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EVALUATING THE COVID-19 SCREENING REGIME FOR CROSS-BORDER WORKERS

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ABSTRACT

Global travel and trade have been hit hard by the COVID-19 pandemic. Border closures have impacted both leisure and business travel. The socioeconomic costs of border closure are particularly severe for individuals living and working across state lines, for which previously unhindered passage has been curtailed, and daily commute across borders is now virtually impossible. Here, we examine how the periodic screening of daily cross-border commuters across territories with relatively low COVID-19 incidence will impact the transmission of SARS-CoV-2 across borders using agent-based simulation. We find that periodic testing at practical frequencies of once every 7, 14 or 21 days would reduce the number of infected individuals crossing the border. The unique transmission characteristics of SARS-CoV-2 suggest that periodic testing of populations with low incidence is of limited use in reducing cross-border transmission and is not as cost-effective as other mitigation measures for preventing transmission.

1 INTRODUCTION

Since its first description in Wuhan, China, the unprecedented speed at which SARS-CoV-2 spread caught many countries by surprise, resulting in a global pandemic affecting 188 countries (WHO 2021). In

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response, local and national governments worldwide have adopted unprecedented control measures. In-country public health measures promoted and implemented in order to reduce onward transmission of SARS-CoV-2 include the wearing of masks (Greenhalgh et al. 2020, Stutt et al. 2020), physical distancing (Jarvis et al. 2020, Prem et al. 2020), contact tracing (Cowling et al. 2020, Hellewell et al. 2020, Kucharski et al. 2020), and regular hand-washing. These have become part of daily life in the “new normal”, albeit to different levels of acceptance across countries. Other measures include travel restrictions, border closures, and lockdowns to curtail the transmission of the virus. More than 90% of the world population lived in a country or region with partial or total border closure to non-residents within the first 6 months of the COVID-19 epidemic (Pew 2020).

Although these control measures have largely worked, they have had a devastating effect on economic activities and livelihoods (Ayittey et al. 2020). In particular, they have drastically reduced human traffic at the major land borders (Shah and Safri 2020, Tang 2020), which is unsustainable in the long term for many countries due to the adverse impact on trade and the economy (Bonaccorsi et al. 2020, Nicola et al. 2020).

All countries have also attempted to ramp up their COVID-19 testing capacity as a critical strategy for pandemic control. These near-simultaneous efforts resulted in a global competition for testing reagents and resources, resulting in severe supply chain shortages and general unavailability of testing for many countries (Nat Bio 2020), ironically exacerbated by the closing of borders and delays in international logistics and transportation (Behnam et al. 2021, Dai et al. 2020). Thus, countries have had to prioritize the various needs for testing, including balancing public health concerns and COVID-19’s impact on the economy with the cost and capacity for large-scale testing.

Governments have recently also attempted to address the problem of how to reopen their country and/or state borders safely. Daily cross-border or cross-state commutes are a particularly important facet of this problem. They are a socioeconomic reality in many countries where workforce shortages as well as differential costs of living and wages result in beneficial trade-offs: for workers where the pain of a long daily commute across country and state lines is preferable to the cost of staying in an expensive city; and for companies where labor costs for such cross-border employees may be lower. Examples include the Singapore-Malaysian border in which many Malaysians commute daily to Singapore for work and the Hong Kong-Shenzhen border through which Chinese workers commute daily to fill job shortages in Hong Kong.

As COVID-19 prevalence rates and capacities for detection differ between countries, it is understandable that some countries – despite the economic imperatives – have been reluctant to open their borders without guarantees that such cross-border movements will not jeopardize efforts at containing SARS-CoV-2 (Gostic et al. 2020, Quilty et al. 2020). Here, we present how regular testing by itself is insufficient to allow limited border reopening for cross-border or cross-state workers while accounting for the costs of testing and the risk of pre-symptomatic and asymptomatic transmission of COVID-19 if there is a desire to use regular testing to detect infectious individuals before transmission. We took into account logistical limitations when proposing probable testing frequencies of once every 7, 14, and 21 days as daily testing of large commuting populations during peak commuting hours will not be practical. We further discuss how safe management measures may be more effective than frequent testing in preventing onward transmissions in the community.

2 METHODS

2.1 Objective and Model Design

To investigate if different testing frequencies will affect the numbers of infected individuals crossing the border daily, we modeled testing regimes that test the entire commuting population once every 7, 14, or 21 days. To add realism to our simulation, we assumed that there is one undetected asymptomatic for every one reported symptomatic. In addition, as temperature sensors and self-declaration forms are now standard features of border crossings, we also modeled the probability of picking up a symptomatic individual once symptoms appear at 0%, 30%, 50%, and 100% daily.

