Doctoral Thesis

A System Dynamics Modelling for Healthcare Demand and Smartphone-based Technology Adoption in Malaysian Public Hospitals

March 2019

Doctoral Program in Technology Management

Graduate School of Technology Management

Ritsumeikan University

FATIN Aminah Binti Hassan

Doctoral Thesis reviewed

by Ritsumeikan University

A System Dynamics Modelling for Healthcare Demand and Smartphone-based Technology Adoption in Malaysian Public Hospitals

（システムダイナミクスを用いたマレーシア公共病院の需給管理とスマートフォン技術採用のモデリング）

March 2019

2019 年 3 月

Doctoral Program in Technology Management

Graduate School of Technology Management

Ritsumeikan University

立命館大学大学院テクノロジー・マネジメント研究科

テクノロジー・マネジメント専攻博士課程後期課程

FATIN Aminah Binti Hassan

ファティン アミナ ビンティ ハッサン

Supervisor: Professor MINATO Nobuaki

研究指導教員： 湊 宣明教授

ABSTRACT

Population rising with an ageing society, expanding income, changing in disease pattern owing to lifestyle behaviours, and many other factors are the reason why society is demanding on preventive and curative care. Persistent increasing in health care expenditure has put pressures on many governments in emerging nations, including Malaysia, to allocate more budgets on health care to meet the massive demand from their citizens. Concurrently, the proliferating in health expenditure has prompted better expectation from Malaysians on the highly subsidised public health care services as a primary source of care and medical treatment. These challenges, therefore, have called for the implementation of digital technologies, information technology and medicalised devices in health care industries as already embedded in other industries. Over the past decades, the Information and Communication Technology (ICT) has become part of our daily lives to make us more informed, connected and our lives become simpler. In the health care sector, ICT and digital devices- based health care are said to be an alternative tool to make health care system around the world becoming more affordable, safe delivery, efficient, and cost-saving for both the providers and patients.

The purpose of this research is to visualize the wide-ranging insights on the interaction between healthcare demand and supply with the presence of the smartphone adoption in Malaysian public hospitals over time. Specifically, the objectives of the study are: (1) To analyse a dynamic interaction between the demand and supply of health care resources. (2) To probe the substantial impact of smartphone-based technology adoption among health care stakeholders (e.g., patients and doctors) on health care service delivery and medical expenses. Based on the intervention results for the first objective, changes in the proportion rate of morbidity and disease prevalence has impacted the three main components of health supply utilisation, namely, bed, doctor and financing, in the same direction. Meaning that the increase

in disease prevalence will increase the utilisation of those health supplies. While the changes in budget allocation have increased the citizens' expectation in their demand for health care, which in turn has impacted on both bed and doctor utilisations in the same direction. Additionally, the last intervention analysis of answering the first objective is to seek for the impact of admission rate on health utilisation. Similar to the results above, this parameter proved to be capable of changing both utilisations of doctor and bed. On the other hand, a second analysis of the impact of smartphone adoption to health services and medical cost borne by providers is to answer the second objective. The analysis intervention of interaction rate through the changes in contact rate variable has proved that when more patients adopt STH, health consultation becomes more effective in increasing the number of patients discharged from the public hospital. Medical consultation is found to be vital to improve the number of patients being discharged from hospital wards, as the doctor-patient communication increases.

This impact is implicitly shown from the model through the effectiveness of health consultation using common available social networking applications. Moreover, the changes in the proportion of STH adoption patients seem to be significant to the perceived medical expenses borne by providers and the patient discharge rate from public hospitals, as an increase in the patient adoption fraction would be developed as a self-treatment mechanism using the mobile health application among the patients. Accordingly, improving hospital utilisation affects the potential of patients being discharged from the hospital, as they are able to monitor their vitality on their own. Significantly, the intent of this research is to comprehend future researchers, citizens, healthcare stakeholders how utilization of smartphone or any digital devices via optimizing the current state of our healthcare delivery in a whole system, rather than mere individual aspects. A guideline to public health and healthcare decision-makers to improve disease prevalence and public health finance of a country, as well as the guidance in managing its resources efficiently, are made available.

ACKNOWLEDGEMENTS

First and foremost, I would like to express my deepest thanks and appreciation to my supervisor, Professor Nobuaki Minato for his vast contribution, persistent encouragement and time spent through the whole-time of carrying out this research. Just as paramount, he has assisted me to be a better researcher and presenter. My sincere gratitude also goes to the rest of my Ph. D committee: Professor Shuichi Ishida and Professor Atsushi Aoyama for his insightful and constructive comments have been of great value to me and the final work as it is presented here.

I am also indebted to the assistance given by the staffs from the Graduate School of Technology Management, Graduate Research Office and International Centre of Ritsumeikan University. Their help has eased my burden and difficulties throughout the course of education here. I am pleased to acknowledge this research has been supported by Kokusaiteki Research Fund of Ritsumeikan University. I owe a lot of thanks to the Japan Student Services Organization (JASSO) and KENKYU-SHOREI scholarship for financial support to study at the Ritsumeikan University. My appreciation also goes to the Foundation for the Advancement of Life & Insurance Around the world (FALIA) for the granted prize-award of Essay Competition for the last two consecutive years.

Special thanks to my great friends: Dr Abdulla Ibragimov and Rawaida Rusli for introducing me to this great system dynamics methodology, and makes it possible for me to implement System Dynamics. A big thank you to Dr Jafri Zulkepli, for providing me information about utilization of system dynamics for healthcare in Malaysia and his easy-to-understand explanation about system dynamics model since before I come to study here. Their deep understanding of the system dynamics approach has been a great inspiration and brings me to study the methodology for my doctoral program here.

I would also like to thank my friend Rozzeta Dollah in Watertown, for her hospitality during my stay for the System Dynamics Summer School and Conference in Boston. Many thanks to all the practitioners in the system dynamics model, health economics and management for all constructive comments on my simulation model and research issues during my participation in abroad and local conferences. I also owe personal thanks to Ts. Dr Zuraida, Suliza Sumari, Dr Farizah Hairi, and MOH officers for their feedbacks and thoughtful advice throughout my research findings. Big thanks to my friend, Nurul Syafika for the contact information of public health consultants from her department and her moral support for me to finish this work.

