***Respons-ableSG*: Strategy to Implement a Nation-wide Fuse System**

Introducing an Adaptive Scoring System to the Standard SIR Model

Introduction

1. This note aims to address how we might reopen and sustain the economy amidst a prevalent infectious disease. There are two main value propositions. First, we will enhance existing GovTech apps to introduce an agent-based *Respons-ableSG* (*R-SG*) score. This will enable us to (1) be more targeted with our measures and resources, (2) engender collective responsibility, and (3) move ahead of the infection curve with the possibility of targeting asymptomatic patients and extending quarantine orders beyond the first contact. There are limitations on accuracy and trade-offs which will be discussed. Second, we developed an approach to operationalise the relationship between the risk of infection and the economy. To do this, we used the infection rate of acute respiratory infections as a baseline pre-COVID-19 proxy in a standard SIR model and designed the optimisation problem with a version of the *R-SG* score for businesses and the estimated quarter-on-quarter GDP impact. As we do not have official firm-level data to work with and without a trial implementation of the *R-SG* score, we used randomised variables as a proof of concept to show that specific interventions for businesses, venues and schools are possible. Taken together, these tools will put us in good stead to selectively reopen parts of the economy and implement a nation-wide fuse system that will allow us to act ahead of time in our containment efforts against the virus.

Key Drivers to Keep the Economy Open

2. We identified three key drivers that will affect our ability to cope and articulated the associated challenges which this initiative will address.

3. <u>Contact Tracing, Testing and Healthcare Capacity</u>. We need to detect and isolate potential cases quickly. Our healthcare facilities must be able to comfortably cope with demand. We have largely demonstrated capacity in these areas. *The key challenge now is to cast a wider net to detect cases that are under-the-radar (pre-symptomatic and asymptomatic cases) but we must also do so sustainably.*

4. <u>Individual Behaviour</u>. Social distancing and hygiene habits at the individual level is vital in preventing large clusters from forming. *At the macro-level, this is difficult to observe and measure for the purpose of informing policy.*

5. <u>Confidence in Safety Measures</u>. Consumers and businesses must be cautiously optimistic that they will not catch the virus for our people to participate in the economy. Aggregated information to the public has been reliable and timely. *As we reopen the economy, our people can be further empowered with individual and context-based risk indicators.*

Respons-ableSG Concept Proposal

6. <u>Central Idea</u>. Social distancing and, at the higher-end, Circuit Breaker (CB) measures, are blunt instruments that have a significant impact on the economy. However, it remains an effective tenet as shown by the downward trend in local community spread after the CB began. We must find a balance and apply distancing/isolation in a targeted manner just as we have done

in our tracing and testing efforts. By extension, that balance exists with being targeted in our understanding and implementation of social distancing in businesses and venues where each will affect the economy in their own way. This requires us to assess social distancing as a spectrum from pre-COVID normalcy to lockdown-levels and to do so at the micro-level with corresponding data on their contribution to the economy. We can then afford to be targeted when specific sectors of the economy trigger a "fuse" for government intervention. This part of the paper introduces the concept of the proposal and leaves the technical aspects to the Methodology section.

7. Product. Suppose as an extension of TraceTogether (or other localisation methods), we have an app on our phone that provides a metric on the probability of being infected based on our last few encounters. With each new contact, our phone updates the estimate and provides the aggregated score. Encounters will be entirely anonymous and only the aggregated score will be used for interventions to close businesses or venues. The metadata of time and scores from each person's visit to the workplace/venue can be consolidated with SafeEntry (or other check-in/out methods) and the net increase in *R-SG* score after leaving the venue gives us a sense of the actual levels of social distancing happening in specific areas. Like traffic information from Google, users will be able to check the real time risk assessment at their destination as well as a forecasted time-slice of how that risk factor changes over the day. They are empowered to make decisions to assess if that trip is needed or adjust the timing of their trips to safeguard their family especially if they have vulnerable members in their household. Furthermore, users will have access to their own scores so that they can self-consciously make amendments to social distancing habits and motivate more frequent hand wash. The following are specific features that will increase the utility of the risk score.

a. *Respons-ableSG* Trickle-down Effect. Each contact does not uniformly increase one's risk score as it depends on the *R-SG* score of the contact. If a person is confirmed to be having or have had the virus, MOH will have access to the history of location (SafeEntry) and contact data (TraceTogether) of the confirmed case for the purpose of updating risk scores of first contacts and past venues visited by the confirmed case during the infectious period. This will have a trickle-down effect on the *R-SG* score for secondary and subsequent contacts.

