A Systems Thinking Analysis of Healthcare Supply and Demand Management: A Case Study of Malaysian Public Hospitals

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Abstract

This study elucidates system structure modelling of how the growing number of patients impacts healthcare service utilization. A dynamic causal loop diagram (CLD) as a qualitative aspect of system dynamics model is employed to provide a holistic view of feedback relationships between patient pathways to the hospital and the supply of healthcare, including factors such as healthcare financing, physicians, and hospital beds. On the basis of knowledge drawn from existing studies, it is hypothesized that morbidity and disease prevalence and budget allocation as indicators of medical need and expected medical demand, respectively, are assumed to positively influence citizens' hospital visits. Healthcare funds allocated to hospitals to improve healthcare facilities and increase the number of staff have triggered positive expectations from Malaysians regarding the utilization of public healthcare facilities. Supplying an adequate medical workforce and hospital capacity via funds spent on this service are indicators of improved service quality. The causal model constructed is the initial phase of a system dynamics model for the development of a quantitative simulation model in the future.

Key words: Healthcare demand, Malaysia, Hospital management, System thinking, Qualitative model

1. Introduction

Difficulties due to socio-developmental changes and the continuous increase in medical costs have been of concern in many developed and upper-income nations. In the early twentieth century, increases in the life expectancy of the population were seen in many developed countries as a result of improved treatments for communicable diseases. Since the 2000s, chronic and non-communicable diseases such as cancer, diabetes, and heart disease have been the leading causes of death. This transformation has been called an "epidemiological transition." Living longer sounds good, but a longer life expectancy sometimes increases the probability of having multiple morbidities and chronic diseases in most developed countries, except for Japan. This phenomenon has caused challenges for the healthcare sectors of these countries, who must handle the demands of the sick population with scarce healthcare resources. Policymakers in these countries strive to elucidate how to adequately supply healthcare services to those who need them.

According to Wren et al. [1], the epidemiological transition confronted by developed nations has had a significant impact on individuals’ health and will lead to demands for health and long-term care increasing in coming years. In most developing countries, the growing health care demand is also driven by the expanding middle class and growth of the gross domestic product (GDP). As a country becomes developed and tries to sustain its rapid economic development (such as in Malaysia), its public expenditure increases, including in the healthcare sector.

Therefore, the purpose of this study is to develop a dynamic causal loop model of healthcare demand using a system dynamics approach. The model will present a holistic view of the feedback relationships between the patient pathways to the hospital and the supply of healthcare elements, such as healthcare financing, the physician workforce, and hospital beds. The qualitative causal loop model is constructed to identify the necessary variables should be included in the simulation model and understand the complexity cause-effect relationship between those variables in the analysis of the healthcare system.

The remainder of this paper is organized as follows. In the next section, a literature review is presented. Then, section 3 describes the system dynamics method as used in this study. Section 4 explains the causal loop model as a qualitative technique in system dynamics approach in more detail. Section 5 discusses the results of the generated conceptual model. Finally, section 6 provides a conclusion to the study and some recommendations for future work.

2. Literature Review

Theories of supply and demand are derived from the concept of utility in economics, where individuals make perceived choices in the market of goods and services.
Based on the demand for the product or service, the theory of supply informs us that the producer or provider will adjust both production and prices to meet the demand unless scarcity of some kind affects production. For instance, a scarcity of medical officers affects admission to medical school; also, many medical students tend to leave the medical field for another course of study due to difficulties in adapting to the medical course. In response, the government will introduce new policies to enhance medical education programs to increase the number of qualified and skillful doctors. Moreover, many studies assert the importance of budget spends on health care for providing a better quality of health care services including hiring high-experienced doctors, more advanced medical equipment and facilities and so on. Hassan & Minato [2], public health financing allotted by the government of one country is vital to improve population health status through facilitating health care facilities and resources. World Health Organization (WHO) suggests the country should allocate 5 per cent of its GDP on health care [3]. However, this increasing budget allocation has increased citizen’s expectation of public hospital.