I wish to thank my colleague of system dynamics, especially Dr Ilham Sentosa, Dr Nipaporn, Lan Ahn who have shared insightful ideas all along the way and guided me for using software tools. A deserve respects and appreciation to my best friends in Malaysia: Suhaila Saad, Hamizah Hamzah, and a group of International friends at Ritsumeikan University: Thia, Nopparat, Liu Feng, Hermy, Khairullah, Titan, Farah, Dessi, Ricky and more friends who always give me assistance, cook food for me and listen to my situation when I feel a little bit depressed and homesick. I am incredibly fortunate to have these friends who always give me a hand when I need them. I also wish to devote special gratitude to my Japanese friend, Yusuke Ohkubo for his continuous support and being patience for my unstable depression since we met for over 2 years. His understanding and warm support motivate me to finish this work.

Last but not least, I would like to devote endless gratefulness to my mother for her unceasing blessings, endless encouragement and inspirations despite my obsessive towards this research. As always, many thanks to other family members who always been cheerful and financially supporting me during my living in Japan. As this research now is concluded I can start to repay you a great debt of devotion and encouraging words. All of those are the prerequisite for the fulfilment of my doctoral journey in Japan.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF ABBREVIATIONS

ASEAN	Association of South East Asian Nations
BR	Birth Rate
DAF	Doctor Adoption Fraction
DOS	Department of Statistics
DR	Death Rate
GDP	Gross Domestic Product
ICT	Information and Communication Technology
IMF	International Monetary Fund
INP	Inpatient
MCMC	Malaysian Communications and Multimedia
MOE	Ministry of Education
MOH	Ministry of Health
MYR	Malaysian Ringgit
OECD	Organization for Economic Co-operation and Development
OPD	Outpatient Department
OUP	Outpatient
PAF	Patient Adoption Fraction
PLE	Personal Learning Edition

POP	Population
SD	System Dynamics
STH	Smartphone-based Technology for Healthcare
THE	Total Health Expenditure
UHC	Universal Health Coverage
USA	United States of America
WHO	World Health Organization
WOR	Walk-out Rate

CHAPTER 1: INTRODUCTION

1.1 Overview of the Chapter

Public hospitals serve as the primary gateway to the Malaysian healthcare system that struggling to provide better health services to the entire population in timely care to a gradually rising number of visitors. This first chapter outlines the overview of healthcare system around the world and the challenges. The characteristics of Malaysian health care system including health status, the performance, smartphone penetration was then particularized. The interrelation between healthcare demand and supply is discussed in detail with followed by the formulation of problem statement of the study, specify the research questions and objective of the study Finally, in this chapter will organize the structure for all chapters in this study.

1.2 Research Background

Economic analysis in health and health care is often undertaken with a view to helping governments and other agencies to better achieve the goals of their health policies. In economics, it is recognised that choices must be made, as not everything that is desired is attainable. Economists in all sectors are concerned with the allocation of resources between the competing demands (Samuelson & Nordhaus, 1998). Demands are assumed to be infinite, in which there is no end to the consumption. In contrast, resources like labour, raw materials, equipment, and land are always finite. Thus, the scarcity of resources in the sense of resource availability relative to the demand becomes the fundamental problem to which economists address themselves to (McPake, et al., 2013). When it comes to the demand approach, it is often thought to be based on the idea that an individual will consume a product and service depending on the concept of marginal benefit. However, in the health care industry, the consumer usually does not pay the full price of the treatment because the cost is frequently covered by the insurance companies or subsidised by the government. This means that the traditional demand approach in economic theory will not work appropriately for health care services.

Theoretically, health economists have broadly argued that the concept of demand for health care is a derived demand from the demand for health. Health care is consumed as a way for people to achieve a substantial stock of health capital. It is often argued that health care differs from other consumer goods because health is a necessity. A characteristic of health is that in some senses, it is viewed as a capital good. Investing in health will produce better health that remains for a long period of time, while health-damaging behaviour can cause it to be permanently lower (McPake, et al., 2013a). The demand for health is unlike most other goods because individuals allocate resources in order to consume and produce health. As most would prefer being healthy than sick, the demand for health care is part of the investment, where the money that you spend today on being healthy is for your own future benefits. Health is complicated; it has many dimensions. Human beings utilise their health for themselves, either to earn a living or to enjoy goods and services that are offered in life. In order to produce health, we can do a number of things, such as live healthier lifestyles and in better housing, eat healthier food, avoid contaminated water, stop smoking, do more exercise, take part in screening for risk factors or early symptoms of diseases, or have medical or surgical treatment. The conditions in neighbourhoods or cities also would profoundly influence the individual's prospects for having a healthy lifestyle. The demand for health care depends partly on how much we value health, and it is sometimes therefore described as a derived demand since the real demand is for health and the demand for health care is to help achieve the desired health. For some people, the demand for health care is a demand for insurance offering guaranteed access to care should the need arise.

Despite prodigiously improved in global health status over the past few decades, growing numbers of health system issues are one of the pressing discourses in many countries, particularly in those with emerging economies. Health services indeed deserve some of the commendations for the impressive achievements in health outcomes experienced in the developing world since the last few decades (Berman, 1999). In the present world's economy, the health care industry is among the most dynamic and rapidly growing industries. It is provoked by the demographic shifts and improvement in socioeconomic status such as growing population with extended longevity, and arise in lifestyle diseases such as hypertension and cardiovascular ailments, cancer, diabetes, and national health care costs that are growing dynamically. The role of health care expenditure on spurring the growth of a country's economy has been supported by Mushkin (1962), where it is known as the health-led growth theory. The theory affirms that health is a capital, thus, investment on health would, in turn, impact on the overall economic growth. The economic growth would then improve the state of the population's health through the purchase of medical care. Life expectancy is influenced by two analogously basic determinants, namely, health, and prosperity shown as income. The driving forces for these factors are characterised by the population structure national GDP (Sutrisno & Handel, 2011).

Over the past few decades, the world has seen major health advancements and as a result, people are generally living longer and healthier lives. According to Rosamond (2016), the number of people on the planet is set to rise to 9.7 billion in 2050, with 2 billion aged over 65. The rate of population ageing has been noted to grow faster in emerging economies than in developed economies. Thus, it will cause these countries to have less time to adjust to the repercussions of population ageing. A growing population with ageing peoples causes a great impact on the health care sector. A proliferating older population is associated with more demands on health care services, outpatient care and hospitalisation, and higher morbidity with a higher possibility of specialised care, leading to an increase in health expenditures.

