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# BAMS 503 - COVID-19 Simulation Report

## ***Part 1: Objective & Key Questions***

Coronavirus disease (COVID-19) is an infectious disease and infected people will have symptoms ranging from common colds to Severe Acute Respiratory Syndrome(SARS). The Ministry of health and BCCDC has implemented several policies to limit the transmission of COVID-19.

Our model is developed to study COVID-19's spread characteristics and the effective preventions to curb its spread in the downtown Vancouver area. We would compare the number of infected people, the cured and deaths in five scenarios: ① the scenario with no policy, ②the scenario with social distance policy, ③the scenario with self-isolation if have symptoms policy, ④the scenario with closing facility policy, and ⑤the scenario with a combination of social distance and closing business policy.

***Questions we would like to know about:***

- ❏ Question 1: How fast is COVID-19 spreading?
- ❏ Question 2: What is the transmission pathway?
- ❏ Question 3: Do different age groups have the same vulnerability to COVID-19? If not, which age cohorts are more vulnerable?
- ❏ Question 4: What policy is the most effective in preventing the COVID-19's spread?

## ***Part 2: Model Assumptions & Parameters***

***Assumptions:***

- ❏ Assumption 1: Our world only has four facilities: schools, offices, grocery stores, and restaurants
- ❏ Assumption 2: People in our model only have four behaviors: going to offices, going to school, dining out in restaurants and shopping grocery stores.
- ❏ Assumption 3: People would not get infected when they stay at home without interactions
- ❏ Assumption 4: Infected people in the incubation period in the symptom period still go to schools and offices.
- ❏ Assumption 5**:** A percentage of adults with strong immune systems would never get infected with COVID-19
- ❏ Assumption 6**:** Cured individuals will never be infected again

***Model Parameters:***

- *population = 5000*
  We assume there are 5000 people living in the downtown Vancouver area.
- *Incubation_min = 1; Incubation_max = 14; Incubation_mean = 5.2*
  Based on WHO, the incubation period for COVID-19 range from 1-14 days, with a mean of 5 days [1]
- *symptom_period_max = 41; symptom_period_mean = 20; symptom_period_min = 10*
  Based on BC Healthlink, the minimum symptom period is 10 days. We assume the max of symptom period is 41 and the mean is 20days [2]
- *children: 0.16, adults1: 0.603, adults2(adults with strong immune systems): 0.067, elder: 0.17*
  Demographic composition of the population
- *children: 0.06, adults1: 0.05, adults2:0, elder:0.1*
  Based on the CDC, the elder has higher risks of getting infected with COVID-19 [3]
- *children:0.9, adults1:0.9, adult2:1, elder: 0.8*
  Curability of different age groups
- *n_offices = 20, n_schools = 8, n_stores = 5, n_restaurants = 8*
  The number of four types of facilities.
- *Office = 0.1, School = 0.1, store = 0.05, restaurant = 0.1*
  Probability of social interaction at different facilities
- *prob_not_shop = 0.6, prob_not_dine_out = 0.6*
  Daily probability of not shopping grocery store and daily probability of not going to restaurants

## ***Part 3: Model Explanations & Outcomes Overview***

***Disease Life Cycle:***

Should an individual be infected by COVID-19, he or she will undergo the following stages:

- **Incubation Period**: The incubation period starts as soon as the infection begins. During the incubation period individuals are unaware of the infection, and thus will continue all kinds of activities as usual. In our model, interacting with ones in incubation imposes the same level of infection rate as interacting with ones with symptoms. The incubation period for each individual is simulated from a triangular distribution with parameters estimated by WTO.

- **Symptom Period**: Immediately after the end of incubation follows the symptom period. Infected individuals will notice the infection during the symptom period. In the base model, no matter how severe the symptoms are, ones will continue with their daily activities. Later after certain policies are imposed, however, individuals with symptoms will be forced to self-isolate until cured. The symptom period for each individual is simulated from a triangular distribution with parameters estimated by BC Healthlink.

