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Optimization and Coordination Strategies for Reducing the Impact of the COVID-19 Pandemic: A Survey

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Abstract: With the emergence of the COVID-19 pandemic, each country had to overcome different organizational difficulties and challenges to the health care system, as well as negative social and economic consequences. A comprehensive management plan was needed everywhere to mitigate the impact of the pandemic and to optimally allocate and use the available resources. For this reason, many researchers have devoted their efforts to developing strategies to combat the pandemic. This paper makes an overview of the optimization and coordination strategies for management of the health and economy crisis, as well as the health, social and economic politics, aiming to reduce the impact of the pandemic. Developed mathematical models for different optimization tasks related to pandemic response measures are considered. Challenges are noted in connection with the data accuracy, coordination and communication between responsible institutions, as well as the need of better strategy planning. Important directions for future research are outlined.

Keywords: COVID-19 pandemic, Optimization models, Optimization and coordination strategies, Policies mitigating the impact of the pandemic.

1. Policies in connection with the Covid-19 pandemic.

The Organisation for Economic Co-operation and Development (OECD) has studied the supporting role of Centres of government (CoGs) during the Covid-19 pandemic [30, 31]. The analysis shows that policy responses to the pandemic coordinated by CoGs are in three main directions: (1) coordination and strategic planning, (2) using evidence to inform decision-making, and (3) communicating decisions to the public.

The Centre of government (CoG) is “the body or group of bodies that provide direct support and advice to Heads of Government and the Council of Ministers, or Cabinet” (OECD, 2018 [29]). Institutions or agencies can be coordinated by CoGs to perform “planning, coordination, prioritization, and policy leadership role” in crisis (pandemic) management. Hence one important strategy is to include and use high-level structures to perform strategic planning in connection with the COVID-19 pandemic. Another type of strategy is to include high-level structures to support the government’s decision-making. The third type of strategy is to organize optimal communications and inform the public about the taken decisions. The CoGs emphasize the importance of leadership and effective coordination of response efforts during crisis moments through various governmental levels and sectors. Their focus is on evidence-based decision-making and public communication [30]. The Centres of government facilitate crisis coordination, promoting inter-sectoral and inter-governmental collaboration, as well as the collection and dissemination of crucial information for decision-making. Challenges include managing vast amounts of information and applying a multidisciplinary approach to address the complexities of situations. like pandemics, highlighting the importance of transparency and public trust in governance [30]. The aim is to enhance public trust in governance and communication efficiency.

The territorial impact of the COVID-19 crisis in “different dimensions: health, economic, social and fiscal” is discussed in [31]. A general strategy to help mitigate the territorial effects of the crisis is proposed, based on ten takeaways for managing the COVID-19 – territorial impact. A perspective on the multi-level management of the pandemic crisis to build more regions that are resilient has also been proposed [31]. This research provides a comprehensive assessment of the COVID-19 pandemic's impact at different territorial levels, with a particular focus on multi-level governance and its diverse health, economic, and social implications. Many challenges related to the rapid pace of pandemic changes that may render some data outdated, as well as limitations in the broad application of measurements due to restricted regional diversity are considered [34]. The strategy for getting out of the crisis is not linear, it can have worsening and improve the situation until the population acquires immunity or an appropriate treatment or an effective vaccine is found. The basic aim is the achievement of a resilient decrease in pandemic impacts.

Directions for future research regarding the long-term impacts of the COVID-19 pandemic are outlined. The focus is on regional inequalities, the effectiveness of crisis management strategies at various governmental levels, and post-pandemic recovery. This work emphasizes the importance of comparative analyses for better understanding the impacts and responses to the crisis, as well

as the role of technology and innovation in addressing and recovering from the pandemic, offering new perspectives for effective future crisis management [34].

The COVID-19 pandemic resulted in numerous health and social crises in society that needed to be addressed [10]. This study evaluates the use of public relations strategies to mitigate the various crises and consequences of the pandemic in Anambra State in Nigeria. The management of all crises related to COVID-19 is examined, and the use of different types of communication and how effective PR strategies are for crisis management is examined. The research method applied in the study is liberal where the researchers depend on secondary data. A variety of public communication channels such as meetings, radio, television, newspapers, media platforms, and others have been used to disseminate important information and appropriate behaviour contributing to overcoming the various crises related to COVID-19.

