally while preventing zones from resource starvation. Additionally, a study by T. Yang et al. (2022) simulated and compared the effects of different cross-regional vaccine allocation strategies using a SEIR dynamic model and a particle swarm optimization algorithm.

Service Delivery Point: This stage covers the vaccine flow from the local storage points to the health care provider. In scheduling, most allocation problems propose different solutions to distribute vaccines at this level. The main characteristic of the "service delivery point" is that the distribution goes from the storage to the final vaccination point. For instance, an optimization model with drones for medical items delivery (e.g., medicines, test kits, and vaccines) is developed by Ghelichi et al. (2021). The optimization model selects locations for charging stations, assigns clinics to providers, and schedules and sequences trips to minimize the total completion time. Furthermore, a collaboration to allocate stockpiles of vaccines and tests to a set of zones was presented by Thul and Powell (2021), suggesting a state-level vaccination and testing to allocate resources to nursing homes.

To promote mass vaccination scheduling during the COVID-19 pandemic, Zhang et al. (2022) studied vaccination site selection, appointment acceptance, assignment, and scheduling problem. Several critical decisions were made, such as which vaccination site to open, which appointment to accept, the site to assign, and each appointment's time slot. A different approach to delivery points was presented with the use of mobile vans by Shukla et al. (2022). Their work proposes an assignment problem that distributes vaccines from the health care centers to the mobile vans, and a scheduling problem that aims to maximize the vaccine distribution efficiency is developed.

3.3 Vaccine Administration and Post-vaccine Administration

To provide the vaccines to the population, it is essential to optimally organize the area's vaccination flow, including healthcare workers and staffing positioning. During the vaccination flow, it also should be prioritized to minimize the contact among healthcare workers, staff, and incoming vaccine receivers to avoid the proliferation of new infections. For instance, to evaluate an employee prioritization/invitation/scheduling system, McDonald et al. (2021) proposed an integrated electronic health record to provide vaccines to their employees where all employees who met COVID-19 allocation vaccine criteria were included. This system optimized the speed and efficiency of vaccine delivery while minimizing the risk of infection during the vaccination process.

Kusuma and Nugrahaeni (2022) formulated a model using the nearest distance-single course timetabling method. They proposed a coordinated vaccine scheduling model that combines the nearest distance and the single course timetabling. The model is then optimized by using a cloud theory-based-simulated annealing algorithm. As a result, this work minimized the number of unserved participants to zero when the number of vaccines was at least equal to the number of participants and created a lower travel distance.

Waste Management: Healthcare waste management is the collection, treatment, and disposal of healthcare waste produced by vaccination. Due to the infectious nature of waste related to COVID-19, the disposal of healthcare waste requires special attention (World Health Organization 2021). For instance, Govindan et al. (2021) developed a bi-objective mixed integer linear programming model that simultaneously minimizes the total costs and risks of the population's exposure to pollution. Some of the realistic assumptions include location-routing problem, time window-based green vehicle routing problem, vehicles scheduling, vehicles failure, split delivery, population risk, and load dependent fuel consumption.

3.4 Records and Analysis

Information management is a critical element in stopping a pandemic emergency. Once the vaccines were produced and shipped, a lot of information and feedback were generated. This could be gathered via daily and monthly reports

such as the actual vaccination capacity of staff, locations, warehouses, and transportation. For instance, Tran et al. (2021) presented an optimal SARS-CoV-2 vaccine allocation model using real-time attack-rate based on current epidemic trends in Rhode Island and Massachusetts. Furthermore, an algorithm to find a near-optimal allocation scheme was developed by Miura et al. (2021). The method can minimize new infections, hospitalizations, or deaths when multiple vaccines are available. The proposed model is evaluated with real COVID-19 epidemiological data in The Netherlands.

