How Flexible OR&A Teams Provided Decision Advantage through Pandemic Uncertainty

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ABSTRACT

The coronavirus disease 2019 (COVID-19) pandemic affected the Canadian Armed Forces (CAF) and its members in multiple ways. As the CAF manages its own healthcare system for its members, it had to consider the impact of COVID-19 not only on the operational effectiveness of its workforce but also on its healthcare operations. Furthermore, given that the CAF continued to deploy on domestic and international operations, it was important for it to maintain local and global awareness of the state of the pandemic. Defence Research and Development Canada (DRDC)'s Centre for Operational Research and Analysis (CORA) operates as small teams of scientists embedded throughout the CAF, and as the pandemic evolved many of those scientists collaborated across teams and built on each other's analyses for individual commanders to ultimately advise the CAF and its Surgeon General more broadly. In many ways, this represents a return to DRDC CORA's World War II roots. This paper highlights the breadth of these contributions and identifies key enablers for success. In doing so, it covers how the distributed model of DRDC CORA lent itself to the rapid formation of both informal and formal teams to provide timely and impactful advice to the CAF, and how both public and internal information sources were leveraged to allow commanders to make informed decisions on operational risk.

1.0 INTRODUCTION

While the precise origins of science being applied to military operations are difficult to pinpoint [1], military operational research (OR) as a formal discipline in Canada began because of the global threat posed during World War II [2]. As with other nations, Canadian researchers were enlisted in the war effort, and a few were embedded in British units where OR in support of the military had recently taken root [1]. It was not long before Canadian senior military leaders recognized the value that these scientists were providing the British Armed Forces [2] and created their own OR units embedded in each of the three traditional environmental services (Army, Navy, and Air Force) [3]. These units were disbanded at the conclusion of the war, but it was only a matter of a few short years before OR was re-established in Canada's Department of National Defence [2]. This capability has evolved through multiple forms since that time, with the bulk of such scientists now forming the Centre for Operational Research and Analysis (CORA), part of Defence Research and Development Canada (DRDC).

The emergence of the severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2), the virus that causes coronavirus disease 2019 (COVID-19), resulted in a pandemic that continues to affect many facets of everyday life to this day. As such, it represents the latest global threat against which OR resources have been mobilized. This paper discusses the factors that facilitated CORA's counter-COVID-19 efforts along with brief descriptions of the work that was accomplished as a result. The goal is to provide an overview of the breadth of this work and refer the reader to its published record should more information be desired.

The remainder of the document is structured as follows. Section 2 provides a general overview of CORA's current structure as well as some of the relevant organizational philosophies which served to enable a successful analytical response during the pandemic. How those factors worked in CORA's favour is described in Section 3, while Section 4 introduces some of the key accomplishments of CORA scientists in support of Canada's pandemic related efforts. Section 5 describes lessons learned from our COVID-19 response. Finally, Section 6 offers concluding remarks.

2.0 AN OVERVIEW OF DRDC CORA

DRDC CORA was born out of a need to support operations during a time of crisis, and while its primary focus has long since shifted away from tactics and strategies in support of combat operations [4], CORA retains many of the features that enabled it to be effective in its response to evolving situations.

Today, CORA's analytical horsepower is provided by approximately 100 scientists who specialize primarily in (quantitative) OR[1] and strategic analysis,[2] along with a few other specialists in fields such as engineering and open-source intelligence. Rather than existing as a centralized capability, CORA's organizational structure still reflects a strong connection to its client-focused origins, with teams geographically embedded across almost all major branches of the Canadian Armed Forces (CAF) and the Department of National Defence (DND), including most major operational headquarters. As we will see in the next section, these relationships with key clients allowed CORA scientists to quickly identify areas of concern where OR&A could benefit decision making. Because of the choice to directly support a large number of disparate clients, CORA's teams tend to be small (fewer than five members for the most part) and coalesced into sections that maximize cross-team synergy. The program of work that any specific team takes on usually has a significant dynamic component to it (often termed as time programmed for "emerging requirements"), allowing the scientists to remain agile in the face of evolving demand as is often necessary when encountering situations such as the COVID-19 pandemic for which there are few, if any, parallels.