2. Optimization strategies to overcome the negative impact of the pandemics

The Different optimization models and strategies have been proposed and studied to overcome in a fast and optimal way the impacts of the COVID-19 pandemic. For example, optimization strategies for healthcare resource planning and also patient transfer are studied in [25]. The aim is to improve the functions and responses of health systems to the extraordinary conditions of increased demand for health care during epidemics and pandemics. The authors have developed a multistage stochastic program (MSSP) to optimize different healthcare resource planning strategies [25]. An agent-based continuous-time stochastic model is formulated. This is a mixed-integer linear programming model. Uncertainty in the stochastic model is captured by a forward scenario tree construction approach. A data-driven rolling horizon procedure is proposed to facilitate real-time decision-making. In doing so, critical limitations of the stochastic programming approach are mitigated. The considered examples demonstrate that the resulting strategies are applicable and contribute to the optimal use of health resources [25].

The study [5] analyzes and summarizes the key contributions of optimization studies addressing the challenges of forecasting, controlling, and managing the COVID-19 pandemic. Including a wide range of strategies, from advanced forecasting models to the optimization of resource allocation and vaccination strategies, the research seeks to provide a robust foundation for supporting strategic decision-making in the combat against the pandemic [5]. The study introduces advanced optimization methodologies, based on mathematical models and sophisticated algorithms to enhance the efficiency of health and logistical interventions. Central to this is the use of advanced mathematical models, which integrate various optimization techniques such as dynamic

programming, to address optimization challenges [5]. This method allows for the analysis of the effectiveness of crisis management strategies for optimal solutions. Optimization aids in the efficiency of pandemic management, but challenges include the complexity of the models and the demand for accurate data [5]. Future research should focus on the development of more advanced optimization models that can adapt to the changing dynamics of the pandemic and address the identified challenges [5].

The research [1] introduces a sophisticated Non-Linear Programming (NLP) model aimed at optimizing the allocation of pandemic control resources, specifically testing and hospital capacities, to manage COVID-19 effectively. By extending the traditional SIR (Susceptible-Infectious-Recovered) model to include asymptomatic transmission and varying infection severities, the study incorporates equity considerations through the GINI coefficient for fair resource distribution. Validated by France's COVID-19 data, the findings underscore the importance of timely testing and equitable resource allocation in curbing the pandemic's spread [1]. The model stands out by simulating various pandemic scenarios, assessing the impact of different allocation strategies, and addressing the dynamics of disease transmission with a focus on minimizing infections and hospitalization-related deaths. Despite its advantages in providing comprehensive pandemic management insights, the model acknowledges limitations such as data accuracy requirements and potential simplification of complex human behaviors [1]. Future research directions include applying the model to other infectious diseases, integrating socio-behavioural factors more deeply, and developing dynamic models that adapt to changing conditions. This study not only contributes to the optimization of health resource distribution during pandemics but also offers a framework for improving global health strategies in facing infectious disease outbreaks [1]. However, challenges such as the complexity of parameter estimation and the necessity for accurate data are noted [1]. Future research directions include refining model parameters, incorporating vaccination strategies, and considering economic impacts, aiming to enhance the model's applicability for diverse pandemic scenarios and improve local-level resource allocation strategies [1].

An investigation on optimizing vaccination strategies against COVID-19 using graph theory and network analysis to identify and target critical individuals within social networks, thereby reducing the spread of the virus, is described in [34]. It highlights the importance of understanding social structures for effective vaccine distribution and proposes a mathematical model that prioritizes key nodes, showing significant potential in outbreak management [34]. The research combines heuristic algorithms, simulation techniques, and network analysis to develop efficient vaccine allocation strategies [34]. While noting the advantages of such targeted approaches, including resource efficiency and adaptability, it also

addresses challenges like mapping social networks, ethical distribution dilemmas, and logistical implementation barriers. Future work must refine the model for higher accuracy and adaptability, extending its application to broader pandemic management efforts [34].

