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Panel on Simulation Modeling for Covid-19

Dionne M. Aleman

Department of Mechanical &
Industrial and Systems Engineering
University of Toronto
5 King's College Road
Toronto, ON M5S 3G8, CANADA

Anastasia Anagnostou

Modelling & Simulation Group
Department of Computer Science
Brunel University London
Kingston Lane, Uxbridge, UB8 3PH, UK

Christine S.M. Currie

Mathematical Sciences
University of Southampton
Highfield, Southampton
SO17 1BJ, UK

John W. Fowler

Department of Supply Chain Management
Arizona State University
300 E Lemon Street
Tempe, AZ 85287, USA

Esma S.Gel

Industrial Engineering
Arizona State University
699 S Mill Avenue
Tempe, AZ 85281, USA

Alexander R. Rutherford

Department of Mathematics
Simon Fraser University
8888 University Drive
Burnaby, BC, V5A 1S6, Canada

ABSTRACT

This is a panel paper which discusses the use of simulation modeling in mitigating the effects of the Covid-19 pandemic. We have gathered a group of expert modelers from around the world who have worked on healthcare simulation projects associated with the pandemic and the paper provides their answers to an initial set of questions. These serve to provide a description of the modeling work that has taken place already and to make suggestions for future directions both in modeling Covid-19 and preparing the world for future healthcare emergencies.

1 INTRODUCTION

The aim of the panel is to provide a snapshot of some of the work that the healthcare simulation modeling community has carried out since the start of the Covid-19 pandemic and to look forwards to future challenges. We see those challenges splitting into immediate questions of how to continue to mitigate the effects of Covid-19 and, looking further ahead, to how the world could be better prepared for another global healthcare emergency. Our focus is on what the simulation modeling community can contribute, building on the very early questions and solutions included in a previous paper on the topic (Currie et al. 2020).

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We have structured the paper around a set of questions, with each of the panellists providing their answer in turn. We use the panellists' initials to identify who has written each response. The paper finishes with a short conclusion that aims to bring together the key points raised by the panellists.

2 QUESTIONS

2.1 What problems due to the Covid-19 pandemic have you been addressing?

DMA: I am currently working with the government of Newfoundland & Labrador (Canada) to advise them on Covid-19 mitigation and vaccine strategies, and I am a member of the Public Health Agency of Canada's external experts modeling group. I use very large-scale, highly granular ABS simulation models to predict the effect of nuanced policy decisions on disease spread and other pandemic outcomes. From the simulation, I extract contact networks and then determine vaccine prioritization strategies using graph theory concepts, most notably by treating vaccine prioritization as a critical node detection problem. Additionally, I am using machine learning to predict health outcomes (e.g., hospitalization, ICU, ventilator, and death) for Covid-19 patients.

ESG: Since March 2020, I have been working on a number of projects regarding Covid-19. Probably two are worthwhile to note. Since about April 2020, I have been building projection models for the State of Arizona with a multi-disciplinary modeling group Modeling Emerging Threats for Arizona, (METAz) at ASU. These projections have been presented to public health officials at the Arizona Department of Health Services (ADHS) at weekly meetings, and have been demonstrated to be highly reliable to predict deaths and hospitalizations in Arizona. Our projections have been featured in various media outlets and have informed public on the state of the epidemic since April 2020. The projections are obtained through a compartmentalized system dynamics (aka, SEIR) model specifically designed for Arizona, initialized and parameterized with data from Arizona. I have found that the main art in using these models is really in fitting them using different sources of data, to obtain a coherent snapshot of the transmission dynamics and a plausible forecast of the near future. We outlined early efforts in (Gel, Jehn, Lant, Muldoon, Nelson, and Ross 2020).