- **Final Judgement Stage**: The final stage begins as soon as the symptom period ends. In our simulated world, each infected individual will eventually have two outcomes --- being dead from COVID-19 or being cured of it. People in different age groups have different curability. Notice that once cured, one will never be infected again, assuming the immune system will ward off the virus with certainty.

***Health Status:***

Every day in our simulation, we monitor each individual's health status and update the status should the health conditions change. The status we track are:

- *Dead*: dead (dead=1) or alive (dead=0)
- *Infection*: infected (infection=1) or uninfected (infection=0)
- *Incubation*: under incubation (incubation=1) or not (incubation=0)
- *Symptom*: with symptom (symptom=1) or not (symptom=0)
- *Cured*: cured (cured=1) or not (cured=0)

Note that some status cannot be up at the same time. Within the disease life cycle, for example, the status of incubation and symptom for an individual are mutually exclusive. As well, after a person is cured, his or her infection status should be off.

***Age Groups:***

The age group that one belongs to  plays a crucial role in our simulation model. The three age groups are children, adults, and elders. The age group determines a person's infection rate and curability of COVID-19, given the research showing that the elders and the children are more susceptible to and threatened by the virus than adults. Note that we designed ten percent of the adults ('adult2') to be immune to the virus, because they have extremely strong immune systems.

***Individual Daily Behaviours:***

There are no weekends in our model. Adults have to work and kids have to go to schools, seven days a week. There only exist four types of locations to go to everyday --- offices (20), schools

(8), grocery stores (5), and restaurants (8). The age group also determines one's behaviour in each simulated day. We designed our model such that every day:

- All children for sure go to schools but have a probability to eat at a restaurant
- All adults for sure go to offices but might or might not go grocery shopping or restaurant dining
- All elders might or might not go grocery shopping or restaurant dining

Before the simulation begins, each adult is randomly assigned to an office, and each child to a school. During the simulation, everyday each adult and elder's decision to go to stores are randomly simulated. Same is done for restaurants.

***Modeling Interactions:***

Human behaviours cause social interactions. Rather than modeling interactions via bouncing balls or moving grids, we use mathematical combinations as proxies for social interactions.

Say, 50 individuals work in office 1. To model their interactions in a day, we first list out all possible pair combinations. There are 1225 of such combinations (50 choose 2), indicating there exist 1225 possible interactions in office 1. Note that we ignore the times the interactions happen between two people, since we are only interested in whether any interaction happens between two people. Then we define a social interaction rate (say 10%) which is used to simulate the actual number of combinations (Number of actual interactions happened = round( Interaction Rate * Number of all possible interactions ) = 123). After that, we randomly pick 123 combinations, which become the simulated daily interactions that happened in office 1.

Different types of facilities have different social interaction rates.

***Modeling Infections:***

Human interactions cause infections. Among the actual interactions, we will first identify all dangerous interactions (i.e. those between one infected person and one uninfected and uncured ). Should an uninfected and uncured person interact with multiple infected individuals in that day, for each interaction, that healthy individual will have a probability to get infected.