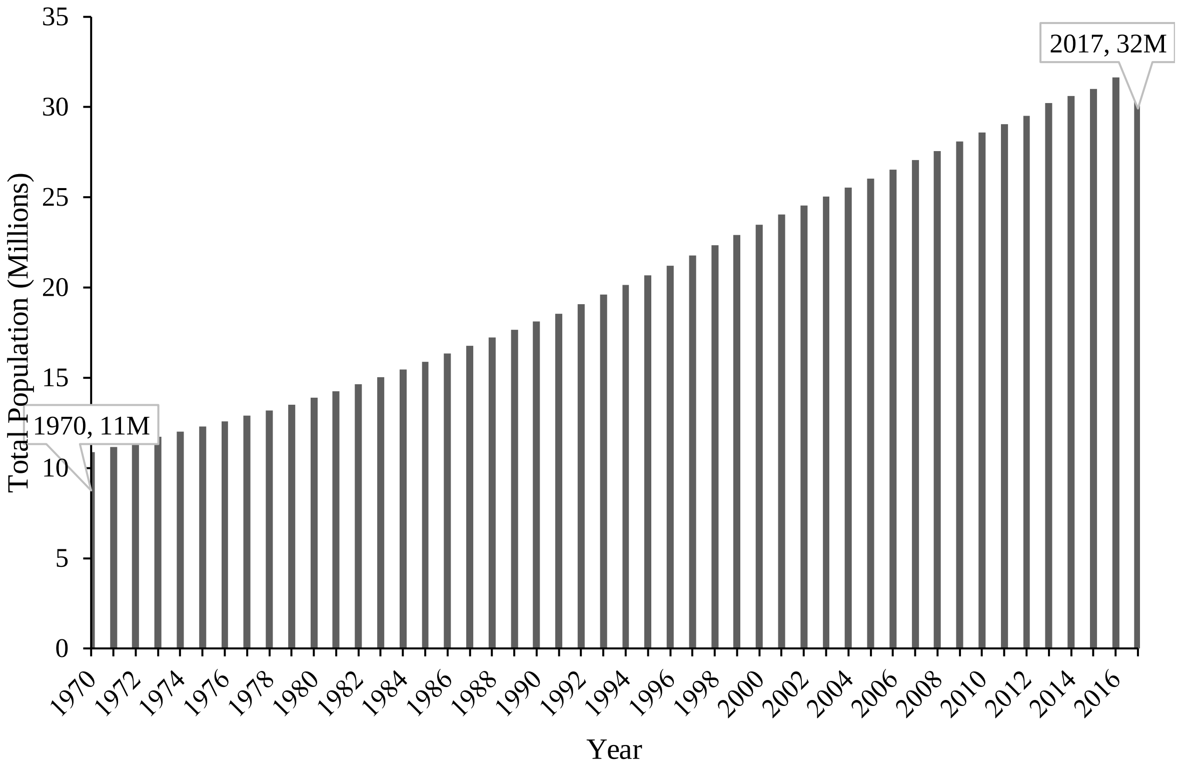


Figure 1.1 Total population over 48 years in Malaysia

Data source: Department of Statistics Malaysia Official Portal (2018)

In emerging markets, the growing health care demand is also driven by expanding middle-class population and rising income. As individuals become more affluent, they spend more on health care. A similar relationship exists across countries; high-income nations allocate a higher share of their aggregate and per-capita incomes on health care, compared to the middle-income nations. The health care system of developed countries is characterised by a substantial amount of funds devoted to public health financing, except in the United States of America (USA) and a few other developed countries, where private financing surpasses public financing. On the other hand, most of the developing countries generally suffer from a lack of financial resources and resources allocated to health, in particular. In the exception of some middle-income countries such as Thailand and Chile, these countries have very efficient and well-financed health systems. However, health financing in all countries is concerned with raising ample funds for the health care sector, abolishing the financial barriers to provide access to care, lessen the financial catastrophe of disease, and making better use of the available resources (WHO, 2010).

World Health Organization (2010) counsels that all the nations should provide the accessible and affordable of health care to their inhabitants equally. Many reforms have been raised to ensure affordable health care goods and services can be accessed to all their citizens. The escalation in health care financing is one of the vital responses to medical prices and disease patterns that are steadily rising. The increasing trend of health expenditure is triggered by several drivers of health care demand such as global ageing population, advance in medical technology, higher cost of health care services, and improvement in health financing management (Savedoff, 2004). At the same time, the industry has become a robust driver for economic growth and it can indirectly create a significant social impact. Higher value jobs can be generated, health care infrastructure and facilities enhanced, and both medical specialist skill and technology can be harnessed to improve the quality of care for patients.

According to Elizabeth Armstrong Moore (2015), the call to improve the quality of and access to affordable health care in emerging countries is affirmed, where almost three over four chronic diseases are occurring in low- and middle-income nations. The surge of the middle class in emerging nations will add more pressure. The region is thoroughly aware of the series of the challenges that they confront in delivering universal health care to 5.8 billion inhabitants. One of the challenges in financing health care is the public risk-sharing and insurance coverage mechanisms, for example, they tend to be paid for through taxes and working salaries that consequently made them substantially inaccessible to the 60–70% of those in emerging nations who work outside the formal economy. Additionally, the climb of chronic diseases in countries such as India and China presently has the largest number of diabetic populations in the world. Lack of preventive care and chronic disease management lead to sicker patients, resulting in more expensive care and adding more pressure to the financial side of things.

In most countries, the health care expenditure has observed a rapidly leap over the years. Health care expenditures of the percentage of national income (GDP) in Malaysia also appear to exhibit an upward trend. Malaysia has successively implemented health reform in financing health care through expanding its public health expenditures. Public health expenditure has begun to be a significant impression in most of the developed and developing countries. Both the supply and demand of health care determinants have been a driver of restriction to use public health services among the poor. Public health systems have better-controlled cost inflation than other types of system, but it is often argued that they are “under-funded”, leading to more rationing of essential care and poor-quality services. In the standard public health service system, funding is provided through general taxation and the system is characterised by public ownership, providers of care are given fixed annual budgets. The services are free to most citizens at the point of use of the service. These challenges are constantly related to the sustainability of health care funding, quality of care, and health care accessibility as well as medical resource efficiency.

On the other side, out-of-pocket payments, where patients are entitled to share the cost of treatment, have altered health services financing. Out-of-pocket payments have driven individuals to ponder on private insurance costs, as opposed to the benefits though it enables patients to reduce the medical treatments. The depletion in public health care funding is averse to the increasing out-of-pocket expenditure, resulting in the expanding revenue flow into private health care providers. It is reported that treatments received in Malaysian private hospital and clinics are paid roughly 79% directly by the patients, while only 18% will be given by insurance coverage (WHO, 2009). This discrepancy exposes patients to the risk of rising costs, especially the poor who are facing the burden of chronic diseases. Increasing costs in private clinics coupled with lower public health care expenditure are also skewing incentives from the medical doctors' viewpoint. The prime accountability of government around the world for the prosperity and well-being of inhabitants is strengthening of the existing health care systems (WHO, 2007), where the importance of public funds devoted to health care sectors has been statistically reported in most countries (OECD, 2011).

