Comparing External and Internal Control Measures during Omicron

Lesson from comprehensive Mobility-based Epidemic Simulation Models for the City of Montreal and Hong Kong

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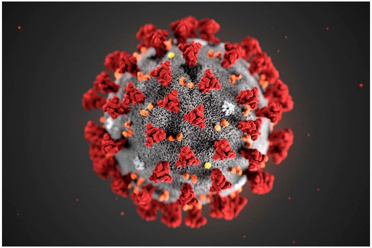
Overview

Introduction

COVID-19 Pandemic

- COVID-19 pandemic: created by SARS-CoV-2 and its variants.
- Emerged in Late 2019 in Wuhan, China.
- Till late 2022, 670 million cases and 6.9 million deaths worldwide.



COVID-19 Pandemic: Spread

Coronavirus spread is attributed to

- Fast air transmission capability of coronavirus variants.
- Local and global activities and mobility dynamics.
- Long-distance travel such as flight and train was found to be responsible for disease transmission.
- Urban travel was found to be responsible for community transmission.

COVID-19:Non Pharmaceutical Interventions (NPI)

Non Pharmaceutical Interventions (NPI)

Interventions to reduce spread that are not pharmaceutical

Governments, therefore, implemented two types of NPIs.

- Stop air transmission of the virus: masking, social distancing, and limit of group size.
- Restrict activities and movements: shutting down businesses, education facilities, and leisure facilities, curfew, and cordon check, etc.

External Control vs Internal Control NPIs

External Control NPIs

Any border control measures, such as mandated and supervised 14-31 days quarantine, travel restrictions from high-risk locations, restrictions on the number of flights, mandatory testing, and quarantine of all international crews and travelers, etc.

Internal Control NPIs

Any measures that inhibit internal activities and mobility of a region. The most common form is activity restrictions, mandated remote working, education facilities closures, leisure facility closures, social gathering restrictions, etc.

External Control vs Internal Control NPIs

Internal control measures are found to have severe consequences on

- The psychological and physical health of city dwellers
- Education
- Food security
- The economy of the country

External control measures are found to

- Cut down the ties between cities
- Harm international trade and movements and hence foreign investments
- Harm the tourism sector and any industries that dependent on it

External Control vs Internal Control NPIs

There exist trade-offs between different NPI strategies.

- The Government of Hong Kong adopted a strategy that emphasized both strict external controls and limited internal restrictions (activities and mobility) in battling the first and second waves of COVID-19.
- The City of Montreal and Canada as a whole had strict internal activities and mobility control with, loose external control measures in the first and second waves of COVID-19 spread.

Both Hong Kong and Montreal have similar trip-making populations and urban mobility profiles but very different COVID-19 containment successes.

Relation to Transportation Engineering and MATSim

All external and internal NPIs are essentially restrictions on activities and trips.

State-of-the-art, agent-based traffic simulators such as MATSim trace individual peoples' daily activities and trips.

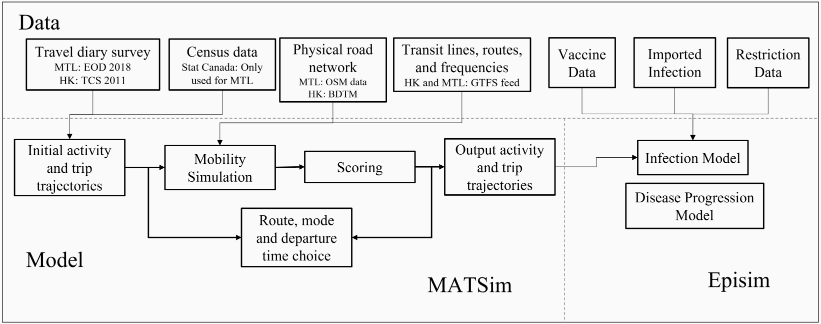
MATSim wields a unique advantage in simulating urban infection scenarios and drawing conclusions on the effectiveness of different NPI measures.