***Modeling Policies:***

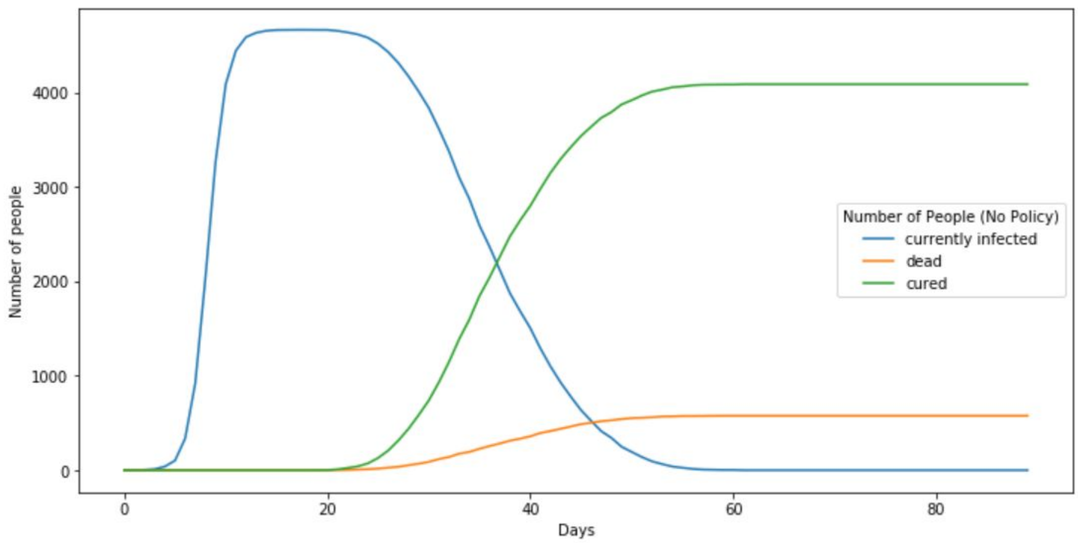
Here are how we model each policy:

- ❏ **Social Distancing**: Since practising social distancing reduces the number of close interactions (less likely to have group events), the social interaction rates at all locations will drop. Additionally, talking with each other at a distance will also reduce the infection rate, as the virus is less likely to spread.

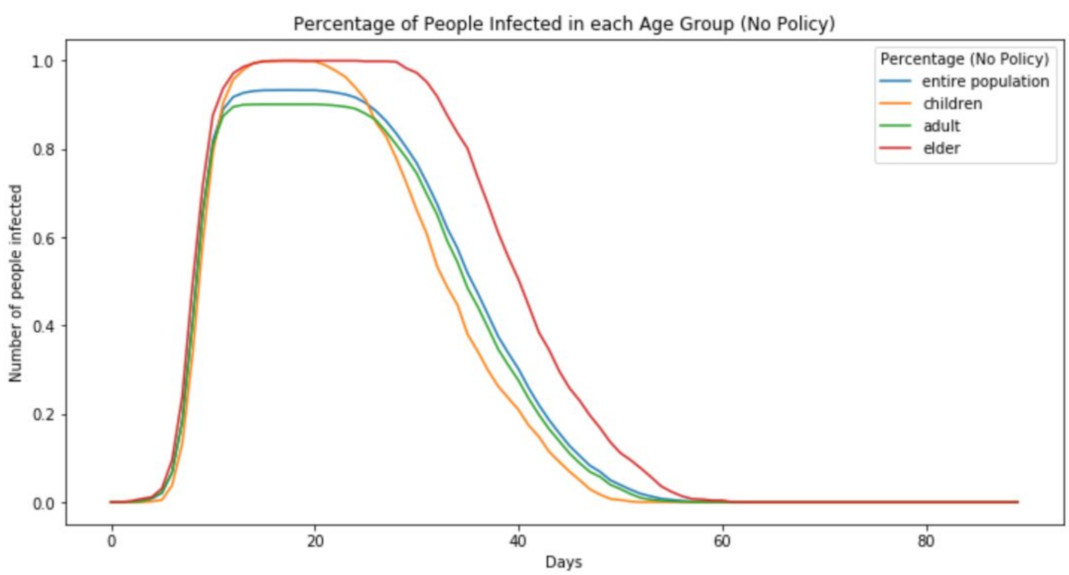
- **Self-isolation if have symptoms**: Infected individuals with symptoms will cease to go to work, schools, or restaurants
- **Shut down offices, schools, and restaurants**: Individuals's daily activities are truncated to only grocery store shopping. Virus can only spread via interactions in grocery stores.

