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A SYSTEM DYNAMICS MODEL OF SINGAPORE HEALTHCARE AFFORDABILITY

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ABSTRACT

In many countries, healthcare expenditure has witnessed an accelerated pace of increase over the years. This has placed a strain on both public and private sectors to effectively mitigate the surmounting pressures of healthcare costs, affordability and accessibility. This paper looks into these issues within Singapore's healthcare system. The system dynamics simulation method has been used to elucidate complexities brought about by multiple interconnected subsystems and their complex relationships. Simulations have been carried out to understand how the different entities in the system influence healthcare affordability. For instance, this included observing how demand for hospital services affected the various critical hospital resources and their respective costs. Four different classes of policies have then been developed and subsequently tested for their effectiveness in improving healthcare affordability.

1 INTRODUCTION

National healthcare affordability is a topic of immense interest to both individuals and national policymakers. In many countries, healthcare expenditure over the past and recent years have witnessed an accelerated pace of increase. In the city state of Singapore, the Ministry of Health estimates that government healthcare expenditure per capita has been increased by more than 1.6 times (www.moh.gov.sg) from 2007 to 2009 alone. This is above the inflation of average Consumer Price Index of 1.07. If not effectively mitigated, the mounting pressures of healthcare costs, affordability and accessibility can have serious social and economic implications at the national level.

National healthcare problems are by nature systemic, complex and involve many interconnected subsystems. An accurate depiction of healthcare affordability requires adequate consideration of the healthcare demand subsystem, hospital resources acquisition subsystems, costing subsystems and their respective relationships. Changing a single part of the system without considering the impact it has on the rest of the system might bring forth unexpected or unintended consequences; hence, it makes the evaluation of policies challenging. In the face of growing uncertainties and increasing complexity associated with such large socio-technical systems, health and social care professionals need to use more systemic and systematic approaches to learn about these systems (Royston et al. 1999). In view of this, we adopt the system dynamics simulation method (Sterman 2004), which is a formal systems modeling approach, to study the healthcare affordability problem in Singapore.

The system dynamics method has been applied to issues of population health since the 1970s (Homer and Hirsch 2006). It has the ability to formalize the collaborative nature of public health practice while strengthening the scientific foundation and active policy focus that are the hallmarks of health protection

(Homer et al. 2004). Its purpose is not to forecast actual future values of the system, but rather to learn about the relative impacts of alternative assumptions and interventions (Homer, Jones and Seville 2006).

This provides a contrast to analytic approaches such as discrete event simulation and mathematical programming methods. Analytic approaches seek to reduce a system into its elementary elements in order to study in detail and understand the types of interaction that exist between them. De Rosnay (1997) adds that by modifying one variable at a time, it tries to infer general laws that will enable one to predict the properties of these elements under very different conditions. On the other hand, system dynamics does not wish to come up with accurate forecasts but to study behavior patterns over time. In the case of a healthcare system, the objective of the model is not to determine annual healthcare costs but to reveal under what conditions the total costs could get lower and to identify policies that could mitigate these costs.

System dynamics thus remains a popular modeling approach for studying various aspects of national healthcare issues such as emergency patient flow in emergency care systems (Milstein and Homer 2006) and healthcare for the aged (Ogawa, Chawla, and Matsukura 2009). General surveys and identified opportunities of system dynamics in healthcare can be found in (Homer and Hirsch 2006) and (Lecir 2006).

In this work, we develop a system dynamics simulation model in order to help policy-makers elucidate system complexities in healthcare affordability. Furthermore, the system dynamics model will be used to evaluate the effectiveness and sustainability of policy instruments over time (e.g., increase the national health budget and raise Medisave withdrawal limits, which is a compulsory national savings program for residents). This therefore provides the requisite decision-support for healthcare policy makers.

The outline of the rest of the paper is as follows. In the next section, we describe the various subsystem models of the healthcare affordability problem. In Section 3, the model projections of the future trends of healthcare affordability in Singapore are discussed. We then test the effectiveness of various policy instruments to mitigate rising healthcare costs in Section 4, and conclude the paper in Section 5.

2 MODEL DEVELOPMENT

2.1 Dynamic Hypothesis

A causal loop diagram is shown in Figure 1 that illustrates the key entities influencing healthcare affordability and their interrelationships.