Objective

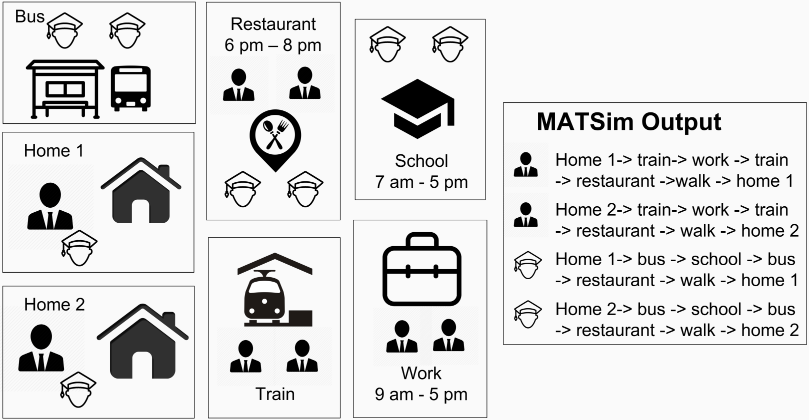
- Develop comprehensive infectious models for the COVID-19 pandemic simulation for the Omicron spread for the city of Hong Kong and Montreal.
- Draw insight into the effectiveness of external and internal NPIs for the two cities from data.
- Draw insight into the effectiveness of external and internal NPIs for the two cities from the developed models.

Model Development

Two Stage Modeling Framework



Model Components: Contact Model



Model Components: Infection Model

Probabilistic Episim Infection Model

$$P_{a,b} = 1 - e^{-\theta U_{a,b}}$$
$$U_{a,b} = T_{a,b} C_{a,b} I_a S_b (1 - M_a)(1 - M_b)\alpha$$

T and C stand for time and contact intensity

I and S are the infectiousness and susceptibility of the infector and infected.

M and α models the face mask models and the effect of external factors on the infection, such as temperature and weather conditions.

Model Components: Infectiousness

In our model, we used the age and progression-dependent infection model, where infectiousness I_a follows a normal distribution profile from the onset of showing symptoms. Additional elements that are considered are:

- Age of the infector.
- Virus strain infectiousness.
- Infector vaccination status.

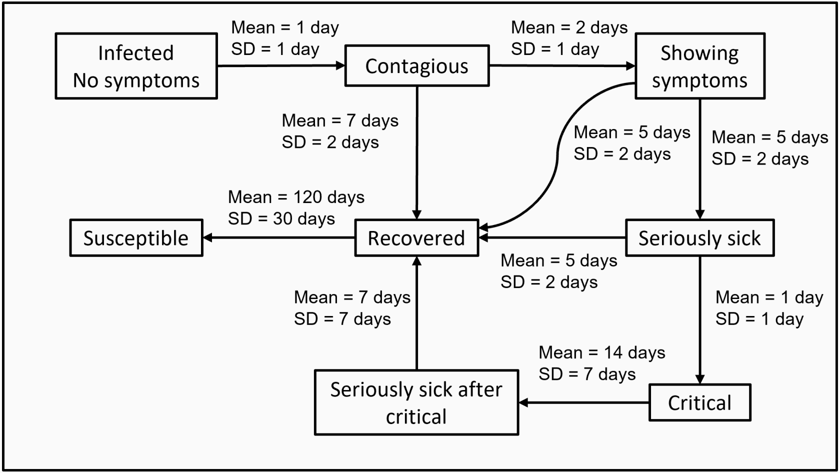
Model Components: Susceptibility

Age: below and above 50

Vaccination rate: from INSPQ data for Montreal and data.gov.hk for Hong Kong

Dose	Days after administration	Vaccine Effectiveness
Single dose	7	0.25
	14	0.5
	Full effect	0.6
Booster	7	0.6
	14	0.88
	Full effect	0.89

Model Components: Disease Transition



Model Components: Disease Transition

Age group	Contagious to Symptomatic %	Symptomatic to seriously sick %	Seriously sick to critical %
Less than 5	75	4	7
5-15	75	1.1	0
15-35	75	2.4	15
35-60	75	5.6	30
60-80	75	23	41
80 and above	75	36	27