1.3 Problem Articulation

Aforementioned in the prior section, with a considerable increase the proportion of older peoples in the population, the dramatic rise of chronic diseases and morbidity prevalence, sociodemographic changes, and advance in medical technology are causing the proportion of GDP spent on health care to proliferate substantially. Like many other countries, Malaysia allocates a tremendously huge share of national gross domestic product to the health care sector. Rapid growth overall expenditure is particularly responsive to the changes in the rate of growth in spending for medical professionals and hospital facilities, as they are the substantial groups of health care resources. These pivotal matters have then demanded the execution of health-based information and communication technologies (ICT) to undertake the load of the country's prolonged budget and unsolved problems of expensive costs of health care, and the cumbersome of the quality of health care services. According to Marschollek et al. (2007), the ICT utilisation in health care has provided patients with more cost-effective health care through online prescription with their physicians from their home. ICT usage such as computerised devices, computers, the internet and many other communication tools could improve the quality of life of elderly people and provide cost-effective care via the providers.

The process of globalisation of health care has risen substantially, expedited by multiple factors since the last few decades (Retzlaff-Roberts et al., 2004). The internet has facilitated the spreading of medical information to both physicians and patients. Most industrialised countries like the USA is the largest exporter of health care technology and pharmaceutical products. These countries have another major issue of determining whether the benefits from the medical expenditure driven substantially by advanced technology will accrue better returns to the country. These issues might be due to technical efficiency [1]in utilising health care resources in relative to the achievement in health outputs. One resolution to breaking out of this negative cycle is to design a system around patients and bring care closer to them, as opposed to having to go to the hospital to attain it. It requires a whole rethinking of how care is being provided, in which a doctor is part of the team, not the centre. Information and Communication Technology (ICT) has become a critical tool in the delivery of health services and has had an innovative effect on the quality of life (Achampong, 2012). ICT demonstrates various opportunities for improving the health system performance of developing countries. ICT is believed to be capable of driving down health care costs and improve the effectiveness of health care services through disease management and patient safety.

Surprisingly, a surge in the number of advanced mobile devices since the past couple of years like tablets, smartphones and other wearables devices in the market is also going to be used in the health care sectors, as it is well-acclaimed to have eased our lives. At present, many health care providers, particularly in developed countries, are going mobile, as it would assist health care personnel such as doctors and nurses to handle a manifold of recurring duties, including transmitting referrals, receiving lab results and examine patient records. Mobile

[1] Technically efficiency is defined as output achieved maximization for a given level of inputs or when input is minimised for a given level of its output (Retzlaff-Roberts et al., 2004).

health (mHealth) technology has apparently become an increasing trend across the globe, as a recent survey reported an escalation of smartphone ownership that approximately 87% of peoples have a smartphone.

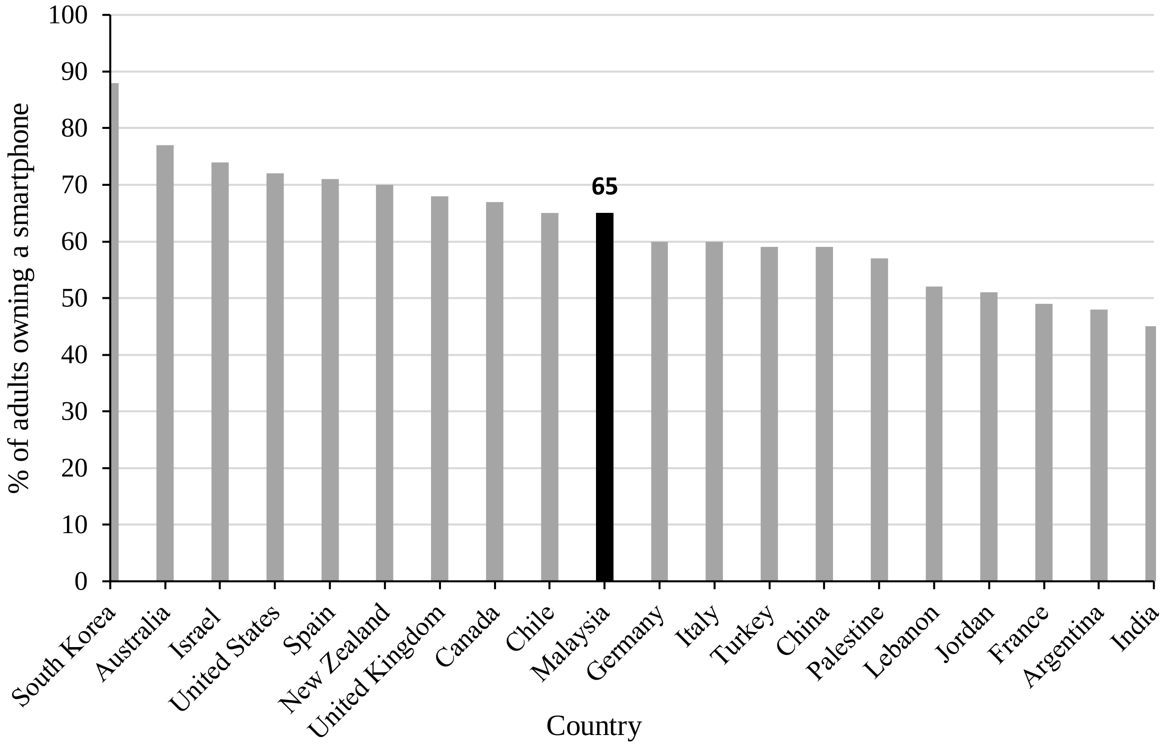


Figure 1.2 Percentage of adults owning a smartphone

This indicates that more people are turning to use their mobile device, particularly the smartphone, to perceive information about personal interests and health-related information such as diet nutrition, fitness, health insurance, mental health (depression, anxiety and stress treatment), and other specific medical problems and solutions. Besides that, the majority of the smartphone users use messenger and social communication applications such as email, Skype, messenger, and Facebook among others to converse with experienced medical consultants for preventive medical care, while the ill patients use it to discuss their vitals with their doctors and nurses (Jonathan, 2015). Smartphone also allows patients and health care stakeholders to access medical information from anywhere and at any time of the day. However, the smartphone-based technology for medical purpose is still a niche in the health care sector in most developing countries, particularly in Malaysia.