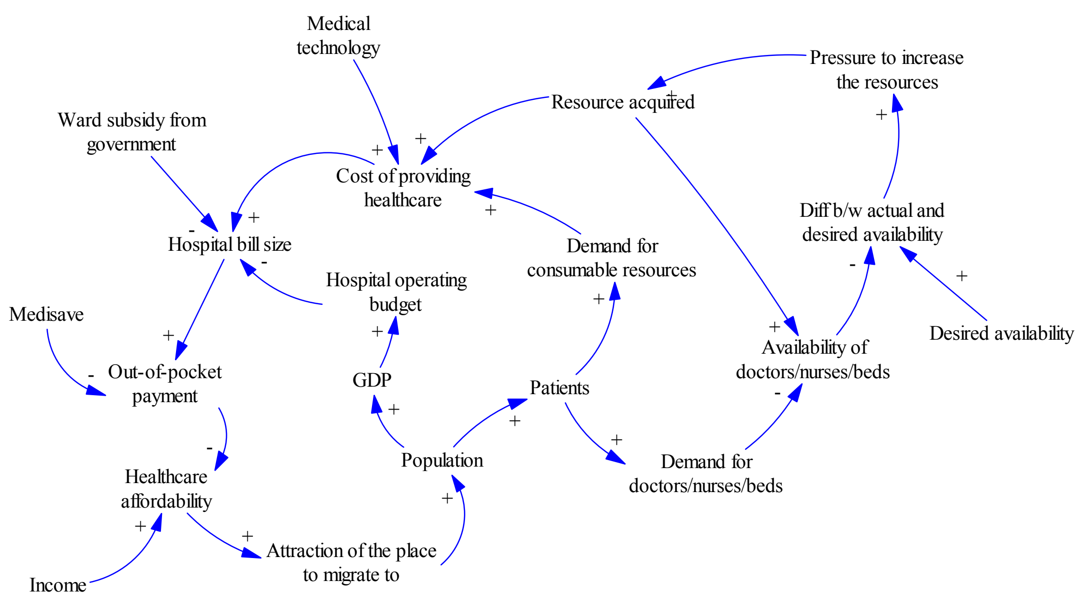


Figure 1: Causal loop diagram of healthcare affordability

Demand for health services and resources are increased by patient load. Increasing demand for resources such as medicine and bed space, and services such as professional medical staff reduces their availability. Over time, hospitals and healthcare givers react to availability pressures by acquiring more resources; hence, increasing the healthcare costs. A major bulk of such operating costs and hospital bills are absorbed by the state's healthcare budget such as hospital ward subsidies. We assume the apportioned healthcare budget is correlated to the economic growth of Singapore, which is stipulated by policy-makers to be a percentage of the national GDP. A compulsory medical saving called Medisave also covers the hospitalization fees in Singapore. The more patients use Medisave to pay, the less they need to pay out of pocket, which in turn improves healthcare affordability.

2.2 Stock Flow Model

A system dynamics simulation model or stock-and-flow model is developed using ISEE's iThink (http://www.iseesystems.com). In the following, we describe some of the key subsystems in the model. An explanation of the stock-flow diagram's schematic is provided in Appendix A.

2.2.1 Demand Subsystem

To model demand for hospital services, the population is disaggregated into three stocks of age groups 0 to 14, 15 to 64, 65 and above. This disaggregation was chosen since the hospital admission rates for the three different age groups are quite different. In particular, the age group 65 and above contributes most to hospital admissions. In this model, population demographics change dynamically due to births, aging, mortality and immigration. Aging is the greatest challenge faced by healthcare policy makers since chronic ailments such as hypertension, high cholesterol and diabetes are most prevalent amongst the elderly. Singapore has one of the fastest aging populations in the world, with over 65-year-olds estimated to represent 23% of the population by 2030 and 85% of this group will have one or more chronic diseases that would require life-long treatment (Singapore Department of Statistics 2010).

Singapore also has a high influx of migrants each year and most of them fall in the age group 15 to 64. The annual hospital admissions are then equated to the sum of hospital admissions for the three age groups. Figure 2 shows the stock-flow schematic of the demand subsystem. In this paper, year 2006 was chosen as the base year for study. Thus, data for 2006 would be used for all the initial values in the model.