2.2 Agent-based Modelling

Agent-based modeling and simulation have been used widely in the investigation of complex systems for dynamics and adaptive behaviors. It is an effective tool for observing and analyzing the collective effects of individuals under a dynamic environment while we may or may not have a full understanding of the individual's patterns and behaviors (Abar et al. 2017, Tao et al. 2021). In the healthcare domain, it has also been intensively used in the areas such as disease projection and mitigation evaluations, and vaccine and medicine studies. For example, Romero-Brufau et al. (2021) studied the impact of delaying the second dose of the COVID-19 vaccine through simulation agent-based modeling; Tracy et al. (2018) reviewed the public health investigations where agent-based modeling has been adopted, including both communicable and non-communicable disease. Specifically, in this study, we employed an agent-based model of 100 000 cross-border workers with daily steps (Figure 1). In the model, we test all individuals for COVID-19 infection regularly at 7-day, 14-day, and 21-day intervals. All individuals are tested when scheduled for testing, and the infected individuals may be detected based on the real-time quantitative reverse transcriptase-polymerase chain reaction (qRT-PCR) sensitivity distribution shown in Figure 2. Susceptible individuals may acquire a symptomatic or an asymptomatic infection with probability proportional to the incidence rate of the population, assumed at one infection per 100,000 population per day for this simulation. They may then go on to develop symptoms or remain asymptomatic. After the latency period (assumed as five days), symptomatic infections will develop symptoms while asymptomatic infections will remain asymptomatic. Infectious individuals will then be able to infect the community based on the infectivity distribution shown in Figure 2.

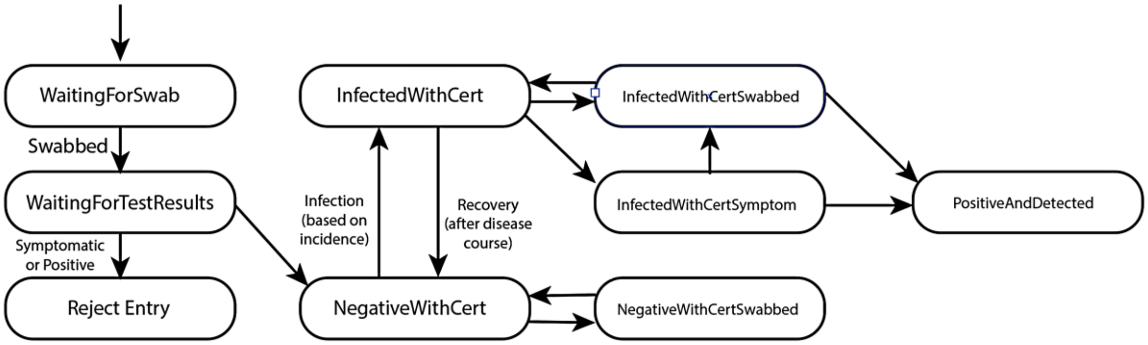

Figure 1: Pathway of an individual in the agent-based model.

As illustrated in Figure 1, individuals (or agents) are divided into different states, represented as bubbles in the diagram. The arrows indicate the possible transition an individual might encounter in the model. In the model, the first entry of an individual (denoted by the WaitingForSwab and WaitingForTestResult bubbles) is granted after testing negative. The individual is virus-free and issued a certificate with a validity period of 7, 14, or 21 days, depending on the testing interval (NegativeWithCert bubble). The individuals are scheduled for regular tests, and if negative, another virus-free certificate will be issued (NegativeWithCertSwabbed). However, an individual may acquire the infection while in possession of a virus-free certificate (InfectedWithCert). Infected individuals with the virus-free certificate may develop symptoms but remain undetected by the surveillance system (InfectedWithCertSymptom). Infected individuals, due for the scheduled test, will be tested and wait for their test results (InfectedWithCertSwabbed). Based on the test sensitivity assumed by the model, infected individuals may remain undetected (InfectedWithCert). Infected or symptomatic individuals detected will then be rejected entry (PositiveAndDetected).

In Figure 2, the average number of individuals infected / day by each infectious individual is plotted against days after initial exposure and symptoms appearing in our model. The area under the curve is equal to 2.5, which represents the R' of 2.5. The corresponding qRT-PCR sensitivity is plotted as well.