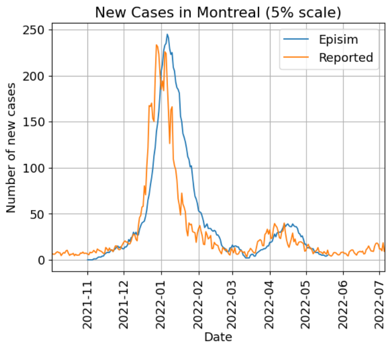
Additional Model Components

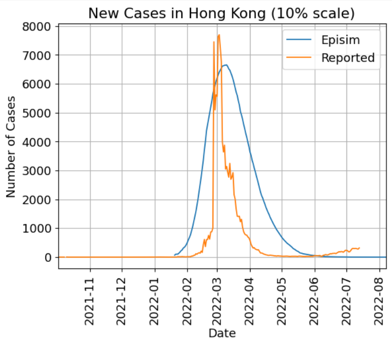
We have added two additional model components:

- Quarantine (After 1 day of being symptomatic)
- Tracing (Infected persons are traced, and the people connected to the infected people are put into quarantine after a tracing delay of 2 days subject to total tracing capacity).

Model Calibration and Validation

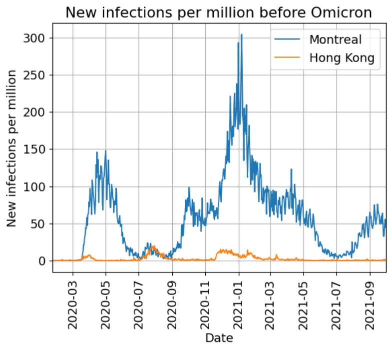
Calibration and Validation Montreal and Hong Kong