Recently, considerable attention has rightly been paid in the literature to the impact on healthcare service utilization of sharp hikes in healthcare expenditure and other drivers of demand. Analyses of the supply of healthcare often treated the supply of healthcare as independent variables in the production of health and healthcare; this was clarified by many economists and should be enhanced via a causal model. In contrast, in studies of healthcare expenditure determinants, healthcare expenditure is often treated as a dependent variable, while socio-demographic factors like GDP and the older population are treated as independent variables that influence healthcare expenditure [4]. Demand-side variables such as healthcare expenditure, education, income, and environmental determinants were treated as independent variables of health production in a study set in a developing country by Hassan et al. [5]. Meanwhile, in a case study of OECD countries, Sen [6] employed both demand- and supply-side variables in an ordinary least squares (OLS) regression model. However, estimating both supply- and demand-side variables simultaneously in the same model using OLS can be a problem [7].

Heckman [8] provides a worthwhile framework for the causal analysis of health variations. His approach defines health as an “intrinsic value” that is generated by an individual through the input of time and products like better food and medical care. Causal relationships can arise through a number of pathways. Models and estimators vary in sophistication with the degree of detail of the causal interaction the modeler is aiming to solve [9]. The conceptual design of a causal model using system dynamic analysis would provide a better understanding of the interaction analysis of healthcare supply and demand management [2, 10, 11, 12]. The model would assist us in organizing information in a more understandable way. The interaction and feedback processes between variables can be seen as a complex system comprising of nonlinear dynamics within the system [13].

To the best of our knowledge, there is a lack of studies covering both the detail and dynamic complexity of causal loop models of the interactions in healthcare supply and demand management for public hospitals in Malaysia. Hence, this study develops a conceptual causal model of the interaction of the supply and demand of healthcare, thus facilitating deeper insights into the current healthcare situation using a system dynamics approach. A respective causal loop model has been developed employing the qualitative phase of a system dynamics model, which enables further development of the quantitative aspect of system dynamics represented by stock and flow diagrams. A conceptual model can help the modeler to comprehend a problem before developing a simulation model [14].

3. Method
Our research methodology was applied to the system dynamics simulation approach. System dynamics is a robust modelling method that enables one to pattern different aspects of problems. System dynamics is also used for testing different alternative scenarios, allowing the decision maker to simulate and test proposed policies and see the long-term outcomes of implementing each policy before making a final decision. System dynamics modelling is an excellent tool for evaluating a system’s ability to adjust and exploring the impact of new decisions that have to be made.

In order to solve a problem by means of system dynamics, there are five essential steps of the model building process for the system dynamics modeler, as follows:

1) Identifying and defining the problem of the study.
2) Developing the dynamic hypothesis through mapping the causal effect model.
3) Formulating the mathematical model through a stock and flow diagram.
4) Model validation tests
5) Generating alternative policy scenarios and evaluations.

Figure 1 shows a simple representation of a causal loop diagram to explain the feedback relations between elements in closed-loop diagrams (CLDs). Causal loop diagrams have been used to describe the basic causal mechanisms hypothesized as underlying the reference mode of behavior over time [15, 16].

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This diagram exhibits the cause and effect of the system structure of population growth in one country and is presented for ease of understanding how to read a causal loop model. The population of a country basically increases and decreases based on the birth and death rates. Each arrow represents a cause and effect relationship between two variables.

The arrows marked as “+” and “−” represent the direction of causality, explaining that a change in a variable will result in a change in the same or opposite direction in the other variable. For example, when births increase, the population will increase, as shown by the marked arrowhead going to population from birth. On the other hand, an increase in population results in a decrease in deaths. The relationship between these variables is posited as a negative one, so the arrowhead is marked as “−”. A closed chain in each relationship is called a loop; it determines the dynamic relationship that occurs in the developed CLD. Each closed feedback loop has a polarity that will indicate the causality direction, showing how a change in any variable within the feedback loop will occur and describing the structure of the system.