The other simulation modeling project I would like to mention is the ABS modeling work that I have done with a multidisciplinary team of clinicians and researchers from Mayo Clinic, MIT and Harvard University. We used an ABS model of a small community to show the effectiveness of delaying a second dose of the Covid-19 vaccine, and showed that the effectiveness of this strategy, in comparison to the standard dosing depends on the vaccination rates (i.e., availability of vaccine and how fast they can be administered) as well as the efficacy of the first dose of vaccine. ABS models are extremely powerful to study these types of issues, but there are certainly computational and technical issues to overcome to make this type of work useful for real-life questions surrounding the pandemic. Our findings were compiled in a manuscript that is currently under review at a leading clinical journal (Romero-Brufau et al. 2021).

AA: My modeling work is focused on three aspects of managing the Coronavirus pandemic: the spread of the disease, ICU capacity management for Covid-19, and the long-term impact of Covid-19 on individual health and the cost-effectiveness of prevention and treatment interventions. At the time of writing (April 2021), I am working in two main projects for pandemic crisis management.

The first project is focussed on Covid-19. The work started in March 2020 when the first Covid-19 wave hit the UK. We, a research team at Brunel University, were approached by two London NHS Trusts to help them understand the progression of the disease in the local area and whether their hospitals would be able to cope with a surge of Covid-19 patients. The main problems we have been addressing in this project are:

- How does Covid-19 spread in local communities?

- How effective the public health prevention interventions are in terms of infections, hospitalizations and deaths?
- Do the character and demographics of an area affect the spread and severity of Covid-19?
- Will the local hospitals run out of ICU resources?
- Do the local hospitals need to reconfigure their wards to manage a surge of Covid-19 patients?
- Do the local hospitals need to limit or cancel routine operations?

It is worth mentioning that the questions we were asked to address with our models were changing at a very fast pace. For example, at the start of the pandemic the hospitals were uncertain whether they would have enough ICU beds with mechanical ventilators. A few weeks later, their main concern was whether they would have enough specialist nurses. When the first wave was starting to ease, the main concern was how they should manage potential future waves while keeping the normal operations of the hospital. Similarly, prevention interventions were changing fast as we were learning more about the disease and the vaccination of the population was starting to roll out.

In the second project, an EU-funded innovation action project, we have been addressing issues around preparedness and response actions for pandemic crisis management. Apart from Sars-CoV-2, we include several pathogens that have the potential to cause large epidemics. We have been trialling the use of different simulation models, in combination with other tools such as early warning systems, wearables, point of care diagnostics, crisis planning and training tools, etc., in scenarios within and among different countries in Europe and neighboring countries. We work with a number of national planners and first responders, such as Ministries of Health, Public Protection authorities, The Red Cross, St John Ambulance and University Hospitals in the area. The questions we attempt to address include among others:

- How can we use the tools in our arsenal in the most effective way?
- What tools are the most appropriate for different levels of command and control?
- How can we enhance cross-border collaboration in a pandemic response?
- What long-term effects will a pandemic have on individual health?

ARR: Since the beginning of the Covid-19 pandemic, I have been leading a research team at Simon Fraser University that is collaborating with the acute care analytics teams in the British Columbia Ministry of Health. We have been developing queue network and discrete event simulation (DES) models of patient flow within the acute care system. Our first project was to develop a generalized Erlang loss queue model for access to mechanical ventilators during the first wave of the pandemic (Zimmerman et al. 2021). Case project input for the model was provided twice per week by the British Columbia Centre for Disease Control (BC CDC) and a report on model output was sent to the Ministry of Health to inform planning during the early stages of the pandemic. Demand for mechanical ventilation for both Covid-19 and non-Covid-19 patients were included in the model, which allowed us to model scenarios such as reducing elective surgeries to increase access to mechanical ventilators for Covid-19 patients. That work has since been extended into two follow up projects. We have developed a suite of DES models to allow analysis of bed requirements to maintain access standards for emergency department admissions for most hospitals in British Columbia. Our initial work on modeling access to mechanical ventilators has been extended to a DES model for the critical care network in British Columbia. This model covers the network of major ICUs in the province. It also includes high acuity units, which have been utilized extensively during the pandemic to care for seriously ill Covid-19 patients who do not require mechanical ventilation.

