Simulation Of COVID-19 Pandamic To Reduce The Impact In Quebec

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***Abstract*— The pandemic of novel coronavirus, SARS-CoV-2, which causes COVID-19 and started from China, is one of the deadliest diseases in the world. Since it is new virus, the countries try to know more about that to deal with it. One of the way of studying about that is simulation of the covid-19 pandemic. In this article, we try to simulate, by Agent based modeling and System Dynamic, Covid-19 spread and how we can decrease the speed of that to have less infected people, especially in Quebec.**

Keywords—Covid-19, Pandemic, Simulation, Agent based, System Dynamics.

I. Introduction

A. Background

The **COVID-19 pandemic**, also known as the **coronavirus pandemic**, is an ongoing global pandemic of coronavirus disease 2019 (COVID-19), caused by severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2).[1] The outbreak was first identified in December 2019 in Wuhan, China.The COVID-19 pandemic is now a major global health threat, with 20,105,982 cases and 735,314 deaths confirmed worldwide As of 10th August 2020. Since the initial identification of the virus in China, global spread has been rapid, almost all countries having reported at least one case [1,2]. The virus was confirmed to have reached Canada on January 27, 2020, after an individual who had returned to Toronto from Wuhan, Hubei, China, tested positive. As of August 10, 2020, there have been approximately 119,451 confirmed cases, over 100,100 recoveries and 8,900 deaths in the country.[2] The Government of Canada has released modelling anticipating 11,000–22,000 deaths over the course of the pandemic, assuming "stronger epidemic control" [3]. The experience in countries to date has emphasized the intense pressure that a COVID-19 epidemic places on national health systems, with demand for intensive care beds and mechanical ventilators rapidly outstripping their availability in even relatively highly resourced settings. This has potentially profound consequences for resource-poor settings, where the quality and availability of healthcare and related resources (such as oxygen) is typically poorer [4].

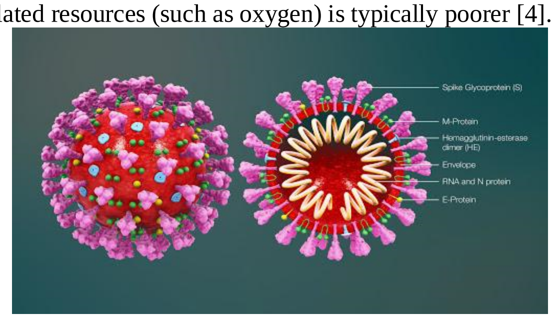

Figure 1: BioVendor offers new SARS-CoV-2 structural protein products for virology research[5].

Regarding the beliefs and misperceptions of the public, information regarding COVID-19 has been dealt with pessimism, conspiracies and even optimism. Political misinformation has also played a role in deviating public opinions and common misconceptions such as the US President promoting an old drug hydroxychloroquine as being very effective against the current coronavirus and considered by him “a game changer” [6]. Study finds that a decent number of people in Canada believe in these misinformation and fake news and are thus more prone to different behaviors and reactions towards COVID-19 and the public; about 12% of the selected 644 believed the coronavirus was as dangerous as the seasonal flu, 21 % believed the virus was not even airborne, 7% believed holding your breath for 10 seconds was a good way of finding out whether or not you had the virus, although these views would be considered optimistic, there are also those who would think of the worst; about 13% believed dogs and cats could spread the virus, 7% believed the coronavirus was created in a lab [7]. In Montreal, people are protesting in Downtown in the thousands regarding the mandatory regulations of wearing masks that was previously enforced by the Quebec government [8].

B. History

Coronaviruses are a group of related RNA viruses that cause diseases in mammals and birds. In humans and birds, they cause respiratory tract infections that can range from mild to lethal. Mild illnesses in humans include some cases of the common cold (which is also caused by other viruses, predominantly rhinoviruses), while more lethal varieties can cause SARS, MERS, and COVID-19. In cows and pigs, they cause diarrhea, while in mice they cause hepatitis and encephalomyelitis. There are as yet no vaccines or antiviral drugs to prevent or treat human coronavirus infections. The IBV-like novel cold viruses were soon shown to be also morphologically related to the mouse hepatitis virus.[19] This new group of IBV-like viruses came to be known as coronaviruses after their distinctive morphological appearance. Human coronavirus 229E and human coronavirus OC43 continued to be studied in subsequent decades. The coronavirus strain B814 was lost. It is not known which present human coronavirus it was. Other human coronaviruses have since been identified, including SARS-CoV in 2003, HCoV NL63 in 2004, HCoV HKU1 in 2005, MERS-CoV in 2012, and SARS-CoV-2 in 2019. There have also been a large number of animal coronaviruses identified since the 1960s. [2]