The COVID-19 pandemic has necessitated innovative optimization strategies for managing resources, forecasting outbreaks, and reducing impacts. The study [38] explores optimization strategies to enhance pandemic management, focusing on resource allocation, healthcare logistics, and public health policy. It introduces advanced mathematical models, predictive analytics for trend forecasting, and strategic vaccine distribution logistics, underpinned by empirical data and rigorous testing [38]. A key feature of this research is a sophisticated mathematical model that combines linear programming, stochastic modelling, and dynamic simulation, aimed at offering actionable pandemic management insights. The strategies presented promise improved resource utilization, better forecasting accuracy, and more efficient response protocols, despite challenges such as data reliability and ethical implementation concerns [38]. Future research directions include integrating real-time data, assessing ethical implications, and developing adaptive models for emerging threats, with a focus on ethical resource allocation and data privacy. The study highlights the critical role of optimization strategies in pandemic response, advocating for a balance between technical innovation, ethical considerations, and stakeholder engagement to advance global health security [38].

A new strategy is proposed in [15], which implements a hybrid optimization approach to address the dynamic challenges of resource allocation during health crises. By combining deterministic, metaheuristic, and stochastic methods, the model offers adaptability and strategic planning capabilities. It is developed with the integration of Excel and GAMS software, facilitated by Visual Basic for Applications (VBA), providing a practical tool for tackling complex optimization problems [15]. The advantages of this strategy include its adaptability to rapidly changing pandemic conditions and its ability to ensure comprehensive resource distribution planning. However, the approach's complexity and its reliance on accurate data pose significant limitations that may affect implementation and effectiveness [15]. Future research should concentrate on the refinement of optimization models to boost their effectiveness in managing crises in the real world, developing more streamlined tools for easier implementation, and incorporating real-time data analytics and machine learning to improve strategy responsiveness [15].

Optimization strategies designed to mitigate the impact of the COVID-19 pandemic with a focus on public health improvements and economic recovery are considered in [4]. The contributions of this research extend beyond theoretical models, incorporating real-world testing of strategies through simulation and

practical application. It emphasizes the development of innovative optimization models and coordination mechanisms designed to enhance the synergy of combined strategies, thereby maximizing benefits [4]. A sophisticated mathematical model serves as the foundation of this study, simulating COVID-19's spread and facilitating optimization tasks through various mathematical methods, such as linear and non-linear programming, stochastic modelling, and agent-based modelling. This approach allows for a systematic assessment and optimization of pandemic response strategies, predicting outcomes under different scenarios for informed decision-making [4]. Despite its advantages, the methodology faces limitations related to data quality and the inherent unpredictability of the virus and human behaviour. Future research directions include refining mathematical models with real-time data, exploring machine learning for dynamic optimization, and developing adaptive strategies for ongoing and future public health challenges [4].

In [8] the supply chain network efficiency for COVID-19 response is improved. The study focuses on hospitalization, medication distribution, and waste management using advanced technology. It introduces a novel approach by initially employing LSTM-RNN for precise demand forecasting, refined by K-means clustering, followed by a sophisticated two-stage stochastic programming model to optimize the supply chain [8]. This multi-objective, multi-period model aims to maximize resource availability, minimize public health risks, and reduce transportation time, addressing the pandemic's challenges [8]. A case study in Tehran demonstrated the model's effectiveness in managing demand fluctuations and optimizing resource distribution, indicating substantial improvements in resource allocation and waste management [8]. However, challenges in forecasting accuracy and real-world application highlight the need for reliable data and more sophisticated, forecasting methods [8]. Future research will focus on advanced forecasting, real world testing, and adapting the model for other infectious diseases, aiming to enhance its relevance and applicability to public health crises [8].

The optimization strategies listed in this and next section are summarized in Table 1.