All symptomatic individuals who are identified by recognition of the symptom or via self-declaration and those who test positive are prevented from crossing the border thereafter. Only individuals who test negative are permitted daily entry for 7, 14, or 21 days, depending on testing intervals, until they are due for another test. We simulated the daily commute of cross-border workers and periodic testing regimes during the COVID-19 pandemic using parameters from the literature as presented in Table 1. We ran the simulation for 50 days when the simulations are stabilized for all scenarios. In this model, we assume homogenous transmissibility across the population, and we also assume that mitigation measures that affect R0 will affect transmissibility across the disease course equally. The infectivity curve (Figure 2) was estimated based on transmission characteristics of SARS-CoV-2 in Guangzhou6. We modeled two scenarios: (i) asymptomatic individuals are 50% as infectious as symptomatic individuals, and (ii) asymptomatic individuals are 5% as infectious as symptomatic individuals.

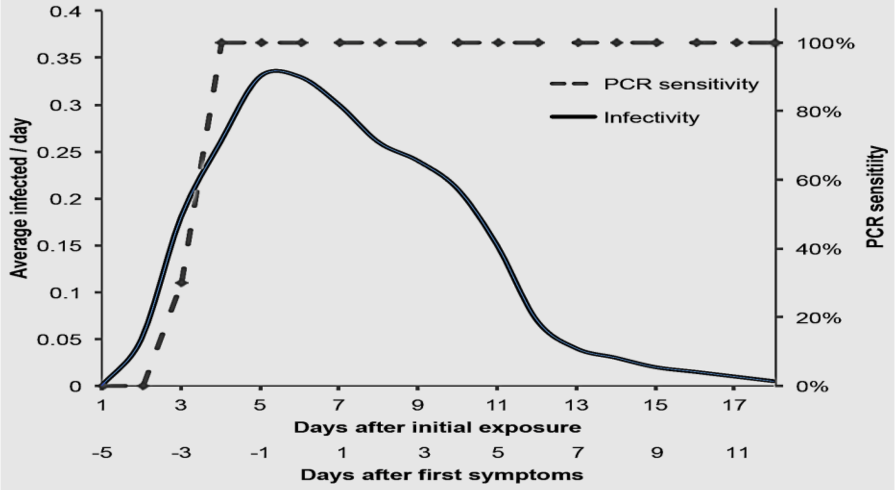

Figure 2: Mean infectivity by day of symptom onset and qRT-PCR sensitivity.

Table 1: Parameters of the agent-based model.

	Values	**References / Rationale**
Incubation period	5 days	He et al. 2020 / Estimation most closely linked to observed incubation period based on feedback from MOH*
Disease course	18 days	He et al. 2020 / Estimation most closely linked to observed disease course based on feedback from MOH
qRT-PCR testing sensitivity	0% on the first and second day after exposure to the infection, 30% on the third day after exposure, and 100% thereafter (Figure 2)	Assumed for model
Symptomatic individual detection by the surveillance system and quarantine	0%, 30%, 100% daily	Assumed by model
Incidence of asymptomatic individuals	1 asymptomatic for every 1 symptomatic	Gudbjartsson et al. 2020 / Estimation most similar to observation based on feedback from MOH

* MOH: Ministry of Health Singapore

As it is widely reported about 40-45% of the infected individuals are truly asymptomatic (Gudbjartsson et al. 2020, Oran and Topol 2020), we assume there is 1 undetected asymptomatic individual for every reported symptomatic individual when calculating the incidence rate. An incidence rate of one per 10 000 population implies a daily chance of 1/10 000 for an individual to become symptomatic and positive and 1/10 000 to become asymptomatic and positive. We assume a pre-symptomatic period of five days where symptomatic infected individuals are only detectable and infectious up to three and five days respectively before symptoms appear (Figure 2) (He et al. 2020). Although the incubation phase of Covid-19 has been reported to be as long as 11 days (Pung et al. 2020), there are negligible transmission and qRT-PCR sensitivity more than five days before symptoms appear, and we did not model the full distribution of the incubation period. We also assumed a disease course of 13 days from the onset of symptoms because, at the tail end of the infection beyond 13 days, the virus titers are so low that it is unlikely these individuals will contribute to the spread of COVID-19 (Wolfel et al. 2020). For qRT-PCR test sensitivity, we assume that the virus is undetectable on the first and second day after exposure, has a 30% chance of detection on the third day, and a 100% chance of detection thereafter, if tested.

As surveillance systems are in place to detect symptoms—such as fever and the appearance of coughing, as well as self-declaration forms at the border—we model the ability of such systems to identify symptomatic individuals at 0%, 30%, 50%, or 100% daily. Figure 1 also presents the different states of an individual (or agent) in the agent-based simulation model. The model population is closed and includes 100,000 cross-border workers, and it ignores all demographic changes in the population (i.e., births, deaths, and aging).

