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ARTICLE

Framework for Optimal Pandemic Management

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1st prize from University of Calgary's Schulich School of Engineering | University of Calgary Office of Chancellor award | Canada National Science Fair: Bronze medal (2022) | Invitation to participate as a panelist in the Canadian Science Policy Conference (2022)

Much like the flu virus, COVID-19 is here to stay (Nature, 2022). Sustainable coexistence with COVID-19 in developing countries requires a vaccination strategy that is optimized in terms of social and monetary loss. This prompts the objective of finding a strategy of vaccine and medication deployment that minimizes total societal and monetary loss while honouring global social justice. A computer simulation of the COVID-19 pandemic progression was coded and used to find the most cost-effective medical response strategies. The simulation is the backbone of a framework that provides actionable insights and direction on coping with global public health crises. The framework is based on economic optimization, thereby maximizing the value of each vaccine dose and the plausibility to coexist with the pandemic.

INTRODUCTION

In an era of increased awareness of Social Justice, COVID-19 demonstrates the dramatic disparity between different regions of the world; COVID vaccine booster doses were made available in certain countries before vast populations of the world could receive their first dose. It has become evident that the ability of developing countries to sustainably coexist with COVID-19 depends on an external long-term support system guided by the spirit of fairness and global social justice (Okonjo-Iweala et al., 2021).

The Organization of Economic Cooperation and Development (OECD) relates sustainable global coexistence with COVID-19 to monitoring long-term costs (OECD, 2022), and is aligned with the International Monetary Fund's proposition "Pandemic policy is economic policy" (Amanpour, 2022). This prompts the question: what is a cost-effective strategy for vaccine and medication deployment that honours global justice and yields worldwide sustainable coexistence with COVID-19?

This paper describes a computerized framework that addresses both the economic and social justice aspects of managing the pandemic on a global scale. *Future total loss* (FTL) is a measure of the accumulated future damage associated with COVID-19 and serves as a proxy for the severity of the pandemic. Minimizing FTL leads to minimizing the total impact of the pandemic. FTL is defined as the sum of the anticipated monetary values of life loss, medical care costs, and labour-related loss. The medical response that minimizes FTL, thereby ensuring a cost-effective method of vaccine and medication deployment, is derived from a simulation of the interaction between society, the SARS-CoV-2 (Omicron) virus, and the impact of vaccines and therapies. A roadmap toward meeting global justice measures while leading to sustainable coexistence with COVID-19 is provided.

METHOD

Viruses are modelled using *lethality* (L) and *contagiousness* (C) levels, which are measured in percent. A virus is represented as a pair [L,C], e.g. [32,12]. Individuals in the community are assigned a health status similar to the [Li,Ci] viruses they carry (a healthy individual's status is [0,0]). At the beginning of the simulation, individuals are assigned uniformly distributed random locations, and randomly chosen individuals are infected with viruses with uniformly distributed [L,C] pairs.

With each step of the simulation, each person's next location is set as follows:

$$(x, y)_{next} = (x, y)_{current} + 0.9 * [(x, y)_{current} - (x, y)_{previous}] + (random_x, random_y)$$

When a healthy individual is exposed to a sick person of status [$random_x$ and $random_y$ are chosen randomly from the set (-1, 0, 1).x,Cx], infection occurs with probability Cx. The infected individual's status changes from [0,0] to [Lx+ΔL,Cx+ΔC], where ΔL,ΔC are uniformly distributed between -5 and 5. Rarely, the virus will mutate during infection, with ΔL,ΔC values of ±20. Once infected, a sick individual is infectious to others for nine days (Takahashi et al., 2022).

Finally, a sick person of status [Lz,Cz] may die within fourteen days of sickness, with probability Lz. If death does not occur, the person recovers and develops immunity against viruses in the range [Lz ± 20, Cz ± 20] for the next five months.

As per the medical management of the pandemic, a vaccinated person's probability of acquiring the virus [La,Ca] is reduced from Ca to 25% of Ca (Kimball. 2022). Similarly, a medicated person with status [Lb,Cb] dies with a probability 50% of Lb (Kozlov, 2021).

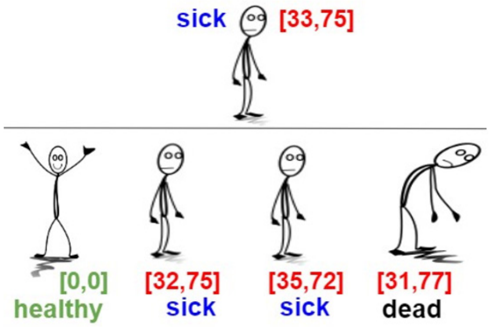

Figure 1: Demonstration of [L,C]: A sick person's status is [33,75] (above). Statistically, 75% of those coming within infection distance will acquire infection, with viruses slightly different than his own (below), and 33% of the infected individuals will die.