One of my PhD students has also been working with the BC CDC on epidemiological modeling of the pandemic. This work has included the impact of public health interventions, such as social distancing and mask wearing, on case projections. More recently, they have been including vaccination strategies in their modeling to optimize roll-out strategies for the vaccination program (Mulberry, Tupper, Kirwin, McCabe, and Colijn 2021).

2.2 What are the origins of your modeling work - how did the people with the questions find you and your team?

DMA: I actually began developing agent-based simulation (ABS) models for pandemics over 10 years ago, when I was approached by Master's student Theo Wibisono, who wanted to do a project addressing public health emergencies, stemming from his observations of a need for industrial engineering approaches to such situations after the 2004 tsunami and earthquake in Indonesia. We decided to investigate pandemic planning and found a collaborator at what is now called Public Health Ontario, and investigated emerging questions during the H1N1 pandemic. Theo now works in the Ministry of Health & Long-term Care, and I have been researching pandemic planning since. With Covid-19, I was approached by Newfoundland & Labrador early in 2020 to work with them after they had seen some of my media appearances on the topic.

ESG: I have to say that the origins of my work is really the starting of the Covid-19 pandemic. Around the beginning of March 2020, I reached out to the team of researchers that I mentioned above to offer my services as a modeler, and I have to say that our work was carried out significantly differently than regular research projects. Mainly, we were interested in useful projections to inform the Arizona State Health Department and the public on a timely basis, so I personally coded and fit the models, and our team, which includes epidemiologists and public health experts, identified likely scenarios that may change the current state of the disease transmission to offer projections for deaths, hospitalizations and ICU occupancy in the near future. Typically, we projected out four to six weeks, acknowledging the difficulties of knowing policy and public behavior changes. I have to say that the effort has been acknowledged by different parties and public health experts in the State, but one of the most important benefits of it has been that it has allowed me to make sense of the plethora of data and gave me a general sense of understanding that has been useful to me to manage the personal risks and stresses during this period.

AA: I have been working in healthcare modeling and simulation since 2015. I have worked with the Department of Health, the National Institute for Clinical Excellence and various NHS Trusts in the UK in modeling clinical pathways, healthcare processes and emergency medical services. I mainly use ABS and DES either standalone or in hybrid approaches. I also use High-Level-Architecture-based (HLA-based) distributed simulation for modeling large-scale systems that are comprised of loosely coupled subsystems. In terms of epidemic modeling, prior to the Coronavirus pandemic, my experience was limited to a single SIR ABS model that I developed as a demonstrator for cloud-based modeling and simulation and Open Science technologies for simulation. Most of my work is conducted within the Modelling & Simulation Group in the Department of Computer Science, Brunel University London.

ARR: I have been working with the Ministry of Health and Health Authorities in British Columbia on healthcare modeling since 2007. At that time, I developed hospital simulation models that were used for many years to support capital planning. Just prior to the pandemic, I had received funding through the Partnership and Innovation Program of the British Columbia Ministry of Health to develop simulation models for acute care capacity and access to critical care. This project was rapidly re-focused to support the response to the pandemic. I have also worked for many years with Vancouver Coastal Health Authority on modeling of their HIV testing and treatment programs. Through this work, I developed a number of connections with the BC CDC that facilitated my recent collaboration with them.

2.3 What methodologies have you employed in studying these problems?

DMA: I use ABS models (built in C++ and parallelized on high-performance computing infrastructure), graph theory and network optimization, and machine learning.

ESG: I have used compartmentalized system dynamics models as well as ABS models for my work. However, these models have always been parameterized through the use of various statistical techniques to analyze the data or fit models. For example, I employ a nonlinear model fit procedure to simultaneously fit three different sources of data to obtain time dependent transmission rate governing the SEIR model.