There remain large uncertainties in the underlying determinants of the severity of COVID-19 infection and how these translate across settings. However, clear risk factors include age, with older people more likely to require hospitalization and to subsequently die as a result of infection4, and underlying comorbidities including hypertension, diabetes and coronary heart disease serving to exacerbate symptoms. Both the age-profile and the distribution of relevant co-morbidities are likely to vary substantially by country, region and economic status, as will age-specific contact patterns and social mixing. Variation in these factors between countries will have material consequences for transmission and the associated burden of disease by modifying the extent to which infection spreads to the older, more vulnerable members of society. [4] To know more about the virus and mitigate its effects, we simulate a model and compare it with the real situation.

II. Input Modeling

With today's lifestyles in pandemic when no one has a clear prediction when everything is going to be normal again. There is no clear prediction from even the scientist about the current situation. Forecasts made during the outbreak were rarely investigated during or even after the event occurred for their rate of accuracy. Recently forecast has been results in a form of code, models, and information is available for making retrospective analysis. To minimize the impact of incomplete data and information we made to run separate incomplete test results which help to make a final test model which was predictable in all current scenarios. But some crucial information remains hidden from the actual situation ongoing. A reliable test to see who has been infected without showing symptoms — and so could be moved to the recovered group — would be a game changer for modelers and might significantly alter the predicted path of the pandemic. There is another important unknown, too: how people will react to forced alterations to their behavior, and whether such changes will reduce infectious contacts by as much as scientists expect. Surveys in China, for example, show that citizens of Wuhan and Shanghai reported that they had between seven and nine times fewer typical daily contacts with other people during the social-distancing measures imposed by the authorities. [9]

A. Conceptual Model

One of the methods that we can use for simulating viruses is the SIR model, which we used. For simulation the first set of dependent variables counts *people* in each of the groups, each as a function of time[10].

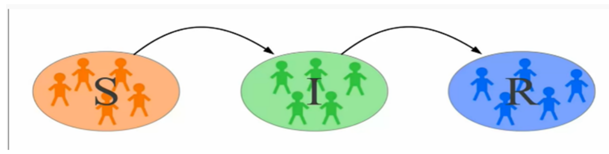

Figure 2: SIR model for spreading the virus

S = S(t)	is the number of *susceptible* individuals?
I = I(t)	is the number of *infected* individuals
R = R(t)	is the number of *recovered* individuals

Assumption:

- No one is *added* to the susceptible group, since we are ignoring births and immigration. The only way an individual *leaf* the susceptible group is by becoming infected. We assume that the time-rate of change of S**(t)**, the *number* of susceptible, depends on the number already susceptible, the number of individuals already infected, and the amount of contact between susceptible and infected. In particular, suppose that each infected individual has a fixed number b of contacts per day that are sufficient to spread the disease. Not all these contacts are with susceptible individuals. If we assume a homogeneous mixing of the population, the *fraction* of these contacts that are susceptible is s**(t)**. Thus, on average, each infected individual generates b **s(t)** new infected individuals per day. [With a large susceptible population and a relatively small infected population, we can ignore tricky counting situations such as a single susceptible encountering more than one infected in a given day.

- We also assume that a fixed fraction k of the infected group will recover during any given day. For example, if the average duration of infection is three days, then, on average, one-third of the currently infected population recovers each day. (Strictly speaking, what we mean by "infected" is really "infectious," that is, capable of spreading the disease to a susceptible person. A "recovered" person can still feel miserable and might even die later from pneumonia.) [11]

If we talk about using the SIR model, we used the already existing data which are available and compared with the result after using precautions during the start and during the COVID crises. We also took examples from the countries which took early precaution, and which don't analyze the result of the simulation at an extent.

III. Implemented System

First, we have to use software to create the model. We have used Vensim Software.