CORA scientists are expected to rotate through a variety of teams over the course of their careers, placing the emphasis on the development of generalists over specialists. While this can be disruptive to an individual's development in the short term, the model aims to establish a breadth of experience that pays dividends both to the individual and to CAF/DND in the form of broader context developed as careers progress. In doing so, the scientists also benefit from the opportunity to work alongside a wide variety of colleagues – both within CORA and the broader CAF/DND enterprise – in fairly short order, exposing them to a greater diversity of approaches to addressing client issues and placing them in a position to better leverage individuals' strengths as required. Additionally, working in this manner requires CORA scientists to not only be able to come up to speed rapidly on a new application area when changing teams, but ideally to anticipate what questions may be coming next in order to allow time for research and considering possible approaches, factors which will be explored in greater detail below.

[1] Typical backgrounds include operational research, physics, applied mathematics, data science, and other related fields.

[2] Strategic analysis can be thought of as "the application of historical analysis and methods of social science to political, economic, social, diplomatic, and technological developments across the globe, and the formulation of approaches to maintain and improve Canada's defence and security posture" [5].

In the next section, we shall see how being embedded within key structures at the onset of the pandemic proved to be fortuitous. We will also see how CORA scientists quickly cut through organizational silos to form ad hoc teams through extant relationships, both formal and informal, stemming from past collocation, shared project work, or shared operational priorities originating from client concerns. For those who had worked through past crises, there was also a shared sense that even if specific questions had not come to CORA yet, they inevitably would.

3.0 KEY FACTORS ENABLING EFFECTIVE COVID-19 MODELLING AND ANALYSIS

This section will focus on the organizational factors that we believe allowed CORA to respond effectively to the pandemic. Examples of individual COVID-19 studies will be presented in the section that follows this one; further details are available in the reports cited therein.

3.1 Collaboration and Networking within DRDC CORA

DRDC's COVID-19 epidemiological modelling and analysis (EM&A) efforts began with the DRDC CORA team embedded at the binational NORAD headquarters (HQ) in Colorado Springs [6-7]. This effort was in response to concerns from the NORAD/USNORTHCOM[3] Commander regarding the ability of the HQ to continue functioning effectively in the face of the pandemic. Similar questions were asked of CORA teams embedded with other clients, but NORAD commanders tended to ask the questions earlier than the other commanders. Fortunately, the CORA team at NORAD had foreseen questions of this nature and was prepared to start to answer them. The number and depth of questions about COVID-19 risk quickly became more than the two-person team could handle itself, so previous scientist-to-scientist networks were accessed to seek additional, informal support in quantitatively assessing the COVID-19 risks. The collaborators drawn from across CORA had all worked with the NORAD team members on other CORA teams in the past – and in many cases collaboratively on ongoing projects – showing the importance of previous working relationships.

3.2 Scientist-to-CAF Professional Networks

Serendipitously, the professional networks developed between CORA scientists and CAF members who had been clients to CORA teams in the past, included CAF members who, at the start of the pandemic, were part of the medical intelligence (MedInt) team[4] and were closely linked to the CAF's Health Services Group.[5] Even though CORA did not have a team supporting either MedInt or the Health Services Group, they both formally requested analytical support from CORA thanks to these previous, trusted, professional relationships. This led to a rapid expansion of the scope of CORA's EM&A support to the CAF, as the Health Services Group is the provider of medical advice and support to the CAF, with its own structure of embedded advisors in some way resembling that of CORA itself.

Harder to quantify is the general familiarity that General and Flag Officers in key positions had gained with CORA staff over the years, e.g., a rear-admiral that had led a deployed task force with an embedded CORA scientist, worked with a CORA team at Canada's Joint Operational Command, and was ultimately one of the Naval formation commanders receiving specific advice on testing and quarantine protocols. Operational HQ commanders with existing working relationships with current CORA teams were initially more receptive to quantitative advice from CORA scientists, whether from their local team or from the more general effort.

[3] North American Aerospace Defense Command and United States Northern Command, respectively.

[4] The MedInt team is part of the Canadian Forces Intelligence Command (CFINTCOM).

[5] The group's official name is the Canadian Forces Health Services Group (CF H Svcs Gp).

3.3 Quick Wins to Build Trust

CORA's first analytical support to the Health Services Group came in the form of very quick turnaround (less than a week), simple analyses to estimate which provinces or territories in Canada might request support from the CAF due to their hospitals becoming overwhelmed by severe COVID-19 cases [8]. The ability of CORA (facilitated by management) to quickly assemble a volunteer team to meet these simple, but urgent, demands built trust and confidence with our new Health Services Group clients, so that these simple analytical tasks led to more challenging questions. These subsequent questions required complicated mathematical epidemiological models to quantify the range of COVID-19 risks faced by CAF members. This pattern would recur as the relationship with Health Services Group matured into a dedicated team of two scientists, with frequent but relatively simple analyses (e.g., [9]) creating and maintaining visibility and trust for the team with the Surgeon General and the regional and command surgeons during their weekly briefings.

