**A Patient Flow Model of Singapore's Healthcare System**

**Abstract**

**Objective:** To develop an evidence-based dynamic model to simulate the likely impact of different supply-side and demand-side interventions on hospital admissions, wait times, and bed occupancy rates for acute hospitals and community-hospitals.

**Data Sources:** Demographic and population data and 2012 Singapore Yearbook of Statistics on health from Singapore Department of Statistics, as well as estimates from physician researchers.

**Study Design:** The patient flow model was created using system dynamics methodology and parameterized using available data from reports.

**Principal Findings:** Due to population aging, between 2014 and 2030, the number of hospital admissions in Singapore is projected to increase 65 percent. By 2030, 58 percent of the admissions are expected to comprise elderly individuals 65 years of age and older. Consequently, wait times for admission to acute care hospitals are expected to increase from within a day of referral to two weeks if current healthcare capacity remains unchanged. In addition, the bed occupancy rate for acute care and community hospitals is projected to reach 100 percent by 2023 and 2025 respectively. All interventions tested would either moderate these increases or decrease the bed occupancy rate for all care venues and wait times.

**Conclusion:** System dynamics modeling was useful in improving understanding of the healthcare system and demonstrating the linkages, interactions and relationships among different parts of the system. Moreover, the model's use in illustrating through a comparative analysis the impact of the proposed interventions could help policy makers to make informed decisions.

## Introduction

Due to the combined impact of a growing and an aging population, healthcare needs in Singapore are expected to increase significantly in the near future. By 2030, one in four Singaporeans will be 65 years of age or older (MCYS 2006). Studies have shown that elderly individuals are more likely to be hospitalized (Haan et al 1997) and, once hospitalized, are more likely to stay longer. Thus, the aging population will be a strong driver for healthcare demand in Singapore.

In order to meet future healthcare needs, Singapore's Ministry of Health (MOH) has adopted a number of supply-side and demand-side interventions. The supply-side interventions comprise investments to scale up manpower and infrastructure in an effort to increase capacity across care venues. The demand-side interventions include providing health education for high-risk populations, promoting public awareness about the benefits of healthier lifestyle choices, and supporting the implementation and translation of evidence-based practices to improve health outcomes.

Given that healthcare needs in Singapore are expected to increase and that different interventions are underway to leverage demand and supply for healthcare, this paper presents an evidence-based dynamic model to simulate the likely impact of different supply-side and demand-side interventions on hospital admissions, wait times, and bed occupancy rates for acute hospitals and community-hospitals. The purpose of this exercise is to highlight the utility of a patient flow model in evaluating the likely impact of the proposed interventions on the health system.

## Methods

The patient flow model presented herein is a deterministic and differential equation model built using system dynamics (SD) methodology (Randers 1980; Sterman 2000; Forrester 1961) and combining available evidence and insights from previous research (Homer & Hirsch 2006). The conceptual model—created using SD iconography of stocks and flows—features several linkages, relationships, and interactions among elements that describe essential interdependence and information feedback. To verify the model structure and bring evidence to bear on strategic issues, the model was presented to physician researchers at the Duke-National University of Singapore Graduate Medical School who are familiar with Singapore's healthcare system. Following iterative model revisions and verification, the model was parameterized using publically available data in Singapore. When data for a model parameter was unavailable, estimates were provided by physician researchers.

The patients flow model has two sub-models: (1) a population sub-model and (2) a patient flow sub-model. The population sub-model simulates the population of Singapore by age, and is used as input to the patient flow sub-model. The patient flow sub-model simulates the flow of patients in the Singapore healthcare system.

## Model Structure

### *Population Sub-Model*

The population sub-model (Figure 1) has been described elsewhere (Thompson et al 2012; Eberlein et al 2012; Ansah et al 2013). Briefly, the model disaggregates the population of Singapore into five-year age cohorts by gender. The population cohorts are affected by births (only for the first age cohort), deaths, immigration, emigration, and aging (except for the last age cohort). Births are calculated based on the fertility rate and the female population in the reproductive age group (15 – 44 years of age). Deaths by age are calculated using mortality rates from life tables. Mortality and birth rates for 2011 are held constant over the simulation time. Immigration is based on available data, and emigration is estimated by calibration. The aging process ensures that, at the end of each year, the surviving population in each age cohort flows into the subsequent cohort with the exception of the final age cohort. The non-surviving population in each age cohort is removed via an outflow that reflects the mortality for that age cohort. The population model is calibrated using publicly available national statistical data (Singapore Department of Statistics 2010).