As we live in a world in which ICT has influenced the many aspects of our lives, in this paper, I have attempted to analyse the smartphone device as the driving force of health informatics between the health stakeholders. The smartphone is a device that can disseminate information through electronic media. Besides that, in the health care perspective, the smartphone is known as one of the powerful tools to make our health care affordable, more efficient and cost saving. Figure 1.2 deduces that about 65% of Malaysian adults own a smartphone, which is an indicator that smartphone is an important device for most Malaysians. There are several types of health-based information technology devices that are growing in its use in the health care sectors, such as telehealth and electronic medical records. However, this study is going to use smartphone devices as a tool to fit Malaysian public health services, as it is known to be a useful tool in making our life simpler.

1.4 Malaysian Health System

1.4.1 Country's Characteristics

Malaysia is recognised as a multiracial and multireligious country with a total population of about 32.05 million in 2017 (Department of Statistics Malaysia Official Portal, 2018). The population is made up of three major ethnic groups: Malay (61%), Chinese (30%), Indian (15%), and other ethnic groups (5%). According to the Malaysian Census 2010, the Malaysian population has reached 28.3 million with the proportion of aged 60 years and above reported to be at 7.9%, in comparison to the 3.9% population in the year 2000. This increment is parallel with the transition towards an ageing population of Malaysia. Unlike other developed Asian countries, countries in Southeast Asia still have a relatively less engagement in health insurance consumption and government health spending, but the region is rapidly climbing in improving their health system. Malaysia is viewed as one of the attractive countries in providing affordable and accessible medical tourism.

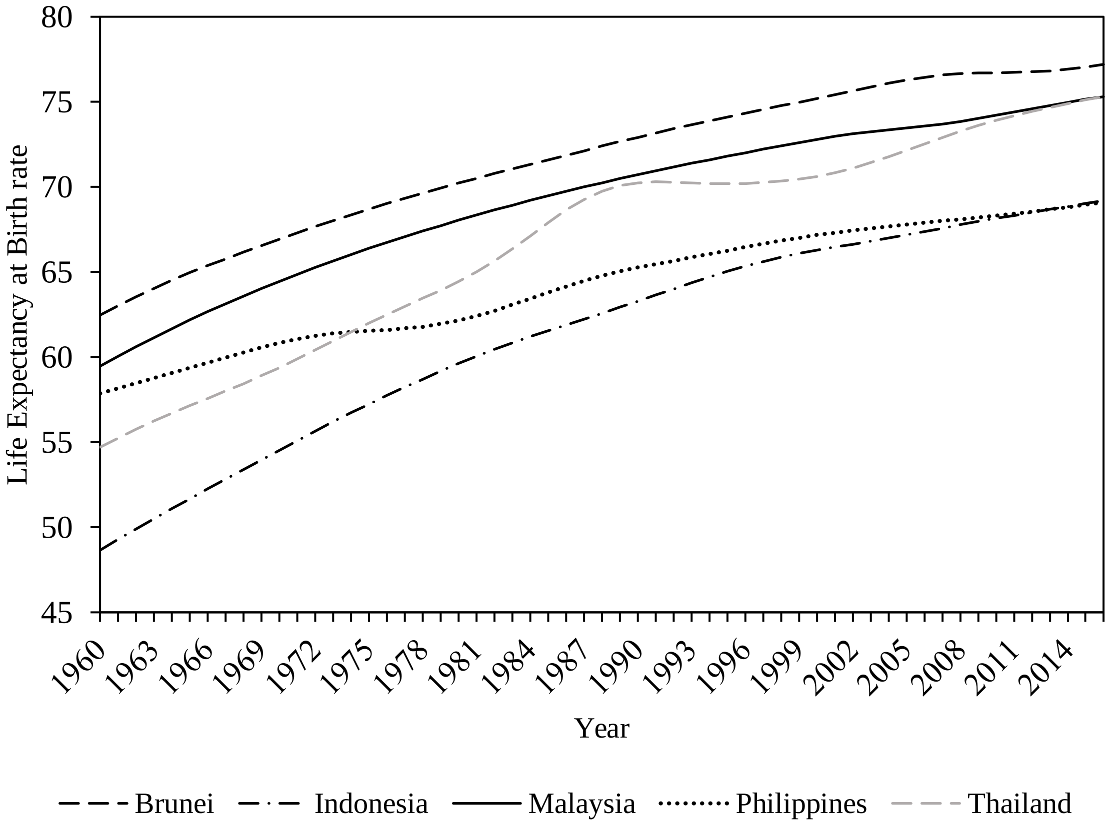


Figure 1.3 Life Expectancy Birth at Rate for five ASEAN countries

Key indicators of a human's well-being such as GDP per capita, life expectancy, illiteracy, access to water and sanitation, poverty, and trade openness have all improved since 1970. Malaysia's health indicator is demonstrated by the life expectancy rate in 2016, which is 75.3 years, second highest after Brunei (77.2 years) in comparison with its neighbouring countries. These trends shown in Figure 1.3 will sustain in its increment for most of the Southeast Asian nations, as their economies are gradually catching up. The World Health

Organization (WHO, 2000) has emphasised on the widespread concern with measuring health system performance. In most OECD countries, the health care system is the largest service industry and it has triggered increases in life expectancy (Retzlaff-Roberts et al., 2004; Anderson, Hurst, Hussey, & Jee-Hughes, 2000; Reinhardt, Hussey, & Anderson, 2002).

In Southeast Asia, the health care sector is going through an episode of revolutionary change due to the rapid growth of the economy, rapidly growing of the population, increasing affluent people that demand better health care, reformation in public health care, and many drivers of the new health care challenges. Health expenditure in the ASEAN region is about 4 per cent of their GDP, comparatively lower than the OECD countries of about 9.5 per cent. However, health expenditure in this region has increased 2.5 times between 1998 and 2010.

Figure 1.4 shows a brief description of the level of health care provision across the Southeast Asia region. As shown in the figure, Singapore is the only country in Southeast Asian countries that have considerable advancements in its health care system. Malaysia, Brunei and Thailand are said to have "good health care system", in which they need to pay attention to improving a better quality of the health care system provided. Health care system in several countries like Indonesia, Philippines and Vietnam are covering basic health care provisions with some challenges in providing the infrastructure and human capital. Meanwhile, the rest of other Southeast Asian countries, namely, Cambodia, Laos and Myanmar, where their health care systems still need immense development for their citizens.