A. Vensim

Vensim is simulation software developed by Ventana Systems. It primarily supports continuous simulation (system dynamics), with some discrete event and agent-based modelling capabilities. It is available commercially and as a free "Personal Learning Edition".[12][13] Vensim provides causal tracing of structure and behavior, and has Monte Carlo sensitivity, optimization and sub-scripting capabilities [14]

B. System Dynamic Based Simulation

System dynamics (**SD**) is an approach to understanding the nonlinear behavior of complex systems over time using stocks, flows, internal feedback loops, table functions and time delays. System dynamics is a methodology and mathematical modeling technique to frame, understand, and discuss complex issues and problems. Originally developed in the 1950s to help corporate managers improve their understanding of industrial processes, SD is currently being used throughout the public and private sector for policy analysis and design [15].

C. Basic Simulation

In this step we try to make a model in Vensim for the conceptual model. The following is a Stock and flow diagram.

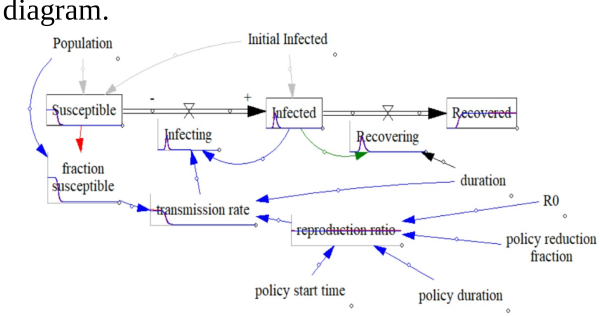

Figure 3: Stock and flow diagram for the basic simulation

1) Parameter used:

Population= total number of the population who have any possibility of getting infection

Susceptible= it is the total number of populations subtracting with the total number of people getting infection

Duration = number of days needed for the people to recover fully

Recovering= people who are getting better in a certain period of duration. (infected/duration)

RO= it stands for the total number of people who got sick from every infected person. (people/infected person)

Policy reduction fraction=the total rate or fraction at which they can reduce the RO rate

Policy duration= the total duration which took to apply the policy reduction which varies from the parameter and precaution used.

Policy start time = the total time which took to start the policy

Reproduction ratio=RO*[1- (policy reduction fraction*policy start time)+(policy reduction fraction*policy start time*+policy duration)]

Fraction susceptible= it stands for the total number of susceptible people to the total number of populations. (susceptible/population)

Transmission rate= reproduction ratio/ duration*fraction susceptible

2) Parameter estimation and assumption

Models of the SIR family, we also model the probability of movement of people from one compartment to another in each time-step as independent of the residence time. Hence ours is a memory-less model in that residence time in each compartment is exponentially distributed. In Spite of all, infectiousness of an individual is not uniform between exposure and recovery

Assumptions with regards to our model are as follows:

- People infected by the virus take some time (incubation period of around 5 days) before they show any symptoms. During this asymptomatic/ pre-symptomatic phase, they are assumed infective a few days prior (~24 to 48 hours prior) to the symptoms.

- The population is assumed to be random and well-mixed. And there is no change in the total population due to births and deaths.
- The effectiveness of individuals is assumed to be lower than that of the symptomatic individuals.
- Asymptomatic individuals may also recover from the disease without showing symptoms.
- Susceptible individuals may recover after a mild illness or get serious and require hospitalization. Serious infected people from the virus may recover or can become critical (requiring ventilator / ICU facilities). The critical patients can recover or, unfortunately, die.
- The progression of the disease is age dependent. Co-morbidity is assumed to be implicitly captured by this.
- The new cases are assumed to be detected only when the individuals are tested positive. This happens when either, (1) mild symptomatic individuals are tested positive, or (2) the disease worsens and the patient seeks treatment at hospital, at which point in time, they are tested and found positive.

IV. Model Design

A. Agent-based simulation – NetLogo

For visualizing how every phenomenon works and how Covid 19 spreads, we used Agent-based simulation and for doing that we used NetLogo software. We start making this model from [19] [20] to simulate the basic model by NetLogo. Agent based modeling mainly essences on the connections between the different agents in the model. State of the system changes grounded on the behavior of each agent at a certain time. Agent based modeling existence used in many fields like healthcare, banking etc since mostly in real life scenario managers are present and each agent effect the output.[21]

B. Input Modeling

The major inputs that we have considered for this model in the NetLogo software are:

1) Susceptible Population Size
2) Initial infected size
3) Total time to stop simulation
4) % population that wear masks
5) % population practicing social distance
6) Distance of Social Distance

We have chosen Agent-Based simulation and NetLogo software to build a software simulation. We chose this model because agents in our model are interacting and in turn there is significant impact on the system.