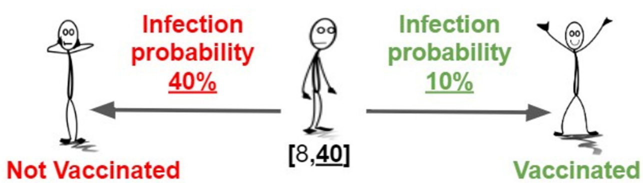

Figure 2: The effect of *vaccines*: a sick person (middle) with status [8,40] infects 40% of his *unvaccinated* contacts (left) and 10% of his *vaccinated* contacts (right).

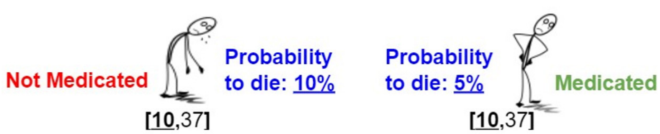

Figure 3: The effect of *medication*: a sick person with status [10,37] dies with 10% probability (left). A *medicated* person with the same status only dies with 5% probability.

Before each simulation, the society's overall vaccination rate is fixed, and a choice on whether to apply medication is made. As the simulation runs, FTL accumulates the daily sum of all monetary values of life loss, cost of medical care (vaccine, medication, hospitalization), and labor-related loss. The monetary values of FTL's components are set as follows: each lost life adds $180,000 to FTL upon industry standard thereby promoting equality of all lives (Kingsbury, 2008). The cost of a vaccine dose is estimated to be $90 (shipping, storage, and administration costs included); the cost of medication administered per sick person is $700 , prorated along the sickness period (Haseltine, 2021); hospitalization costs are $23,000 per patient (Canadian Press, 2021). Labour-related losses are taken as the daily GDP per capita multiplied by the number of sick people.

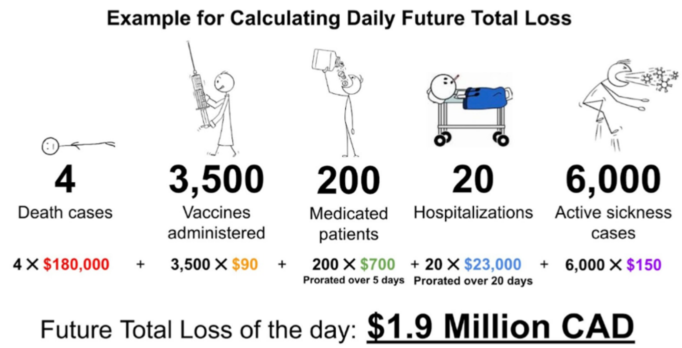

Figure 4: The accumulation of loss due to pandemic is calculated daily and added to FTL

RESULTS

Viruses are modeled using the pair [Lethality and Contagiousness], making it easy to visualize the progression of the pandemic on a 2-dimensional plane using the [L,C] components as coordinates (Simantov, 2022). Recalling that viruses' pairs change randomly with every infection, every possible pair may appear and disappear at some point along the simulation. However, viruses that are contagious but not lethal show a higher likelihood to survive as the simulation progresses, thereby demonstrating the emergence of natural selection.

Results of the simulation in Alberta are summarized in Table 1. The simulation runs multiple times, with and without medication. The results are ordered in batches, each containing 100 simulation runs. In each batch, the society's overall vaccination rate is unique (ranging between 40% and 75%). FTL is calculated for each simulation run and is averaged for each batch.

The *most cost-effective deployment method* (MCDM) minimizes FTL. If it is obtained when medication is used it is marked MCDM+ and if it is obtained without medication, it is marked MCDM-.

Alberta's MCDM is 50%, implying that a vaccination rate different than 50% results in excessive economic loss (not to be confused with the fact that a higher vaccination rate may save more lives).

DISCUSSION

Angola and Ghana, two countries with comparable population sizes, are among the countries on the receiving end of Canada's vaccine donations (Government of Canada, 2021). MCDMs of the