There are two types of feedback loop indicated by the symbols (R) and (B) in the center of a closed loop. The first type is a reinforcing feedback loop (R), which means that a change in a node flows around the closed loop and will change the same node in the same direction, eventually generating behavior of exponential growth. The second is a balancing or negative feedback loop (B), which means that the feedback flows of the elements in the system structure will bring the current state of the system into its goal and maintain stability. A more complicated causal loop model related to the problems being addressed in this study will be discussed in detail later.

The quantitative approach of system dynamics model (as indicated in step four of the model building process) in which beyond the scope of the current study can be quantified and evaluated through stocks and flow diagram as concisely described in the appendix. The illustrative stock and flow diagram and mathematical equations are presented here in the hope of helping readers or health researchers to understand and build quantitative evaluation of the future research in the healthcare system.

4. Development of the Dynamic Hypothesis: Conceptual Model

The dynamic hypothesis, which states the structure of the causal loop model as a qualitative system dynamics approach, is mainly based on theories from the healthcare literature and consultation with healthcare stakeholders such as medical practitioners, public health researchers, and consultants. The model’s structure consists of four major types of sub-system model interacting with each other; namely, patient pathways, healthcare financing, medical physicians, and hospital capacity. Figures 2 to 5 outline the significant elements, causal relationships, and closed loops of each sub-model, providing a deeper understanding and holistic view of healthcare service utilization. The highlighted grey variables indicate that these variables are interconnected with the other sub-system. This representation explains that not only do causal relationships exist between variables within a subsystem, but feedback relationships also exist between variables in one sub-system and those in another sub-system. This study employed computer simulation software named Vensim PLE in constructing the causal loop diagrams.

4.1 The Loop of Patient pathways

According to Mardiah & Basri [17], patient flow is one of the principal components to improve efficiency in healthcare services delivery as it reflecting the progression of a patient’s health outcomes. In general, demand for healthcare services can be represented by the patient-visitor flow to the healthcare service. In other words, demand for healthcare services and resources has increased due to the new patient load in hospitals. As in many health care demand models from prior system dynamics model, the present study also assumed the patient flows into hospitals is an indicator of the citizen demand for health care. In this study, the focus is Malaysian public hospitals.

The sub-model captures the dynamics associated with where visiting patient numbers increased based on two major factors—namely, the sick population due to morbidity and disease (medical need) and the expectations of residents related to fund allocation for healthcare (medical demand). The prevalence of diseases and the increasing and ageing population has had a large impact on healthcare utilization in Malaysia [18]. In this model, we assumed that a number of patients are disaggregated into two types of patient: outpatients and inpatients as illustrated in the following Figure 2.
Table 1. Chronicles of Patient Pathways

<table>
<thead>
<tr>
<th>Loops</th>
<th>Chronicles</th>
</tr>
</thead>
<tbody>
<tr>
<td>B1: Untreated patients</td>
<td>This loop depicts the fraction of untreated patients who leave a government hospital due to the long waiting time. The rising number of patients in outpatient departments creates more patients on the waiting lists and long waits to see a general physician. Patients unsatisfied with the long wait for care tend to give up on seeking care at the public hospital and so the number of patients eventually reduces. This loop produces a negative or balancing loop as the initial increase of outpatients will gradually decrease as more patients leave the hospital and are expected to receive care at another healthcare service provider. These “untreated patients” are sometimes called “unmet demand,” derived from analyses of waiting lists [1].</td>
</tr>
<tr>
<td>B2: Treated patients</td>
<td>This loop shows the fraction of treated patients who successfully meet their specified physician and are allowed to return home after being treated without continuous care at the hospital. From this loop, we can see the negative feedback loop where there is an initial increase in sick patients who have been treated and allowed to leave the hospital.</td>
</tr>
<tr>
<td>B3: Waiting for ward admission</td>
<td>Some visiting patients who are checked by a physician as outpatients will move on to be admitted to a hospital ward as they need to receive continuous care. However, admission to inpatient care depends on the available beds and bed turnover time from patient discharge to new patient [19].</td>
</tr>
<tr>
<td>B4: Patient moved to an available bed</td>
<td>This loop depicts waiting patients being able to move into an available bed and receive further treatment in the hospital. An increase in the proportion of admissions is expected to increase the number of admitted patients, thus impacting the hospital’s capacity—namely, bed utilization. An increase in bed utilization will reduce the vacant beds, reducing the hospital’s admission rate. Bed capacity utilization is often indicated as “occupancy rate,” explaining the rate of available beds occupied or being utilized in hospital wards.</td>
</tr>
<tr>
<td>B5: Admitted patients treated</td>
<td>This loop shows the fraction of patients discharged after being assessed and deemed as medically fit to return home. The patient discharge rate is basically determined by the length of the hospital stay. The mean length of stay in the figure above indicates the arithmetic average of a hospital stay. However, in some cases, chronic patients might need to stay longer in the hospital.</td>
</tr>
</tbody>
</table>