Using data from 44 provinces in Thailand, Jarumaneeroj et al. (2022) proposed a susceptible, infectious, quarantined, recovered, dead, vaccinated with immunity model that is later combined with a proposed COVID-19 vaccine allocation problem to determine the optimal allocation strategies that minimize total weighted strain on the whole healthcare system. Furthermore, a different contribution was presented by McPhedran et al. (2021). They performed an online discrete choice experiment to understand population preferences to get vaccinated, considering four attributes: delivery mode, appointment timing, proximity, and SMS sender. Finally, a systematic review of strategies for policymakers to allocate scarce resources during a pandemic is presented by Hempel et al. (2021). They found over 200 relevant research studies and grouped the evidence into four approaches: strategies to decrease healthcare demand, to optimize and augment resources, and adopting crisis standards of care when standard care or contingency standards cannot be maintained.

3.5 Testing

Another area where scheduling has been implemented to optimize resource allocation is testing. For instance, to maximize the number of tests a country can perform and validate the approach on both real-life data and synthetic examples, Santini (2021) proposed an integer programming formulation with the objectives of maximizing the number of tests performed and minimizing the average time a swab waits before it is tested. Furthermore, a testing facility location with demand uncertainty was presented by Liu et al. (2021). Their research focused on locating the testing facilities to satisfy the varying demand (i.e., test kits) caused by pandemics.

A study about COVID-19 testing queues was presented by L. Yang et al. (2022). That work studied how testing facilities should set scheduling and pricing policies to incentivize individuals to test to identify the most cases of infection. Additionally, Chatzimanolakis et al. (2020) presented research to optimally allocate limited test resources for quantifying COVID-19 infections. This work combines a Bayesian experimental design with an epidemiology model and proposes a methodology for the optimal allocation of limited testing resources.

3.6 Developed Tools

Zabinsky et al. (2021) developed a tool to optimize the distribution of vaccines by providing faster routes called the route optimization tool, using a variant of a vehicle routing and scheduling algorithm. Additionally, Zabinsky et al. (2021) developed a web-based application for the optimal allocation of COVID-19 vaccines. Two models were developed; a model that minimizes the number of vaccines required to decelerate the spread of the disease and a model that determines the optimal allocation at the minimum reproductive number. Furthermore, Pryor et al. (2021) developed a COVID-19 mass vaccination resource calculator, which optimizes resource allocation while maximizing efficiency. This calculator determines the maximum number of vaccinations that can be administered per hour, the check-in staff needed, the vaccination staff, the required room capacity for the immunization, and more.

3.7 Healthcare Scheduling

A significant number of research about scheduling in hospitals has been found due to its direct relation to the COVID-19 pandemic. In addition, human resources scheduling has been a crucial topic as it can result in the lack of unlimited labour (Vital-Soto et al. 2022). For instance, Fattahi et al. (2022) introduced an integrated resource sharing and demand redistribution problem during pandemics for various patient types and healthcare resources such as beds, ventilators, staff, and laboratories and a multi-stage stochastic program is developed to obtain the optimal sharing, patients' transfer, and capacity allocation decisions. Another research work about staff scheduling was presented by Güler and Geçici (2020), who developed a decision support system for scheduling the shifts of physicians during the COVID-19 pandemic. They proposed a mixed integer programming model to address the shift scheduling problem and transform it into a decision support system.

Garrido et al. (2021) presented a SEIR model to study the transmission dynamics of COVID-19 in Granada, Spain, to perform wise redistribution of hospital resources in advance. Furthermore, a slightly different approach was presented by Yadav and Tanksale (2022), who developed an integrated routing and scheduling problem for home healthcare

delivery with limited person-to-person contact. The objective was to maximize the revenue, generating proper assignments, schedules, breaks and routes to serve the maximum number of patients.

Surgery Planning: Studies related to elective surgery planning during the COVID-19 pandemic were also included in this section. Dai et al. (2022) proposed a bed configuration to ensure that elective patients are not affected by non-elective patients such as COVID-19 patients. The presented problem is more complex than the classical surgical scheduling problem because it proposes a hybrid algorithm (GA-VNS-H) based on a genetic algorithm, variable neighbourhood search, and heuristics for problem traits.

On the other hand, El-Boghdadly et al. (2021) used evidence from a systematic review and expert opinion to highlight key principles in the timing of surgery. Results suggest that most patients with no symptoms should have surgery scheduled at least seven weeks after the diagnosis of infection. Additionally, Shehadeh and Padman (2022) developed a stochastic optimization (SO) approach for elective surgery scheduling and downstream capacity planning. That work formulates and solves resource-constrained scheduling problems where existing SO methods and their challenges were analyzed.