3.4 Coordinated, Portfolio Approach

Very early in the pandemic, the collaboration of CORA scientists on COVID-19 analyses was "organic" without centralized direction. Once the demand for CORA support increased significantly, especially with the requests for support from the Health Services Group, it became apparent that coordination was necessary to avoid duplication of effort and increase the impact of each piece of analysis. This was achieved by having a single CORA manager take on the responsibility for coordinating all COVID-19 EM&A. The rest of CORA's management strongly supported their staff's COVID-19 efforts being coordinated by one manager.

In the early stages of the pandemic, it was not obvious which epidemiological models would be best suited to address the range of possible questions from CAF clients, so CORA took a purposeful "portfolio approach" by assembling multiple, informal teams of volunteers[6] to pursue the development of a number of different epidemiological models for use in CAF scenarios. These epidemiological models include standard compartmental models [10], a stochastic multi-sub-population compartmental model [11-12], an agent-based model [13], and a branching process model [14]. All of these models were eventually used to address different operational questions.

3.5 Collaboration and Networking outside of DRDC CORA

A vital factor in the success of DRDC's EM&A support to the CAF was our collaboration and networking outside of DRDC CORA with the following organizations: (1) CAF's Health Services Group, (2) DND's Analytics Branch[7], (3) DRDC's Ottawa Research Centre, (4) Public Health Agency of Canada, and (5) USINDOPACOM[8] COVID-19 Modelling Working Group. In responding to the Health Services Group's request for analytical support, we worked very closely with their medical, epidemiological and infection disease experts in the development of EM&A tools. Their input and expertise were critical to the credibility and uptake of these models and tools.

The Analytics Branch provided expertise and infrastructure to deploy DRDC's first web-based tools for COVID-19 decision support [15-16]. The interactive, web-based tools allowed CAF medical advisors to obtain answers to their specific questions immediately, without having to wait for one of DRDC's scientists

[6] CORA scientists were available to volunteer to carry out COVID-19 EM&A due to three factors: (a) all were working from home and some were not able to do their "normal" work remotely so had spare capacity for this new work; (b) CORA has a "culture of agility" where it is expected that client priorities will change frequently over time so we must be ready to adapt; and (c) all CORA managers were in agreement that our COVID-19 response was higher priority than any other work going on at the time.

[7] The DND Branch responsible for analytics is known as Assistant Deputy Minister (Data, Innovation, Analytics) or ADM(DIA).

[8] United States Indo-Pacific Command.

to respond. The web-based tools dramatically increased the impact of our work. All of the early response, including tool development, was carried out without any contractor support (which would have taken weeks to months to obtain). This speaks to the value of having "in house" resources capable of carrying out all of the needed tasks quickly in an emergency; in this case, that meant sufficient IT infrastructure and programming expertise to create these online tools. More details on some of these tools will be provided in the following section.

Although more than fifteen scientists from across DRDC CORA volunteered to take part in the COVID-19 EM&A, this was not sufficient to cover all the necessary modelling and analysis tasks; CORA's management therefore sought collaboration from additional (non-OR) scientists and engineers with modelling and analysis experience at one of CORA's sibling organizations within DRDC: the Ottawa Research Centre (ORC). Not coincidentally, the collaboration from ORC was largely based on previous professional networks.

As DRDC had very little expertise in EM&A at the start of the pandemic, interacting with external experts early in our response was crucial to getting up to speed as fast as possible. This was achieved by weekly participation in Public Health Agency of Canada's "External Experts Modelling Group" in order to learn what expert EM&A academics and scientists from other government departments were doing to model COVID-19 risks. This helped us answer questions posed by our CAF clients faster. Through this group, DRDC gained access to epidemiological models that we were able to adapt or re-write to answer CAF client questions, and we learned from the experts who had developed the original models.

Since summer 2020, DRDC has also taken part in weekly "five-eyes" COVID-19 Modelling Working Group meetings which fall under the auspices of the USINDOPACOM and The Technical Cooperation Program (TTCP). This allowed us to get further up to speed with military specific problems through our allies' experiences in the United States, United Kingdom, Australia and New Zealand.