3 RESULTS

3.1 Low Incidence Rates Required for Border Reopening Results in Low Daily Number of Infected Commuters

Table 2: Expected number of infected individuals in the cross-border population.

Incidence	**Number of infected individuals crossing the border per day**	
	100,000 workers	500,000 workers
1 in 10,000	360	1800
1 in 25,000	144	720
1 in 100,000	36	180
1 in 250,000	14.4	72
1 in 1,000,000	3.6	18

Based on reported daily crossings between selected borders (Appendices Table S-1), it is reasonable to base our model on a subpopulation of 100,000 commuters who will traverse the borders daily. Assuming a daily chance of infection between 1 in 10,000 to 1 in 1,000,000, a daily commuting population of 100,000 and 500,000 workers results in relatively small numbers of potentially infectious individuals across the border daily, many of which are crossing daily (Table 2). Realistically, as countries are likely to reopen only when incidence rates decline to low levels (e.g., below 1 in 100,000), the expected number of infected individuals allowed across the border per 100,000 workers is relatively small.

3.2 Periodic Testing of Daily Commuters Reduces the Number of Asymptomatic Infected Individuals Crossing the Border Daily

The model is based on 100,000 daily cross-border commuters with a disease incidence rate in both countries of 1 in 100,000 under a no testing, 21-day / 14-day / 7-day periodic testing. Figure 3A shows the average number of infected individuals crossing the border daily across 20 days under different regimes. Figure 3B illustrates the percentage of daily infected individuals crossing detected by qRT-PCR and quarantined compared to no testing. Figure 3C further depicts the effect of different efficiency of spotting symptoms daily on the daily undetected numbers across different testing regimes.

As expected, the more often the population is tested, the fewer infected individuals are allowed through daily (Figure 3A). Not unexpectedly, if we can detect symptoms with 100% efficiency, symptomatic individuals are removed primarily by the onset of symptoms and periodic testing primary functions to remove asymptomatic individuals (Figures 3A and 3B). As a follow-up to that, even if the identification of symptoms is not efficient (e.g. 30% and 50%), symptomatic individuals are still primarily removed by the appearance of symptoms (Figure 3C) and the function of periodic testing remains to identify asymptomatic individuals.