C. Class Diagram

A type of conceptual model for representing the agent-based model. Class diagram consists of different agents, attributes of each agent, methods. Agents that are listed in the below class diagram are: Total Populations, Susceptible Populations, Infected Populations., Death Populations.

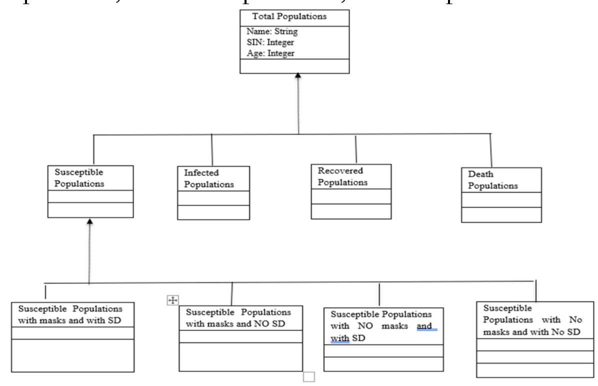

Figure 4: Class Diagram

D. User Case Diagram

The main system functions in user case diagram are listed as following:

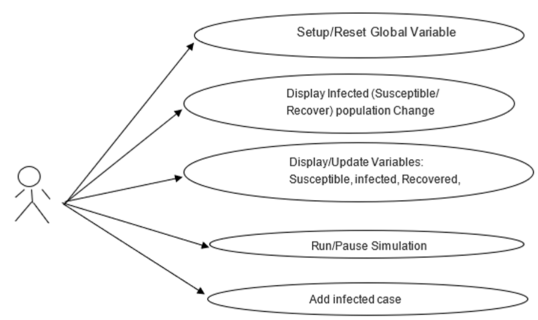

Figure 5:User Case Diagram

E. Sequence diagram

Below diagram shows the flow of messages between the Susceptible, Exposed, Infectious, Recovered and Dead populations.

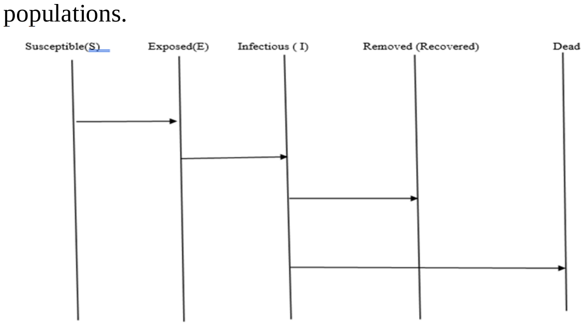

Figure 6: Sequence diagram

F. State Transition Diagram

The transition diagram for the Covid-19 is below.

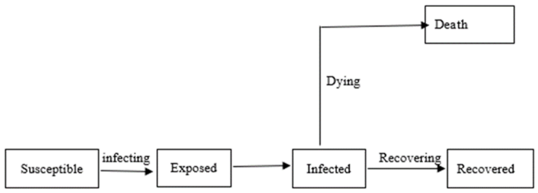

Figure 7: State Transition Diagram

G. *Agent based model in NetLogo software*

In the interface we will set initial-Susceptible Population-size and initial Infected case before the setup. Red symbol in the simulation represents the infected person, Blue symbol in the simulation represents the susceptible person, Green symbol in the simulation represents the Recover/Immune person.
When we click on setup and then click on <**Setup**>, initially susceptible (Blue)people and infected population (Red) will be present. If we set the percentage of the population wearing mask to 50%, then half of the susceptible population will be White.

