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## **Introduction**

The history of OR began in the times of crisis when scientific research was used to improve military operations. One of the founders of OR, Patrick Blackett, advocated for scientists to advise on matters of strategy and tactics. Since the war, OR has spread into business, government, public services, education, defence and beyond, improving performance and helping people make evidence-based decisions.

Most of the problems OR tackles are messy and complex, often involving considerable uncertainty. OR uses advanced analytics, modelling, problem structuring, simulation, optimisation and data science to determine solutions to problems and practical courses of action. OR is also called the Science of Better because OR aims to improve business, government and society, using models, proposing interventions, implementing them, and determining the actual improvements.

COVID-19 represented, and still represents, an unprecedented time of crisis and OR scholars and practitioners have taken an active role in developing models, proposing interventions and implementing them during this time. In this special issue (SI), we aim to publish rigorous accounts of OR practice in areas such as the interplay between models and judgement and messy and complex problems that may require the combination of one or more methods.

## **Papers in the Special Issue**

While we received a large number of papers for the SI, the final number of articles for the SI is eight, with one of them is a commentary, covering different aspects of the impact of the pandemic on society and organisations across the world. We present the papers in more detail below.

Nikolopoulos et al (2021) discuss if operational research is the science for better or worse in the absence of hard data, which was the main issue at the beginning of the pandemic. They argue there is “a devastating contradiction in fact: those mostly in need of our modelling exercises, are the very ones not providing the hard data” (page 1). The authors suggest two solutions. A long-term solution will be to create a comprehensive repository of data from industries, organisations and society managed by Universities. The short-term solution is the use of ‘auxiliary data’ such as the social media and engine search data during this special time.

Liu et al (2021) offer an approach to address the issues of using data of uncertain quality in epidemiological models, e.g. SIR models. This paper should be considered together with the previous paper discussing the impact of lack of hard data on OR practice. The authors focus on the problems associated with use and interpretation of limited data and the presence of

sudden (or episodic) changes derived from behavioural changes, regulations or mutations of the virus that affect model parameters linked with historical data. Their solution combines statistical learning methods together with parameter fitting for ordinary differential equation models in order to find the adjustment for the parameters of SIR models. The main contributions of the paper are: (a) providing interpretation of the parameters of the model with different data, (b) determining which parameters of the model are more important to produce changes in the results, and (c) using data-driven discovery of sudden changes in the evolution of the pandemic. This paper considers data from the United States of America.

Sbrana (2022) deals with another important problem related to the lack of hard data: intermittent time series. Intermittent time series contain zeros in the series distributed sporadically. At the beginning of the pandemic, the lack of testing sites or continuous efforts to collect data generated many intermittent time series. The author proposes a novel approach known as Intermittent Local Level (ILL), which he compares against other models, using data from 3000 counties in the United States of America. The model outperforms other forecasting methods over a two-week period horizon.

Strong et al (2022) showcase another approach to support decisions with limited hard data. The authors suggest using expert judgements in a Bayesian decision support system to evaluate different strategies related to the pandemic. The approach evaluates the impact of uncertainty of the science, e.g. tests and virus behaviour, dynamic shifts between regimes, e.g. social distancing vs. lockdowns, and the fast moving stochastic development of the pandemic. One of the main challenges faced at the beginning of the pandemic for this type of models was the lack of historical data to estimate aggregate utilities from the attributes. Thus, the authors offer a set of steps on how to construct a framework for a decision support system using a multi-attribute Bayesian model, which addresses the deep uncertainty in this complex situation.

Werner (2022) also offers a discussion on the impact of absence of historical data used as inputs for simulation models, which is a characteristic of unexpected situations like pandemics or disasters. The author proposes an iterative multi-method framework that combines uncertainty elicitation using structured expert judgement, mathematical scoring rules and combining problem structuring method with discrete event simulation. The framework has been tested in the early waves of the pandemic with ‘walk through testing’ sites in Scotland. This paper can also complement the next two papers in terms of problem situation solved using OR to manage processes, as well as the previous papers in terms of how to deal with lack of data.