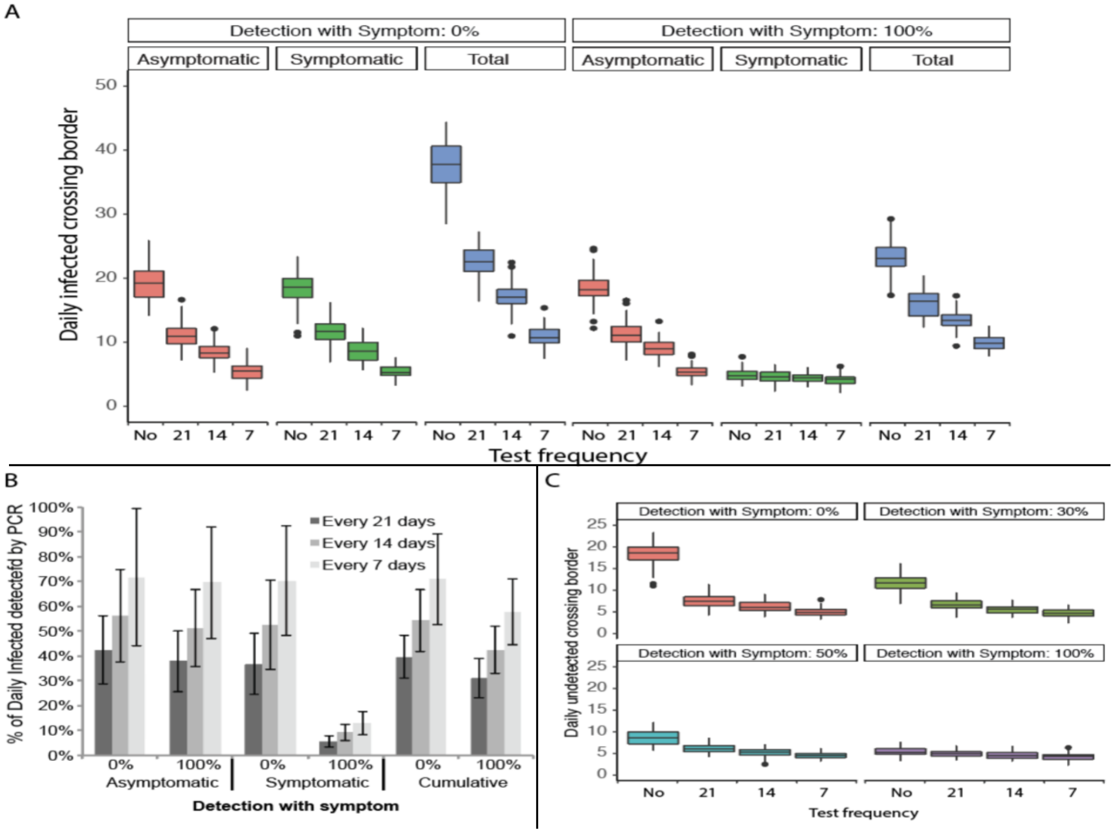

Figure 3: Projected number of positive individuals crossing the border daily under different incidence levels (Average of last 20 days). The model is based on 100 000 daily cross-border commuters with a disease incidence rate in both territories of 1 in 100 000 under a no testing, 21-day / 14-day / 7-day periodic testing. **A,** average number of infected individuals crossing the border daily across 20 days under different regimes. **B,** the percentage of daily infected individuals crossing detected by qRT-PCR and quarantined compared to no testing. **C,** the effect of different efficiency of spotting symptoms daily on the daily undetected numbers across different testing regimes. The results are based on 50 runs of each scenario using agent-based modeling. Error bars reflect standard deviation.

3.3 Pre-Symptomatic Transmission of SARS-COV-2 Reduces the Effectiveness of Periodic Testing in Preventing onward Transmissions

The model is based on 100,000 daily cross-border commuters with a disease incidence rate in both countries of 1 in 100,000 under a no testing, 21-day / 14-day / 7-day periodic testing. Figure 4A shows the results of the total number of the next-generation infections seeded by cross-border commuters in 28 days (1 month) under different testing regimes with different efficiency of detection based on the onset of symptoms assuming Rt is 2.5 and asymptomatic carriers are 5% or 50% as infectious as symptomatic individuals. Figure 4B shows the percentage of the next-generation infections averted if infected individuals are detected and quarantined under the different testing regimes with different efficiency of detection based on the onset of symptoms. Figure 3C highlights the effect of different Rt values on the next-generation infections in a month across different testing regimes with 30% efficiency at spotting symptoms and asymptomatic 50% as infectious as symptomatic individuals. The results are based on 50 runs of each scenario from the agent-based model.