Table 1. Optimization strategies for overcoming the impacts of the COVID-19 pandemic

No	**Optimization strategies, developed**	**Mathematical models and algorithms**	**Source**
1	Healthcare resource planning. Patient transfer planning.	Agent-based continuous-time stochastic model (Mixed-Integer Linear Programming model)	[25]
2	Strategic decision-making in the fight against the pandemic. Vaccination strategies. Resource allocation.	Advanced forecasting models. Vaccination measures. Logistical interventions.	[5]

No	**Optimization strategies, developed**	**Mathematical models and algorithms**	**Source**
3	Optimization and allocation of pandemic control resources, specifically testing and hospital capacities.	Non-Linear Programming (NLP) model	[1]
4	Graph theory and network analysis to identify and target critical individuals within social networks. Efficient vaccine allocation strategies.	Heuristic algorithms, simulation techniques, and network analysis	[34]
5	Optimization strategies to enhance pandemic management, focusing on resource allocation, healthcare logistics, and public health policy. Predictive analytics for trend forecasting, and strategic vaccine distribution logistics.	Sophisticated mathematical model that combines linear programming, stochastic modelling, and dynamic simulation.	[38]
6	Hybrid optimization approach to address the dynamic challenges of resource distribution planning during health crises.	Combination of deterministic, metaheuristic, and stochastic methods. The model offers adaptability and strategic planning capabilities.	[15]
7	Optimization strategies designed to mitigate the impact of the COVID-19 pandemic, with a focus on public health improvements and economic recovery.	Sophisticated innovative mathematical model. Linear and Non-linear Programming, Stochastic and Agent-based modelling.	[4]
8	Hospitalization, medication distribution, and waste management strategies	LSTM-RNN for precise demand forecasting, refined by K-means clustering, followed by a sophisticated two-stage stochastic programming model to optimize the supply chain. Multi-objective, multi-period model.	[8]
9	Optimization strategies to mitigate the supply chain vulnerabilities and to enhance their resilience. Adaptive strategies to fortify supply chain transparency and coordination.	Mathematical model for supply-demand balance, highlighting the potential for improved service levels, social responsibility fulfilment, and supply chain resilience. Bibliometric and network analysis.	[25], [30]
10	Implementing smart lockdowns by identifying high-risk areas	Dynamic model of SARS-CoV-2 transmission, economic model, model managing health risks	[11], [17], [19]
11	Models for the spread of the infectious disease among the population and its dynamic development	SIR model and its extensions	[13], [15]

3. Coordination strategies for management of the products supply

The study [33] synthesizes key findings and strategies from the research on managing the supply chain for high-demand items, notably toilet paper, during the COVID-19 pandemic. The research aims to enhance service levels and uphold social responsibilities amidst shortages through the development of an analytical model. This model, leveraging optimization and simulation, suggests resource sharing and collective emergency sourcing as viable solutions to improve service levels and address social responsibility [33]. The supply chain vulnerabilities exposed by the pandemic are critically examined. The authors propose optimization strategies to mitigate these issues, thereby enhancing supply chain resilience. The strategies include collaborative approaches and a mathematical model for supply-demand balance, highlighting the potential for improved service levels, social responsibility fulfilment, and supply chain resilience [33]. Furthermore, the research advocates for future exploration of adaptive strategies and technological innovations like blockchain and IoT to fortify supply chain transparency and coordination. The aim is to develop a resilient supply chain framework capable of withstanding global crisis impacts, emphasizing the necessity for adaptable, technologically advanced strategies to manage disruptions effectively [33].

The research [27] addresses challenges in supply chain management due to COVID-19, aiming to enhance resilience and sustainability. This study employs bibliometric and network analysis to comprehensively chart the existing terrain of research, pinpointing key authors and emergent themes [27]. A set of optimization strategies is developed to improve supply chain agility and robustness, including adaptive models, strategic stockpiling, and dynamic resource allocation. A complex mathematical model is proposed to simulate and optimize supply chain operations, incorporating various parameters for a detailed analysis [27]. The strategies aim to improve supply chain visibility, risk management, and adaptability but face challenges like the need for technology investments and cross-sector collaboration [27]. Future research is suggested to integrate advanced technologies like AI, blockchain, and IoT for better supply chain management and to develop practices resilient to global disruptions [27].

The negative impacts of COVID 19 pandemics on the supply of products are described in [7]. The positive role of digital transformation in this branch of economy is considered.