4.2 The Loop of Healthcare financial

The rising number of visiting patients has induced a desire to increase the amount of health expenditure borne by health providers. Principally, a country’s healthcare budget is sourced from its annual GDP. If a country has earned more income, its allocation of funds to many sectors, including the healthcare sector, will increase for the benefit of its population. This relation is why richer nations spend more on healthcare than emerging and low-income nations. The Malaysian government is currently providing low-cost medical services to its citizens. A large proportion of the healthcare budget is used to cover approximately 95 per cent of visiting patients’ actual medical costs [20]. This broad coverage by health providers is the reason for the growing number of patients seeking treatment at public hospitals.

Figure 3. Healthcare financing loop

As explained in the patient-flow sub-model above, some visiting outpatients will leave public hospitals due to the length of the wait, causing them to seek alternative treatment at a private hospital or clinic. This phenomenon is expected to increase the amount of healthcare spending from their own pocket, putting constraints on their monthly income, especially for middle- and low-income groups. Rising healthcare spending could lead to a financial meltdown and influence healthcare affordability for these vulnerable groups in the future [2]. Even though the government subsidizes the universal healthcare system, Malaysians...
contribute over 35 per cent of medical payments out of their own pockets [21]. According to the WHO, a country with an out-of-pocket spending rate exceeding 15–20 per cent will face a higher risk of financial catastrophe due to sick and chronically ill people not having enough money to pay their medical bills [22].

4.3 The Loop of Physician flows

The number of available physicians in most hospitals is presumably determined by physician recruitment, leaving off the retirement rate. In economic terms, like the labor production in other sectors, physicians are a key input for the production of healthcare and one of the best ways to measure healthcare resources.

**B7: Retirement rate**

How the number of physicians is reduced by the retirement rate is depicted in this loop. The proportion of retired physicians is determined by the retirement age that is set by the government of a country. In this study, with 2010 as the base year, the retirement age was set at 58. If the retirement age is extended to 60 years old, for instance, in the current year, fewer physicians would retire from health services in comparison to the previous year.

4.4 The Loop of Hospital capacity

In addition to the health workforce, this study also analyzed the impact of healthcare demand on the main component of hospital capacity utilization—that is, hospital beds. Available hospital beds are vital to house admitted patients (inpatients) who need further medical treatment at the hospital. Similar to the physician workforce, the accumulation of bed capacity also relies on the allocation of budgetary funds by the MOH, as shown by the negative feedback loop of B8 in Figure 5. Meanwhile, the negative feedback loop of B9 shows the pressure caused by the rising number of hospital beds due to an increase in the number of admitted patients. Bed capacity utilization is a vital factor of healthcare performance that is usually measured as the ratio of total inpatients to available beds [11]. This is because as bed capacity increase, the ability of the hospital management to accept more patients will also increase.

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5. Results
In this paper, the causal loop structure of healthcare supply and demand was derived. In particular, the current study focused on finding the key variables and their relationships, which was an appropriate further step in modelling. In this research, we identified the key parameter variables that are hypothesized in the literature and used them in developing a healthcare supply-demand simulation model. The theoretical underpinning and major assumptions generated in deriving and developing the model were also discussed in detail. Importantly, our conceptual model provided new evidence that the expected demand factor represented by the government’s budget allocation to hospitals seems to have triggered a desire among groups of citizens to seek care at public hospitals; this is separate from their regular need for medical care due to sickness. Based on the constructed model, we can also understand how the interactions in healthcare demand may affect healthcare utilization. There are important implications from the findings of this study about the substantial projected demand and need for healthcare across the country that will trigger challenges for hospital management. For instance, due to a projected increase in the population of Malaysia, an increase in patient visits will have major implications for capacity planning.