3.8 Others

Scheduling has been implemented in other different areas to tackle the COVID-19 pandemic. An example is presented by Tazrin et al. (2021). They constructed a drone scheduling model called UV-C drone-based sterilization to minimize the drone's energy consumption while disinfecting areas with a fixed number of drones. The scheduling function was also found in the industry as a COVID-19 pandemic response. Due to the outbreak of COVID-19 many interventions such as social distancing and virtual or remote work had to be implemented, which led to interruptions in regular production schedules. Hu et al. (2022) proposed and solved an unrelated parallel additive manufacturing machine scheduling problem to substitute personnel with machinery.

4. Discussion

The scope of the papers presented in this literature review can be analyzed in Figure 3. The VOS software clustered the author's keywords into 3 groups. The green group (A) presents an epidemiological perspective correlated to the search scope due to the implemented predictive models to understand the pandemic. The red group (B) is focused on using scheduling and mathematical models, whereas the blue group (C) presents a perspective of optimization in the healthcare area. Additionally, all papers included in this literature review are summarized in Table 1. The table shows whether the papers implemented Linear Programming (LP), Mixed Integer Linear Programming (MILP), Stochastic Programming (SP), any variant of the SIR model, Heuristics or Metaheuristics. Also, it provides miscellaneous information and the objective functions used in the works reviewed.

Regarding the first research question, "How has scheduling been used in the distribution of vaccines?" the scheduling function has been used widely in the distribution of vaccines during the COVID-19 pandemic. Table 1 shows how 74% of the papers present objective functions which tend to minimize allocation elements such as transit time, cost, travel distance, and waiting times or maximize vaccine distribution or vaccinated population. Another insight from Table 1 is that 44% of the papers propose a model related to either LP or MILP. Additionally, 28% of the included research work implemented either heuristics or metaheuristics to find optimal or near-optimal solutions to their models, such as the genetic algorithm, particle swarm, greedy algorithm, and simulated annealing.

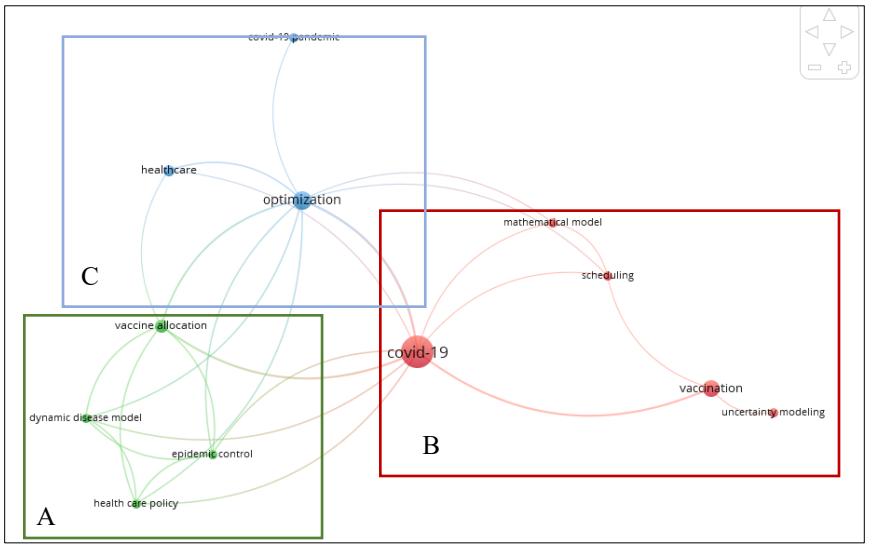

Figure 3. VOS visualization of the included papers.

To better understand the pandemic dynamics, at least 23% of the research work included a variant of the SIR model, which provides researchers with a forecast to make better predictions of vaccines or testing demands. Finally, less than 16% of the reviewed literature implemented stochastic programming. This outstands that scheduling has indeed been implemented to approach vaccine allocation problems and provides the answers to our first research question.