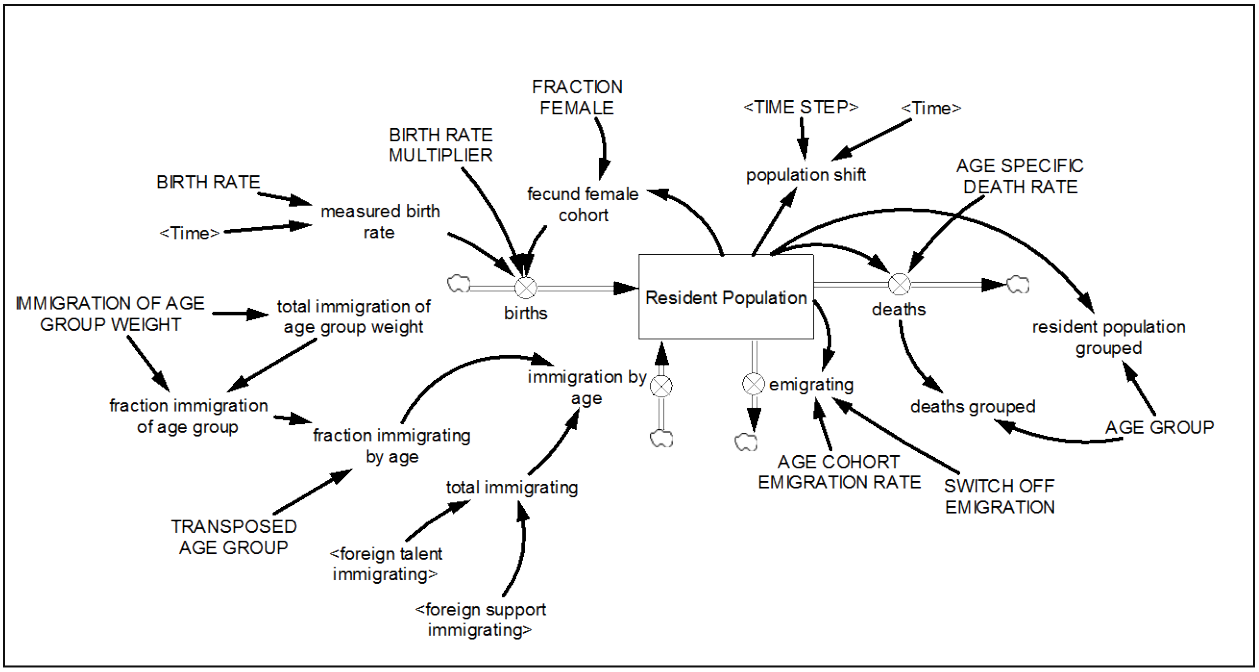



Figure 1: Population Sub-Model

***Patient Flow Sub-model***

Figure 2 shows the patient flow sub-model of the Singapore healthcare system. The model is a simplification of the complex micro-level flow of patients through the healthcare system. The patient flow sub-model simulates the flow of patients through the primary (general practitioner [GP] and PolyClinic), secondary (specialist outpatient, accident & emergency [A&E] departments, and acute care hospitals) and community (community hospitals and nursing homes) healthcare sectors. The patient flow sub-model integrates the demand and supply of healthcare to understand the effect of a demand-supply gap on hospital wait times and the bed occupancy rate across care venues. Patients enter the healthcare system by consulting a GP (at outpatient clinics or poly clinics) or visiting A&E department. Following a GP consultation, patients may receive a diagnosis and/or prescriptions or be referred to a specialist outpatient clinic if the case so requires. For A&E consultation, patients may be discharged after receiving medical attention, be referred to specialist outpatient clinic or be admitted to an acute care hospital. Specialist outpatient clinics receive referred patients from GPs and A&E departments. Patients in specialist outpatient clinics may be discharged after receiving specialized medical care or be referred to an acute care hospital for admission.