AA: In the first project we adopted a hybrid approach using ABS for modeling the spread of Covid-19 and DES for modeling ICU capacity. We developed a geospatial ABS to capture the services and functions in a local area as well as the demographics and residential settings. The model includes a SEIRD epidemic model and is being used to experiment with different public health prevention interventions and predict their impact on infections, hospitalizations and deaths at a community level (Mahmood et al. 2020). The predicted hospitalizations due to Covid-19 are then being used as hospital admissions input for the DES. This model is being used to support planning for hospital ward reconfiguration to efficiently manage a potential Covid-19 surge while maintaining the routine hospital operations. In the second project we use seven different models, ranging from compartmental models, ABS, DES and deep neural network models, to study different aspects of an epidemic. I, in particular, employ ABS to study the long-term impact of Covid-19 on individual health and the cost-effectiveness of prevention and treatment interventions. This model includes individual demographic and physiological data as well as epidemiological and economic cost data for communicable and non-communicable diseases and the associated interventions.

ARR: We have used DES models programmed in AnyLogic, which has allowed us to rapidly develop and modify the models to meet the changing needs of the Ministry of Health. Simulation optimization was used to determine the number of resources required to meet access targets. For example, we determined the number of ventilators required to maintain an upper bound on the probability that a patient would be unable to access a ventilator when required for different case projection curves. Our simulation optimization approach uses approximate methods from queuing theory to obtain initial starting points, and a stochastic root finding method to refine the solution.

2.4 How much have you been able to exploit previous pandemic modeling efforts (yours or from others)?

DMA: All of my work in pandemics is designed to be generalizable—population and disease details are just values in input files—so my previous work is immediately applicable. Still, we spent significant time updating the simulation model to contain new details (e.g., comorbidities and specific business industries and their unique risk factors) and new policy levers (e.g., quarantining an individual class in the event of a case in a school) to reflect real-world pandemic concerns and responses.

ESG: Since I was new to the field, I was not able to exploit my previous work so much, but of course my previous work on data mining and machine learning, statistical analysis were all very useful. The epidemiological modeling using compartmentalized system dynamics modeling, and their deterministic and stochastic simulations is a very well established field, with almost 100 years of literature. Hence, anything you can think of with respect to building or parameterizing these models, in all likelihood, has been done before. It is very hard to claim novelty in the techniques that you use, so it is important to produce results that are timely and useful to answer important real-life questions surrounding the Covid-19 pandemic.

AA: We have indeed been able to reuse our own previous modeling efforts at various levels. For example, we reused an ABS model we previously developed to study the long-term effects of physical activity on individual health and the cost-effectiveness of physical activity interventions (Anagnostou et al. 2019). This model was repurposed to describe the long-term impact of Covid-19 on individual health and the cost-effectiveness of prevention and treatment interventions for infectious diseases. The geospatial ABS we used to model the spread of Covid-19 was built anew. To build the model however we reused an ABS framework we developed in previous work to model forced displacement and migration due to conflict. In the case of the ICU capacity DES, we decided that it was more efficient to build the model anew. In all cases we certainly exploited experiences from previously published work although we did not use the actual implementation per se.

ARR: The basic structure of our simulation models of the acute and critical care system is based on previous work that we did on simulation modeling of hospitals. However, many of the details of the models were re-designed to address the current situation. The importance of access to mechanical ventilators for Covid-19 patients required that we treat this as a key constrained resource within the critical care model. This was done to the extent that we even included in our model the time required to clean and maintain ventilators between patients.

2.5 Where have you obtained the data needed for your pandemic modeling work?

DMA: We were fortunate to have provincial support to collect the necessary data for every project, and even still, it took about two months to gather appropriately detailed data for the simulation. When I was modeling pandemic influenza and H1N1 for the Greater Toronto Area, it took multiple summers of undergraduate students assembling the data from disparate sources.

ESG: Initially, the data we had access to was limited to the publicly available data on deaths and confirmed cases. Later on, the State of Arizona started posting, at their data dashboard, data on hospitalizations and ICU occupancy, and we started using that data to fit the hospitalization rates in our model, in addition to using deaths and confirmed cases. Over time, we have moved away from using confirmed cases to initialize and parameterize the model since this data is subject to a lot of different issues such as lags in reporting, testing availability, etc., so we have found that relying on death and hospitalization data and using case counts as a validation point have worked better to get a more coherent picture of the transmission and disease dynamics and impact over time in Arizona.