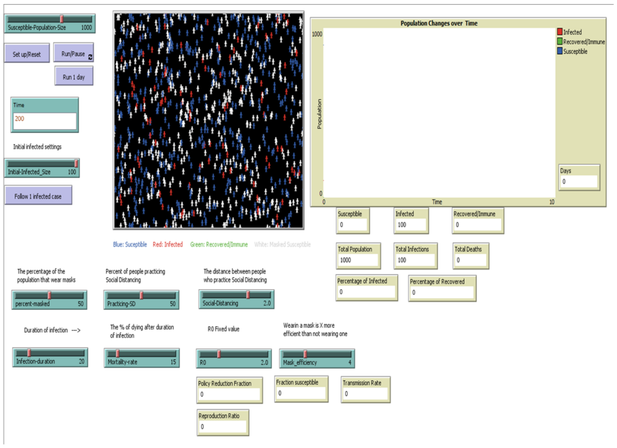

Figure 9initial setup

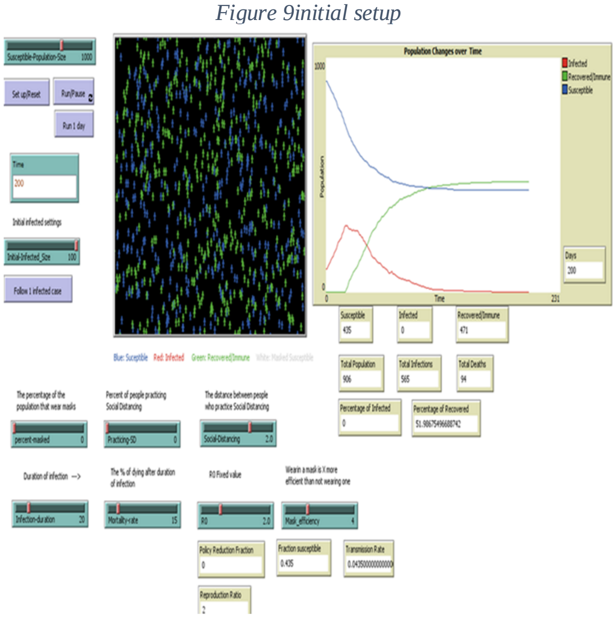

Figure 10Figure 10: Interface after clicking on Run （With NO Mask and NO SD)

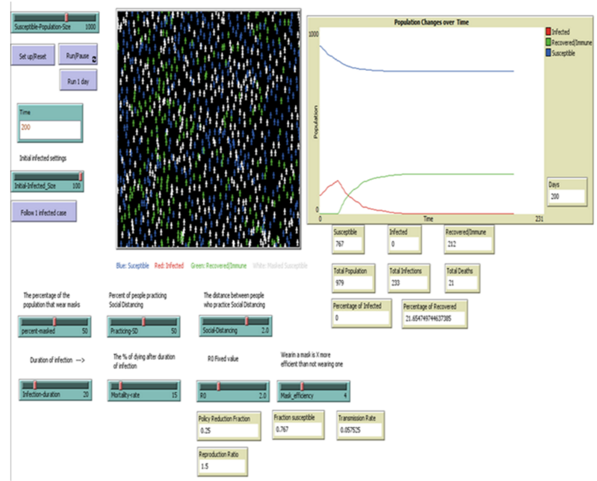

Figure 8Interface after clicking on Run （With Mask and SD）

V. OUTPUT ANALYSIS

Here initially some population-size and time are being set-up in the model.
From figure 9 and figure 10, we can see the difference that there is less death and less infected population after increasing % of masks and % of social distance. Additional note is that the trace of infected population is flattened with a mask and social distance is set. The trace of the infected population has a spike when mask and social distance are not taken. It is important the red graph (infected population) does not spike compared with it did when with no mask and social distance are set.

VI. MODEL VERIFICATION AND VALIDATION

In this project we have 3 different models and we have to verify and validate each of us. The first model is the conceptual model that is applied by Vensim. Then we use the same function and variables to apply it in NetLogo for the visualization. The third model is the improved Vensim model that shows us the real number in the world. For each model we can use different methods to verify but totally we can use each model to verify another one. Now we are going to validate the first model.

A. *Model Validation*

For Validation we check our model with the real data. The following figures show that we our model is look like the natural trend of Covid-19 in the world[22]

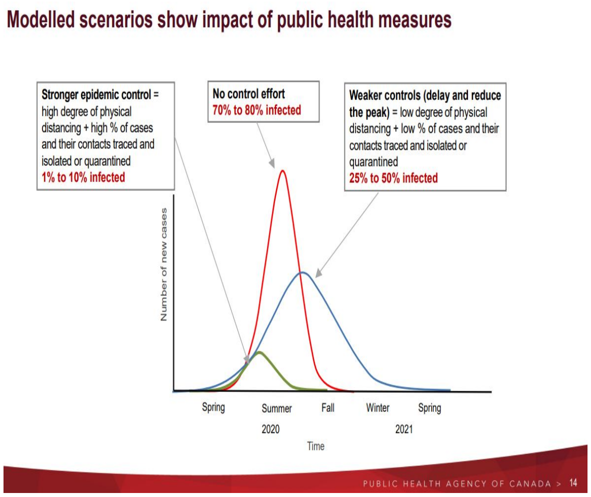

Figure 11: Natural trend of Covid-19 in the world[22]