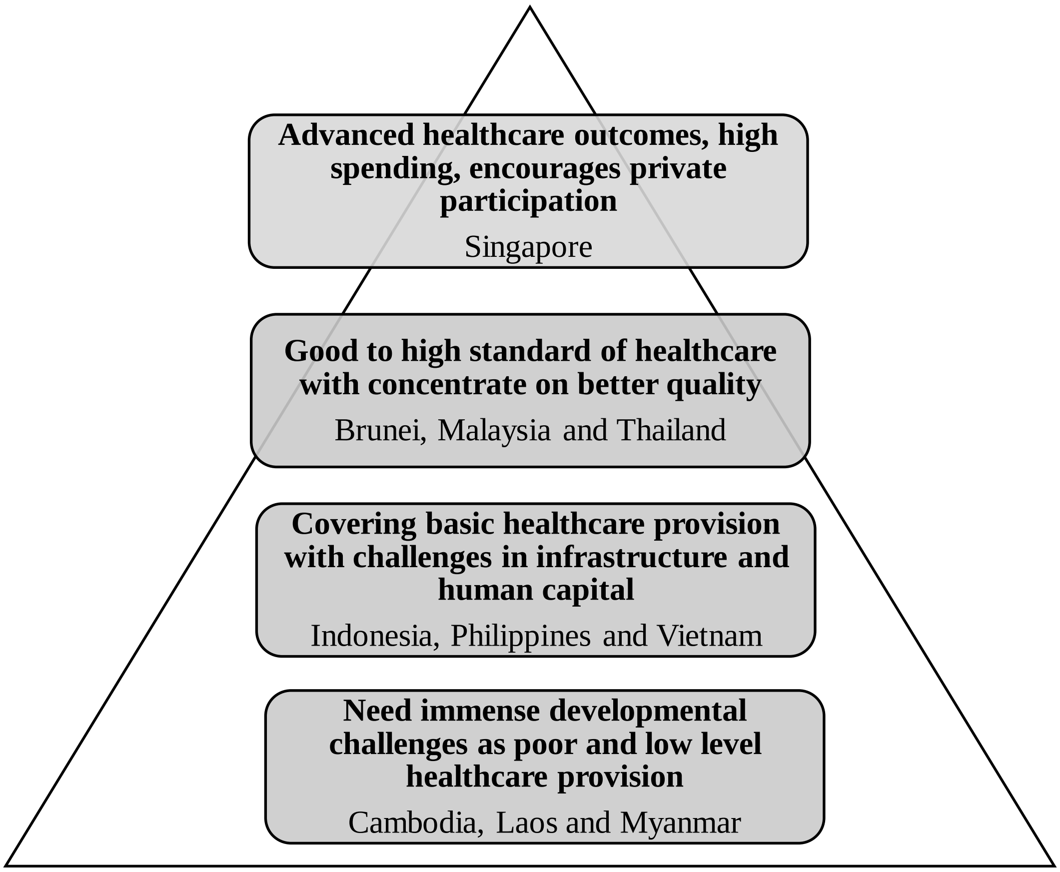


Figure 1.4 Snapshot of Health care system among South East Asian countries

Note: the figure is modified based on the source from "The State of Healthcare in South East Asia," 2013)

1.4.2 Health care in Malaysia

Malaysia has successfully performed a relatively better standard of care with a comparatively low total of health expenditure. Howbeit, as the country develops, the spending allotted on health care has risen and put pressures on its health care system. In recent years, health care costs are exponentially increasing to the changing in its demographic, disease patterns, implemented medical technologies and better expectation. This common trending pattern was also reported in other wealthier nations, burdening them in view of the health care expenditure. Therefore, due to of these challenges and dynamics intricacies of the health care systems, the Ministry of Health (MOH) Malaysia has proposed a framework for the health sector, named

"1Care for 1Malaysia (1Care)". 1Care is drafted in its aim to ensure an integrated health care delivery system that compromises the universal coverage of health care for the population with a better quality of care. The mobilisation of resources through private health care is one of the options open to the government that seeks to increase the availability of services and decrease the load placed on the public sector. This reform is specifically promoted by international agencies such as the World Bank and International Monetary Fund (IMF) to developing countries.

Malaysia is among the countries with the government funding and regulating its health care system heavily. Government health care operations encompass curative, rehabilitative, promotive, and regulatory matters. The Ministry of Health (MOH) is the prime government bureau that is responsible for the delivery of health care in Malaysia (Chee, 1990). Government provision is primarily intended to ensure access to care for the poor and reduce the financial catastrophe to those groups from having to spend their out-of-pocket savings on health. Outside the MOH, the other major government providers are the MOE-owned facilities, mainly, the university hospitals. Although they are officially part of the same governmental structure with similar regulations as that of MOH facilities, university hospitals have greater internal decision-making authority that is monitored by professors of medicine or medical representatives, rather than ceded to MOE bureaucrats. Usually, university hospitals have their own system of user charges that are different from the regulations by MOH.

1.4.3 Differences between Public and Private Health Care Sectors

Principally, the health care sector in Malaysia operates a dynamical, two-tier health care system that comprises both the public and private sectors (Hassan & Minato, 2017). Figure 1.4 shows that the proportion of total expenditure on health care is substantially coming from the public sector over the past twenty years.

