A Simulation Study of the Probability of Contracting SARS in a School Compound

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Abstract

The purpose of the project is to show the susceptibility of students and staff of Hwa Chong Junior College to contracting SARS in the school compound. This is done by simulating the spreading of infection in the school compound using a computer programme called Axon Idea Processor. The simulation is loosely based on existing infection models, but the results are different in that they show how the extent of infection is affected by the frequency of temperature checks (speediness of detection) and the degree and duration of contact between people in the school. In conclusion, the simulation results are useful for the planning and designing of schools in future, such that minimal spreading of viruses occur.

Introduction

This project is done using a knowledge of, among others, Operational Research, the human and architectural topology of the Hwa Chong Junior College compound, and the workings of the Simulator Tool in the Axon Idea Processor version 2005. (Axon Research, 2004)

The objective of this project is to show the susceptibility of students and staff in a typical school in Singapore to contracting a major disease, in this case, SARS (Severe Acute Respiratory Syndrome) in the school compound. In the past year, 2003, SARS had caused a great global uproar as it spreads quickly and could escape undetected in certain cases, thus becoming an imminent threat to the public.

SARS is a form of atypical pneumonia caused by a coronavirus, and it spreads among humans through airborne particles more than 5 μm in size, large pathogen-laden droplet infection, or close contact with infected persons. The virus is believed to have the resilience to survive out of the human body for a few hours. (Leung and Ooi, 2003) Therefore it is necessary to deem how much close contact an individual undergoes in the school compound and the quality of air in each distinct venue he visits, as these affect the speed of spreading directly.

Many SARS spreading models have been built to predict its spread in the country in wake of last year's outbreak, and many of the assumptions and aspects are reused in this simulation, however, some are not valid and have been omitted.

Firstly, the foundation for many of the SARS models and this simulation is the SEIR model. It consists of 4 general stages: Susceptible (able to contract the virus), Exposed (but not yet infective), Infective (has contracted the virus) and Removed (formerly infective cases that are taken out of the model because they are quarantined, have recovered or have died). (Lee, S. L. et al, 2003) The SIR model omits the Exposed stage as it is usually used in the case where the population of individuals is homogenous and they mix with each other uniformly. However, it fails to acknowledge that most diseases feature an incubation period that corresponds to the Exposed stage in the SEIR model. (Toft, Kristensen and J∅rgensen, 2001) As the environment for this simulation is very different as compared to the previous models, the SIR or SEIR structure has been modified extensively when applied to a school compound. 'S' and 'E' are incorporated into the infectious rates and thus do not need to be identified as separate processes. 'R' is redundant as the simulation ends before that stage is reached, that is, once a positive case has been discovered.

Some models are more complex with the introduction of branching. In the Ma and Lipsitch (2003) model, the SEIR structure is divided into sub-stages and a complicated web of functions links them together. For example, an infectious, undetected case can become infected and isolated, and die, or bypass the isolated sub-stage to reach the death stage, or recover. Brown and Lewin-Koh (2003) make use of the Galton-Watson branching process, where "parents" are individuals who have been infected and "offspring" are those that will be infected by the "parent". A chain effect results and the distribution of the "offspring" is analysed. In this project, branching is not utilised because the model is fairly simplistic, with a population whose interactions with the outside world are not taken into account since the project is not concerned with cases of infection outside of the school. Infected "offspring" are also not differentiated into sub-stages, excluding the classification of them into undiscovered cases, where they remain in the simulation until the routine temperature checks are conducted, or discovered cases (discovered to be a carrier by the same temperature checks), where they exit the simulation immediately.

The Simulation Model

In the Axon Simulator Tool, an entity that moves from node to node is known as a Packet. In the model (refer to Fig. 1), a Packet represents a person and the time unit is one hour. Only one Packet is created at the beginning of the simulation (at 'Create1'), signifying that initially one person is infected with SARS. The 'Init' node is to clear results of the previous simulation. An infected person goes through a period of incubation (in 'Incu') during which the person is not yet infectious. After that the person becomes contagious (in 'Contag'), and remains so until the disease is detected. The range of the average detection time is 6 hours to 48 hours, as this translates into temperature checks in a range of roughly every 12 hours to every 4 days, which is applicable in real life. A contagious person can infect another person with interval TBI ('Time Before Infection'). The TBI depends entirely on the degree of contact with other people in the school (which in turn depends on how enclosed and crowded the venue is), as well as the duration of contact (how long the person stays in that venue).