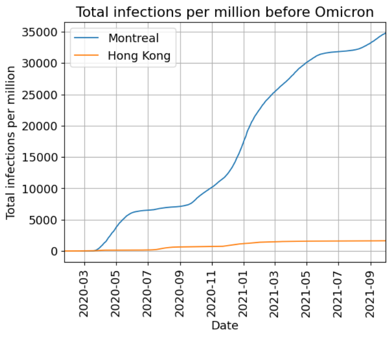




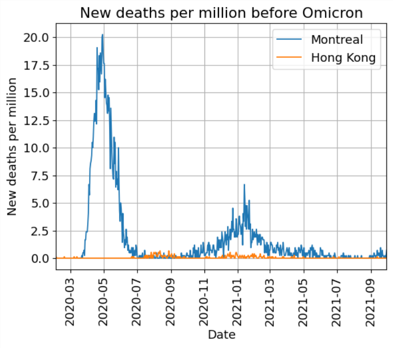
Insights From Data

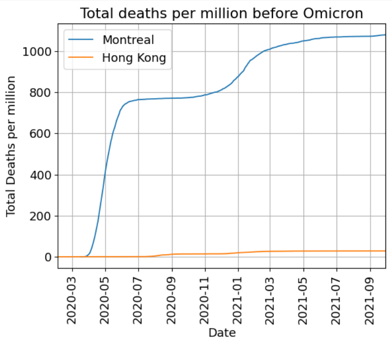
New and Total Infections Before Omicron



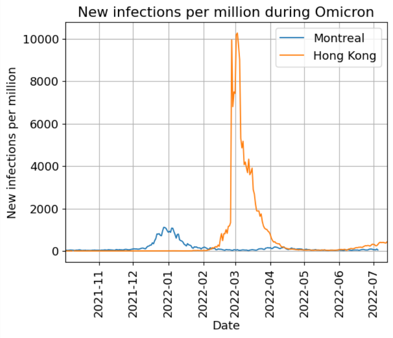


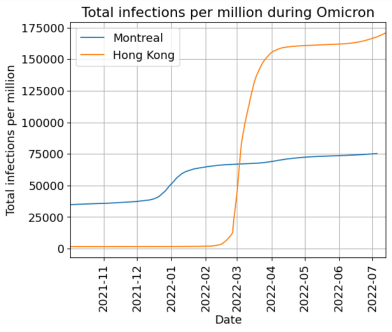
New and Total Deaths Before Omicron



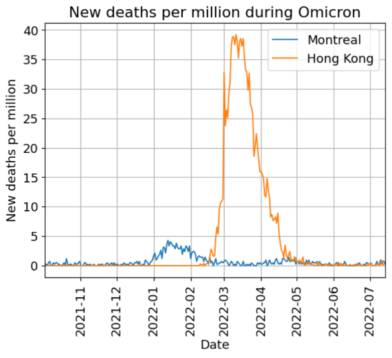


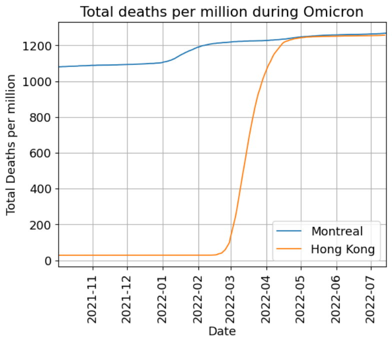
New and Total Cases After Omicron



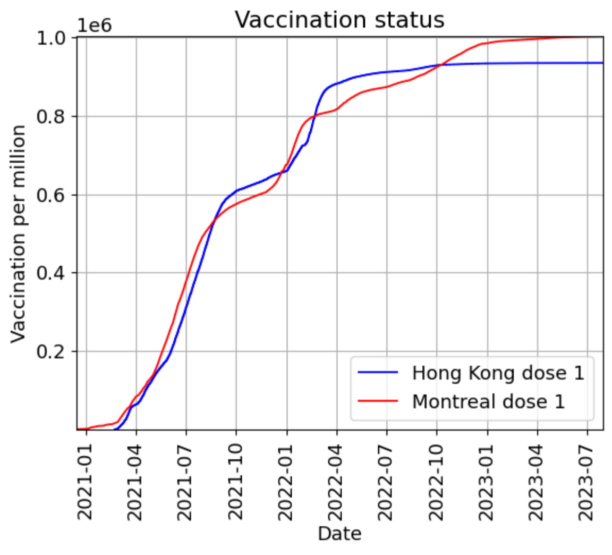


New and Total Deaths After Omicron

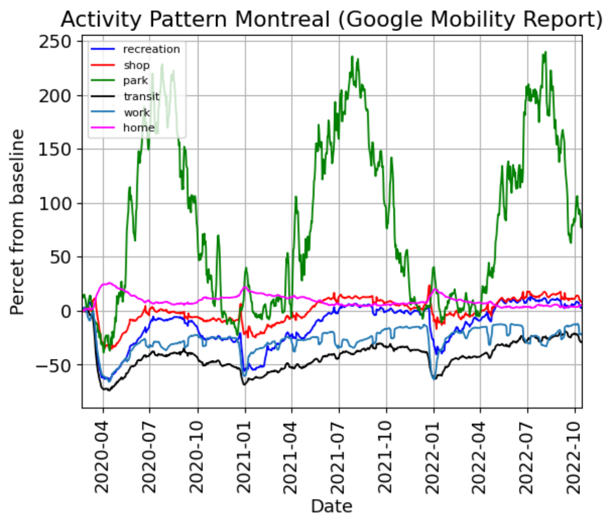




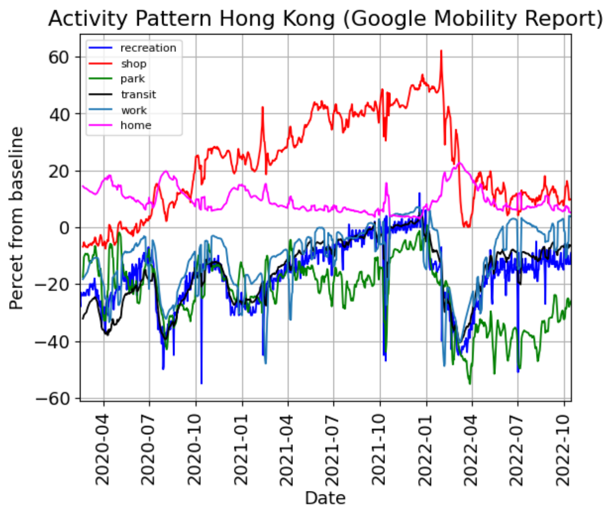
At least one dose of vaccination per million of population



Activity Restriction Montreal (Google Mobility Report)



Activity Restriction Hong Kong (Google Mobility Report)



Insight From Models

Simulation Baseline

Specifically, we focus on three key aspects:

- the proportion of internal restrictions imposed
- the level of external control in terms of introduced infection
- the time delay in introducing on-demand internal restrictions

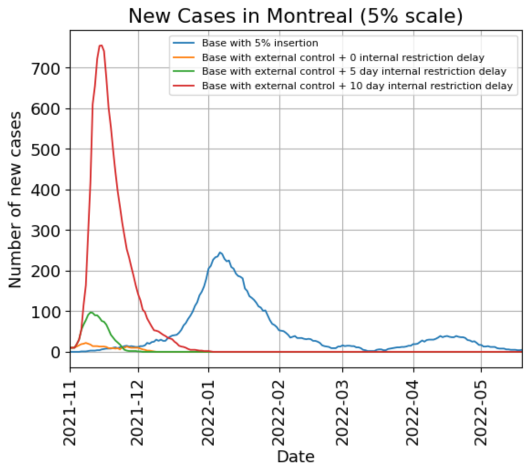
The baseline scenario is generated by applying internal and external restrictions recorded in reality. Google Mobility Report supplies restrictions data, and world data on COVID supplies the newly reported infection data.