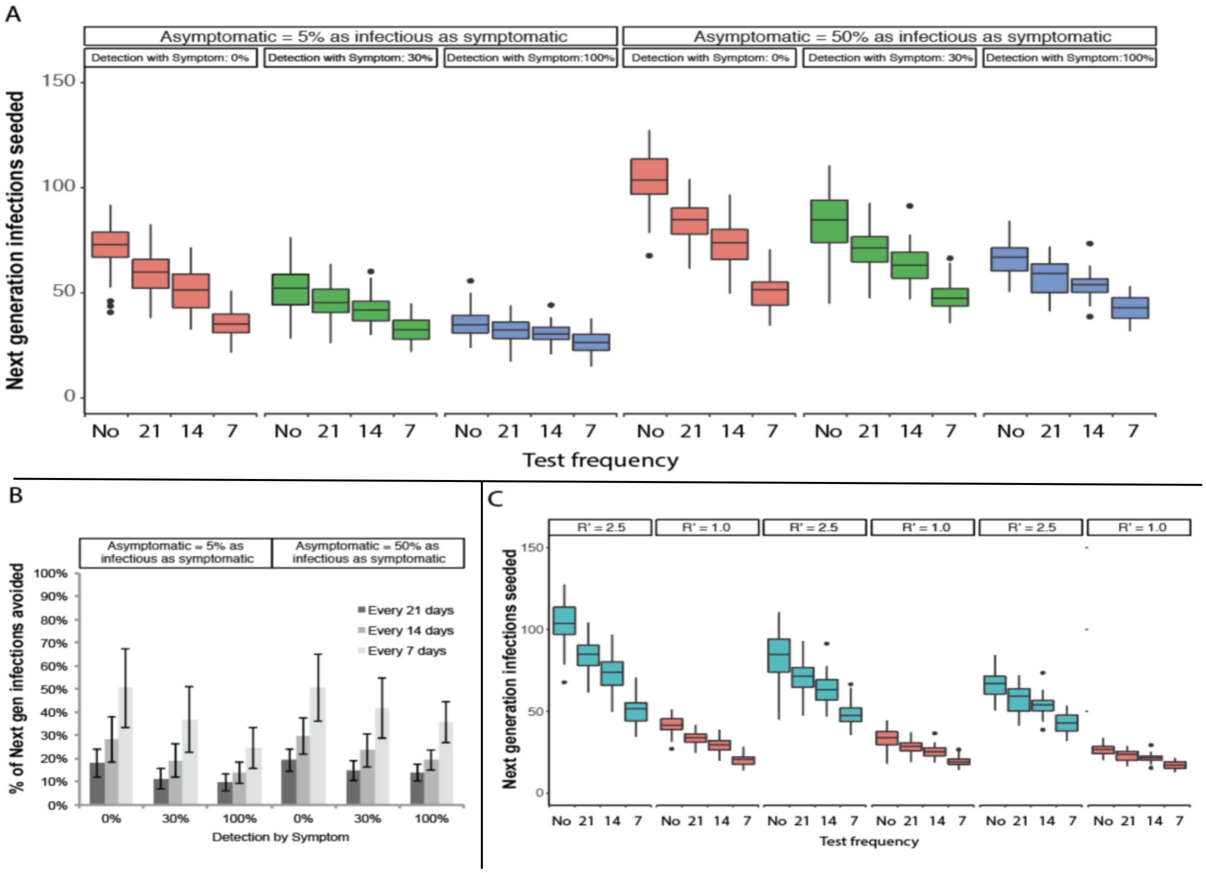

Figure 4: Next-generation infection in the community transmitted by the cross-border infected individuals. The model is based on 100 000 daily cross-border commuters with a disease incidence rate in both territories of one in 100 000 under a no testing, 21-day / 14-day / 7-day periodic testing. **A,** total number of next-generation infections seeded by cross-border commuters in 28 days (1 month) under different testing regimes with different efficiency of detection based on the onset of symptoms assuming R_t is 2.5 and asymptomatic carriers are 5% or 50% as infectious as symptomatic individuals. **B,** percentage of next-generation infections averted if infected individuals are detected and quarantined under the different testing regimes with different efficiency of detection based on the onset of symptoms. **C,** the effect of different R_t values on next-generation infections in a month across different testing regimes with 30% efficiency at spotting symptoms and asymptomatic 50% as infectious as symptomatic individuals. The results are based on 50 runs of each scenario using agent-based modeling. Error bars reflect standard deviation.

Given the effectiveness of periodic testing and symptom surveillance at identifying and quarantining asymptomatic and symptomatic individuals, respectively, we explored if the measures could effectively reduce community transmission of COVID-19. Using the assumed transmissibility distribution, we find that these measures do not seem to reduce community spread by more than 50% (Figures 4A and 4B). However, more frequent screening (e.g., every seven days) can prevent more onward transmissions. This percentage reduction does not change much whether we consider asymptomatic to be 5% or 50% as infectious as symptomatic individuals. When we assume that asymptomatic individuals are almost non-infectious (at 5% of symptomatic individuals), the symptoms surveillance system that is 30% effective at detecting symptomatic individuals can avert about a third of the next-generation infections. This is a little more efficient than less frequent testing (e.g., every 14 days). However, in almost all testing scenarios, the model suggests that periodic testing alone does not prevent the seeding of the majority of next-generation infections, which is predominantly an effect of the short but infectious pre-symptomatic phase that is responsible for the majority of the next-generation of infections. Unless there is a daily testing regime, effective onward transmissions by both symptomatic and asymptomatic individuals are almost unavoidable.

What may be more effective in preventing next-generation infection are strategies to reduce the effective reproduction number, Rt, through the combination of control measures such as mask-wearing, social distancing, and contact tracing. In our model, if we managed to reduce Rt to 1 through these measures, we could mitigate community transmission more effectively than periodic screening (Figure 4C).

3.4 Mask Wearing and Social Distancing More Cost-Effective at Reducing Community Infection by Cross-Border Sources than Periodic Testing

The estimated cost (Table 3) of removing each next-generation infection every 28 days (1 month) as calculated by the cost of screening 100,000 individuals every 7, 14, and 21 days assuming \$20 per test over the amount next-generation infection per month assuming 30% efficiency at detecting symptoms per day and asymptomatic individuals being 50% as infectious as symptomatic individuals. The costs are computed using the agent-based model for the 1/100,000 incidence scenario and scaled to different incidence rates. For comparison, we also calculated the effect of masks and hand sanitizers, assuming the cost of \$20 per month and the ability to lower R’ from 2.5 to 1.0, as suggested by Stutt et al. (2020) in their study of the effectiveness of facemasks in combination with lockdown for managing the COVID-19 pandemic.