Accordingly, we can say that both healthcare budgets and morbidity and disease prevalence, which are respectively treated as medical demand and medical need, are expected to significantly impact healthcare utilization, including factors such as physicians, hospital beds, and medical costs borne by health providers. To validate the variables used, we asked for opinions from health researchers and modelers to ensure that the variables employed were reliable. The causal map included in this paper is also expected to explain approximate healthcare system behavior and provide a crucial implication in respect to the entire process. It is hoped that the information provided in this paper will be a useful initial clue for hospital managers and policymakers who are looking for ways to make leverage points to deliver better practices in healthcare management.

6. Conclusions and Future Works
Global demand for healthcare services is projected to continue rising in the future due to several drivers such as socio-demographic changes, the epidemiological change from communicable diseases to non-communicable diseases, high prices of medical technology, and many other factors. Improvement in healthcare accessibility will lead to a better quality of health services represented by physician and bed capacity utilization. In this research, we developed a causal loop diagram to help readers understand healthcare supply and demand interactions. The purpose of this model was not to make an accurate estimation for forecasting, but to understand the mechanism of the system through cause-and-effect interactions.

The general scheme of the dynamism of systems and the findings presented here would perhaps provide some ideas and directions for further study. However, it must be admitted that the model has yet to be refined and expanded by identifying more variables and analyzing their related data in a more rational manner. Those causal loop structures may then be converted and expanded into stock and flow simulation models in future works. This stage of model building is necessary for formulating and estimating the parameter value and equations of each element and the links identified in the models. In future research, we may also conduct a test of the model vis-à-vis historical data, and explore leverage points to improve patient flow and healthcare utilization, which seem significant to hospital management as well.

6.1 Contribution to Academia and Management Practice
In the study of principle of economics, social science researchers have been exposed and clearly introduced to the basic concept of demand and supply. The demand of certain product or services describing an economic agent (e.g. an individual consumer or firm) makes choices to pay for that product or services depending on the price of product or services itself or their incomes. Holding other things constant, when the price of goods or services increases, the consumer will reduce the demand, and vice versa. While the supply is defined as the interaction between the availability product or services and suppliers’ decision to determine the price of the product or services depending on their cost of production. In the supply of health care services, the production function of a hospital comprises of health labors (includes doctors, nurses administrative), hospital’s capital stock (includes hospital beds and diagnostic tools) and other inputs.

However, in the concept of health economics applying for healthcare service, the concept of demand for healthcare differs from demand for other product or services. In the most countries around the world, government acts as the main role in providing the quality of healthcare services to all citizens, especially to vulnerable peoples at a low price of healthcare products or services, where Malaysian public healthcare system offers low-cost universal costs to all legal residents. Moreover, theoretically, the concept of demand for healthcare derives from the desire to gain better health status or being health rather than being sick. In relation to the theoretical perspective, the current paper provides a valuable contribution to the study of health economics describing the conceptual model of the interaction of the healthcare demand and supply of healthcare for the case study of Malaysian public healthcare service.

The qualitative analysis presented by causal loop model in system dynamics offers a clear picture of the interaction among economic agents in which between patients and the main provider of public healthcare (in this case Malaysian government). The model would assist the public health and health care management to understand resource capacity and the bottlenecks of
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the health care system, thus, making a decision to improve the health care service prompted to a fact of the global demand for health care consistently to grow faster than the availability of health care supply. Significantly, the constructed qualitative causal loop models to assist future researchers and health care management understand the system complexities of healthcare delivery process.