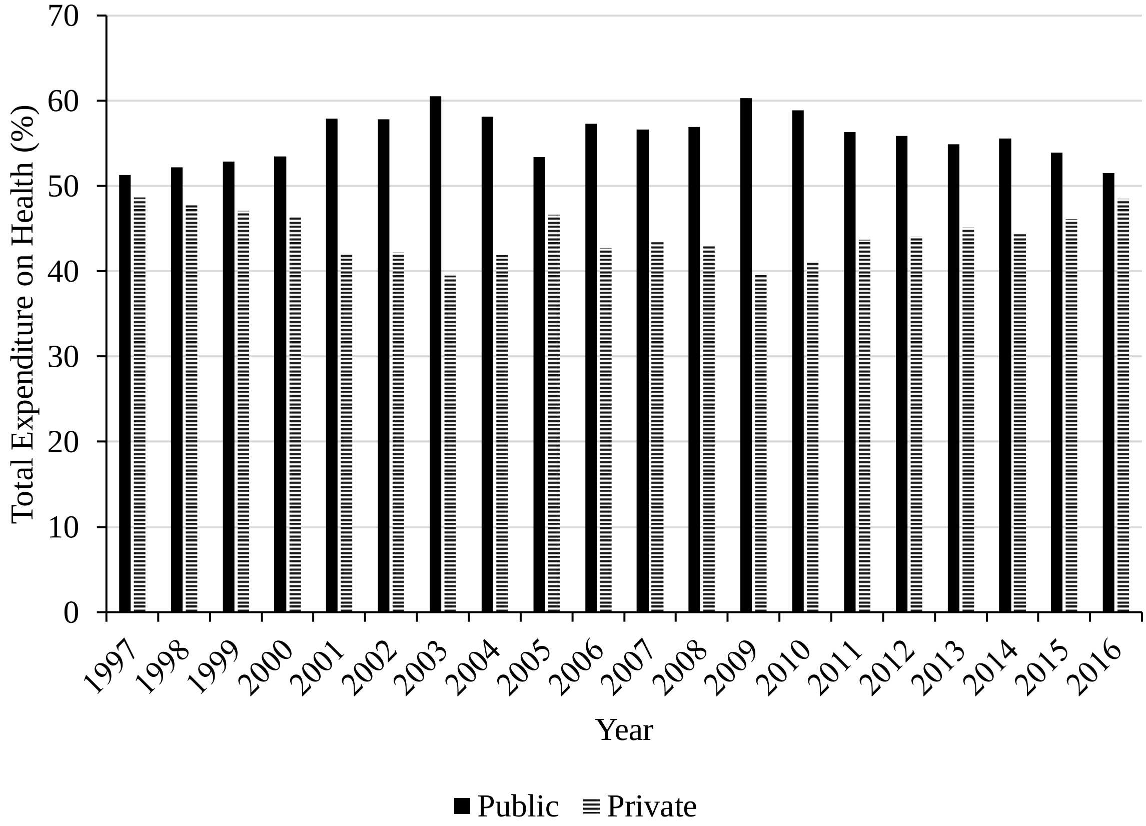


Figure 1.5 Health care Expenditure: the proportion of public and private sources of funds

Data source: Ministry of Health Malaysia (2017).

1.4.3.1 Role and Functions of Public and Private Health Services

In Malaysia, public health services play a critical role as the primary health care provider to the entire population, where they are hugely funded by the federal government, in which the source of finance is primarily from the tax payments paid by the affluent peoples. The focal point of the care services provided from this sector concentrates on health promotion, rehabilitative and curative care or treatment. Conversely, profit-oriented of private health services such as high-quality medical facilities and private-owned health clinics act as the second alternative care for medical treatment for most citizens, depending on their economic status and health conditions. Mostly, public or government health facilities are in situated both the urban cities and rural areas, where the ill who come to these hospitals only need to pay the nominal fee of treatment, and at times, the treatment given is free of charge to those who unable to pay. Overcrowding and overwhelmed with the number of patients in the outpatient departments and specialist clinics of Malaysian public hospitals is not a rare situation (Manaf, 2006), as the service provided is almost free for all the citizens, particularly to vulnerable populations like the elderly and poor. Congestion of these hospitals causes a dearth and pressure on the health services and capacities, and the waiting space is full of waiting patients. In terms of human resources, public hospitals are primarily run by the housemen and trained staffs, as they need to retain for three-year compulsory service.

On the other hand, private health facilities are principally located in metropolitan cities and provide expensive curative and rehabilitative care. In other words, in comparison to the public medical centre, private medical centres offer non-subsidised treatment that requires payment on a fee-for-service basis. These private hospitals might charge fees up to ten times more than public hospitals do, hence, it is one of the key reasons that is pushing patients to attend public hospitals. Furthermore, the public hospital caters a large portion of the lower income earners and public servants that would turn to the overcrowd phenomenon. However, private health services deliver better and high-quality treatments and health consultations with great facilities and high medical equipment and technologies, luxurious wards, and more availability of health personnel, including medical specialists. Private practices are mostly run by more experienced and senior doctors.

1.4.3.2 Relations between Public and Private Health Services

The mushrooming of private medical facilities are stimulated and supported by the government policy, as the existence of this sector would contribute to the country's economy and more specifically, to the nation's health care system. The crucial role of the emergence of private sectors in health care industry would lessen the burden of escalating public health spending and congestion phenomenon of sick patients at most government hospitals in this country; therefore, the private sectors are necessarily licensed by the Ministry of Health. Additionally, the rapid increase of private medical insurance businesses would assist to reduce the financial catastrophe of societies and during uncertain situations, to pay for the expensive treatment fee received at high-class hospitals. In recent years, many political discourses have raised an agenda related to transforming the country's health financial system for implementing national health system like in most other countries, where their citizens can go for any health services they wish to, either in public or private health sectors. Conventionally, both public and private sectors are crucial players in Malaysia's health care delivery system. Indeed, the private sector has also played an important role in delivering health care alongside the public sector.

1.5 Research Purpose and Objectives

1.5.1 Purpose of the study

In light of the unexpected consequences that the health care systems can bring, the purpose of this research is to visualize the wide-ranging insights on the interaction between health care demand and supply with the presence of smartphone adoption in Malaysian public health care hospitals over time.

1.5.2 Objectives of the study

The objective of the study will be further described more specifically, as follows:

i. To analyse a dynamic interaction between the demand and supply of health care resources

ii. To probe the substantial impact of smartphone-based technology adoption among health care stakeholders (e.g., patients and doctors) on health care service utilisation and medical expenses.

1.6 Research Questions

Based on the problem statement discussed in the prior section of this chapter, the study presents a system dynamics methodology to model the dynamic flow of patients in the Malaysian health care system, aiming at capturing better insights of the dynamic complexity arose by the system's varied parameters. To achieve the objective of the study, the study attempts to solve the following research questions:

i. How does the growing patient attendance at public hospitals affect the utilisation of health care provisions such as medical workforces, hospital capacity and health financing?
ii. How does the smart-health adoption among health care stakeholders impact the health care service and medical expenses?

To deal with the abovementioned research questions, this thesis focuses on the development of a framework to aid in the building of a simulation model that can assist in managing the public health services in Malaysia

1.7 Research Significance

The findings of this research will redound to the benefit of society while considering its important role in the country's economic growth and the person's well-being. The model, which will be created for this study, will be used to understand the underlying behaviour of the health care system in Malaysia. The simulation model showcases the dynamics of the healthcare system and the trending of the behaviour patterns with the utilization of the system dynamics methodology. With this understanding comes the ability to simulate policy experiments and perceive the effects on the system over time. Furthermore, it will further advance the literature covering on health care system in Malaysia and model-based studies covering the health care demand and smartphone device impact in academia. For researchers, it will help to uncover the critical areas of the health system that are yet to be explored. Thus, new perspectives on the impacts of policies on the health care system can be studied.