b. Medical/Self-Assessment Updates. There are similarities between the symptoms of COVID-19 and common upper respiratory tract ailments. Statistically, this means that contacts with symptoms should have higher risk scores. This can be updated in the app through daily self-assessment or by a medical professional.

c. Enhance Incentives for Individual Responsibility. The transparency of *R-SG* scores provides awareness for individuals to prevent themselves from being infected and to prevent themselves from infecting others. To spur this further, we may include gamification and rewards for keeping within certain *R-SG* score brackets after adjusting for household close contacts and the workplaces for essential workers. See Figure 1 for a mock-up interface. Without qualifying in this paper, the introduction of this feature should be considered only after an initial deployment so that we can narrow-down the target audience and avoid crowding out the noble effort of the majority who are already inherently motivated to uphold individual responsibility. It is more important that

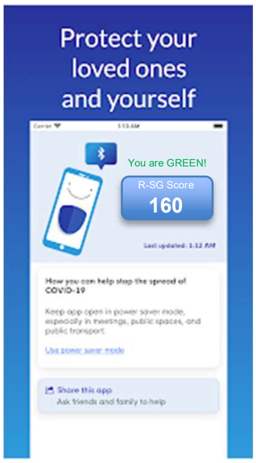

Figure 1: Adapted from TraceTogether.

the *Respons-ableSG* serves as a reminder. This includes the option to turn on notifications or vibrations whenever in close contact with another person.

d. <u>Acting Swiftly when a Critical Threshold is Reached</u>. Our current response is to isolate first contacts of confirmed cases. In theory, we should be able to quantify the *R-SG* score of confirmed cases and implement it as a benchmark that will act as a no-worse off critical threshold for individual *R-SG* scores that exceed this regardless of their degree of contact. This will give us a reasonable level of assurance that we will be able to sieve out some of the under-the-radar cases. We will attempt to prove this with mathematics subsequently.

8. <u>Assess Firm-level Cost-to-Risk Ratio</u>. With each SafeEntry check-in we can aggregate the *R-SG* score at the employer-level to make an informed decision on the cost-to-risk for each firm. <u>Figure 2</u> shows a random scatterplot of firms containing information on their economic contribution and *R-SG* score. We will require firm-level data through the first quarter of 2020 from MTI to gauge economic contribution and make a heuristic initial assessment on the firm-level *R-SG* scores based on certain characteristics such as the industry type, sedentary versus non-sedentary, number of employees, etc. We will expand the list of characteristics according to the number of variables and granularity from available data.

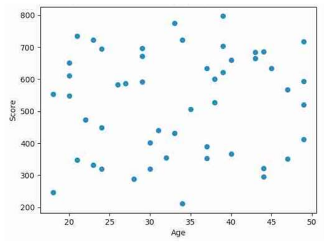

Figure 2: Sample scatterplot of firms with axes risk (y) against economic contribution (x)

9. <u>Optimisation for Selection of Firms</u>. Healthcare risks and economic considerations fundamentally exist on different value planes. To establish their relationship, we explored the following two options.

a. <u>Option 1: Cost Equilibrium Approach</u>. The first option quantifies healthcare risks in economic terms based on the cost of healthcare and loss of income. We then include these costs in the production function and maximise economic production. At the equilibrium, we will then select the firms that satisfy the condition.

b. <u>Option 2: Pre-Covid-19 Proxy Approach</u>. The second option attempts to establish a link between healthcare and economy using pre-COVID-19 precedence. To this end, we will use the hospitalisation rate of upper respiratory tract ailments[1] before COVID-19 as a baseline. If our selection of firms result in a predicted rise in hospitalisation rates that exceed the baseline, our programme must automatically "trigger specific fuses" where a recommendation of businesses or venues are flagged out for intervention - either through assistance to help with operationalising safe distancing measures or through shutting down the workplace/venue entirely. The recommendations will be based on a selection of firms that should remain open such that the economic production is maximised, but risk of contracting COVID-19 is below the threshold. We will also consider using the fatality rate pre-COVID-19 as a proxy instead of hospitalisation rates as pre-COVID-19 is known to have an approximate mortality that is

[1] We look at this specific set of ailments because they are human-to-human transmissions compared to other communicable diseases like dengue which follow a different vector.