Strict External Control and On Demand Internal Control

Case	External control through insertion	Internal restriction proportion	Implementation Lag	Note
Testing with implement lag of internal restriction				
Base with 5% insertion	5%	Base restriction	0	Perpetual internal restriction
Base with external control+0 Implementation Delay	10 initial insertion	Base restriction	0	Perpetual internal restriction with sudden external infection
Base with external control+5 day Implementation Delay	10 initial insertion	Base restriction	5	On-demand internal restriction with sudden external infection
Base with external control+10 day Implementation Delay	10 initial insertion	Base restriction	5	On-demand internal restriction with sudden external infection

Strict External Control and On Demand Internal Control

Assuming a sudden external infection, in this method, we implement the base internal control on demand at a lag of 0, 5, and 10 days from the day of infection.



Conclusion

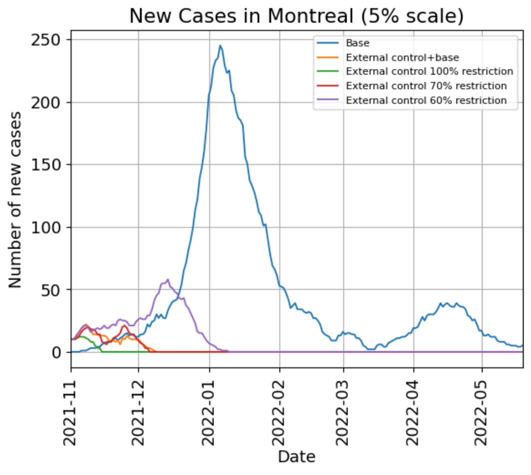
- This experiment simulates Hong Kong's policy of Covid control.
- The result indicates that the policy is quite successful if internal restriction can be applied without major delay.
- Policy success depends mostly on the detection of the external infection, minimizing the time lag in enabling on-demand internal restriction.