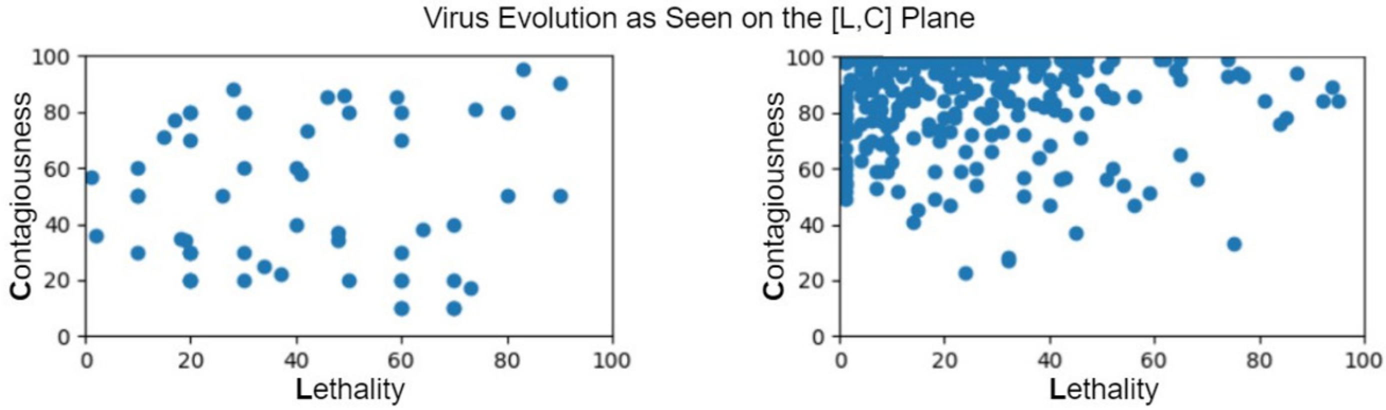

Figure 5: Each virus is placed on the Lethality-Contagiousness plane based on its [L,C] pair. In the beginning of the simulation (left), viruses are assigned random uniformly distributed values of [L,C]. As the simulation progresses (right), natural selection emerges, eliminating viruses that are highly lethal and mildly contagious (Simantov, 2022)

Averaged FTL per Vaccination Rate [Million of CAD]

	Population's Vaccination Rate							
	40%	**45%**	**50%**	**55%**	**60%**	**65%**	**70%**	**75%**
FTL (Medication applied)	$1.48	$1.46	**$1.45**	$1.47	$1.51	$1.56	$1.64	$1.75
FTL (Medication NOT applied)	$1.90	$1.85	$1.82	$1.80	**$1.79**	$1.83	$1.87	$1.98

Table 1: Accumulated simulation results for Alberta, ordered in batches. The daily average of *Future Total Loss* (FTL) in millions of CAD varies with the percentage of the population that is vaccinated (columns) and the availability of medication (rows). Alberta's most cost-effective vaccination rates, with and without medication, are 50% and 60% respectively.

two countries, with and without the use of medication (MCDM+ and MCDM-, respectively) are compared, as well as the current vaccination rates in those countries (Ritchie, 2020).

Despite the similar percentage of population that is fully vaccinated in both countries, respectively 18% and 16%, Angola is fast approaching the halfway point towards meeting MCDM, while Ghana is left behind. Recalling that MCDM signifies the optimum, this comparison demonstrates the inequity between the two countries and the relevance of MCDM values to measuring global justice.

Country	Population	Population Fully Vaccinated	MCDM+	MCDM-
Angola	32MM	18%	**30%**	**40%**
Ghana	31MM	16%	**40%**	**50%**

Table 2: Vaccination rates and MCDM in Angola and Ghana. The difference in MCDM is mainly due to population density differences (Angola: 26 people per km^2; Ghana: 137 people per km^2)

CONCLUSION

The implications of this project are immense. They can be tailored to the current pandemic as it evolves, as well as to future pandemics. The use of MCDM provides a way to simplify complex interactions and ripple effects in modelling pandemic response scenarios, so that decisions can be made to optimize public health with clarity, transparency, and objectivity. To state leaders, MCDM is an objective to aspire to in order to minimize future societal loss associated with the pandemic. On a global scale, the differences between countries' vaccine rates and their MCDM values construct a roadmap for allocating scarce resources to countries in need, while meeting global fairness criteria.

Future Total Loss is a proxy to the severity of the pandemic and its impact on society. Therefore, minimizing Future Total Loss leads to minimizing the impact of the pandemic on society. Since it is defined in terms of economic measures, long-term global costs are reduced, billions of dollars may be saved, the value of each vaccine dose is maximized, and plausibility to coexist with the pandemic is enhanced.

The framework integrates models of the virus' biology, human biology and interactions, medical intervention, and societal loss, all of the components that characterize pandemics. Assumptions may be adjusted and parameters added as more is learned in order to improve accuracy, keep the framework up-to-date as the virus evolves, or prepare for future pandemics. Extending FTL to account for non-monetary components (e.g., enhanced protection of specific populations and resources) and logistic constraints (e.g., availability of hospital beds) may further improve resilience in managing the pandemic.

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Rachel Simantov is a high school student in Calgary, AB. Her work on her project 'Framework for Optimal Pandemic Management' granted her first prizes in Canada's largest regional science fair, the Calgary Youth Science Fair, and took her project to the national competition in 2022. Using Python programming language, Rachel simulated the impact of medical interventions on the course of COVID-19. Following her findings, she developed a framework to calculate the optimal allocation of resources to each country, aiming to maximize the likelihood of financial sustainability and address social justice considerations in times of global crisis.