As we see without any controlling around 75% will get it by the middle summer. In the following model we can see how the model is near the this diagram

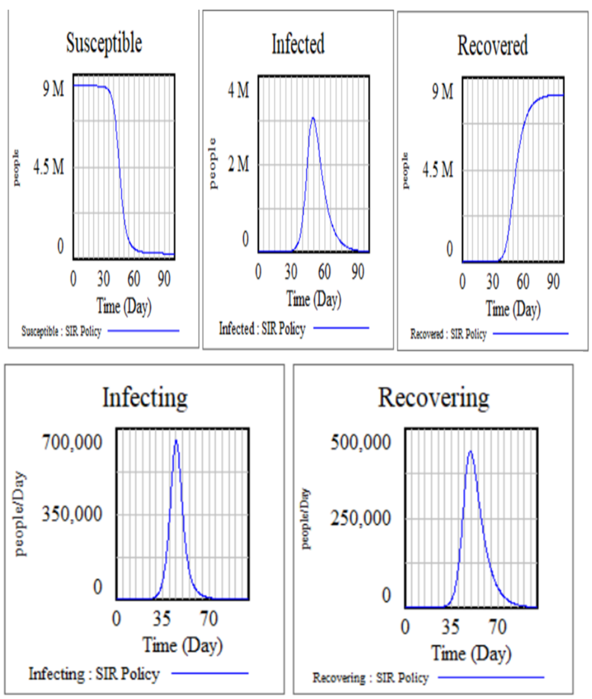

Figure 12SD model without any precautions

Then we tried to apply this model in the NetLogo and as we see in that also we have the same trend.

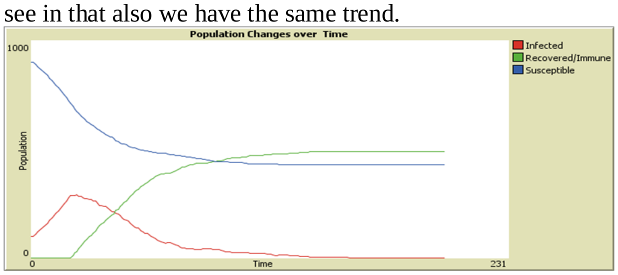

Figure 13:Agend Based Model without any precautions

Now we want to validate our model with the real data that is happening in Quebec. The following is the real data happening in the Quebec.

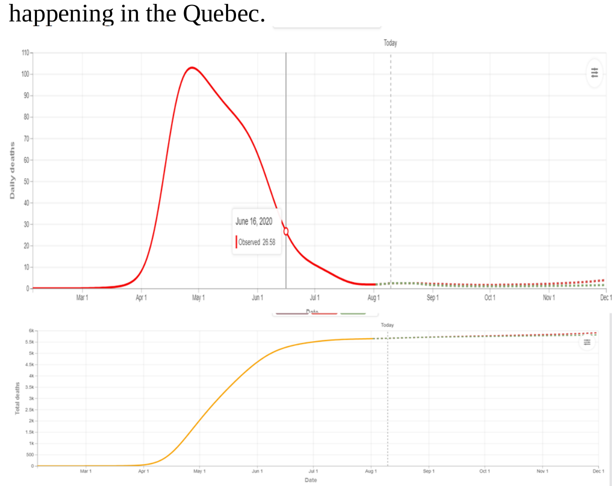

Figure 14: Real result in Quebec[17]

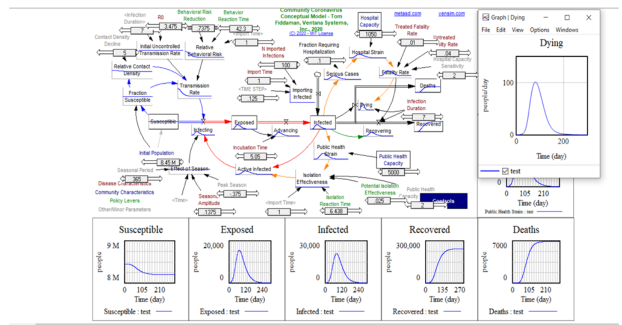

Figure 15Model result in Quebec

VII. Model Verification

Conceptual models have agents like susceptible populations, infected populations, recovered populations and these are reflected in the Net Logo Software.