Admission to acute care hospitals for medical treatment depends on bed availability (i.e., capacity). As bed capacity increases, the ability of the hospital to take in more patients increases. The number of patients in acute care hospital wards increase via admissions and decrease via discharge (including in-hospital deaths) and transfers to community hospitals after medical treatment. Acute care hospital discharge is determined by the number of patients in hospital wards and the average length of stay (ALOS) of patients. The transfer of patients from acute care hospitals to community-hospitals is a function of number of available beds in community hospitals and the acute care hospital to community hospital referral rate. The acute care hospital to community hospital referral rate is a function of the perceived attractiveness of community hospitals, which is defined in the model as the ability of community-hospitals to provide quality care to ensure smooth transitions from medical dependence to optimal functional independence, as well as the relative out-of-pocket cost of community hospitals to acute care hospitals. From the community-hospital, patients are discharged (including deaths) to the community, referred to a nursing home, or transferred directly from a community hospital to a nursing home. Nursing home admissions depend on available capacity.

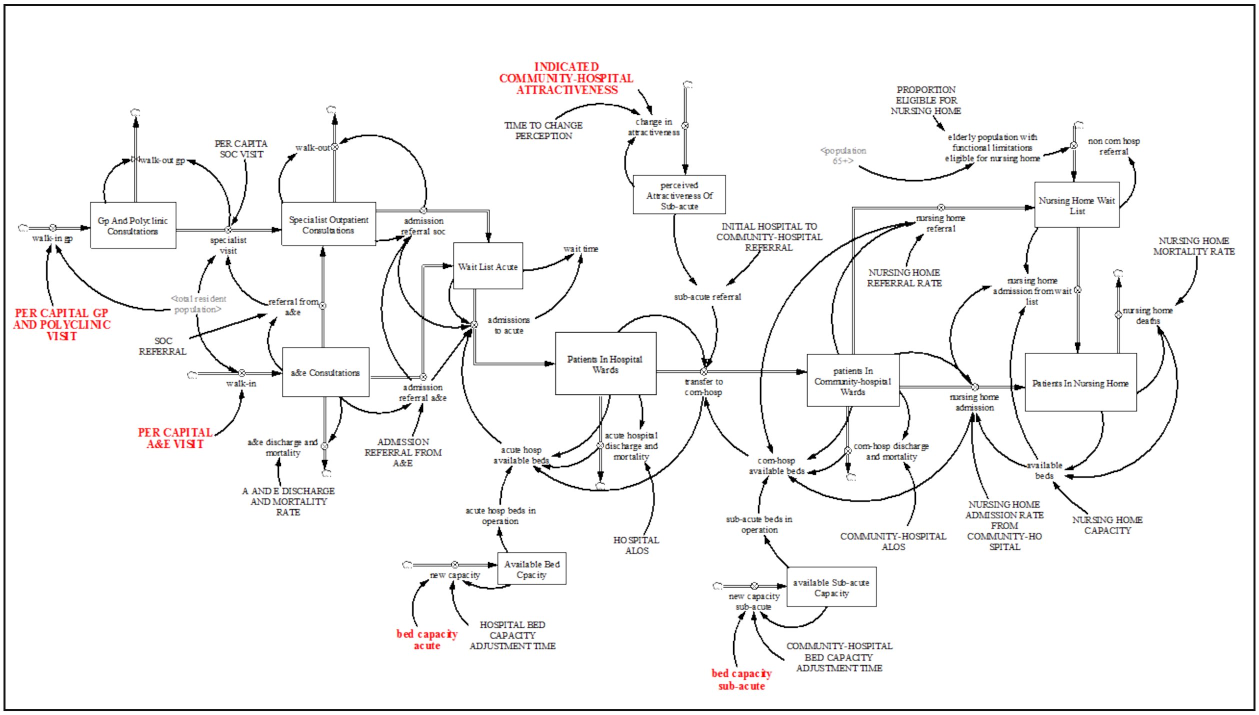



Figure 2: Patient Flow Sub-Model

**Data Sources**

The demographic and population data used in the patient flow model was obtained from the Singapore Department of Statistics. Data on healthcare capacity, acute care and community hospital admissions by age group, specialist outpatient consultations, and A&E visits, were obtained from the 2012 Singapore Yearbook of Statistics. For parameters with no available data, estimates were obtained from physicians with expert knowledge of the Singapore health system. Table 1 shows the list of model parameters.