To answer the second research question: "How has scheduling been used to tackle the COVID-19 pandemic?", Figure 4 depicts the percentage of papers included in each category. It was found that 60% of the reviewed literature belongs to the "vaccines" group, being this the most comprehensive and dominant area. Additionally, the literature review provided three other areas that have used scheduling to tackle the COVID-19 pandemic: Healthcare scheduling, testing and developed tools.

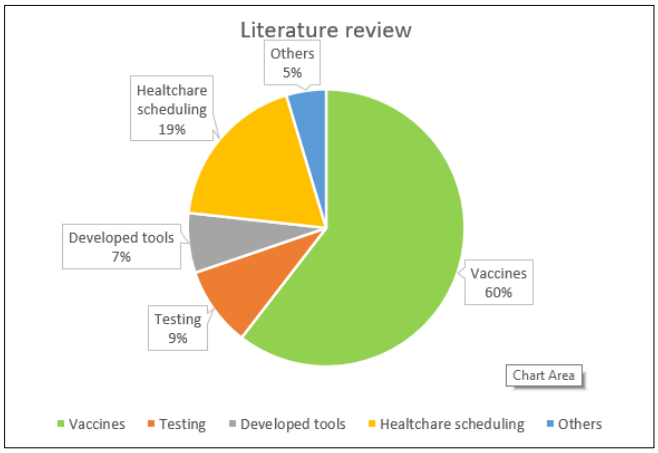

Figure 4. Literature review per category.

Scheduling has allowed researchers to develop helpful models in other areas, such as "healthcare." It is evident that one of the most affected areas in a pandemic is the healthcare system. Therefore, scheduling has helped to optimally allocate resources such as beds, ventilators, staff, surgeries, patients, and laboratories to face the snowball situation generated during an outbreak.

Table 1. An analysis of included papers.

Author (year)	LP	MILP	SP	SIR, SEIR, SEIRD*	Heuristic/ meta-heuristic	Miscellaneous	Metaheuristic algorithms	Objective function
Calafiore et al. (2022)	✓		✓			Second-order cone program		Max. Vaccination coverage
Chatzimanolakis et al. (2020)			✓	✓		Bayesian experimental design		Min. Prediction uncertainty. Max. Information gained on unreported infections
Dai et al. (2022)					✓		GA-VNS-H	Min. Priority and waiting patient's time, extra beds and idle time, changes for re-planning surgery day
El-Boghdadly et al. (2021)						A systematic review and expert opinion		Min. Time spent within healthcare environments
Emu et al. (2021)		✓				Constraint satisfaction programming		Max. Distribution of vaccine Min. Average distance travelled by individuals
Fattahi et al. (2022)			✓			Multi-stage stochastic program		Min. Non-accepted patients and allocation of new resources to hospitals
Ferreira et al. (2022)		✓		✓				Min. Vaccine stock for time intervals between doses
Foderaro et al. (2022)	✓				✓		Greedy algorithm	Min. Maximum workload of the system and number of vaccinated people per day
Garg et al. (2021)						Analytical hierarchy process		
Garrido et al. (2021)				✓				
Ghelichi et al. (2021)		✓				Multi-stop drone location and scheduling problem		Min. Total trips competition time
González-Parra et al. (2022)				✓		Nonlinear system of ordinary differential equations.		
Govindan et al. (2021)		✓			✓	Municipal solid waste management		Min. Supply chain's cost and population exposure risk
Güler and Geçici (2020)		✓				Shift scheduling problem and decision support system		Min. Exposure of physicians to the virus
Hempel et al. (2021)						Systematic literature review		
Hu et al. (2022)					✓	Additive manufacturing scheduling		Min. The completion time of the last batch
Jarumaneeroj et al. (2022)				✓		The covid-19 vaccine allocation problem		
Książek et al. (2022)		✓				The problem of distributing protective actions		Min. Incidence of the disease
Kusuma and Nugrahaeni (2022)					✓		Simulated annealing	Min. Total travel distance
Li et al. (2021)			✓					
Liu et al. (2021)						Markov decision process		Min. Total operational cost

Table 1. Continued.