30 times[2] that of the common flu. Between these two rates, we should take the more conservative approach. As the number of Recovered/Immune population increases (due later deployment of vaccines), the risk of infection will reduce, and we will eventually reach the state of pre-COVID-19 normalcy where all firms are open.

10. Analysis. The pre-COVID-19 proxy approach is recommended as it will put less strain on the healthcare system giving us good margins for uncertainty. It will also mean that we will be operating further from the normal production levels. However, if the *Respons-ableSG* implementation can shape our collective behaviour in combating the virus (thus bringing down risk levels), we will be able to make Pareto improvements in the economy gradually. Besides the optimisation approach, as a system, because we can be deft with our automatic implementation of fuses surgically across the economy, we will be able to respond more robustly against unanticipated mutations of the virus.

Methodology

11. This part of the paper presents a simple implementation of *R-SG* and parameters for specific components in the model. We will elaborate on the *R-SG* scoring system and touch briefly on the SIR model which is widely used[3] in the literature. We will leave discussion on the limitations and way ahead in the next section.

12. Definition of Close Contact. We use MOH's definition of a close contact to model, c, the proportion of contacts in a person's social network - sustained contact within 2 metres and for 30 minutes or more. It is however useful to explore, within the limitations of the accuracy of the localisation method, whether we could adjust the scoring system to measure social distancing as a continuous variable where we parametrise the probability of disease transmission, $\boldsymbol{\tau}$, of the close contact definition using the number of confirmed cases from first contact tracing and then trawl the current TraceTogether records to create a distribution of probabilities across a spectrum of time (e.g. 0 to 30 mins) and distance (e.g. 1m to 3m). See Figure 3 for a sample probability distribution heat map assuming normal distribution. This distribution is in turn constantly updated as we obtain more data.

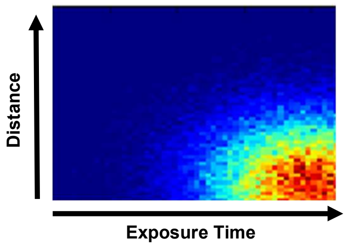

Figure 3: Sample probability distribution of the probability of disease transmission in a continuous interpretation of contacts

13. Estimating the Epidemic Threshold. At the core, the *R-SG* score can be translated to a population-wide estimate of the epidemic threshold, β, where we determine the average number of contacts per person per time unit, multiplied by the probability of disease transmission in a contact between the Susceptible and Infectious compartments of a standard SIR model. The following equations shows a breakdown of the variable at the individual level β_i, business level β_b and national level β_N where N is the total population and N_b is the total number of employees in a firm b based on MOM records. We can switch out the notations accordingly for βestimations of public venues, restaurants, and schools to evaluate policy options. Each aggregation of β only

[2] WHO (2020), "Influenza and COVID-19 - similarities and differences", updated 17 Mar 2020, https://www.who.int/emergencies/diseases/novel-coronavirus-2019/question-and-answers-hub/q-a-detail/q-a-similarities-and-differences-covid-19-and-influenza
[3] Koo J, et al. (2020), "Interventions to mitigate early spread of SARS-CoV-2 in Singapore: a modelling study", Lancelet: Infectious Diseases, 23 Mar 2020

records up to 6 days[4] which is the current estimated virus incubation period.

$$\beta_i = \sum_{j=1}^{c} \beta_j \tau \qquad \beta_N = \frac{\sum_{i=1}^{N} \beta_i \tau}{N} \qquad \beta_b = \frac{\sum_{i=1}^{Nb} \beta_i \tau}{N_b}, \text{ for employee } i \text{ in firm } b$$

14. <u>Objective Function for the Pre-COVID-19 Proxy Approach</u>. For each firm b, we will have to tap on MTI firm-level data for pre-COVID-19 economic production contribution[5] of the firm $y_b$and apply a 10.6% quarter-on-quarter contraction[6] (uniformly if data is not available). We will maximise total economic production $Y$with respect to a selection of firms $\{X_{y_b,\beta_b}\}$ subject to the inequality of constraint of ensuring β_N is no worse off than the Pre-COVID-19 threshold proxy for upper respiratory tract ailments β_ρ. See objective function below. With information on Singapore's hospitalisation/fatality rate[7] for common upper respiratory tract ailments last year[8] we will parameterise $\beta_\rho$using the standard SIR model to reach the same peak prediction. As it could get computationally laborious with a comprehensive firm-level database, we included a draft of a possible optimisation algorithm implementation with a sample dataset in <u>Annex A</u> and attached *opt_firms.py* in our submission.