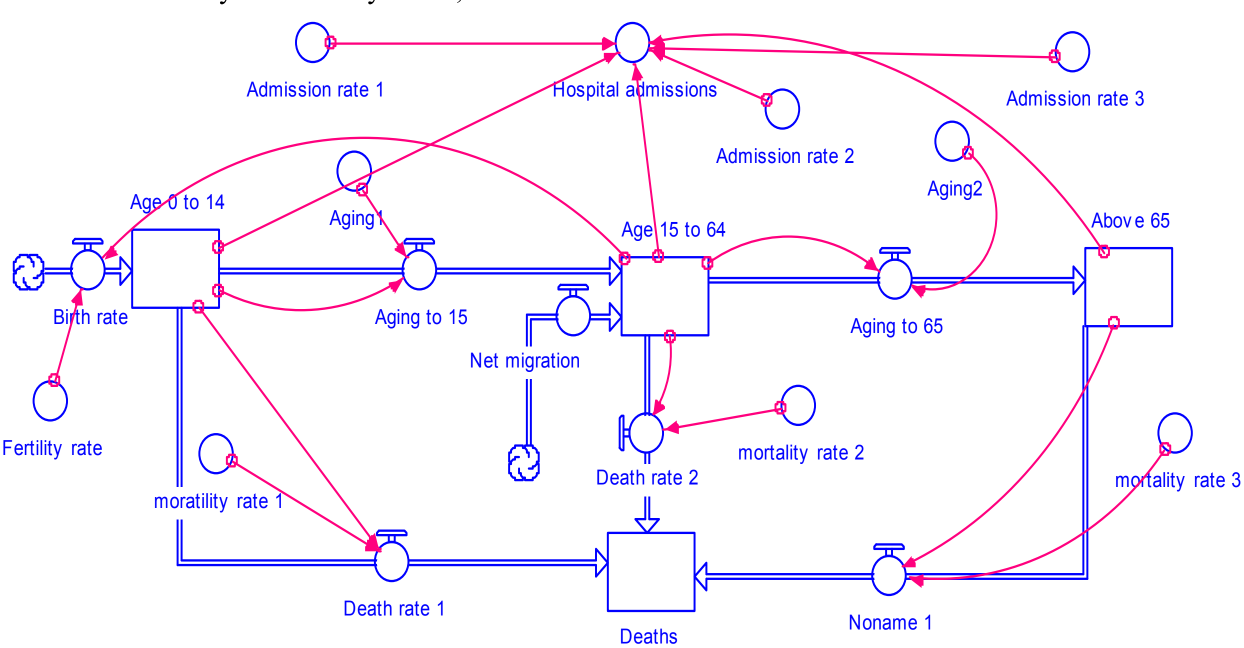


Figure 2: Demand for healthcare

2.2.2 Healthcare Budget and Cost Subsystem

The public healthcare budget is treated as a fraction of GDP, which is estimated to be 1.3% for Singapore (Singapore Department of Statistics 2010). GDP is positively correlated to the population of age 15-64 since the majority of working population is expected to fall within this group. Public healthcare budget is split into operating budget and development budget. The bulk of operating costs is attributed to the cost of doctors, nurses, hospital beds, medication and overheads. These are in turn positively correlated to the number of hospital admissions, cost of utility fees and amortized equipment. Figure 3 shows the budget and cost calculation subsystem in the model.

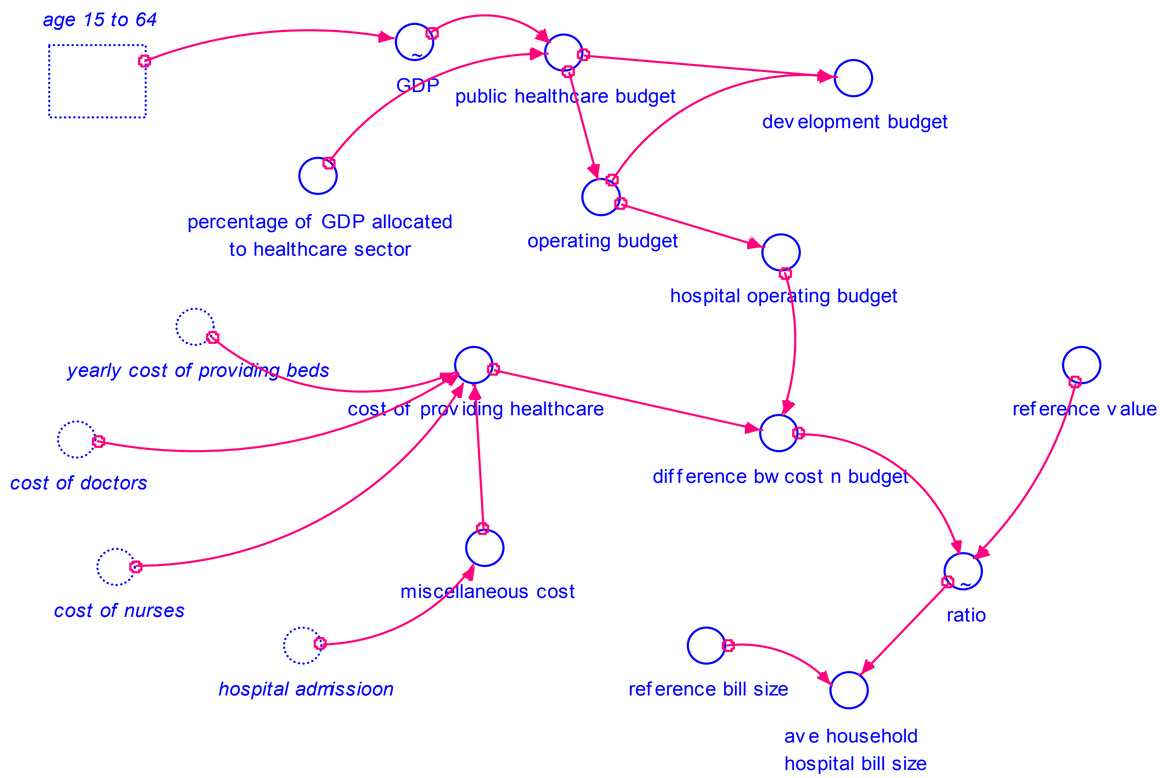


Figure 3: Cost of providing healthcare

2.2.3 Healthcare Resources Subsystem

Bed occupancy rate is an important indicator of healthcare performance. It is measured as a ratio of beds occupied by patients over the number of beds available. The inflow is controlled by the number of hospital admissions while outflow by the average length of hospital stay, which is set to be 5 days in the model. Apart from bed occupancy, the availability of doctors and availability of nurses are also modeled for the same reason stated above. The structures are also similar to the bed occupancy sector in Figure 4.