AA: Our main sources of primary data have been and still are our stakeholders. We also use open data published by public health authorities and national statistic agencies. A particularly valuable source, especially at the start of the pandemic when very little was known, was secondary data mainly from published cases in Wuhan. However, despite the close collaboration with our stakeholders, due to the many unknowns, a considerable amount of assumptions needed to be made. These assumptions were informed from published literature on previous epidemics.

ARR: We were fortunate to have data sharing agreements with the Ministry of Health to allow us to use anonymized extracts from the Discharge Abstract Database for all hospitals in British Columbia, and the British Columbia ICU Database. These two databases provide extensive details on all hospitals admissions, with further granularity for patients admitted to intensive care.

2.6 What problems do you wish you could tackle (via modeling) related to pandemics?

DMA: Lack of centralized, consistent data reporting has hampered modeling efforts around the world, whether modeling pandemic spread or modeling an individual's health outcome after infection. If I could tackle one problem to better prepare for the next pandemic, it would be to create a global database that connects all points of care (hospitals, family doctors, vaccine clinics, etc.) for seamless and automated reporting of cases with detailed information about patients and outcomes.

ESG: I also agree that availability of reliable sources of data is extremely important for preparing for future pandemics. Beyond data, I would love to have more information on social and employment networks and access to better modeling of interactions, preferences and vulnerabilities of individuals at a population level to identify best use of interventions and resources such as vaccines.

AA: Managing a pandemic is a multifaceted problem that requires cross-sector and cross-border collaboration. The coronavirus pandemic made it very clear that the adopted policies affect not only the healthcare sector but almost all sectors and they have both short-term and long-term consequences across the world. We have also seen an enormous amount of modeling effort enriching an already large pool of infectious disease and crisis management models. Having done work on distributed simulation, I am very keen to investigate further how we can create interoperable and reusable models to study emergency services interoperability in a response to a pandemic. Another problem that I am keen to model is climate change and environmental factors as determinants of emerging epidemics and how we can consider these factors in pandemic response planning and equitable care delivery.

ARR: Our modeling was largely focused on operational modeling of the acute care system during the pandemic. We were able to link somewhat to epidemic modeling at the BC CDC to connect the impact of public health measures on alleviating the strain on the acute care system. However, I would have liked to be able to do more integrated public health and acute care modeling to better inform which public health measures would have the greatest impact on alleviating the strain on hospitals. For example, better age-structured epidemiological models would have allowed us to be more accurate in projecting the number of patients on mechanical ventilators.

2.7 What lessons have you learned as a modeler that could help with being better prepared for any future health crises?

DMA: There is so much around pandemics, and Covid-19 in particular, that models truly cannot capture. Covid-19 often spreads in sudden super-spreader events, rather than exclusively following expected exponential curves and waves. These events are often just bad luck or one bad actor, and while ABS models are better equipped than typical models to allow for such events to happen just through the vagaries of random number generation, they still can't predict when or where they might happen. We can really only model how best to respond to such events. The phrase we use in our modeling team, which consists of both my lab doing ABS and another team of math and stats researchers doing compartmental models, is "don't wait, re-escalate". But, modelers do not set policy, and the policymakers in many regions make decisions for political reasons rather than for public health or even economic reasons, and I do not know what preparation could avoid ultimately poor decision-making by those in charge. Stopping disease spread is not rocket science, but it does take commitment from politicians and the population, and this pandemic has shown that there is a finite window during which there will be buy-in for hard but necessary measures like lockdowns; if you do not get disease spread under control in that time, you cannot expect a safe return to normalcy (with occasional circuit breakers), and instead are resigning the population to long, drawn-out measures that fall short of the goal to actually stop spread.