$$max\left(Y = \sum_{b=1}^{B} \{X_{y_b,\beta_b}\}\right) \text{ subject to } \beta_N \leq \beta_\rho$$

15. <u>Initial Estimation Methodology with Incomplete Information</u>. In the concept section, we mentioned using a heuristic initial assessment on the firm-level epidemic threshold, β_b. We will run the objective function using our initial assessment numbers and rank-order the selected firms in accordance to those with the lowest β_b in $\{X_{y_b,\beta_b}\}$and gradually open up firms in that order. As we do so, we will also start receiving actual $\beta_b$data and give us manoeuvre space to adjust our plans if there are unanticipated interactions (we will discuss more of this in the next section).

16. <u>Capturing the Second Degree Under-the-Radar Cases</u>. With the *R-SG* implementation we mentioned that it is possible to identify under-the-radar cases with reasonable confidence. Mathematically, the probability of disease transmission for a first contact, second contact and a case that is a double second degree contact to be infected is given by the following equations.

Pr(First Contact Infected) = $\tau(1 + \sum_{j=1}^{c-1} \beta_j)$, assuming $\beta$is constant, we have $\tau + \tau\beta(c-1)$
Pr(Second Contact Infected) = $\tau + 2\tau\beta(c-2)$
Pr(Second Contact Infected | Link to another First Contact) = $2\tau + 3\tau\beta c - 4\tau\beta$

If we set the critical threshold for the *R-SG* score of any individual to be flagged out for testing at a score similar to the first contact regardless of any known links, we are essentially solving for the

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[4] WHO (2020), "Coronavirus Disease 2019 (COVID-19)", updated 17 Apr 2020, https://www.who.int/emergencies/diseases/novel-coronavirus-2019/question-and-answers-hub/q-a-detail/q-a-coronaviruses
[5] From the 2019 singstat.gov infographic, Business Services (14.8%), Manufacturing (20.9%), Construction (3.7%) and Retail (17.3%) with the remaining percentages mostly operational during the CB measures.
[6] Channel News Asia (2020), "Singapore's economy contracts by 2.2% in Q1 as COVID-19 outbreak hits construction, services sectors", updated 26 Mar 2020, https://www.channelnewsasia.com/news/business/singapore-gdp-growth-slows-advance-estimate-covid-19-12577146
[7] Interestingly, with the CB measures, the number of cases of upper respiratory ailments have decreased to less than 700 visits to polyclinics per day after new norms and CB measures are in place. This is compared to the usual 2019 baseline of 2500-3000 visits per day.
[8] Straits Times (2020), "Coronavirus: Doctors see huge drop in flu, common cold, diarrhoea and conjunctivitis cases since circuit breaker measures", published 13 May 2020, https://www.straitstimes.com/singapore/health/coronavirus-doctors-see-huge-drop-in-flu-common-cold-diarrhoea-and-conjunctivitis

following inequality to find the conditions where an unknown second degree under-the-radar case would remain undetected.

$$2\tau + 3\tau\beta c - 4\tau\beta \leq \tau + \tau\beta(c-1)$$
$$c \leq \frac{3\beta - 1}{2\beta}$$

When $\lim_{\beta \to 0}$, c will tend to $-\infty$. $\lim_{\beta \to 0}$, c will tend to 1.5 where both solutions are not feasible because the worst under-the-radar case must have a minimum contact of 2 people. Hence we have reasonable confidence that, subject to the availability of testing for all first contact infected people, we will be able to capture a 100% of under-the-radar cases if we implement the *R-SG* score critical threshold no worse than what we will do for first contacts. This percentage capture will decrease if our testing capacity decreases and we only perform quarantine for first contacts.

Discussion on Limitations and Way Ahead

17. This part of the paper discusses some limitations to the above concept and the way ahead as we begin to design our detailed proposals to reopen the economy after lifting CB measures.

18. Accuracy of Contact Detection and Establishing Hardware Standards. The accuracy of the *R-SG* implementation is only as accurate as the localisation technologies used to record contacts on-board the device. There are also challenges regarding ownership of smartphones, battery drain and the lack of app adoption especially for the older generation which are also the more vulnerable. Even as Google and Apple continue to refine their app-to-hardware interface protocols, one separate track to mitigate this would be to source for a low-cost mass production Bluetooth enabled device which can be carried around by all Singaporeans. This is akin to the mass deployment of National Steps Challenge wristbands that was introduced in 2015 which also gained strong traction with the older generation.