3.6 Cloud Computing, Open Data, and Open Source

Individuals at several levels within DRDC, and DND more broadly, also showed a willingness to take appropriate risks and try new ways of working to enable the time-critical pandemic response. In particular, the more widespread use of cloud computing was serendipitously at its early stages in DND, and COVID-19 models and tools were quickly prioritized for early deployment. The Canadian government's stated intent to increase the use and creation of open data, open source code, and open access papers was relied upon to enable new ways of working, even in cases where processes were still maturing.

3.7 Dedicated OR Team to Support COVID-19 EM&A

The long-term success of DRDC's COVID-19 EM&A support to the CAF was made possible by transitioning from the initial, "all-volunteer" effort to a dedicated two-person OR team (created in late 2020) supporting the Health Services Group. While continuing to be augmented by the participation of scientists from CORA and ORC, this embedded team became the focal point for all of DRDC's EM&A support to the CAF. The team also compensated for the increased demand on the COVID-19 EM&A volunteers to return to their "regular" OR work for their usual CAF clients or to step away from the work due to a further shift in priorities.

4.0 COVID-19 MODELLING AND ANALYSIS EXAMPLES

As with CORA itself, the development and conduct of pandemic-related analyses involved a great deal of work and ideas flowing back and forth, while results were all the while being developed and delivered. This section will be structured following the logical flow of an individual complete analysis, but it must be recognized that much of this work evolved in parallel. Four main aspects can be considered: how many people are infected, how many of them are entering a group, how the virus spreads once it enters a group, and finally what the consequences are. A fifth, and final, subsection summarizes other CORA COVID-19 EM&A that falls outside these four categories. This section does not provide detailed results, nor does it show how the models were validated. Those details are contained in the papers referenced in each subsection. The intent is to show a broad overview of the modelling and analysis effort to support DND/CAF's COVID-related decision making.

4.1 Prevalence Estimation

A basic function of military operations is to maintain situational awareness. Particularly early in the pandemic, when testing protocols were still evolving, it was difficult to understand how many infected – or perhaps more importantly, infectious – people were present in a geographic region, let alone how many there *would* be in the near future. Unsurprisingly, some of the earliest work completed was in understanding where Canadian hotspots were (available as a map [15]), and which regions could be forecast to be the next hotspots [10]; weekly updates to this information were integrated into the situation awareness tools of the CAF's operational command. The forecast of hotspots [17] and predictive mapping [18] continue to be available online. However, the reported case numbers are never the full story of infection, and early work began to point to how the actual prevalence could best be estimated [7].

The ultimate result of this work is the COVID-19 Point Prevalence Estimation Tool (PPET) [19] based on prior work from the Priesemann group in Germany [20]. The PPET combines an epidemiological model with Markov Chain Monte Carlo techniques to estimate current and near-term point prevalence leveraging openly published case data [21-22]. Figure 4-1 depicts an estimate for a single health unit using data from the full course of the pandemic to September 2021. This allows CORA scientists as well as the Health Services Group's medical advisors to directly access recent estimates of prevalence levels both in Canada and globally. The PPET is run on a regular basis for each health region in Canada, each county in the US, and other countries around the world. Its output is reported publically on the COVID-19 Point Prevalence Map [19] (see Figure 4-2). Modelling applications will be discussed below. Perhaps its most visible application is that its estimates are referred to directly to guide decision-making on changing public health measures at CAF installations [23]. The PPET estimates a "modified" point prevalence which is the fraction of the population who has an *undetected infection*, on the assumption that individuals with symptoms or who receive a positive test comply with self-isolation requirements and therefore do not represent an exposure risk to others in the community [24].[9]

[9] This contrasts with the more typical definition of point prevalence as the fraction of the population that is infected at a specified point in time, whether detected or not [25].