**The 90 days simulation results (with and without policies) are as follows:**

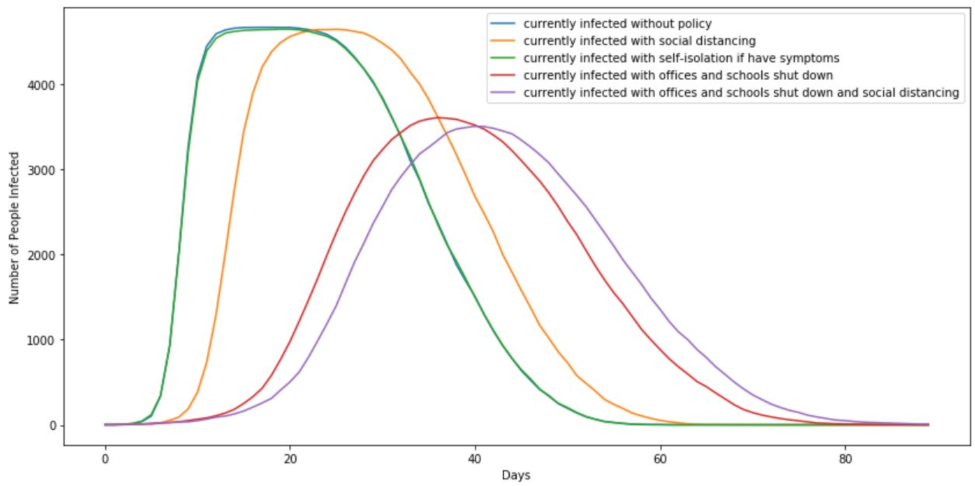
➢ Total number of infection, deaths and recovery under no policy:

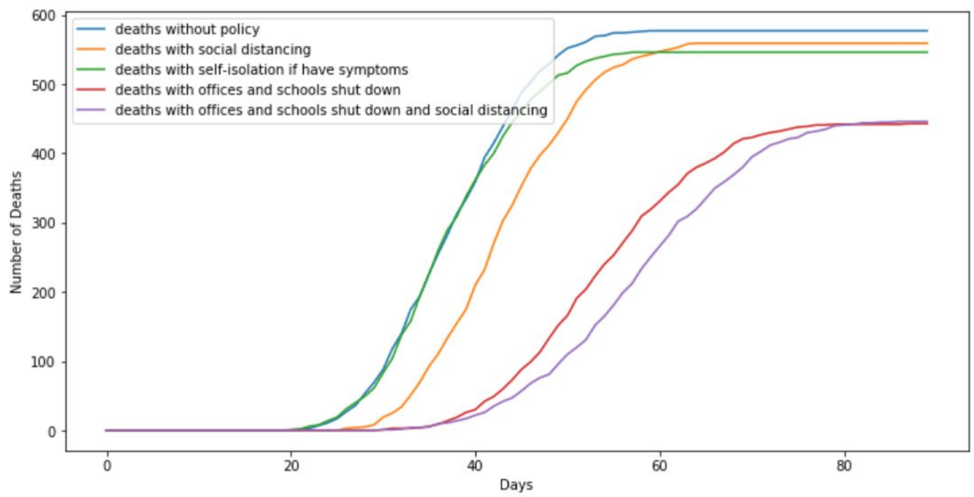


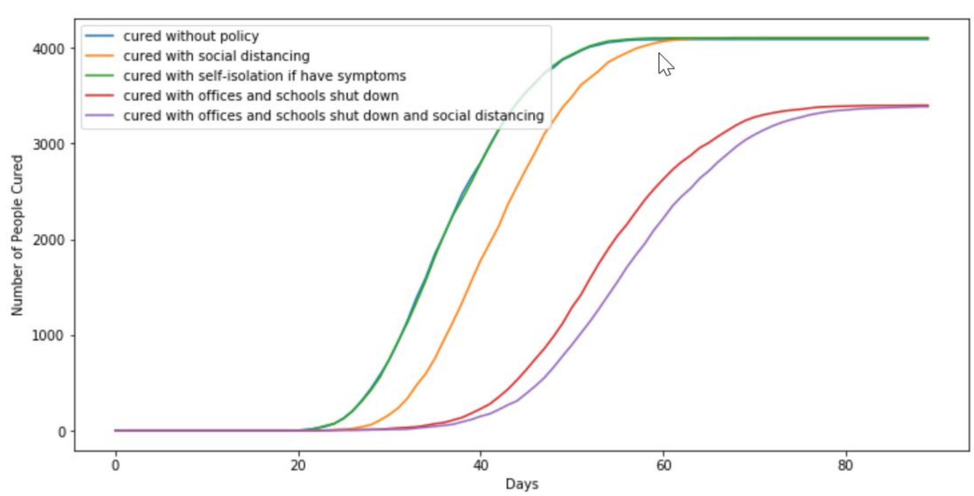

➢ Compare number of infection for different age groups under no policy:



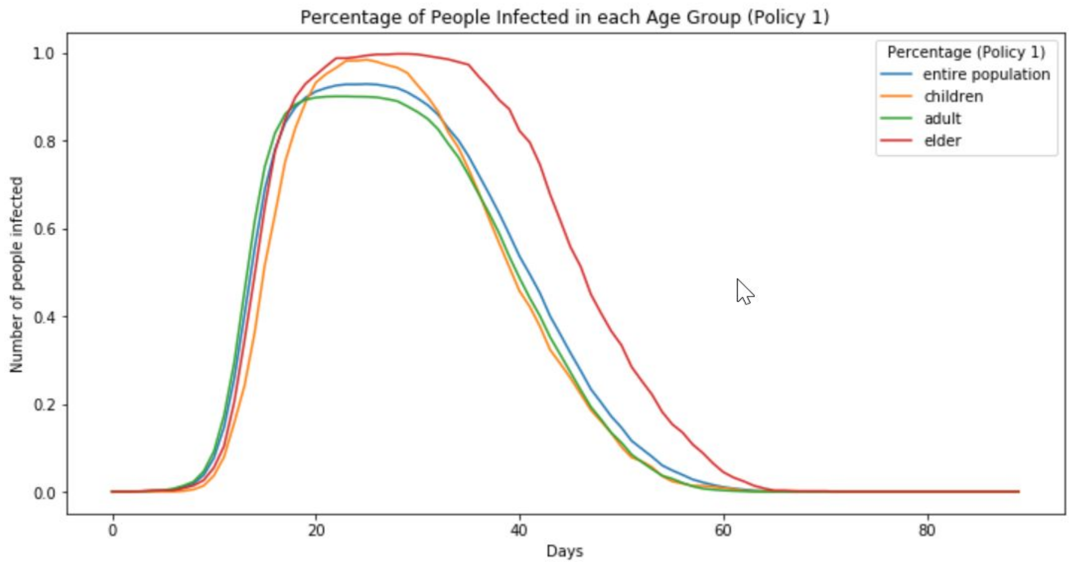
➢ Comparison infection cases, death cases and recovery cases under 5 scenarios:

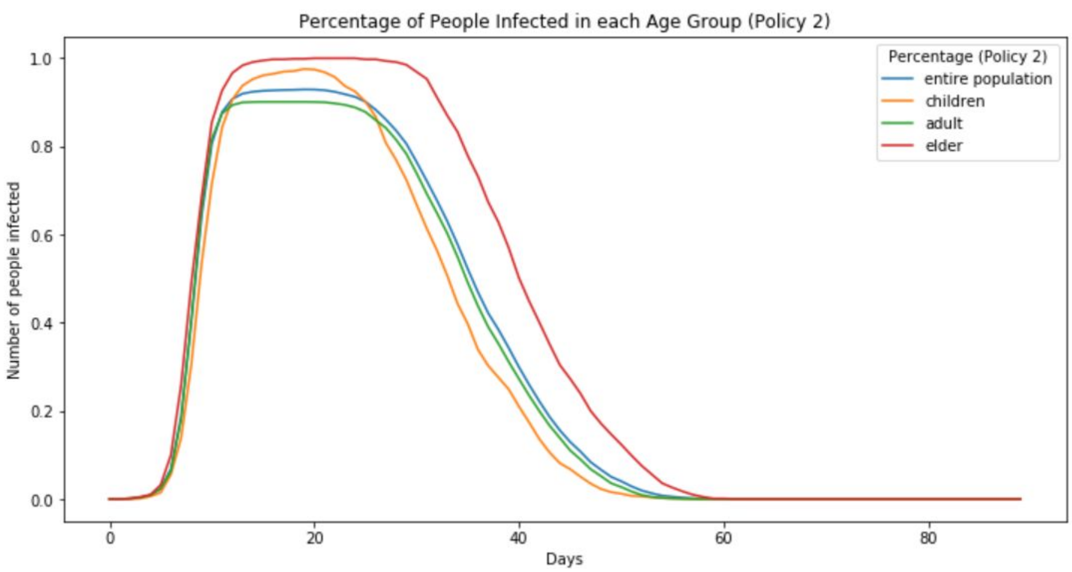


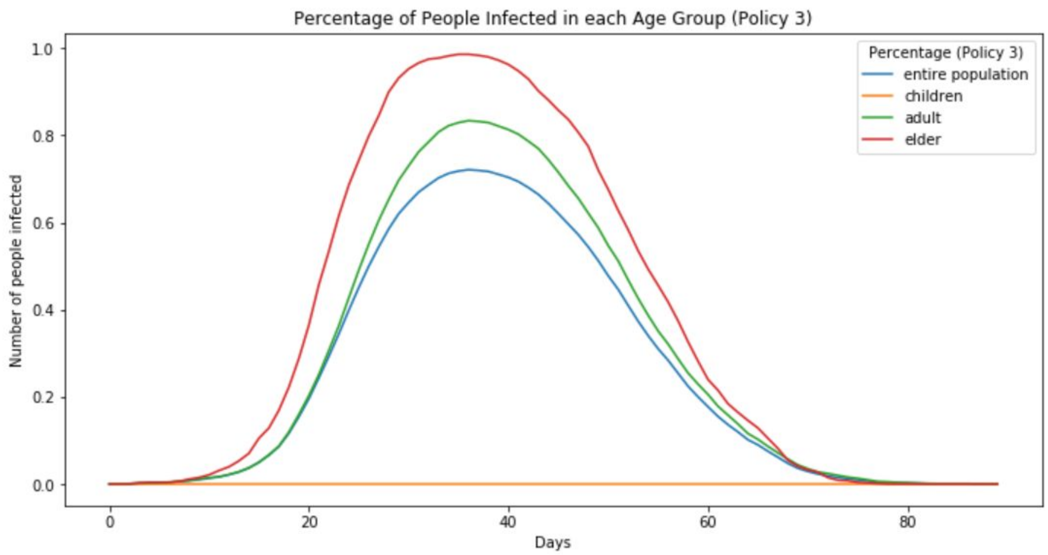



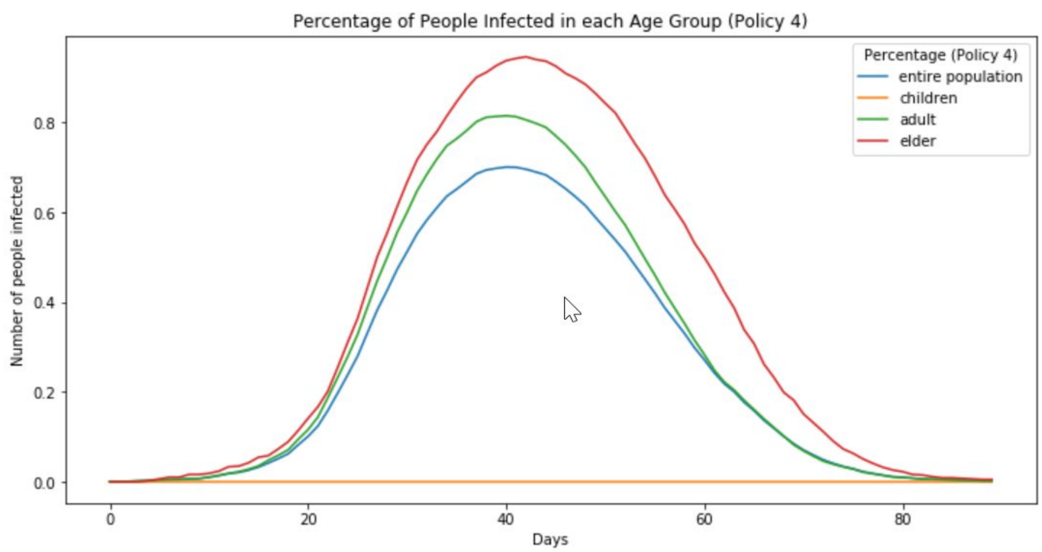



➢ Compare infected cases of different age groups under 4 policies:






## ***Part 4: Model Discussion & Insights***

The World Health Organization (WHO) has declared the COVID-19 outbreak a global pandemic on March 11, 2020. In this project, our objective is to learn about the COVID-19's transmission and to minimize the COVID-19 spread in our community under different policies. We build up a base model with no policy implemented - the government and people do nothing to protect themselves from the virus. This simulates the situation at the early stage in each country when people know little about this virus. As more people from different age levels are infected, both the government and people start to react to that. Based on real life scenarios, we define 4 policies to protect people from infection in our simulation:

- ❏ Policy 1: Social distancing
- ❏ Policy 2: Self-Isolation if one has symptoms
- ❏ Policy 3: Shut down offices, schools and restaurants
- ❏ Policy 4: Combination of Policy 1 and Policy 3 - Implementing social distancing and close offices, schools and restaurants

From our infection comparison plot under different policies, we see that the curves of the number of infected people are almost coincident under no policy and under self-isolation if someone has symptoms. This is actually very consistent with what scientists and doctors have learned about the peculiarity of COVID-19. It is able to transmit among people even when potential carriers have no symptoms at all. So this confirms that only self-isolation is not enough to help stop the virus from transmission. Social distancing slowers the infection rate. But it does not eventually flatten the curve which indicates that the total number of infected people is not reduced.