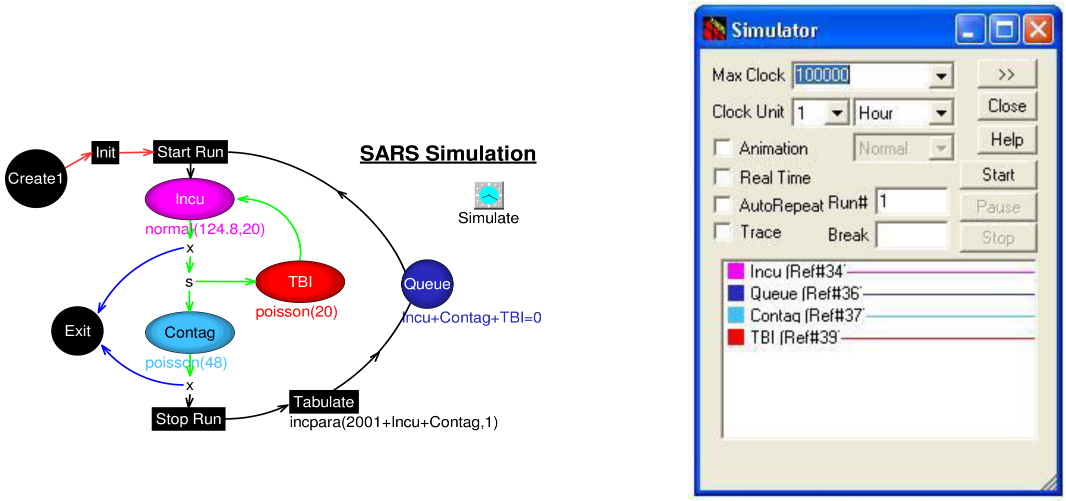

Fig. 1: The SARS Simulation Model built using the Axon Idea Processor.

A large number of runs are carried out during the simulated time of 100 000 hours for each TBI and 'Contag' value. The begging of a run is signaled by the 'Start Run', and the end of a run is signaled by 'Stop Run'. A run is stopped when the first SARS victim is detected. When a run is over, all Packets (except the one along the black path) are removed via the 'Exit' node. The purpose of the 'Queue' node is to ensure the completion of the removal before starting the next run. The simulation results, (i.e. the frequency of having 1, 2, 3 etc. infected persons when a run ends) are recorded by the 'Tabulate' node.

The following descriptions further explain the construction of the model:

Red link - Only one packet passes through during a simulation
Black links - Only one packet passes through during a run
Green links - Many packets pass through during a run
Blue links - Packets pass through only after the end of a run
Black nodes - No packet cumulates in these nodes.

The model essentially simulates 'Incu', 'Contag' and TBI as Random Variables. 'Incu' follows a Normal distribution with mean μ = 124.8 hours and standard deviation σ = 20 hours. The distribution is due to a random incubation period that each infected individual will have. The μ value is derived from the findings of other reports (Lipsitch et al, 2003; Lee, S. L. et al, 2003 and Lee, M. L. et al, 2003). All three agree on a value that is roughly 5.2 days. The value for σ is derived from the estimation by researchers that the incubation period of the virus is between 3 and 7 days (Leung, P. C. and Ooi, E. E., 2003). 95% or almost all cases would fall within 2σ, and the incubation period was taken to be 5 days with an error of about 2 days for almost all cases. Thus, σ was determined to be 20 hours to fit both the estimation and the value for the calculated mean.

TBI follows a Poisson distribution and its value is varied from 1 hour to 20 hours to reflect the range of the most likely duration before one student or staff infects another. Likewise, 'Contag' follows a Poisson distribution and its mean value is varied from 6 hours to 48 hours, translating into temperature checks in a range of every 12 hours to every 4 days.

Simulation Results

The simulated frequencies are collated in a spreadsheet and processed to derive the probabilities of 1, 2 or 3 people being infected at the time an infection is detected. The resultant data roughly follows the predicted trend of probability of infection decreasing with TBI values and also increasing with 'Contag' values. It initially increases for 1 infection, and later drops while the probability of 2 infections increase, and that of 2 infections drops when the probability of 3 infections increase and so on for the variations of both TBI and 'Contag'. The graphs of 1 and 2 infections, which have clear trends, are shown below in Fig. 2 and 3. However, either the 'Contag' values are too high or the TBI values are too low for the trend for 3 infections to be seen clearly. Almost all the time when 3 infections are detected, the 'Contag' value is above 24 hours, and so few detections occurred that a trend could not be easily deduced. In all cases, the probabilities of more than 3 infections are nil.