ESG: I have learned that humans, in general, are bad at four things that impact the effectiveness of our response to a pandemic event like this: (i) understanding dynamics over time, (ii) appreciating the implications of stochasticity, (iii) imagining exponential growth, and (iv) receiving bad news. I thing that a pandemic involves all of these four things, and this has affected our ability to respond to this crisis. I truly do not think that the science needed for this work was very difficult, but we, as the scientific community, had difficulty communicating our results to the public. I feel that we should really improve our skills to communicate and at the same time spend time and effort to improve the public's understanding of mathematics and statistics to be better prepared for future public health crises.

AA: Modeling has been an invaluable tool throughout the pandemic. Numerous models have been used to inform policies across the world. Although this is great news for the modeling community, it comes with a huge responsibility. As modeling experts, we are aware that models do not make decisions, they can only inform decision-making. We are also aware of the limitations and uncertainties of the models especially when the data is limited. But, how do we communicate this to a wider audience? How do we argue that models are not the oracles that tell the future but mere scientific tools with their limitations? So the first, and arguably the most important, lesson to be learnt is that we need to better communicate our models, not only their glories but their limitations as well; and we need to do that in a way that is easily understood by experts and non-experts alike. Another important lesson learnt is that we need to find ways to be more agile in developing and adapting models as well as to speed up experimentation. The fast pace of change, especially in the early stages of the pandemic, meant that most of the times we were one step behind the curve. I should also mention the importance of making our models open and use standardised reporting practices so they can be confidently reused by other modelers (Taylor et al. 2017).

ARR: Throughout the course of the epidemic, we have often been playing ”catch-up” in developing our acute care models. Developing these models requires that we consult with experts within the system (healthcare providers and managers) to understand patient flow and other operational details. During a pandemic, healthcare providers do not have time to be working with operations researchers. I feel that healthcare systems should already have in place simulation models required to manage the system in a crisis.

2.8 What do you think are the greatest long term problems facing health services in the wake of the Covid-19 pandemic and how can modeling help?

DMA: At least in Canada, basic health services have been largely suspended due to lack of capacity for normal procedures in ICUs and wards due to Covid-19 bed occupancy. Wait times for elective procedures have skyrocketed, and the need for industrial engineering solutions to maximize throughput and re-imagine the surgical process from the family doctor to hospital discharge are required. I have actually spent the past few years researching collaborative surgical scheduling among hospitals—finding tremendous efficiency gains—and am launching a province-wide study of single-entry surgical queues together with other industrial engineers and surgical experts, with the anticipation that such systems will be critical to return our health services to normal in a post-Covid-19 world.

ESG: I believe that the Covid-19 pandemic has highlighted the importance of having well-established public health services and the good that community health driven organizations can do to control outbreaks and help people in need. I feel that this will lead to the development of infrastructure around these needs, as well as a stronger drive for public health interventions like vaccination campaigns. Modeling can help tremendously to improve operations and save costs in all facets of this work.

AA: There are many. Where shall I start? Arguably the most obvious is to efficiently schedule the backlog of elective surgeries that have been postponed due to Covid-19. Another issue is the possible increase of advanced cancer patients due to screening and treatment delays. There is also uncertainty around Long Covid and its long-term effect on patients. Will healthcare systems face a surge of seriously ill patients with complex healthcare needs? The pandemic has also highlighted the need for better collaboration between social care and health services. I should also mention the increasing risk of emerging epidemics. So, how can health services manage these challenges? And how can they be better prepared for a future pandemic? Modeling can arguably help in planning for all these complex issues but we need to make our modeling practices more open and more efficient. I will stress the importance of creating open models that are findable, accessible, interoperable and reusable; that is adhering to open science practices and create models that are compliant with the FAIR principles. In an interconnected world we need interconnected models to tackle global challenges.

ARR: I feel that the Covid-19 pandemic has highlighted an under-investment in public health. Furthermore, we need to look at the healthcare system as an integrated system, rather than viewing public health, community care, and acute care as separate systems. In the fight against Covid-19, we will need to learn how to optimize vaccination strategies in the context of both the community care and acute care systems. This is especially true if protecting against Covid-19 variants requires annual vaccinations or perhaps even more frequently.