The most efficient way is Policy 4: the combination of shutting down schools, offices and restaurants and social distancing. People are currently following the realistic policy in the Vancouver area. The number of people passed away from COVID-19 is reduced by around 3.2% after implementing Policy 4. This percentage is a remarkable improvement because Zhong Nanshan, an authoritative Chinese Epidemiology Professor, discusses that the mortality rate due to COVID-19 is normally 1% - 2%. Our simulation's result further confirms that Vancouver people are using the most efficient ways to make less people infected.

By comparing different age groups, Policy 3 and Policy 4 slower the overall infection and the virus transmission. Elderly people are the most vulnerable group whose mortality rate is twice more than that of the whole population under Policy 3: Shut down offices, schools and restaurants. One main reason is that elderly people still need to do regular grocery shopping which increases their interaction with random people.

Even though the social distancing policy is also implemented under Policy 4, elderly people's mortality rate is the highest. It is hard to maintain social distancing at supermarkets or on buses. Some Costco locations reserve 8:00am to 9:00am for elderly people to create a safer environment. Given that all 4 policies do not improve the situation much for elderly people, we suggest that elderly people should reduce the frequency of grocery shopping. If possible, their children could deliver groceries for them once a week or two weeks. Or, supermarkets like Walmart and Save-on foods provide delivery services by ordering online. This could be an option to help elderly people reduce the exposure and the interaction with infected people when they go out. Wearing face masks is another essential option suggested by some countries because one major transmission pathway is through droplets generated when an infected person coughs, sneezes or even talking to you face to face with no cover.

**Reference:**

[1]https://www.cps.ca/en/documents/position/current-epidemiology-and-guidance-for-covid-19-march-2020
[2] https://www.healthlinkbc.ca/health-feature/coronavirus-disease-covid-19
[3] https://www.cdc.gov/aging/covid19-guidance.html