Here, only the structure for cost of nurses is explained since the structure for modeling cost of nurses, cost of doctors and cost of hospital beds are quite similar. The hiring cost of nurses is the product of the annual salary of nurses and the number of employed nursing staff. The stock of nurses is increased by hiring trainees. Trainees inflows are in turn triggered by the desired or target nurse headcount that the hospital wants to maintain. The target headcount is adjusted based on the hospital's projection of staff nurse availability. Figure 5 shows the schematic of the stock-flow model for the nurse supply line.

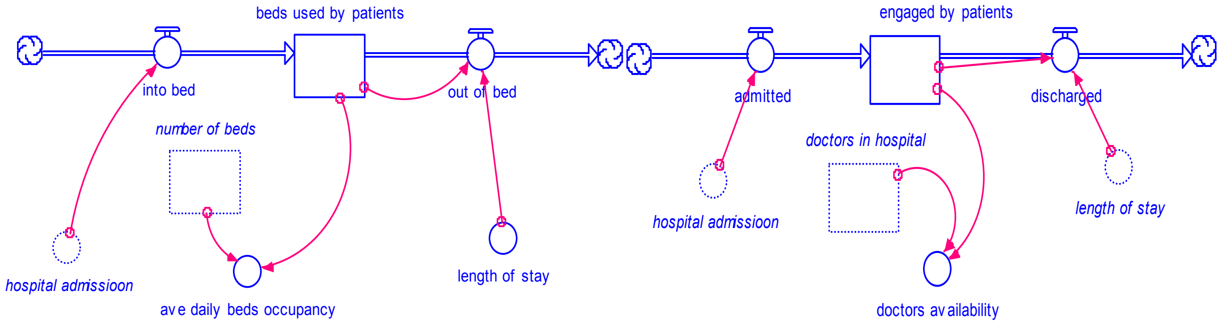


Figure 4: Bed occupancy and doctor's availability

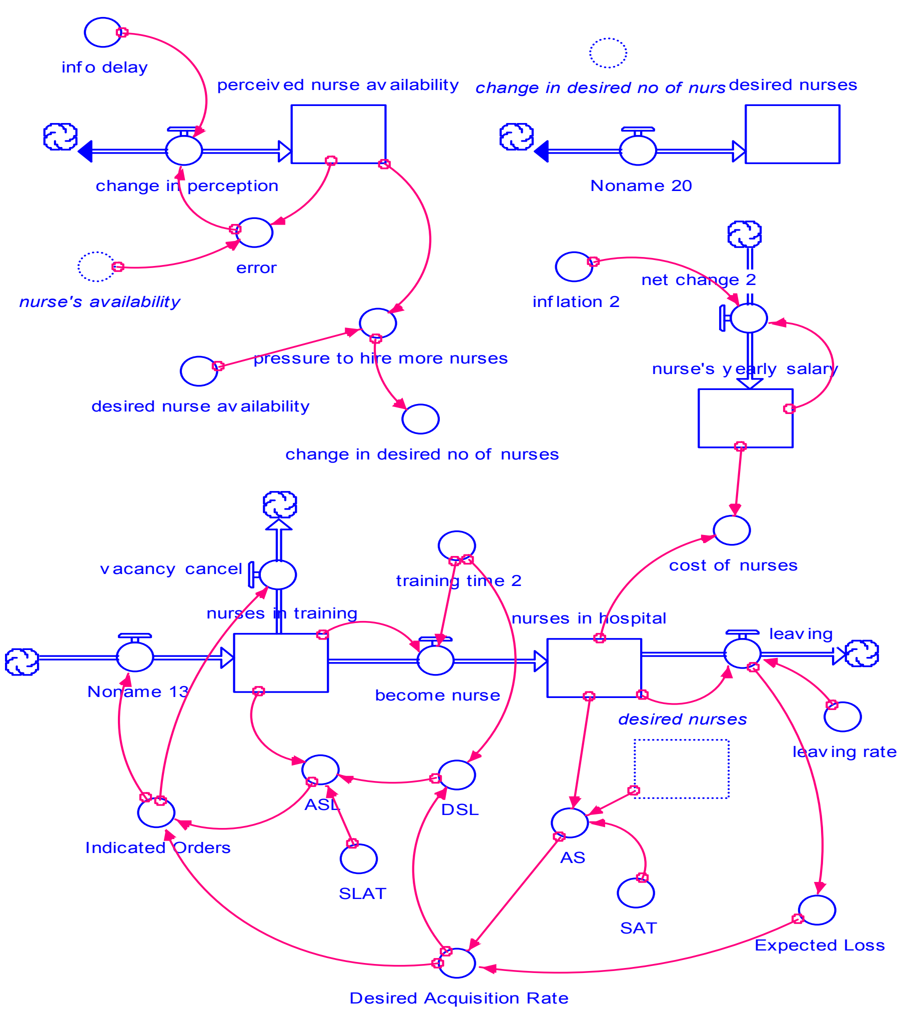


Figure 5: Cost and supply of nursing staff

2.2.4 Hospital Billing Subsystem

The patients are stratified by their income level. The reason for the disaggregation being that healthcare affordability can be very different for different income groups. In addition, different ward types have different hospital bills and are subjected to different level of government subsidies. Since the objective is to study the affordability of healthcare in Singapore, distinguishing the income level and ward classes would be able to capture the real situation more accurately and be able to provide more insights about factors affecting affordability of healthcare service in Singapore.