• It is executable in Net Logo software and there were no errors present in our code

• **Static Testing**: Structure of the conceptual model is being reflected in the code.

Initially we have taken as 1000 susceptible- population-size and initial -Infected size is 100.

• **Dynamic Testing**: In dynamic testing, we use different inputs and corresponding outputs are analyzed. Our model has been tested with different inputs and corresponding outputs have been observed. We kept initial susceptible-Population as 1000, initial-infected size is 100, and other parameters as flowing:

Test Case1: percentage of mask=0

Percentage of social distance = 0,

Social- distancing = 0

Expected: Infected trace have a spike during early stage of pandemic

Result: PASS

Test Cases 2: percentage of masked =50% percentage of social distance = 50%, Social-distancing = 2

Expected: Infected trace get flattened during early stage of pandemic

Result: PASS

A. Checking with the another model:

If we improve the basic model of Vensim we reach the model[16] and If we compare the real data[17] we can find that this model works so near the reality. For doing that first we set each parameter for Quebec province. And then we checked it with real data .

According to this diagram that we have taken from [17] we have a pick infection around 105 and total death is around 6000. Now we check this number with the improved model. As we can see the model is almost near the real data.

1) System Dynamics Model without precaution parameters (worst case scenario)

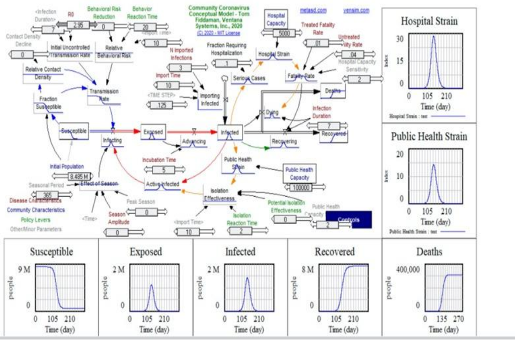

Figure 16System Dynamics Model without precaution parameters (worst case scenario in Quebec)

In this diagram, each box represents an accumulation of people and the pipes that connect them represent the flows from people from one state to another. So, in this case the people start by getting infected, then they are exposed and get the virus, however some of them are asymptomatic and do not show any symptoms. After getting infected, some of them die and some recover. The casualties are indicated by arrows and it usually determines how fast the propagation is happening. For example, if you have people that are infected, they become actively infected in the community and then they will infect other persons and will create more exposed people after a few days of incubation. In this part, incubation time is equal to 5. We can name this process a positive feedback loop of growth infections. The speed of the process of the growth infections is called RO, which is the base reproduction ration, in this case RO is equal to 2.95. It is the number of new infections created by infected persons. Concerning the recovering process in the green loop , we have a balanced feedback over there and what will be best to do it Is to try to cut off the red loop (infected people) so the green loop (Recovering process) can function and more persons will get better. The other loop is the saturation loop, we have susceptible people, smaller fraction of susceptible persons and the transmission rate will go a little down with low density relative contact. The reason behind the fact that it is best to control the propagation is mainly because the consequences are bad, people can die but also with serious cases, they will get hospitalized and the hospital can run out of capacity if they don't have enough bed and the fatality rate will go up because people will not get the treatment they need. In the public heath side, there is also possible infected people that are in quarantine and in order to take them out of active infected population and reduce the expansion of the virus, a set of policies were made in place but the capacity of the public health should be good enough to be able to do the contact tracing to make It work. The problem with this loop is that to be able to work the number of infected people has to be lower than the hospital capacity. The other solution is also to reduce the transmission rate by applying some behavior like behavioral risk and their reaction like keeping distance, doing quarantine, cancelling meetings, washing hands, wearing a mask. Without precautions as you can see in the diagram the susceptible persons go from 0 to 9Millions with the peak of infection and exposure very high

2) System Dynamics Model with precaution parameter:

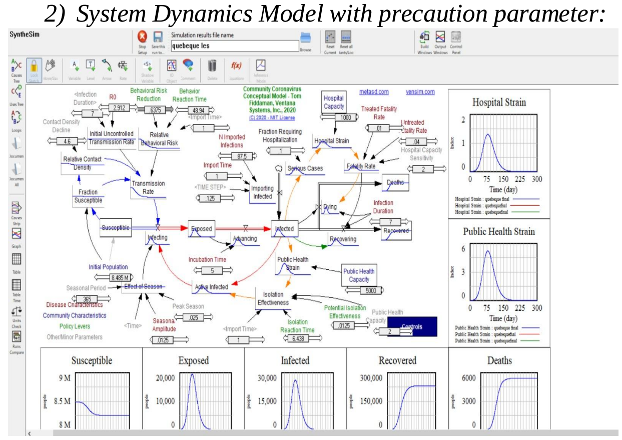

Figure 17System Dynamics Model without precaution parameters (Current scenario in Quebec)

This diagram starts with people who are more susceptible to have the virus. Those people get infected by being exposed to the virus. Among the infected people, some of them recover while others die. Compared to the diagram without precaution, we observe an increase in the reaction time and the potential isolation effectiveness. – We also observe the decrease of RO. Concerning the solution to help decrease the transmission rate, the rate of behavioral risk and behavior reaction time are also increased compared to without precaution where we were at 0 and 20. In addition to all the precautions they took, they also made sure to isolate more people when they are infected, so we noticed an increase of the isolation reaction time. More people were recovered and there was also less death than in the model without precaution. The overall input for our analysis model was the number susceptible, time and initial infected person. Also, we have the options of the percentage of the population that wears masks, the population which practice social distancing and the distance between the people who practice social distancing. The output of this system comes out to be in the form of percentage of how much the population has recovered, how much higher transmission rate is, how safe is wearing a mask or performing social distancing. It also reflects the total number of deaths and how practicing various measures decreases the death rates and rate of transmission of coronavirus.

Under the scenario analysis, we try to implement our model under various scenarios. For each scenario the input varies and corresponding output changes. Whenever the changes occur in the inputs, let us say people start practicing social distancing properly and whole population of Montréal starts wearing the masks and proper distance is maintained between

each individual, the corresponding outputs change in the form : the number of susceptible and infected population is almost zero whereas the masked population and recovered or immune population is there.
Output analysis is the demonstration stage worried about structuring replications, registering insights from them and introducing them in printed or graphical format. Output analysis centers around the investigation of simulation results. In our model, if we reduce the number of people wearing masks and the number of people practicing social distancing is reduced then the infected population increases thereby increasing the susceptible population. Similarly, if the number of people wearing masks in reduced drastically and there is no practice of social distancing then there is drastic increase in the number of covid positive patients along with huge increase in the death rate otherwise the death rates get lowered by increase in the percentage of people wearing masks and practicing social distancing properly. IN our Netlogo, there were no errors present and our code was fully executable.
Static testing : Initially there will be a less number of people with masks and who are performing social distancing properly and a more susceptible cases then there is rapid increase in the death rates along with the total infections which results in decrease in the total percentage of recoveries.
Dynamic testing: in this we gradually increased the percentage of population that wear masks and practice social distancing which automatically results in huge decrease in the number of susceptible populations along with very less death rates and a huge increase in the recovery population.

VIII. Conclusion

Coronavirus has been affecting people in different ways and different backgrounds lately. From most common to less common symptoms, most people will develop it and recover it without being hospitalized. In this report, we implemented and simulated a model and compared it to the real situation of the coronavirus. We have shown through literature review and our experiment simulations the impact of covid awareness, safety protocols such as wearing and practicing social distance. We were also able to see a considerable difference between a country that does not impose such regulations and one that follows strict rules. Even though masks, social distance can help, there is a lot of impact when only a certain percentage of the people follow safety protocols. The small percentage of the populations that follow safety rules depends on their education, morals and cultural difference as well as government influence. We demonstrated this system in the discrete event simulation model, agent-based model netlogo and also reported with vensim and all the simulations are verified and validated.
Strength
It is possible to visualize each phenomenon affecting the system and also, we can use the notation of probability in our system. So, by both of these we can easily understand the working of our model and predict the projections easily.
Weakness
In netlogo, we cannot have the exact number and population since it becomes too crowded. Moreover, having some inconsistencies with real data we need to consider more parameters.

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