We calculated the cost per next-generation infection averted. The ‘gold standard’ nasopharyngeal swab qRT-PCR tests cost between \$20 – 400 USD per test. As seen in Table 3, as incidence drops, the cost of next-generation infection avoided per month increases as the number of positive cases decreases. Assuming an upper estimate of incidence rate (1/100,000) that will allow for border reopening, the cost of avoiding each next-generation infection is prohibitive at approximately \$270,000 per case even when the model uses the lower bound of the test cost. When we assume the upper bound of \$200 per test, the costs would be tenfold higher.

In comparison, if one could hand out reusable masks and hand sanitizers once a week, estimated at \$20 per individual per week, while promoting social distancing, the cost of avoiding each next-generation infection comes down tremendously. The wearing of masks has been modeled and shown in the model to reduce R’ from 2.2 to 1.0 (Stutt et al. 2020). It may thus be more cost-effective to promote social distancing and mask-wearing than proactive testing.

Table 3: Cost efficiency of testing.

Cost per next-generation infection avoided per month ($,000) assuming tests are $20 (low end)						
Incidence	1/25k		1/100k		1/250k	
AS = 50% S	R' = 2.5	R' = 1.0	R' = 2.5	R' = 1.0	R' = 2.5	R' = 1.0
Every 21 days	67	168	270	673	674	1,683
Every 14 days	71	176	282	705	706	1,764
Every 7 days	62	154	247	616	616	1,541

Cost per next-generation infection avoided per month ($,000) assuming $20 per month for masks and hand sanitizer			
Incidence	1/25k	1/100k	1/250k
Cost	21	42	206

4 DISCUSSION

COVID-19 testing regimes and surveillance rates differ across borders. Many governments are reluctant to permit cross-border travel, fearing that such travels would jeopardize their efforts to contain COVID-19 (Gostic et al. 2020, Quilty et al. 2020). Some countries are rapidly ramping up COVID-19 testing capacity to reduce the delay in detecting and treating infected individuals. To evaluate the effectiveness of different testing frequencies (once every 7, 14, or 21 days) in averting infection from daily cross-border travels, we developed an agent-based model of the transnational commuting population. In the model, we accounted for the existence of surveillance systems at border crossings.

Mathematical models can help guide decisions in this pandemic (Gostic et al. 2020, Paltiel et al. 2020); they can be used to inform control measures that might allow for the safer reopening of border crossings. We simulated the daily movement of cross-border workers to investigate the effectiveness of the different testing frequencies. Our model accounted for the risk of pre-symptomatic and asymptomatic transmission of COVID-19 at varying levels of COVID-19 incidence. Reopening the borders to regions with low incidence rates resulted in a small number of infected commuters. We also found that periodic testing of transnational commuters reduces the number of asymptomatic infected individuals crossing the border daily. However, the pre-symptomatic transmission of SARS-COV-2 reduces the effectiveness of periodic testing in preventing onward transmissions. A study by Paltiel et al. suggests that periodic screening every two days is required for the safe reopening of college campus12. This corroborates our finding that periodic screening only every 7, 14, or 21 days is insufficient to reduce the transmission of COVID-19.

One of the primary rationales we considered for not testing more frequently is the limited capacity of testing. Large-scale testing brings about operational challenges, as swabbing requires the involvement of trained professionals (CDC 2020), a scarce resource during a pandemic. The other practical limitation is that daily commutes for work would presumably be clustered around morning and evening peak periods in which the surge in numbers would result in delays at border crossings, unpalatable queues and possibly gatherings of individuals at checkpoints.

The capacity to screen more often may improve with the availability of self-administered swabs, although the comparative efficiency of self-swabbing may result in lower sensitivity (McCulloch et al. 2020). Because the livelihoods of these daily commuters may depend on them testing negative, self-swabbing may not be feasible without adequate supervision. The collection of oral fluids may help (Kojima et al. 2020), but there is still debate on the sensitivity of oral fluids for the detection of SARS-CoV-2.