Figure 6 shows the affordability computation subsystem for the top income strata. The average hospital bill size after subsidies is computed based on the proportion of top income strata patients in each of the three ward types. Out of pocket payments are then the hospital bill size less the Medisave, which is able to cover 65% of the hospital bill for most of the people (MOH 2010). Finally, the affordability of health service is measured as a ratio of average per capita household annual income to out-of-pocket payment.

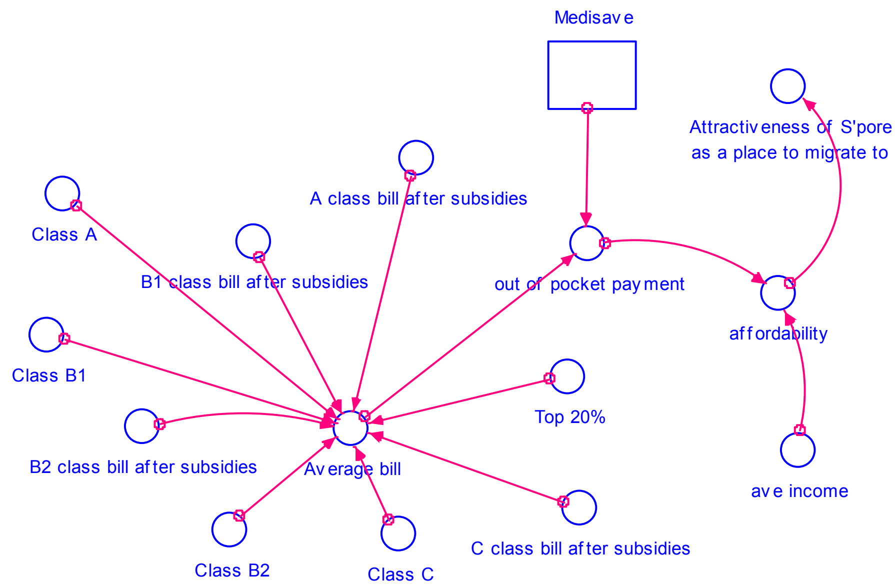


Figure 6: Healthcare affordability for top income group

2.3 Model Validation

A battery of model tests was conducted, with the help of subject matter experts, on the developed model. These included model boundary tests, structural assessment tests, extreme conditions test, integration error tests, etc. (Sterman 2004). Sensitivity tests were also performed on model parameters that lacked data references such as delay times and hospital resource availability adjustment time constants. The tests indicated that the model was reasonably insensitive to these parameter variations.

3 MODEL PROJECTIONS

This section looks into various scenarios that may occur within the current system. Specifically, we observe how healthcare affordability is affected by the changes in demand and supply of hospital services and resources, respectively. The evaluation of behaviors generated from these scenarios would facilitate the development of policies and strategies to improve healthcare affordability.

Figure 7 shows that the annual demand for hospital services over 30 years beginning from 2006 will grow significantly. This is primarily attributed to the aging population in Singapore.

Figure 8 meanwhile shows the resources' response to the increasing demands (i.e., increasing hospital beds and employed doctors in hospitals). The increase in demand leads to the subsequent increase of hospital resources. However, even with the increases in medical staff, doctors' availability barely manages to stay stable. The fluctuations in the supply of doctors are partly due to the long delays involved in training of doctors. This suggests that the availability of doctors will continuously lag behind demand given the current situation of the system.