3 CONCLUSION

The (Currie et al. 2020) paper laid out a number of areas where modeling and simulation could be used to support decisions aimed at reducing the impact of the Covid-19 pandemic. The paper classified the efforts into three main decision areas: 1) decisions affecting disease transmission; 2) decisions regarding resource management; and 3) decisions about care. All of these main areas were covered by our panellists from around the world. As the answers above show, modeling has helped support policy-makers across a range of heath-related questions during the Covid-19 pandemic that begin with the projection of cases and deaths but go beyond that to optimize responses. Just in this paper, the questions answered include mitigation and vaccination strategies; capacity management of hospital resources, particularly ICU and mechanical ventilator beds; determining how the impact of Covid-19 on routine operations can best be dealt with; and the impact of Covid-19 on patient flows. As befits the different questions, the models used range from queuing, to differential equation models to DES, ABS and hybrid DES-ABS. All of the work described here was useful and helped with the effort against the virus and there are two characteristics of the projects described here that may explain that. First, the majority of projects involved inter-disciplinary teams, pulling together modelers, clinicians and public health experts. Second, there were strong partnerships between the modeling teams and the stakeholders, built up via good communication links and, in many cases, a long history of successful modeling projects.

Looking forwards, we can draw together the answers from the panel into a few key points. First, models need data and in a pandemic situation, better and more immediate access to reported case numbers and patient outcomes would aid model-building. More generally, the projects described here often worked because existing data-sharing agreements were in place and this suggests that building close links between modelers and healthcare providers before a crisis hits is important in generating a fast response. Following on from that, the second point that comes over is that there is a need for better availability of models. This incorporates advance building of simulation models for modeling a healthcare system in a crisis but also better sharing of models. Using open science ideas to ensure that models are easily reusable and flexible to being adapted to a new disease or situation would speed up model (re)development. Adopting an open science approach would also allow modeling groups to easily repeat analyses, engendering more trust in the recommendations emerging from modeling studies. This is important where these recommendations are being used to guide policy. Third, integrating the modeling of different aspects of the healthcare system is important - particularly combining public health and epidemiology with acute care modeling. The final point concerns communication and increasing the impact of modeling on policy. There is a hint of frustration that policy-makers do not always listen to modeling results, and the delays in declaring lockdown policies are a good example of where not listening initially has most likely made things worse in the long run. Two suggestions are made for improving this: better education of policy-makers and the population as a whole and for modelers to give more thought on how to present the uncertainties in their results. Training modelers to better understand the political decision process may pay dividends here, but communicating uncertainty while still presenting a clear message is not easy and is a point that we hope to return to during the panel discussion.

Our aim was to showcase how beneficial modeling has been since early 2020 in reducing the impact of Covid-19 but also to describe positive actions that the modeling community can take to improve responses to any subsequent healthcare emergencies. We look forward to continuing the discussion during the WSC 2021 conference.

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AUTHOR BIOGRAPHIES

DIONNE ALEMAN is an Associate Professor in the Department of Mechanical & Industrial Engineering at the University of Toronto, with appointments in the Institute for Health Policy, Management & Evaluation; the Institute for Pandemics; and the University Health Network Techna Institute. She is also co-Lead for the Toronto-Manchester Joint Translational Centre for Digital Health, and is a member of the Public Health Agency of Canada's external experts Covid modeling group. Her research focuses on the application of operations research to medical and healthcare systems to improve the quality, timeliness, and efficiency of care. This research includes using optimization, simulation, machine learning, and graph theory to solve problems in pandemic modeling, radiation therapy, hospital scheduling, and organ transplant matching. This research has been supported by NSERC, CIHR, CFI, ORF, and NSF. She additionally is a

two-term past President of the Canadian Operational Research Society (CORS-SCRO). Her email address is aleman@mie.utoronto.ca.