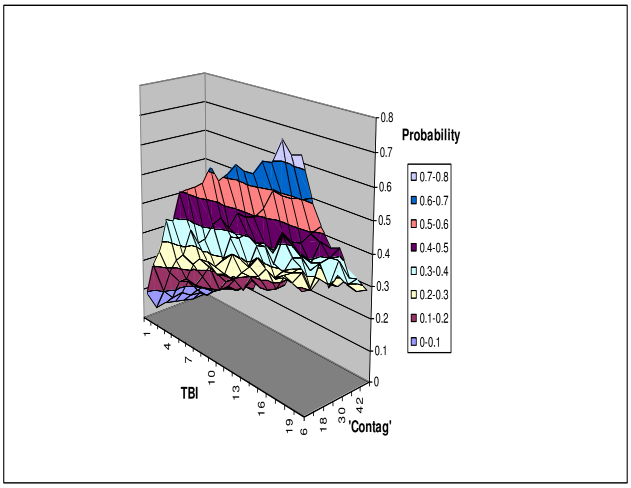

Fig. 2: Graph showing the probability of 1 infection for various TBI and 'Contag' values.

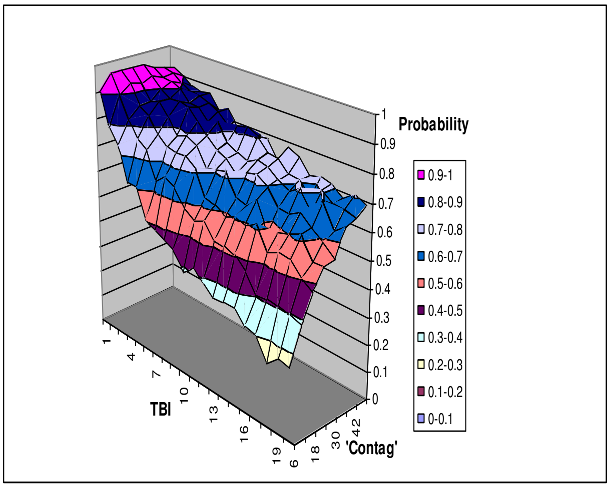

Fig. 3: Graph showing the probability of 2 infections for various TBI and 'Contag' values.

Discussion

Hwa Chong Junior College (see Fig. 4) has an air-conditioned library and six lecture theatres (inclusive of the auditorium), and both air-conditioned and non-air-conditioned classrooms. The Science laboratories, canteen, sports courts and first floor of both the right and left wing buildings, where the class benches are situated, are all non-air-conditioned. Of these places, the venues with larger open spaces are notably windy. Students spend most of their time in all the venues mentioned above, and it is estimated that they spend half the time in air-conditioned venues, which have regulated ventilation, and the other half in non-air-conditioned venues. The main staff room is air-conditioned, and teachers estimate they spend half their time there. Of the remaining half, half of it is spent in non-air-conditioned venues.

Ranges of TBI values are assigned to each type of venue depending on relative crowding and air quality. Air-conditioned venues have about half the TBI value of a non-air-conditioned venue with the same crowding. For non-air-conditioned classrooms, TBI can be estimated to be between 2 and 4 hours. Other venues can be assigned values using these classrooms as a standard for comparison. For locations outside of the school, the TBI value is infinite (in other words, rate of infection = 0) as infections of people other than Hwa Chong students and staff outside the school are ignored in this simulation. Thus, using the aggregate formula shown below, a student can have an average TBI value range of 4 to 6 hours, and a teacher would have a range of 3 to 5 hours.

$$1 / \text{Average TBI} = \sum_j \left(1 / \text{TBI}_j \times (\text{Probability of being in location } j) \right)$$