Table 1. Patient flow model parameters

| Parameter | Value | Unit | Source |
|---|---|---|---|
| Specialist Out-patient referral from A&E | 0.1 | Dmnl/week | Estimated by researchers |
| Admission referral from A&E | 0.5 | Dmnl/week | Estimated by researchers |
| Hospital ALOS | 1 | Week | OECD 2011 |
| Initial hospital to community-hospital referral | 0.2 | Dmnl/week | Estimated by researchers |
| Hospital bed capacity | 6,295 | Person | Singapore Department of |

| | | | |
|---|---|---|---|
| | | | Statistics 2012 |
| Hospital bed capacity adjustment time | 2 | Week | Estimated by researchers |
| Indicated community-hospital attractiveness | 1 | Dmnl | Estimated by researchers |
| Time to change perception | 12 | Week | Estimated by researchers |
| Community-hospital ALOS | 3.5 | Week | Estimated by researchers |
| Community-hospital bed capacity | 2,010 | Person | Singapore Department of Statistics 2012 |
| Community-hospital bed capacity adjustment time | 2 | Week | Estimated by researchers |
| Nursing home bed capacity | 9,300 | Person | MOH 2012 |
| Nursing home admission rate from community-hospital | 0.1 | Dmnl/week | Estimated by researchers |
| Nursing home referral rate | 0.3 | Dmnl/week | Estimated by researchers |
| Nursing home mortality rate | 0.1 | Dmnl/week | Estimated by researchers |
| Proportion eligible for nursing home | 0.001 | Dmnl/week | Estimated by researchers |
| Per capital GP and Poly Clinic Visit | 0.02 | Dmnl/week | Singapore Department of Statistics 2012 |
| Per capital A&E visit | 0.0035 | Dmnl/week | Singapore Department of Statistics 2012 |
| Per capital specialist out-patient visit | 0.019 | Dmnl/week | Singapore Department of Statistics 2012 |

**Model-based Interventions**

*Base-case Scenario*

The base-case scenario is a status-quo simulation that assumes hospital admissions by age group and acute care hospital and community hospital bed capacity remain unchanged over the simulation time. The scenario is used to project the number of acute care and community hospital admissions, hospital wait times, and the acute care and community hospital bed occupancy rate in the absence of policy interventions.

*Pre-Hospital Intervention*

The pre-hospital intervention aims to control the growth of demand for healthcare by raising public awareness about the benefits of healthier lifestyles, implementing health education for high-risk populations, and supporting evidence-based practices to improve health outcomes. Under this intervention, between 2014 and 2030, GP and A&E consultations are assumed to decline by 20 percent. The effect of this intervention on acute care and community hospital admissions, wait times and bed occupancy rates are studied.

*Proposed Policy Intervention*

The proposed policy intervention simulates the planned increase in acute care and community hospital capacity. Under this intervention, from 2014 to 2030, 2,500 beds are added to acute care hospitals, and 1,600 are added to community hospitals (Gan 2013).

*Proposed Policy plus Community Hospital Intervention (Pro-community Hospital Intervention)*

The pro-community intervention is identical to the proposed policy intervention, except for a significant relative increase in the perceived attractiveness of community hospitals, which causes transfers from acute care hospitals to community hospitals to increase from 20 percent to 32 percent by 2030. This intervention emphasizes the perceived attractiveness of community hospitals without limiting the provision of acute care and community hospital beds.