Kheybari et al (2021) propose an approach to select temporary hospital locations, which was one of the responses taken by governments during the initial stages of the pandemic. Their approach combines two steps. First, the authors use risk-averse multi-criteria decision making (MCDM) to evaluate different criteria, e.g. environment, social, economic and infrastructure, to decide the best location. Second, the selection for all hospitals is optimised using a portfolio optimisation model to enhance patient coverage. The authors applied the approach in Iran.

Dundar and Karakose (2021) offer a comparison between two approaches to one of the critical decisions regarding capacity during the pandemic: seat assignments. Decisions related to seat assignments are key for service organisations, such as hospitals, universities, theatres, planes, trains, sports facilities, restaurants, etc., especially when social distancing and ventilation need to be considered in the decisions. The authors provide a comparison between optimisation models and graph-based heuristic algorithms, and they find heuristics are much faster than optimisation models. A decision support system is also explained in their paper. This paper showcases an application in a university in Turkey.

Otten et al (2021) present an extension of the previous paper with a dynamic perspective. The authors consider restrictions in seating, different patterns of patients' arrival, bridging and waiting time to define the schedule of an outpatient clinic. Scheduling patients was another critical problem facing healthcare organisations during the pandemic. A problem that led to increasing backlogs in treatments for millions of patients. They use simulation optimisation where the optimisation determines an optimal schedule and simulation evaluates the impact of randomness on the system. This paper reflects issues faced in The Netherlands.

### **Others Related Papers to the Special Issue included in this Issue**

The following papers were submitted to the general track, but we believe they can complement the papers of the SI.

Teberga Campos et al (2022) offer a different approach to the same decision discussed in Kheybari et al (2021): the creation of temporary hospitals. Their approach defines number of beds rather than location as in the previous paper. The authors combine several methods. Discrete event simulation is employed to represent the hospital system. Then, the model is used to generate multiple experiments to satisfy different objectives using multi-objective optimisation programming techniques such as response surface methodology and normalized normal constraint. The model has been applied in Brazil during the pandemic.

Mitropoulos et al (2022) also discuss the location of healthcare facilities. In this paper, two methods are combined: system dynamics and mathematical programming. System dynamics is employed to generate scenarios for future healthcare demand. Then, a stochastic facility location model defines the location in two stages. First stage determines the range and type of services for each facility. Second stage assigns patients to each health facility depending on the scenarios. The project evaluated a network of 32 primary healthcare facilities in Southern Greece.

Chen et al (2022) present a multi-method approach to the allocation of medical resources during emergencies. This paper may be considered together with the first four papers of the SI. The authors propose a two-stage prediction-then-optimisation framework. Initially, a deep learning epidemic transmission model predicts the number of cases. One of the contributions from the authors is to address the “cold-start problem” in machine learning models, which is the lack of historical data and expert experience to seed them. Then, a

resource allocation model considers two-dimensional resource flows, vertical between two echelons and horizontal intra-echelon, in a multi-echelon system to account for movements of medical resources in the healthcare system. The approach has been applied in China.

Li and Liao (2022) propose a method to support large scale group decision making. The method involves assessing expert preferences on their own merit, as well as on the relation with other experts' evaluations, to generate clusters of experts and their weights for the criteria used in each alternative. The authors also propose a feedback mechanism to improve the allocation of experts to clusters if there is no consensus. They apply the approach to the selection of COVID-19 vaccines in a synthetic case study in China.

## **Conclusions**

The first five papers in the SI address one of the critical issues in OR Practice during unexpected situations, such as pandemics or disasters, incomplete or non-existing hard data. The authors propose different approaches to tackle the problem from shared data resources to novel methods that use intermittent data, as well as expert judgments. The papers showcase the breadth of the OR field and the suitability of diverse methods to different data. One of the important contributions is the presentation of different frameworks to use in this type of situation, which have become frequent in recent years with climate change and international conflicts. Another critical contribution is the use of multiple methods to address complex and unexpected situations.

The next three papers in the SI show different solutions to resource decisions during a crisis. Firstly, the location of resources, such as hospitals, is discussed in Kheybari et al (2021). Secondly, two papers address the optimisation of the capacity of existing resources with different scope and approaches. The three papers may be combined to give a comprehensive solution to decision makers that involves multiple aspects of resource allocation using soft and hard data.

The four papers from the general track show the breadth of the OR field bringing additional methods to address similar problems associated with the pandemic: allocation of resources, predicting the epidemic and making complex decisions.

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