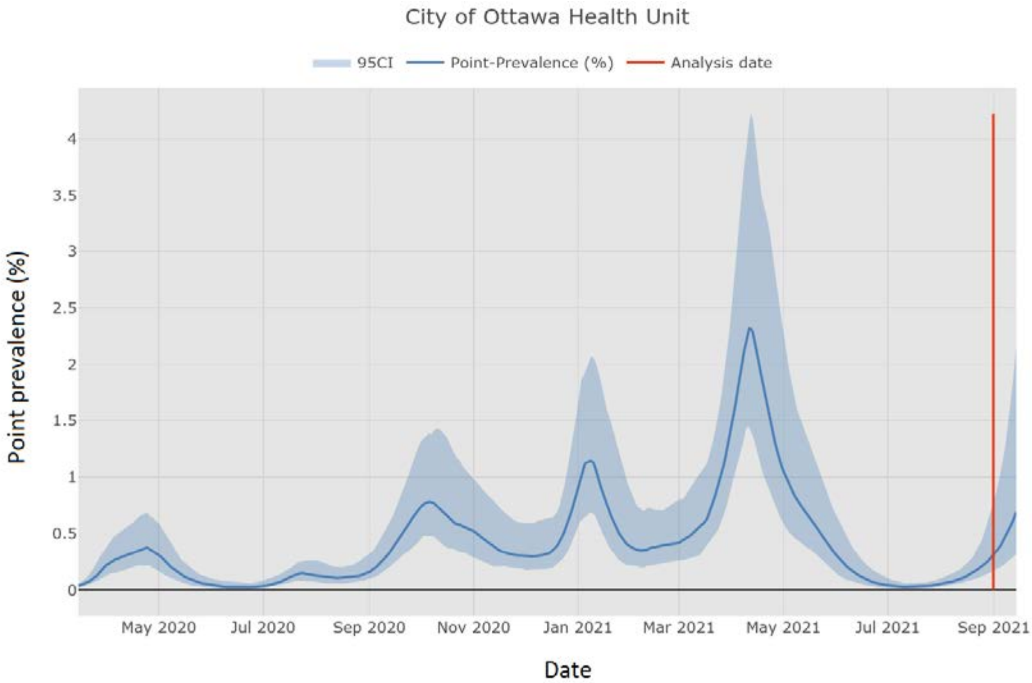

Figure 4-1: Point prevalence estimate for the City of Ottawa Health Unit from the start of the pandemic to September 2021, including a short-term forecast. Sourced from [19].

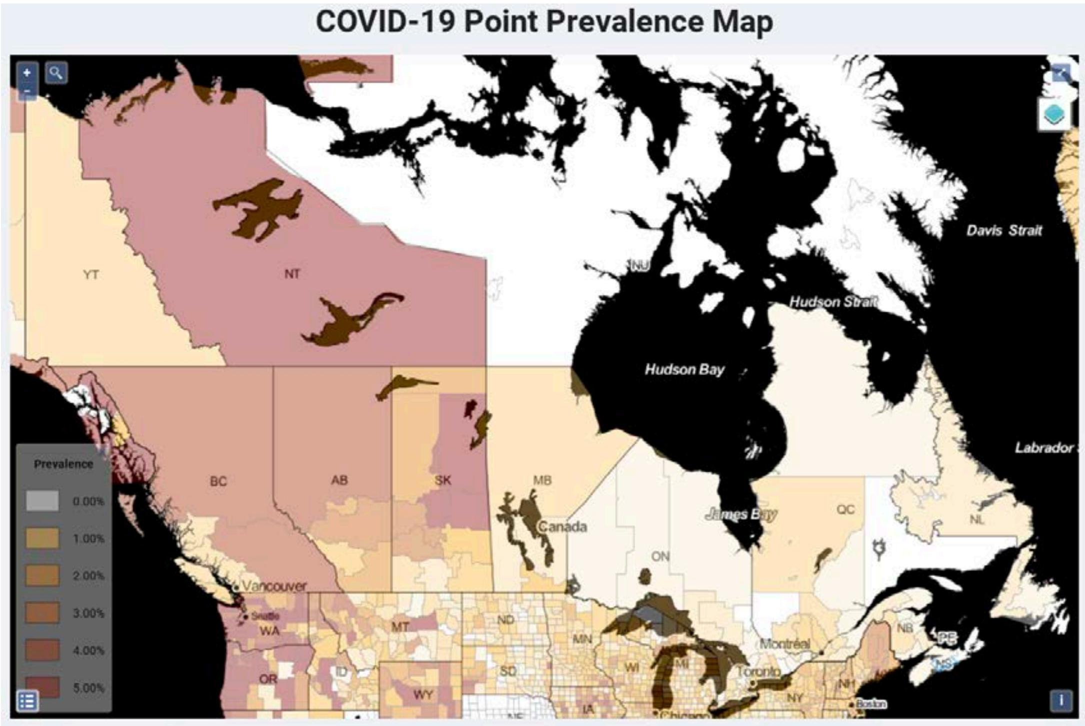

Figure 4-2: Map view of estimated point prevalence across Canada and the northern United States as of early September 2021. Sourced from [19].