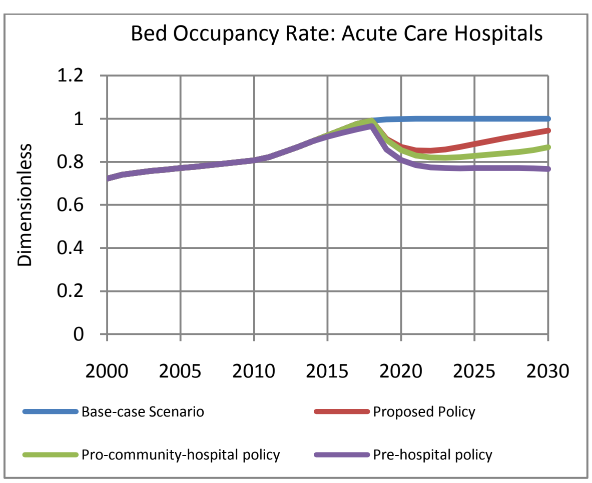
**Results**

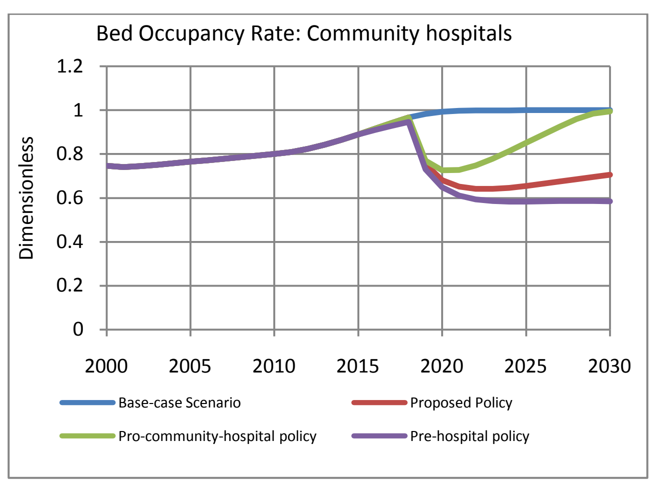
Under the base-case scenario, from 2011 to 2030, total hospital admissions among resident Singaporeans are projected to increase from 380,000 per year to 580,000. By 2030, 58 percent of total hospital admissions are expected to comprise elderly individuals 65 years of age and older. In addition, wait times for admission to acute care and community hospitals are projected to increase from a couple of hours (within a day) in 2013 to two weeks by 2030. In addition, the bed occupancy rate for acute care and community hospitals is projected to reach 100 percent by 2023 and 2025 respectively.

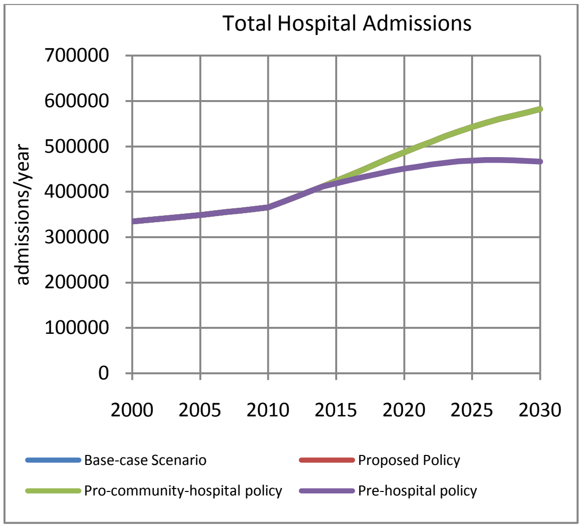
The proposed policy intervention is projected to maintain wait time for hospital admission to within a day. However, the acute care hospital bed occupancy rate is projected to increase from 85 percent in 2013 to 94 percent by 2030. In contrast, the community hospital bed occupancy rate is projected to decrease from 84 percent in 2013 to 70 percent by 2030.