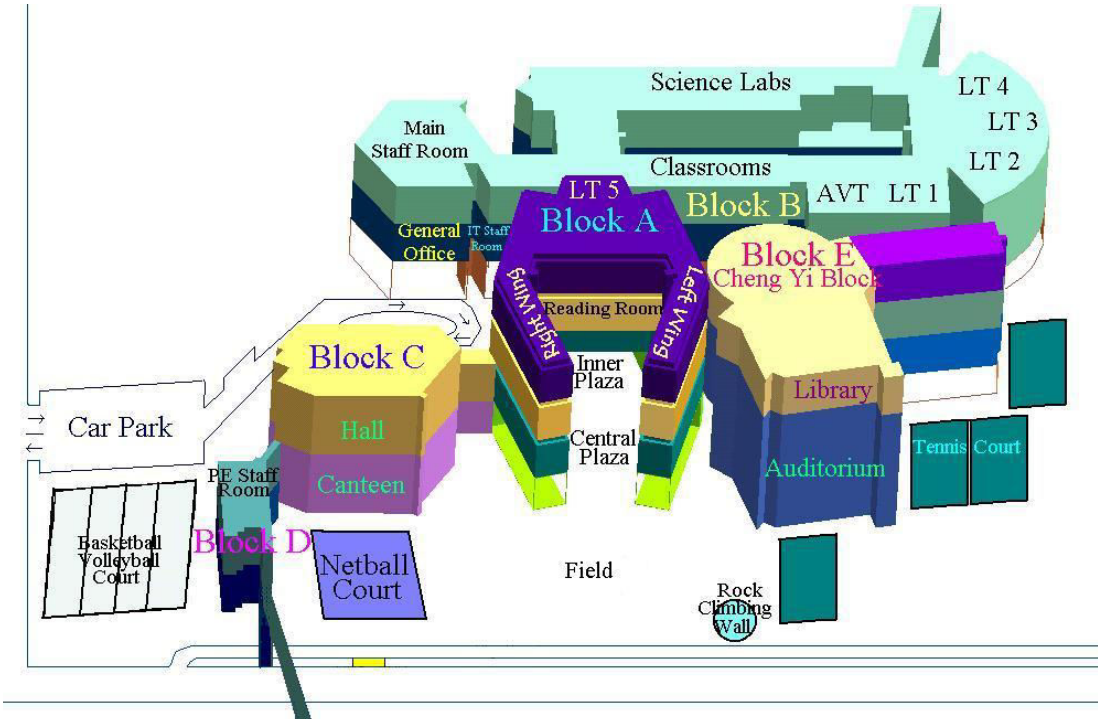

Fig. 4: Campus map of Hwa Chong Junior College. (Hwa Chong Junior College, 2004)

In Fig. 5, a graph of probability against TBI is plotted to show the relation between both values for 1 infection and 2 infections more clearly for a scenario where temperature checks are held approximately once a day. This is similar to what was implemented in 2003 in all Singapore schools, as although they were held twice, in the morning before lessons started and just before recess time, they were held only 2 to 3 hours apart. Thus they were almost as effective as having a little more than one temperature check per day. It is seen that the probability of 2 infections decreases when the probability of 1 infection increases, while there has yet to be an occurrence of 3 infections, and this confirms the prediction that the extent of infection decreases with an increase in TBI. Also, if temperature checks are to be held at the same regularity in future, it is necessary that the TBI value be increased, preferably to 15 hours and above, as the probability of 1 infection would then be higher than that of 2 infections. This can be done in various ways, just as long as the school topology is changed such that crowding of students and staff is avoided and the air circulation in the school compound is good enough to prevent the rapid spread of viruses.

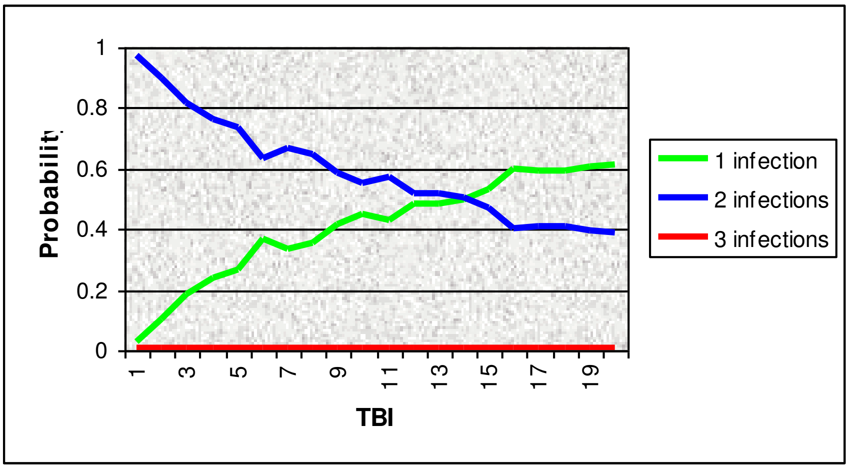

Fig. 5: Graph of probability against TBI when 'Contag' = 12 hours.

In conclusion, the school is a place where SARS and other diseases can spread fairly easily. This may be prevented if the school uses air-conditioners that cycle air more frequently, improves ventilation facilities, and implements measures to prevent SARS according to the government's guidelines. (Singapore Government, 2003) From the graphs in Fig. 2, 3 and 5, we can predict how the extent of infection is limited by TBI and 'Contag'. Changing timetables to allow students and staff to spend less time in air-conditioned venues should increase the former, while making temperature checks more frequent, preferably every 12 hours or less should reduce the latter. These findings should hopefully be of use in the design of schools in future.

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