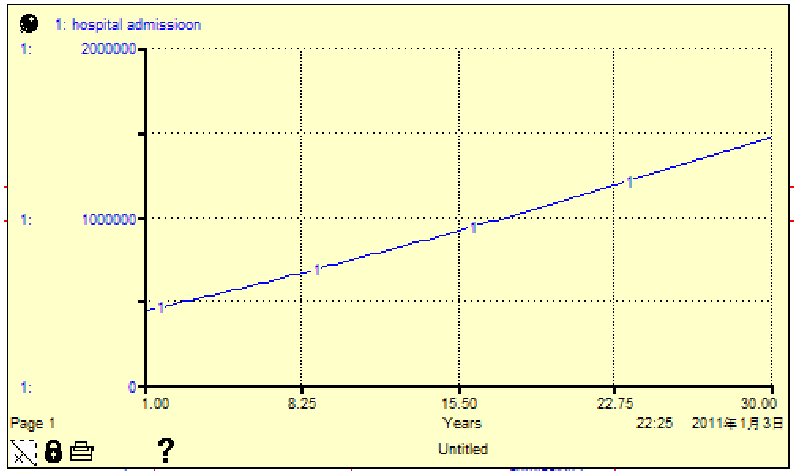


Figure 7: Demand for hospital services

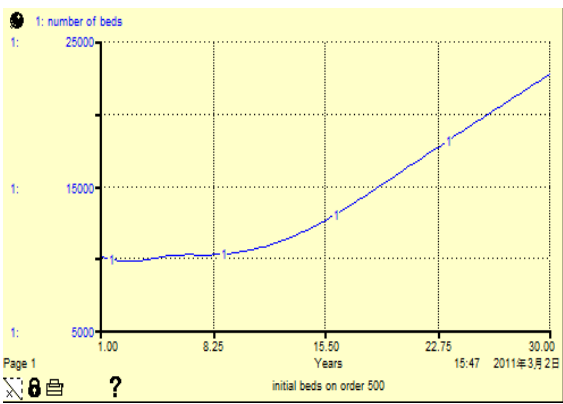


Figure 8: Trends of hospital resources (number of beds and availability of doctors)

Finally, Figure 9 shows rising costs of providing healthcare alongside the decreasing affordability of healthcare. The graphs demonstrate how the model also forecasts that the affordability of healthcare services in Singapore will degrade substantially for people from all income levels given the current situation. This is because healthcare costs after state subsidies increase rapidly due to the passing of costs associated with the increase in hospital resources. Once again, this can be attributed to the disparity between the supply of resources and the demand for hospital services. In order to decrease the gap between the two, hospital resources need to be increased. This inevitably incurs costs, which are eventually borne by the patients.

4 IMPROVEMENT POLICIES

Due to demand generated by the aging population, the number of hospital admissions is increasing every year. Furthermore, the pace of increase is so fast that it exerts a great burden on the healthcare system, which threatens the accessibility and affordability of healthcare. In order to handle the increasing number of patients, hospitals need to recruit more doctors/nurses and purchase more hospital beds. This is to maintain the bed occupancy at a desirable rate and to ensure that there would be enough doctors/nurses to cater to patients. However, increasing the number of doctors, nurses and hospital beds inevitably increases the cost of providing healthcare. The additional cost would most likely be borne by patients themselves, thereby placing a strain on the affordability of healthcare. Thus, policy makers have to take both the accessibility and affordability of healthcare into consideration since leaving either one out will endanger the other one.

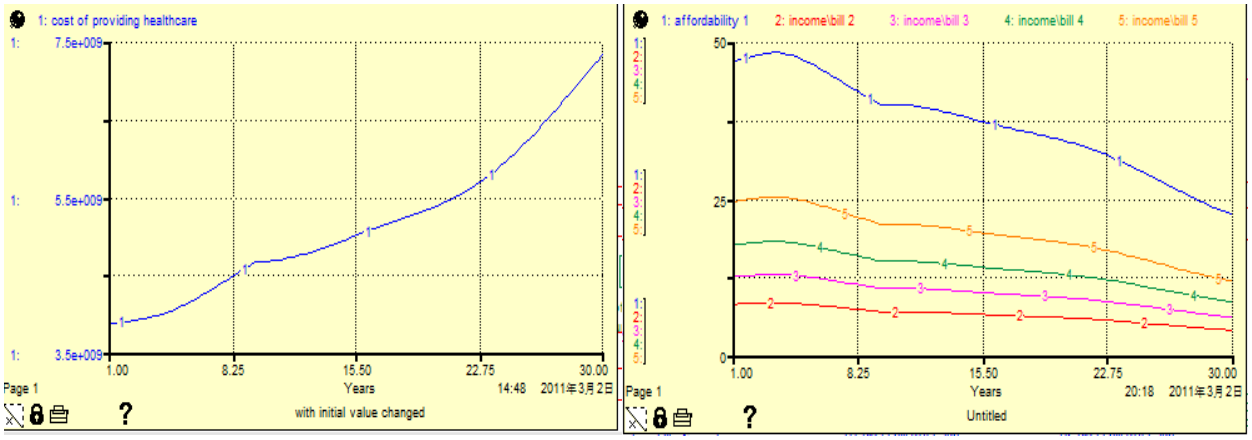


Figure 9: Increasing healthcare costs and decreasing affordability in Singapore

In the following section, a few possible policies for improving healthcare affordability will be tested using the model constructed and the usefulness of the policies will be discussed.

4.1 Assigning a Higher Percentage of GDP as Healthcare Budget

From the graphs in Figure 10, we can see that as the percentage of GDP allocated to healthcare sector increases, healthcare gets more affordable to the lower income group. This is also true for the other income groups. However, it is noted that the policy is more effective in the first 20 years and the impact diminishes after 20 years. This is because the increasing burden on healthcare resources and costs is likely to outstrip GDP growth; hence, reducing the benefit of increasing healthcare budget. Clearly, to sustain affordability by depending solely on this instrument would mean that an increasing percentage of the national budget needs to be apportioned to subsidize public healthcare expenses as time goes on, which is unlikely to be feasible from a national policy point of view.