4. Strategies slowing COVID-19 pandemic spread

From a social point of view, it is important to find optimal strategies to mitigate the effects of the COVID-19 pandemic, which limit the number of deaths, but are

not so severe as to cause economic catastrophe. In doing so, mathematical models are used for the spread of the infectious disease among the population and its dynamic development [16]. The SIR model, defined based on "susceptible-infected-recovered" cases, is very popular (see [18]). Many other mathematical models represent extensions of this model.

An approach and tool for determining important policies and cases, when government intervention policy needs to be changed, is proposed in [17]. The model applied is based on control theory and is called "SIDARE (Susceptible, Infected undetected, Infected detected, Acutely symptomatic — threatened, Recovered, Deceased — Extinct)". It considers the effects of government policies. Important factors in this case are the population testing rate and the capacity of the health system to cover new cases of infected people.

Containing outbreaks early and slowing the spread of the infection as much as possible helps the health system to cope with the situation, as the number of cases increases quite smoothly, not in an avalanche. In this way, the overloading of doctors and medical staff is also avoided. In this regard, social measures such as limiting travel, avoiding the gathering of many people in one place, reducing the duration and frequency of people's contacts, quarantining the sick, etc. the like are of great importance (see [9, 37]). However, these measures can be applied within certain frameworks so that the economy does not collapse.

According to the World Health Organization, "The number of deaths directly or indirectly related to the COVID-19 pandemic from January 1, 2020 to December 31, 2021 is approximately 14.9 million (13.3 million to 16.6 million)". The pandemic helped to pinpoint the weakest links in the health care system, as well as to reveal the interdependencies of some social, economic and health structures. The conclusion in [14] is that a transformation towards sustainability is needed within countries and globally. The role of four main factors in increasing the resilience of structures affected by the pandemic is examined.

A “dynamic model of SARS-CoV-2 transmission” combined with an “economic model”, including 63 sectors, designed to optimize the economic production and manage the “public health risks” is proposed in [11]. The results illustrate the slowing and controlling the spread of COVID-19 by means of “targeted lockdown measures”, which contributes to mitigate of negative economic consequences.

The study [19] proposes a deep learning framework for accurately predicting COVID-19 hotspots. The model aids in implementing smart lockdowns by identifying high-risk areas, thereby allowing for targeted interventions and reducing the need for widespread restrictions.

Optimized strategies to limit the spread of the pandemic are developed in [21]. An epidemiological model for South Africa is used, where five levels of lockdown the spread of COVID-19 were implemented. Different policy scenarios

are considered and a hybrid model is applied to optimize lockdown management. Thus, the optimal policy is determined, which mitigates economic losses and reduces the number of patients to a level that does not exceed the capacity of the health system.

Lockdown strategies are useful, but they represent only a second stage in the fight against the pandemic and could be seen as consequences of mistakes made in the first stage of this fight (see [20] where the pandemic spread in Greece is considered). Given the very rapid spread of the virus among people without immunity, a strategy to immunize as many men and women as possible, especially among high-risk groups, should be the focus. Such measures representing *primary* public care are emphasized in [20]. The authors also emphasize the importance of *secondary* public care related to preventing hospitals from being overloaded and caring for mild cases of the sick at home.

Organizational and management strategies for primary care health facilities in Spain are offered in [35]. Digital health solutions to combat the COVID-19 pandemic are proposed in [12]. The use of telemedicine leads to a reduction in the risk of infection. The digital healthcare model can be successfully used in primary care. The challenges in this case are related to potential conflicts, which are due to the moral, cultural and religious background of the users. When implementing the digital model, the undermining of individual freedoms must be avoided, and vulnerable groups of the population must not be left behind.

Strategies to mitigate the impact of the COVID-19 pandemic have resulted in some slowing of the spread of the infection. Unfortunately, this does not stop the pandemic and the consequences in countries with lower incomes can be severe (see [32]) due to the smaller capacity of the health system and the lack of health care for all the sick. Achieving good results in the fight against the pandemic in these countries requires a faster response of the authorities managing the crisis, as well as timely implementation of optimal strategies and policies.