4.2 Missed Infection Calculator

While the raw level of prevalence can guide broad decision-making in a region, many client questions took the form of understanding the likelihood of persons with unknown infections entering a building [7-13], a ship [26] or other closed setting. While initially this could be handled through custom analyses, the volume of such requests to CORA rapidly increased beyond our ability to respond to all of them in a timely manner. Rather than force every analysis to flow through a scientist, we developed an online calculator that allows medical advisors throughout the CAF to perform these analyses themselves using the same method: the COVID-19 Missed Infection Calculator (MIC).

The first version of the MIC was published in early July 2020. It was embedded in an interactive report that described the background and assumptions behind the tool [16]. It was used by medical advisors throughout the CAF to advise their commanders until early 2021, at which point a version more tightly integrated with the PPET was launched [27]. At its peak, the tool was viewed 120 times per workday. It was also shared with military allies, other government departments in Canada and provincial health organizations. In order to keep it simple, version 1 of the MIC required only two inputs: the group size and the point prevalence in the region from which the group members departed. While group size is a straightforward parameter, it was initially difficult for medical advisors to estimate point prevalence. The integration with the PPET allowed us to add a health region field to the MIC which directly populates from the estimates in the tool. Version 2 of the MIC also has the ability to consider: groups composed of people coming from multiple regions or travelling to a series of different locations, daily variations in point prevalence, vaccination, imperfect and full quarantine, antigen and polymerase chain reaction (PCR) tests, time-dependent test sensitivity, and correlation between repeated tests. Figure 4-3 provides an example input, showing how a period of quarantine followed by a test can bring down the likelihood of a missed infection within a group.

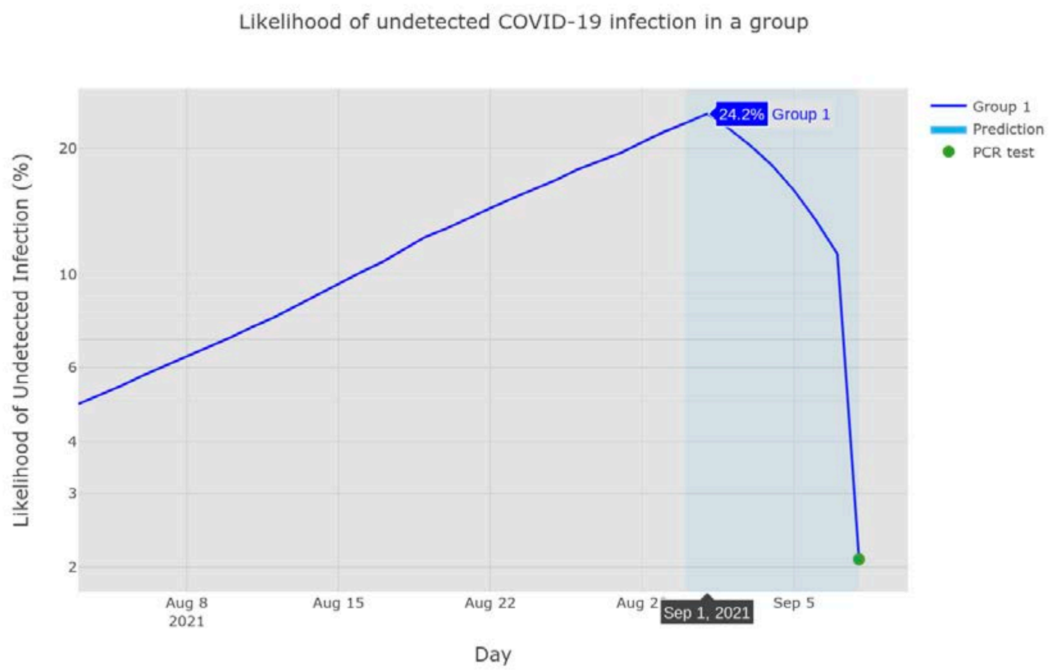

Figure 4-3: Example missed infection estimate for a group. The shaded region indicates a period of quarantine, while the green dot indicates the implementation of a PCR test at the end of the quarantine period. Sourced from [27].

As mentioned above, the MIC provides an estimate of the likelihood of undetected COVID-19 infections and was designed to support medical advisors. We also provided an online application programming interface so that it could be accessed by other tools. This was leveraged by the Air Force to develop their own "COVID Ctrl" application [28], which combines the output of the MIC with guidance from their Commander to provide staff with quarantining and testing recommendations. It was used regularly in the Air Force. For instance, it was accessed 70 to 100 times per workday in January 2021.