Figure 10: Increasing national healthcare budget from GDP (1.3% (1), 2% (2), 3%(3))

4.2 Changing Migrant Flow

The graphs in Figure 11 show that affordability improves slightly when the number of migrants increases. This is because most of the migrants fall within the working population range. They contribute actively to the GDP, which in turn contributes to the public healthcare expenditure. At the same time, this group of migrants does not significantly contribute to the hospital service demands.

The government can thus attract more foreigners to take up residency in Singapore in the future in order to help boost the economy and also improve healthcare affordability. The attractiveness of the state, on the other hand, depends on healthcare service and affordability, and hence such policies are best adopted earlier. However, increasing migrant influx is only effective in the short term. This is shown by the peak in the graphs at the earlier parts of the simulation. The affordability decreases because this group of migrants will soon contribute to the aging population and might eventually worsen the affordability given that the birth and death rates do not change.

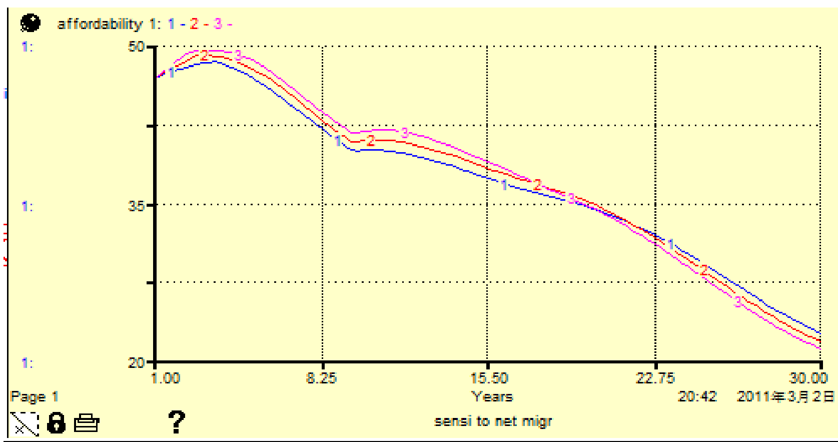


Figure 11: Healthcare affordability with varying annual migrant inflow rates- 150k (1), 200k (2), 250k (3)

4.3 Differentiating Subsidies According to Income Group (Means Testing)

Table 1 shows the distribution of patients together with the average bill size for different ward types found in government hospitals for the year 2009. The wards are differentiated by the costs associated to each one. Specifically, type A is the most expensive ward while type C is the least expensive ward that patients could choose. As calculated, the total ward subsidy received from the government is around S$1.65 billion in that year. With the ever-increasing average bill size, the state would need to pay out more subsidies each year. In Singapore, ward class C and B2 are heavily subsidized with the motive to help those who have low incomes and thus have difficulty in paying their bills. However, many high income patient groups also opt for ward type C and B2 even though they could actually afford to go for the higher ward types. This results in a degradation of the subsidy effectiveness. An alternative is to implement a means testing policy so that patients from different income groups will receive different amounts of subsidies even if they apply for the same type of wards.

Table 2 shows one proposed system to test the effectiveness of this policy in improving healthcare affordability. The policy indicates that only ward type B2 and C are now eligible to receive subsidies. Furthermore, the level of subsidies will also depend on the income level of the patients. Currently, the government can subsidize up to 65% of hospital bills if a patient opts to stay in ward type B2. With this policy, patients from the top income group can receive at most 60% subsidy while the bottom income group would receive a larger level of subsidy at 70%.

Table 1: Distribution of patients and their respective bill sizes

Ward type	Average bills (after subsidies)	Distribution of patients	Subsidies	Bill before subsidies
A	4751	8 %	0	4751
B1	3873	12 %	20 %	4841
B2	1660	39 %	65 %	4743
C	1506	41 %	80 %	7530

*Number of patients in 2006= 435,628
Subsidies=(4841*0.2*0.12+4743*0.65*0.39+7530*0.8*0.41)*patients= 1,650,322,000

Table 2: Proposed means testing policy-change in subsidies

	B1	B2	C
Top	-	60 %	62 %
Bottom	-	70 %	87 %
20-40	-	68 %	87 %
40-60	-	54 %	84 %
60-80	-	62 %	80 %

From the model outputs shown in Figure 12 and Figure 13, it can be observed that implementing the discriminated subsidies policies resulted in a significant increase in the affordability for the lower income strata. Meanwhile, this marginally decreased the affordability for the high income strata. In any good state policy, it is important to prioritize the welfare of the lower income strata to make sure that healthcare is made affordable even to the poorest group of population.