19. Economic Impact of Closing Schools. Even though we mentioned that we could aggregate an *R-SG* score for each school using individual student and teacher *R-SG* scores, it is difficult to ascertain the economic impact of school closures because they drive our economy in the long term and the short term impact of productivity loss due to Work-from-Home (WFH) parents having to supervise Home-based Learning seemed intractable. The school *R-SG* scores after schools reopen are not for the design of policy to discriminate the closure of certain schools, short of the development of a cluster. Rather, school scores could be used for MOE to channel their resources on implementing more measures in specific schools which may, due inherent characteristics of venue size or class size, have greater deviation in risk scores.

20. Increase in Productivity over time for Companies that Gradually Adapt to WFH Practices. We have not addressed the learning and adaptability of firms in our study. The *R-SG* scoring for firms incentivises investment into remote collaboration technology and WFH practices to reduce the companies' overall risk score so that they can continue to sustain and remain open. For specific firms and retail/restaurant venues that require intervention, we are also able to target our resources to assist them with reducing risks in their daily operations and eventually explore if some of their functions can be shifted to a WFH mode.

21. Increase Accuracy and Policy Evaluation Options with More Complex ODE models. We should be able to partner academics in using existing more sophisticated SEIR models with network effects to model agent-based interaction more deeply. For example, the interaction of firm-level scoring and economic contribution where the opening of one but not the other does not necessarily bring it back to Pre-Covid-19 levels of economic contribution. Subject to existing datasets, a better estimator can be obtained if we use different regression techniques which we can employ (include interaction variables, run fixed effects, etc.)

22. Integration with Existing GovTech Apps. To avoid app fatigue, we should explore integrating the *R-SG* scoring system with existing GovTech apps like TraceTogether and SafeEntry. There is also synergy to integrate both apps as it could potentially save time for contact tracers. Our next steps are to gain access to a more comprehensive set of data and integrate a working implementation of the *Respons-ableSG* system with existing government app efforts and experiment this at scale with government officers prior to roll-out.

Conclusion

23. *Respons-ableSG* score can be treated like weight data, heart rate or step count. These are indicators that allow individuals to feel their own pulse and, in the case of this paper, also allow social planners and individuals to assess the pulse of certain venues. To move beyond the Circuit Breaker, we must invent adaptive measures that will allow us to react upstream - that means (1) being more specific and targeted on the specific sectors of the economy so that we can sustain after opening up, (2) being able to act before infection take place - act on the symptom which is the lessening of social distance, and (3) determine very conservatively the optimal point for sustainability whenever there are unanticipated clusters. What we are essentially proposing is to install specific fuses that allow us to contain the situation whenever there is an overcurrent, when social distancing rates deteriorate, we intervene with assistance to enforce or develop new measure so as to replace the fuse. We will need to do this if we want to combat the virus sustainably for the long haul.

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Respons-ableSG is a working title for this project to encapsulate a play of words – Responsive and Responsible. The opinions expressed in this paper are those of the author's alone and they do not reflect the opinions or views of the author's organisation or unit.

Annex A

Sample Code for the Selection of Firms based on the Pre-COVID-19 Proxy Approach

This implementation was written with Python 3.6; wall times could extend with larger datasets.

```
'''
Programme to determine list of firms which will maximise GDP
with an average r that will not exceed 1.0

Working Dataset
Firm A    0.6 R   30 GDP
Firm B    0.9 R    8 GDP
Firm C    1.1 R   79 GDP
Firm D    1.6 R   54 GDP
Firm E    0.3 R   17 GDP
'''

data = [('A',0.6,30),('B',0.9, 8),('C',1.1,79),
  ('D',1.6,54),('E',0.3,17)]

r_ne = 1.0

track = {}

for i in range(len(data)):
  r_total = data[i][1]
  firm_list = [data[i][0]]
  gdp_total = data[i][2]
  for n in range(len(data)):
      if data[n] == data[i]:
          continue
      r_total = r_total + data[n][1]
      r_avg = r_total / len(firm_list)
      gdp_total = gdp_total + data[n][2]
      if r_avg > r_ne:
          r_total = r_total - data[n][1]
          r_avg = r_total / len(firm_list)
          gdp_total = gdp_total - data[n][2]
          continue
      firm_list.append(data[n][0])
  track[gdp_total] = firm_list

tmax = max(list(track))
for obj in track[tmax]:
  print(f'Firm(s) {obj}')
print(f'Combined max GDP of {tmax}')
```