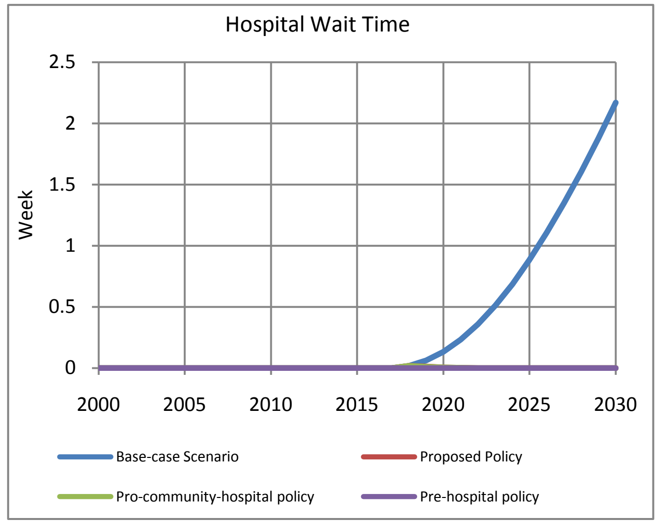
Under the pro-community hospital intervention, by 2030, the acute care hospital bed occupancy rate is projected to remain unchanged at 86 percent, whereas the community hospital bed occupancy rate is projected to increase from 84 percent in 2013 to 99 percent. In addition, wait times for acute care and community hospital admissions are projected to remain unchanged (within a day).

Under the pre-hospital intervention, by 2030, the number of acute care hospital admissions is projected to decrease by 20 percent relative to all other interventions. By 2030, acute care and community hospital bed occupancy rates are projected to reach 76 percent and 58 percent, respectively, whereas hospital admission wait times remain unchanged (within a day).






**Discussion**

Due to population aging, between 2014 and 2030, the number of hospital admissions in Singapore is projected to increase 65 percent. By 2030, 58 percent of the admissions are expected to comprise elderly individuals 65 years of age and older. Consequently, wait times for admission to acute care hospitals are expected to increase from within a day of referral to two weeks if current healthcare capacity remains unchanged. In addition, the bed occupancy rate for acute care and community hospitals is projected to reach 100 percent by 2023 and 2025 respectively. All interventions tested would either moderate these increases or decrease the bed occupancy rate for all care venues and wait times.

The pre-hospital intervention would have the strongest impact on reducing hospital admissions, bed occupancy rates and wait times for admission. This is because this intervention increases healthy lifestyle behaviors and the number of GP consultations and A&E vists, which ultimately cause referrals and hospital admissions to decrease. Consequently, bed occupancy rates and admission wait times decrease. This intervention requires effective public health policy to increase public awareness about the benefits of healthier lifestyles by educating high-risk populations and supporting the implementation of evidence-based practices to improve health outcomes. The results from the proposed policy intervention suggest that increasing community hospital bed capacity without increasing the attractiveness of community hospitals is likely to have less impact on decreasing bed occupancy rates as the referral rate from acute care hospitals to community hospitals stays unchanged due to the relative unattractiveness of community hospitals. In contrast, as demonstrated by the pro-community hospital intervention, as the attractiveness of community hospitals increases, the transfer of patients from acute care hospitals to community hospital also increases, resulting in the number of patients in acute care hospital wards decreasing, which causes the bed occupancy rate in acute care hospitals to decrease.

Comparing simulation results from all the interventions suggest that changes to GP and A&E consultations and admission rates across age groups (alteration of flow variables) in the healthcare system provide more leverage than changing healthcare capacity (alteration of stock). The implication of this insight is that since more than half (58 percent) of hospital admissions comprise elderly individuals, any intervention that focuses on decreasing hospitalization and re-hospitalization among this high-risk population will decrease healthcare needs.

One limitation of this study is that, because the model is an aggregate model that seeks to analyze the aggregate impact of different interventions, the use of mean values to represent wait time and bed occupancy rate may under or over estimate what actually happens in some specialized wards. In addition, the outcome values of hospital admissions rely on the projected population trend in Singapore. Any changes observed in the population are likely to change the numerical values from the simulation. Lastly, improving awareness about health conditions in the general population may lead to more people being screened and diagnosed with health conditions, thus it may not necessarily lead to a reduction in healthcare utilization as assumed in the patient flow model.

**Conclusion**

System dynamics modeling was useful in improving understanding of the healthcare system and demonstrating the linkages, interactions and relationships among different parts of the system. Moreover, the model's use in illustrating through a comparative analysis the impact of the proposed interventions could help policy makers to make informed decisions. This work is at an early stage, but Singapore Ministry of Health has expressed interest in developing a similar model to study the impact of the planned increases in acute care hospital and community hospital capacity on wait times, bed occupancy, patient days and medical workforce requirement. This model has the potential to be used as a boundary object for communication with stakeholders.

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