Author (Year)	LP	MILP	SP	SIR, SEIR, SEIRD*	Heuristic/ Meta-Heuristic	Miscellaneous	Metaheuristic Algorithms	Objective Function
Matrajt et al. (2021)				✓	✓			Min. Cumulative number of infections and symptomatic infections, deaths, and hospitalizations not requiring and requiring intensive care
McDonald et al. (2021)	✓							Min. Risk of infection during the immunization process
McPhedran et al. (2021)			✓					
Miura et al. (2021)				✓			Greedy Algorithm	Min. New infections, hospitalizations, and deaths
Moghadas et al. (2021)						Delayed second dose strategy		Max. Vaccination program effectiveness
Pryor et al. (2021)	✓					Calculator		Max. Efficiency
Rao and Brandeau (2021)				✓	✓			Min. Reproduction number
Roy et al. (2021)	✓			✓				Min. The cost of transporting vaccines and the distance
Santini (2021)		✓						Max. Number of swabs tested
Sarfraz et al. (2022)						Vaccine 4.0 framework		
Shehadeh and Padman (2022)			✓			Operations research and healthcare scheduling		
Shukla et al. (2022)	✓							Min. Distance
Sy et al. (2021)	✓							Min. Of covid-19 fatalities Min. Disease transmission
Tazrin et al. (2021)					✓		Dynamic programming and colony Optimization	Min. Drone's energy consumption Min. Path length
Thul and Powell (2021)	✓		✓					Min. Cumulative number of new infections
Tran et al. (2021)								Min. Death counts
Yadav and Tanksale (2022)	✓				✓		Modified genetic algorithm	Max. Generated revenue
L. Yang et al. (2022)			✓					Max. Case detection
T. Yang et al. (2022)				✓	✓		Particle swarm	Min. Total number of confirmed cases
Zabinsky et al. (2021)	✓				✓		Nielson's usability heuristics	Min. Transit time Min. Risk penalty
Zhang et al. (2022)		✓			✓	Exact logic-based benders decomposition method and a metaheuristic method		Min. Fixed cost for operating vaccination sites, the travelling distance of vaccine recipients, appointment rejection cost; and the vaccination tardiness cost

*Any other variant of the model

Furthermore, scheduling has also been implemented in "Testing" due to its close correlation with the infection's identification, strengthening the researcher's intention to develop alternatives to tackle the COVID-19 pandemic. In testing facilities, the role of scheduling has been related to queuing theory, facilities, and resource allocation. Moreover, three papers about technology to optimize resource allocation were included in the "Developed tools" group, highlighting the importance of artificial intelligence and information technology tools to speed up decision-making. Finally, the group "Others" includes a drone allocation and a manufacturing scheduling problem directly related to tackling the COVID-19 pandemic.

This literature review has found that most of the papers present a model, a simulation, and a case study to demonstrate the optimality of the proposal. However, most of the reviewed literature does not mention critical drivers to link the proposed models to reality (e.g., which authorities to give the information to). Additionally, implementing digital twins could contribute to a better understanding of the models and strategies before their execution. Another insight from this literature review is that most papers work with a "limited number of available vaccines," which was the situation at the beginning of the COVID-19 pandemic. However, it is a reality that a sufficient number of vaccines will be available in the future, and strategies that consider an unlimited number of available vaccines and mixed vaccination campaigns (i.e. flu, COVID-19, etc.) will be needed. Furthermore, almost none of the papers considered models with booster doses and children, which are the most recent stages of vaccination campaigns.

5. Conclusion

Between 2020 and 2022, a large amount of research on the COVID-19 pandemic has been developed to understand better and help authorities tackle the outbreak. This literature review showed how scheduling models and simulations could contribute to the decision-making process toward the best strategies to target desired objectives (e.g., minimizing mortality and maximizing vaccinated people). Although the findings of this literature review are clearly clustered, it is essential to mention that some of the included literature does not implement scheduling from an optimization perspective. Still, their contributions are highly necessary for developing accurate scheduling models. For instance, some papers focus on arranging appointments based on people's preferences, providing further researchers with more accuracy in the appointment scheduling models.

Limitations of this research are regarding the selection process of the documents, classification, and interpretation of them, which could lead to biases given the human intervention.

Acknowledgements

The authors want to acknowledge the Mitacs Globalink program for providing funding to the first author.

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