Strict External Control with Varying Internal Restrictions

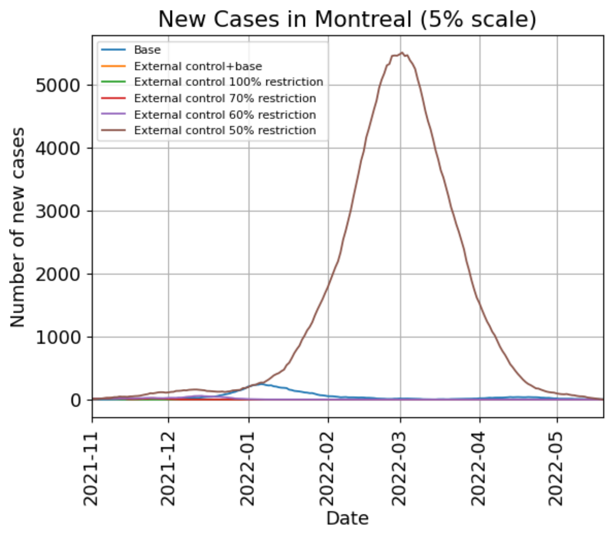
Case	External control	Internal restriction	Implementation Lag	Note
Testing with internal restriction				
Base	5%	Base restriction	0	Perpetual internal restriction
External control+base	10 initial insertion	Base restriction	0	Perpetual internal restriction with sudden external infection
External control+100% restriction	10 initial insertion	100%	0	Perpetual internal restriction with sudden external infection
External control+70% restriction	10 initial insertion	70%	0	70% internal restriction with sudden external infection
External control+60% restriction	10 initial insertion	60%	0	60% internal restriction with sudden external infection
External control+50% restriction	10 initial insertion	50%	0	50% internal restriction with sudden external infection

Strict External Control with Varying Internal Restrictions

This experiment applies strict external control and checks what proportion of the base internal restriction could be alleviated for similar and even better infection control.



Strict External Control with Varying Internal Restrictions



Conclusion

The results show that when a strict external control measure is applied, there exists a threshold value for both the time lag for on-demand internal restrictions (10 days) and the proportion of internal restrictions (50%), after which the number of infections has a sudden exponential increase.

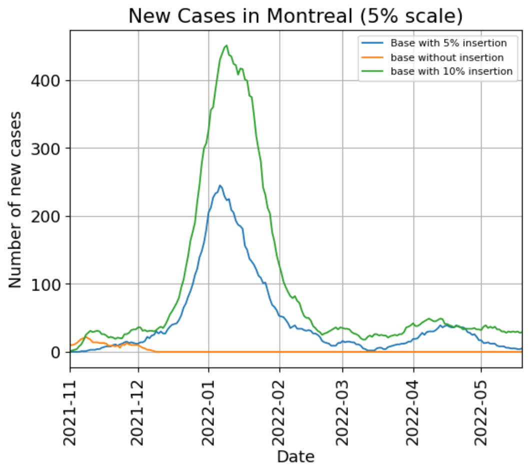
The success of the external control policy only holds if this threshold value is appropriately identified and avoided.

Varying External Control with Base Internal Restrictions

Case	External control	Internal restriction	Implementation Lag	Note
Testing with external restriction				
Base with 5% insertion	5%	base	0	Perpetual internal restriction with loose external control
Base with 10% insertion	10%	base	0	Perpetual internal restriction with loose external control
Base without insertion	10 initial insertion	base	0	Perpetual internal restriction and sudden external infection with tight external control

Varying external Control with Base Internal Restrictions

Finally, we run the simulation with varying external infection insertion and base internal restrictions. The result indicates that the infection number is linear in external infection.



Conclusion

Conclusion

- Qualitatively, the results indicate that the policy Hong Kong implemented, i.e., strict external control with on-demand internal restrictions, is a better policy alternative compared to the reduced external control and stricter internal restrictions if the time lag and internal restriction thresholds can be properly identified and avoided.
- In the future, we plan to do a complete utility-based social welfare analysis that can show the true economic benefit of the two control measures and quantitatively show the better policy alternative in mitigating the spread of infectious diseases in dense cities like Montreal and Hong Kong.

Have Questions???

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