This research also offers a starting point for future research in the healthcare and system dynamic fields in Malaysia particularly. Through the application of system dynamics technique, we can observe how does citizens’ reaction towards healthcare subsidies from government and their health condition would impact on the scarcity of healthcare resources. The usefulness of developing the system dynamic model, it would assist in exploring possible many side effect factors and understanding the unanticipated consequences of behaviour. As health care organisation and the systems will continuously deal with many challenges in meeting the rising demand of the finite resources, significant changes in their operation are necessary using system dynamics simulation to understand the effect of those changes in this kind of complex systems. The causal loop model illustrates a logic model that represents the interrelations among the key factors in both demand and supply models.

Appendix

The quantitative aspect of the system dynamics model can be evaluated by converting causal loop diagram model in Figure 1 (in section 3: Method) into the following stock and flow diagram:

![Stock and Flow Diagram of Population Growth Model](image)

Figure 6. Stock and Flow Diagram of Population Growth Model

From the above Figure 6, the state of population (initial population) represented by rectangular is known as a stock. Stock is a variable that can be increased or decreased over time. In the population model, the stock of population is accumulated or depleted by the variable births (inflow) and deaths (outflow) respectively. Both inflow and outflow variables are the only variables that can alter the stocks represented by the double line arrows directed into and out from the stock. The Loop named “R: Population Growth” explains the exponential growth of the size of the population in which the state of the population grows exponentially from its initial value at a constant fractional birth rate per time unit. In other words, increase in “births” will increase the size of population, and vice versa. On the other hand, the size of population in a country is also affected by the “deaths” in which will proportionately decrease the current state of population as shown in the loop “B: Population Decline”.

Mathematically, a state of stock at the time \( T \) can be expressed as an integration of the difference between inflow \( (t) \) and outflow \( (t) \) over a specified interval of time. Whereas, the flows typically are measured over a certain interval of time and can be viewed mathematically as the derivative of the stock with respect to the time, which is its net rate of change. In this example, the population model displayed in Figure 6 can be mathematically expressed as follows:

\[
\begin{align*}
\text{Population (T)} &= \int_{t_0}^{T} (\text{Births} - \text{Deaths}) \, dt + \text{Population (t_0)} \\
\text{Births} &= \text{Birth rate} \times \text{Population (T)} \\
\text{Deaths} &= \text{Death rate} \times \text{Population (T)}
\end{align*}
\]

where,

\[
\text{Population (T)} \quad \text{is the state of the current total population} \\
\text{Population (t_0)} \quad \text{is the initial total population at the time (t)} \\
\text{Births} \quad \text{is births at the time (t);} \\
\text{Deaths} \quad \text{is the deaths at the time (t)}
\]

Equation (1) explains the mathematical equation for the population, where the current population is the integration of the flow of births and deaths plus the initial state of population stock. Whilst, Births (or Deaths) variable can be calculated by multiplying birth rate (or death rate) and current state of the population as indicated in equation 2 and equation 3 respectively. The crude birth and death rate are the number of live birth and death occurring in a certain period of time. Based on the example of stock and flow diagram for population growth, it can then be apply by future researcher to construct the other stock and flow diagram of each close-loop models such as patient pathways, healthcare financial, physician flows and hospital capacity demonstrated in previous Figure 2 to 5 in section 4.

Once the stock-and-flow diagram of each submodels built completely, the entire healthcare system dynamics model can be simulated and validated using several model validation analyses to determine the fitness of the model with real-world data. Commonly used model validation tests are behavior reproduction test (as shown in Figure 7) and statistical comparative measurement test of the model structure, for instance, using the coefficient of determination r-squared \( (R^2) \), and the mean absolute percentage error (MAPE) as follows:

\[
R^2 = r^2 = \frac{1}{n} \sum \frac{(X_d - \bar{X}_d)(X_m - \bar{X}_m)}{\sigma_d \sigma_m}
\]

(4)
MAPE = \frac{1}{n} \sum_{i=1}^{n} \frac{|y_{mi} - y_{di}|}{y_{di}} \tag{5}

where, \( y_{mi} \) and \( y_{di} \) indicate the output of the model and the historical data respectively.

Figure 7. The illustrative of behavior reproduction test of population model in Malaysia over period 2010-2016

Note: Model and Data indicate the simulation model and historical data respectively

References