Statistics in China show that approximately 19% of the patients infected with the corona virus are critical or severe cases. This leads to a heavy burden on hospitals. In this connection the optimal mobilization of available intensive care resources in Singapore is discussed in [25]. Attention is paid to the planning of critical care resources and the implementation of management strategies in this area.

In [39], the emergency response coordination system in Pakistan is considered. A centralized incident management system is available there, that coordinates the responses of multiple agencies and defines their roles and responsibilities in combating the pandemic. Unfortunately, there is no system for joint emergency planning because most organizations do not have a system for tracking logistics and human resources. The regular mapping of the available resources and introduction of a system for planning their use is proposed.

Strategies for dealing with the challenges during the COVID-19 pandemic in Iran are proposed in [26]. Four types of activities are considered, structured in 2-3 subcategories each, for which corresponding strategies are proposed. Data for the study were taken from four major hospitals in Iran.

In order to inform the society and engage people to actively participate in the measures to combat the Covid 19 pandemic, ten considerations are proposed in [13] for effective managing the transition from a crisis to a normal state.

An overview of strategies to mitigate barriers to testing for COVID-19 is presented in [6]. The main barriers are "low rate of health literacy; low trust in the health system; the cost of testing; availability and accessibility of testing sites; the consequences of a positive test". Financial and explanatory measures such as: "free testing; promoting awareness of the importance of testing; presentation of different testing options and types of testing centers (testing at home); providing transportation to testing centers; and offering support for self-isolation". This can help overcome the hesitancy in testing and, consequently, slow down the spread of the infection.

The business of the companies can be supported using business intelligence systems (see [2], [3]). One of the negative consequences of the COVID-19 pandemic is the increase in cybercrime due to the mass shift from traditional to virtual work environments. In this regard, phishing websites and phishing attacks have increased. A new approach to detect phishing URLs by applying Gated Recurrent Unit (GRU) is proposed in [28], achieving high accuracy of phishing classification.

An approach for use the Twitter messages of people from National Capital Region (Metro Manila) of the Philippines concerning COVID-19 is considered in [23]. This communication can play role for data actualization and providing real-time situation updates.

A hybrid Barnacles Mating Optimizer with Least Square Support Vector Machines (BMO-LSSVM) is proposed for prediction of Covid19 confirmed cases is proposed in [40]. This is very important for the proper prevention and precaution steps. Daily data for the Covid19 cases in China are used. BMO was applied to generate optimal values of LSSVM hyper-parameters.

A hybrid approach combining Least Square Support Vector Machine (LSSVM) and improved BMO (IBMO) for time-series forecasting in order to adjust the parameters and to enhance the kernel-based LSSVM model is proposed in [24]. Based on the total number of vaccination cases, LSSVM is able to forecast very precisely the COVID-19 confirmed cases in Malaysia using the optimal values predicted by the IBMO.

A futuristic scenario for the next pandemic in the near future is discussed in [36]. It provides an opportunity to mentally rehearse pandemic countermeasures and anticipate the consequences of user actions and inactions.

5. Conclusion

This brief overview examines important strategies and approaches to manage the COVID-19 pandemic and to overcome its harmful social and economic consequences. Various methods are listed that aim to improve the efficiency of health systems, minimize social and economic consequences, and increase resilience to the impact of pandemics. The application of mathematical models and advanced algorithms to address the challenges of the pandemic is discussed, including stochastic models, linear programming models, and nonlinear programming models. Some of the considered models are multi-objective. These models support strategic decision-making in the fight against COVID-19 and the determination of optimal policies, providing a solid foundation for effective public health emergency responses. The optimal resources planning, and distribution contribute essentially to mitigate the negative effects of the pandemic.

Several challenges related to the implementation of the reviewed optimization strategies are also mentioned, such as the need for accurate data and real-time updates, as well as the complexity of the models and the need for intergovernmental and cross-sectoral cooperation. Also, the heterogeneity of pandemic in different regions must be considered. Future research directions include the development of more advanced and appropriate models that can adapt to the changing dynamics of pandemics and integrate socio-behavioral factors for more effective crisis management.

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