ANASTASIA ANAGNOSTOU is a Senior Lecturer in the Department of Computer Science at Brunel University London and the co-lead of the Modelling and Simulation Group. She holds a PhD in Hybrid Distributed Simulation, an MSc in Telemedicine and e-Health Systems and a BSc in Electronic Engineering. Her research interests are related to the application of modelling and simulation techniques in Industry and the Healthcare sector. She is principal investigator of the STAMINA project (grant number: 883441) where she is leading the development of seven predictive models for pandemic crisis management and the health technology assessment of the STAMINA toolset. She was Conference Co-Chair for the 10th OR Society Simulation Workshop (SW21), Chair of the 2018 Winter Simulation Conference (WSC) PhD Colloquium and organising committee member of the 2015 ACM/SIGSIM Principles of Advanced Discrete Simulation (PADS 2015) and the 20th IEEE/ACM International Symposium on Distributed Simulation and Real Time Applications (DS-RT 2016). She is also external expert for the European Commission. Her email address is anastasia.anagnostou@brunel.ac.uk and her ORCID iD is https://orcid.org/0000-0003-3397-8307.

CHRISTINE CURRIE is a Professor of Operational Research in Mathematical Sciences at the University of Southampton and a member of the Centre for Operational Research, Management Sciences and Information Systems (CORMSIS). She is Editor-in-Chief for the Journal of Simulation and has previously co-chaired the UK Simulation Workshop. Her research interests include simulation optimization, applications of simulation in health care, optimal pricing and disaster management. Her email address is christine.currie@soton.ac.uk and her website is http://www.southampton.ac.uk/maths/about/staff/ccurrie.page.

JOHN W. FOWLER is the Motorola Professor of Supply Chain Management and recently served as Chair of the Supply Chain Management department in the W.P. Carey School of Business at Arizona State University. His research interests include discrete event simulation, deterministic scheduling, multi-criteria decision making, and applied operations research with applications in semiconductor manufacturing and healthcare. He has published over 130 journal articles and over 100 conference papers. He was the Program Chair for the 2002 and 2008 Industrial Engineering Research Conferences, Program Chair for the 2008 Winter Simulation Conference (WSC), and Program Co-Chair for the 2012 INFORMS National Meeting. He was the founding Editor-in-Chief of IISE Transactions on Healthcare Systems Engineering and currently serves as a Healthcare Operations Management Departmental Editor. He is also an Editor of the Journal of Simulation and Associate Editor of IEEE Transactions on Semiconductor Manufacturing and the Journal of Scheduling. He is a Fellow of the Institute of Industrial and Systems Engineers (IISE) and served as the IISE Vice President for Continuing Education, is a former INFORMS Vice President, and served on the WSC Board of Directors. His email address is john.fowler@asu.edu.

ESMA S. GEL is an Associate Professor of Industrial Engineering at the School of Computing, Informatics and Decision Systems Engineering of Arizona State University. Gel's research focuses on the use of stochastic modeling and control techniques for the design, control and management of operations in various settings, with emphasis on manufacturing and service systems, business and logistics processes, and health care systems. Since the beginning of the Covid-19 pandemic, she has been working as the lead modeler for the Modeling Emerging Threats for Arizona (METAz) workgroup of ASU with a group of epidemiology and public health experts. The projections produced by the group have been able to predict trends in hospitalization and deaths from May 2020 to present and is informing projection updates provided to the Arizona Department of Health Services by ASU. Gel's work has been published in leading journals of her field and funded by the National Science Foundation as well as several industrial partners such as Intel and Mayo Clinic. Gel holds a B.S. degree in Industrial Engineering from Middle East Technical University, Turkey, and M.S. and Ph.D. degrees in Industrial Engineering from Northwestern University, obtained in 1995 and 1999, respectively. Her email address is esma.gel@asu.edu.

ALEXANDER RUTHERFORD is an Adjunct Professor in the Department of Mathematics and Acting Director of the Centre for Operations Research and Decision Science at Simon Fraser University. His research focuses on applications of operations research to health systems, public health, and epidemiological modeling. He has worked extensively on modeling testing and treatment within the continuum of care for HIV. Currently, he is leading a group of researchers at Simon Fraser University who are collaborating with the British Columbia Ministry of Health to model acute and critical care capacity during the Covid-19 pandemic. His email address is arruther@sfu.ca.