4.3 Spread within a Group

Often paired with the question of how likely one or more infected individuals are to enter a group is the likelihood of further spread *within* that group. In a military context, this group could be students in a training school, a ship crew, deployed staff on a base, or participants in an exercise. Three primary classes of models have been used by CORA and their colleagues to address these problems: epidemiological compartmental models (usually variants of a Susceptible-Exposed-Infected-Recovered (SEIR) model), agent-based models (ABMs), and branching process models (BPMs).

The aforementioned forecast map [10] and PPET [19] themselves both embed elements of SEIR models, while primarily focusing on displaying the "infected" compartment. A stochastic SEIR model named PyCoMod [11] was built by several CORA scientists (including one with prior epidemiological modelling background [29-30]). An important feature of PyCoMod is that it can model the spread not only within but between groups, so it can be used to examine the effect of limiting the interaction between cohorts, such as separate classes in a school or individual platoons on an exercise. PyCoMod has been used to model several different scenarios for CAF training schools at different stages of the pandemic, as well as the Maple Resolve Exercise – work which is being presented in parallel at this same conference [12].

The Public Health Agency of Canada has used an ABM built in a commercial package for broad scale modelling of public health interventions since nearly the start of the pandemic [31]. A version of that model was rebuilt in Python by a DRDC Ottawa Research Centre (ORC) engineer, and used to provide advice on spread within an operational building [13], as well as on Naval ships prior to the introduction of vaccination. Over time the results of the ABM and BPM were used to cross-validate each other, and to assess the impact of changes in parameters.

The final class of epidemiological model being used is a BPM. The model developed by DRDC scientists was based on a model created by former CORA scientists now working for another government department [32]. The BPM simulates the downstream infections each infection creates, allowing rapid computation of how likely an outbreak is to go extinct, and how many individuals are infected in the meantime. The BPM also allows analytical solutions to be calculated for many relevant epidemiological outcomes. Its primary drawback with respect to ABMs and compartment based models is that it does not model a bounded population, and so does not account for an outbreak being limited by running out of susceptible individuals to infect. Conversely, its efficiency also allows for the rapid exploration of a parameter space, which is useful when the effectiveness of new vaccines or the impact of new variants is not precisely known. It became particularly useful for modelling the likelihood of persistent outbreaks in heavily vaccinated ships, whereby the PPET, the MIC and BPM were used together to determine the level of relaxation of pre-embarkation protocols that could be allowed while allowing it to achieve a particular likelihood of a shipboard infection leading to a medical evacuation [26].

4.4 Consequences

An important aspect both for running models and interpreting the results is estimating the key parameters of the virus, and in particular how they apply to CAF military members, who tend to have fewer risk factors than the general population, and are largely constrained in age between 18 and 60. Early on, senior commanders were concerned with estimating the total likely burden in terms of mortality within the CAF. Several CORA scientists worked with a science advisor and an epidemiologist from Health Services Group to conduct a rapid literature review to estimate the overall likely infection fatality rate [33], which CORA scientists later made more specific to CAF age groups [34]. When it became clear that the fatality risk for CAF members was relatively low, attention shifted to understanding the risk of severe illness in terms of the likelihood of hospitalization or medical evacuation, which has negative implications both for the individual and potentially for the mission. For instance, the advice to the Navy on pre-embarkation protocols was tied to the likelihood of needing to medically evacuate a member during an operation [26]. As new variants emerged with potentially higher rates of severe outcomes, CORA scientists continued to systematically search for updates to these key parameters [35].

4.5 Other analyses

In addition to the four areas of analysis summarized above, DRDC has pursued several other lines of effort related to COVID-19 EM&A with varying degrees of impact:

1. Early in the pandemic, a small team of scientists used publicly available modelling and healthcare data to rapidly assess the likelihood that Canada's provinces and territories might request aid from the CAF due to their medical systems being overwhelmed by COVID-19 patients [8].

2. A large team of scientists also spent significant time early in the pandemic reviewing emerging EM&A literature for CAF's MedInt and Health Services Group in order to help them keep up-to-speed with the extremely high rate of global COVID-19 publishing. This effort was augmented by an assessment of a commercial natural language processing tool to categorize pre-print and published COVID-19 literature [36].