In our model, we assume that a qRT-PCR-positive test will lead to isolation until virus clearance. However, qRT-PCR positivity does not necessarily indicate that an individual is infectious. Results have shown that infectious virus could not be cultured from patients after eight days of symptoms (Wolfel et al. 2020) and high Ct individuals are likely to carry viral fragments rather than intact virus (Hu et al. 2020). Furthermore, prolonged shedding of viral fragments even after full recovery of COVID-19 patients had been observed. The discrepancy between the reduction in the daily infected number and the decline in community infection can largely be attributed to the fact that a considerable proportion of the infected identified by testing are already late in their infection and will not contribute much to the transmission of Covid-19. The persistence of SARS-CoV-2 that results in positive COVID-19 tests long after the infectious phase suggests that the benefits of periodic testing of a cross-border population are not limited to mitigate the spread of the virus. Periodic testing also enables both regions to objectively measure the incidence rate of the disease among the daily commuters and thus build confidence in better calibrating their opening strategies against potential risks of overwhelming their healthcare systems.

The high costs of testing are a major consideration. Even with the lowest cost estimates, periodic testing of border-crossing daily commuters appears to be prohibitively expensive (Dai et al. 2020). Other mitigation measures like safe distancing and mask-wearing are likely to be more cost-effective than testing. Cost-effectiveness analyses would be needed to identify the circumstances for which periodic testing is cost-effective and feasible.

In this study, we did not consider the use of periodic serological testing for immunity passports (Phelan 2020), which could be useful as serological tests get more sensitive, more specific, and cheaper. In populations with high immunity, infrequent serological tests coupled with periodic qRT-PCR tests could be administered to build the public's and governments' confidence in border reopening. However, ongoing research has revealed that immunity against COVID-19 may not be long-term and varies to large extents across the same population.

5 CONCLUSION

In this study, we examined how the periodic screening of daily cross-border commuters across territories with relatively low COVID-19 incidence will impact the transmission of SARS-CoV-2 across borders using agent-based simulation. The models can help guide decisions in this pandemic and can be used to inform cost-effective control measures that might allow for the safer reopening of border crossings. We find that periodic testing at practical frequencies of once every 7, 14 or 21 days would reduce the number of infected individuals crossing the border. The unique transmission characteristics of SARS-CoV-2 suggest that periodic testing of populations with low incidence is of limited use in reducing cross-border transmission and is not as cost-effective as other mitigation measures for preventing transmission.

The next logical extension of this study would be to investigate leisure and business travels across borders. The key question this investigation poses for public health officials would be the length of quarantine and frequency of testing pre-departure and post-arrival. However, other control measures, e.g. mask-wearing, social distancing, and contact tracing, that lower the potential for transmission will continue to be more cost-effective and important for the gradual reopening of the border and relaxation of quarantine rules compared with a more frequent testing regime. The projected impact of the periodic testing is sensitive to the region-specific COVID-19 incidence rates, and the frequency of test schedules; regular screening (every 7-days) in the absence of other public health measures would be insufficient to mitigate the onward transmission of SARS-CoV-2. Regular testing may also serve to help countries build confidence in reported incidence rates across borders and facilitate gradual increases in border opening.

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APPENDICES

Table S-1. Daily crossings across five selected borders.

Area	Border	Land checkpoint	Daily total cross-border crossings (nearest 1 000)	Source(s)
East Asia	Singapore–Malaysia	*Johor–Singapore Causeway* and *Malaysia–Singapore Second Link*	390 000	Estimated from [1] ICA Annual Statistics, and statistics from [2] Chang Airport Website, Passenger Movements, [3] Singapore Cruise Centre
	Macau–Zhuhai	Gongbei	357 000	[1] 2019 Yearbook of Statistics, Government of Macao Special Administrative Region Statistics and Census Service [2] Government of Macao S.A.R., Public Security Police Force Newsletter Vol 95, 2014
	Hong Kong–Shenzhen	*Hung Hom*	11 000	[1] Hong Kong Immigration Annual Report 2017 - Appendices 7 and 9 [2] Jianfa Shen (2003) Cross-border connection between Hong Kong and mainland china under 'two systems' before and beyond 1997, Geografiska Annaler: Series B, Human Geography, 85:1, 1-17, DOI: 10.1111/1468-0467.00127
		Lo Wu	224 000	
		Lok Ma Chau Spur Line	163 000	
		Lok Ma Chau	102 000	
		Man Kam To	16 000	
		Sha Tau Kok	11 000	
		Shenzhen Bay	124 000	
		Total	651 000	
United States of America (US)	US–Canada	84 checkpoints	294 000	[1] US Bureau of Transportation Statistics, average numbers over the period of 2014-2019, Inbound numbers were doubled to account for outbound numbers (not collected by U.S. Customs and Border Protection)
	US–Mexico	27 checkpoints	1 026 000	