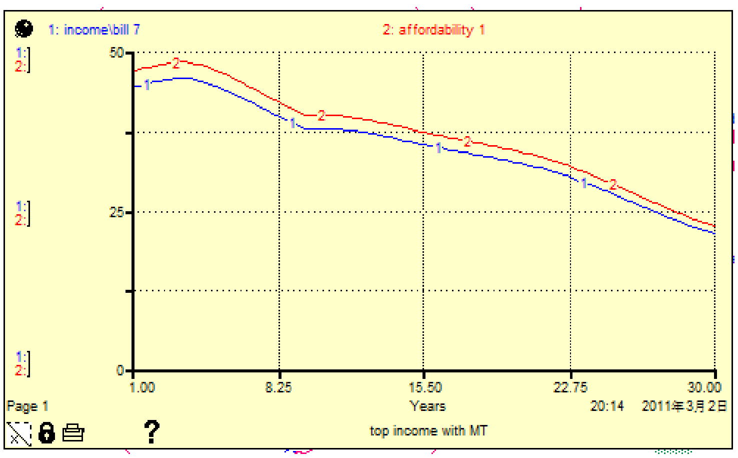


Figure 12: Healthcare affordability for top income group with (Graph 1) and without (Graph 2) implementation of discriminated subsidies.

4.4 Shortening the Length of Hospital Stay

When the average length of hospital stays is shortened, the impact and benefits on affordability are not immediately apparent as indicated by the graphs in Figure 14. However, in the long run, resource availability can be sustained in the face of increasing patient load. Hence, if the healthcare providers do not see a need for a patient to stay in the hospital anymore, they should require the patient to be discharged immediately. This will not only improve doctors' and nurses' availability but will also make hospital beds more available to patients who need them.

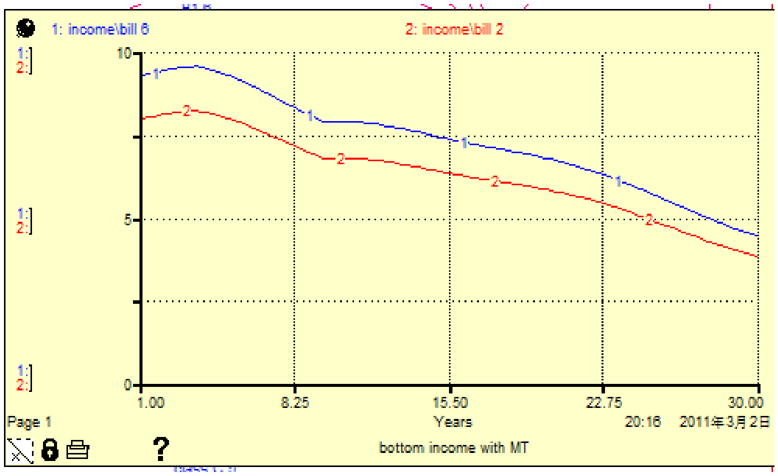


Figure 13: Healthcare affordability for bottom income group with (Graph 1) and without (Graph 2) implementation of discriminated subsidies.

Figure 14: Affordability and hospital stay duration: 5days (Graph 1), 5.5days (graph 2), 6days (graph 3)

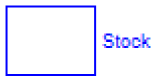
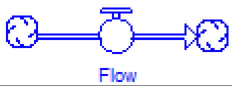
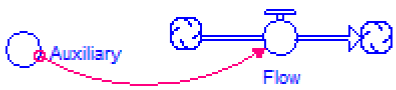
5 CONCLUSION

In this work, a system dynamics model was developed to study the affordability and accessibility of healthcare in Singapore. The model accounted for the demand for hospital services and the various critical hospital resources and their respective costs. Given the current population demographics, it is anticipated that the affordability will decrease significantly into the next three decades. Four different classes of policies are then tested for their effectiveness in improving healthcare affordability in Singapore. These policies, while useful to a certain extent, are not by themselves able to reverse the trend of decreasing healthcare affordability in Singapore. Such work requires the investigation of more fundamental root causes such as the aging population. Current and future tasks include integrating the healthcare model with higher resolution birth and aging policy models, household savings and expenditures models.

A STOCK FLOW SCHEMATIC

iThink is among the variety of software packages (*STELLA, Powersim, DYNAMO, and Vensim*) capable of high level simulation in system dynamics. It uses a set of diagramming notations shown in Table 3 to represent the components of the stock flow diagram:

Table 3: Diagramming notations in iThink

	Stocks are represented by rectangles
	Flows are represented by the valves connected to stocks
	Auxiliary variables are represented by circles
	Connectors serve as the links between the model elements

The stock flow diagram has the capability to provide quantification for the relationships that had been identified in the system. This is translated into integral equations with the following general form:

$$Stock(t) = \int_{t_o}^{t} [Inflow(s) - Outflow(s)]ds + Stock(t_0) \quad (1)$$

Stocks represent the accumulations in the system. As mentioned by Sterman (2004), they characterize the state of the system and generate the information upon which decisions and actions are based from. They create delays by accumulating the difference between the inflow to a process and the outflow from it. These variables determine the state of the system and are dependent on past values. In contrast, flow variables are unable to accumulate through time. They simply alter the quantity of the stocks by being either an inflow or an outflow to it.

Aside from stocks and flows, the diagram also consists of auxiliary variables. These have not been explicitly modeled in the causal loop diagram but are necessary in the construction of the stock flow diagram since some flow equations cannot be directly formulated without the use of auxiliary calculations. These variables comprise the model's parameters and are in the form of constants or exogenous variables.

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