3. A prototype Partial Observable Markov Decision Process for COVID-19 management was developed with the intent to better understand the implications of community spread for military decision-makers [37].

4. An analysis of CAF members' COVID-19 infection rates due to their support in some of Canada's hardest hit long-term care facilities was carried out to parameterize and validate the PyCoMod SEIR model [11].

5. Finally, the CAF's contact tracing capacity was also evaluated using our ABM and a purpose-built discrete event simulator [38].

Some of these efforts produced significant outcomes, but not all did. This experience showed that *a priori* it is difficult to predict which efforts will be most impactful.

5.0 DISCUSSION OF LESSONS LEARNED

While CORA's response to the pandemic in Canada can be qualified as a success in an overall sense, there are nonetheless lessons to be learned from these efforts. One such area is in the deliberate planning for mobilization of OR support for operational crises. The informal manner in which this was accomplished during the early days of the COVID-19 pandemic was not necessarily optimal as it took a few weeks before most scientists were working on COVID-19 analysis topics in a coordinated manner; future crises might not afford that much time to respond. While informal arrangements offer many advantages, they are not without risk. In Canada, the fragility of some temporary working arrangements became apparent as other analytical priorities regained importance or outside forces intervened. Also, CORA's EM&A scientists had limited engagement with experts on war-gaming and disinformation, which, in retrospect, might have added significant value.[10]

[10] There was work conducted in both of these areas related to the pandemic, but there was little to no interaction with the main thrusts of pandemic support described herein.

The factors that had the greatest impact on delivering effective modelling and analysis during the pandemic were (1) the flexibility of the individual scientists to take on new analytical problems, coupled with (2) the strong collaborative spirit that allowed scientists to reach out to trusted colleagues and beyond when they needed help to solve a modelling problem. Also, (3) collaborating with epidemiological experts from outside organizations was also highly impactful as adapting the models of collaborators made it much faster and easier to provide decision support to CAF clients.

Two key changes to how CORA worked during the pandemic included (1) using the cloud for running computationally intensive models, and (2) producing interactive, web-based reports/tools for clients to repeat analyses with new input data without the intervention of OR&A scientists. We hope that these changes will be enduring. Cloud computing allows far more sophisticated models to be implemented without extensive in-house computing facilities. Interactive, web-based tools allowed the impact of our work to be far broader and persistent over time. As the dynamic tools are accessed dozens of times per day and by people around the world, far more decisions were informed by our analysis than is possible through a traditional, static report. Using both cloud computing and interactive tools requires more IT support than CORA currently has in-house. During the pandemic we received substantial DND IT support from outside CORA. In the future it would be better to have dedicated, in-house support who are familiar with and responsible for these types of analyses.

Finally, the development of multiple epidemiological models in parallel was shown to be advantageous as it allowed us not only to be flexible in the types of problems we could address, but in some cases, it also allowed cross-checks between models. This was a form of validation that would not have been possible if we had put all our effort into a single model. Our cross-validation exercises invariably revealed mistakes made in one or more of the models being compared. This was an important lesson learned (or reinforced).

6.0 CONCLUSION

Through their efforts, CORA and other DRDC scientists were able to provide the CAF with decision advantage during periods of uncertainty associated with the COVID-19 pandemic. While good luck, in the guise of having the right people in the right place at the right time, was undoubtedly a contributing factor, the nature of CORA’s structure, its relationships with its military clients, and the manner in which it manages the career development of its scientists all played important roles in enabling CORA’s pandemic response. The agility with which CORA responds to evolving needs was not only evident during the crisis phase of the pandemic, but also through the creation of a dedicated OR team in support of the Health Services Group to deal with ongoing decision support needs as the situation “normalized” with time. Having become trusted advisors to new clients, CORA’s professional networks have grown over the course of the pandemic to include epidemiological modelling counterparts at the national and international levels.

Like military OR&A scientists everywhere, CORA scientists are trained and socialized to strive to contribute meaningful decision support in the face of uncertain situations. In the case of its COVID-19 response, CORA’s initial expertise in key areas like epidemiology and viral transmission was essentially nil; however, after some exploration and partnering with relevant experts outside of CORA, it did not take long for CORA scientists to carve out several important niches and provide useful products that enabled their CAF clients to expand their evidence base for decision-making. As an organization built to pivot long before “pivot” became the “pandemic buzzword” [39], CORA has been able to not only adapt, but to thrive, during the COVID-19 pandemic.

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