1.8 Research Structure

The fundamental structure of this dissertation is depicted in Figure 1.6 in which full thesis is organized into eight chapters as following descriptions.

Chapter one is the introduction and background of the study. In this part would tell the problem statements of study, research question, research objective, and the motivation of the study. Chapter two is a literature review which discusses the relevant literature of this study for identifying the gaps between the current study and former studies. Abundant of literature are reviewed thoroughly for building simulation model as well. This part also presents the theoretical framework that related to this study. Chapter three provides a description of system dynamic methodology as an appropriate modelling approach to adopt in current research. Chapter four provides the conceptual framework and causal loop diagram of smartphone-based healthcare technology adoption in Malaysian Public Healthcare services is further designed to gain a basic comprehension of the interaction among sub-systems. Data sources, types of variables and time horizon applied in this research also explained in this chapter. In chapter five, the whole simulation model of smartphone-based healthcare technology that depicted by stock and flow diagram is analysed in detail. The development of a simulation model is built based on the insights gain from previous chapter three. The results of model testing comprising of the behaviour reproduction test, dimensional testing, and analysis of statistical test to certain parameters also presented in this chapter. Chapter six discusses the finding of the analyses demand and supply of health services in order to answer the first research question of the study. Chapter seven discusses the discusses the finding of the Analysis of Smart-Health Technology

Adoption in order to answer the second research question of the study. In chapter eight, the conclusion and suggestion for future work in the field of the health system are presented.

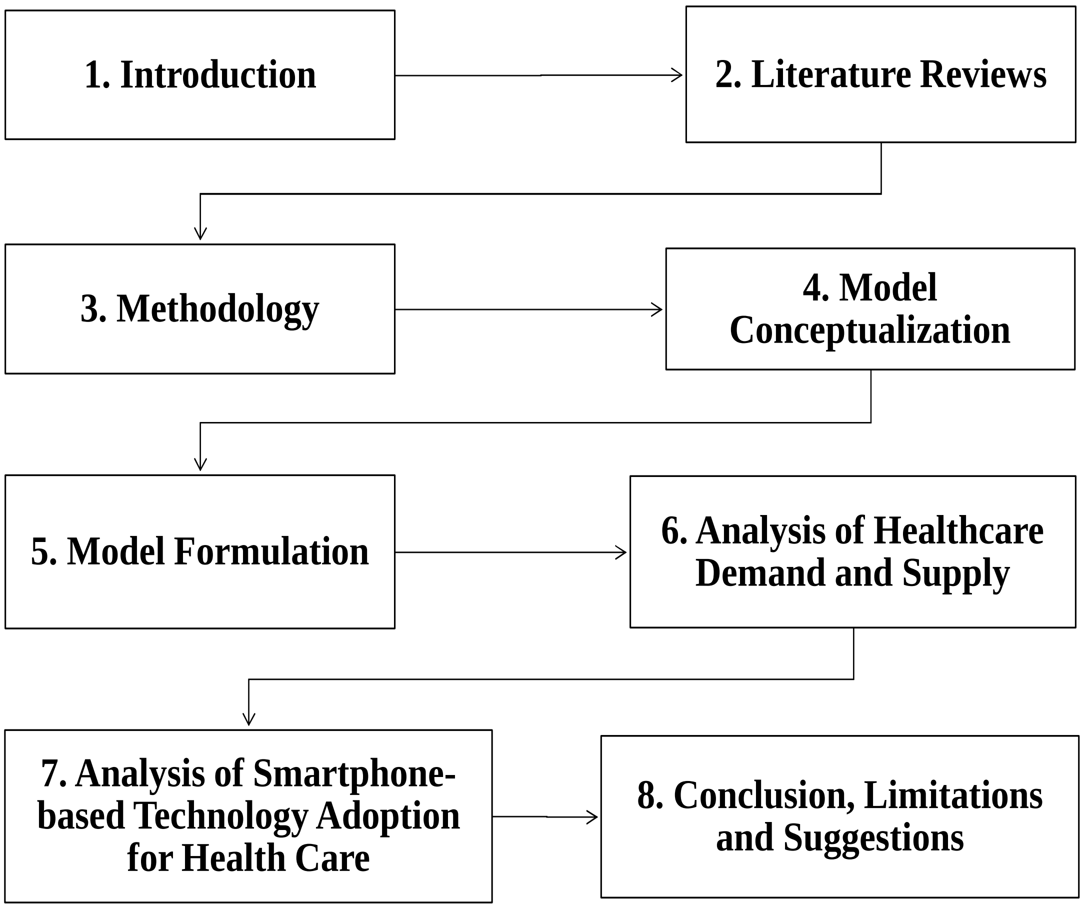


Figure 1.6 Research Contents

CHAPTER 2: LITERATURE REVIEW

2.1 Overview of the Chapter

This chapter reviews the theoretical and empirical literature on healthcare demand, healthcare supply, technological adoption. The development of this chapter starts with an economic theory of demand and applies it to health and health care. Empirical researchers investigating the interaction between healthcare demand and supply also reviewed to identify the gap in the literature to justify the present study. The following literature reviews, along with the principal information on healthcare demand and supply presents the former works underlying the logic and assumption of the model. This chapter also includes novel literature to the fundamental of system dynamics as practices in healthcare systems around the world. Besides that, this chapter also highlighted a few studies in relation to the application of system dynamic used in the health and healthcare issues in Malaysia. My studies, therefore, would like to emphasize three aspects of research gaps that have been found from the existing studies, and henceforth providing the originality of the study.

2.2 Theoretical Literature Review

This theoretical section provides the aggregate of the production of health by understanding the impact of various determinants on health in our society as a whole picture. How individuals allocate their resources will be seen in this chapter. A deepened understanding of the work by Michael Grossman has been well accepted by many economists and in particular, the health economists.

2.2.1 The concept of Demand for Health Capital

The prominent theoretical framework in the area of health economics and public health studies with regard to the demand for health care was first introduced by Michael Grossman in 1972 to describe the demand for health and health capital. Several prior researchers have used different terms for conveying similar theoretical analysis of Grossman's demand for health capital, such as "health investment theory" by Rizzo & Han (2012) and "the productivity of health care" by (Koç, 2004). Grossman has developed a model demand for health in terms of "good health" and provided a solution of the dynamical optimisation problems in regard to the pathways of optimal health life-cycle, the gross investment of each time spans, and the consumption of medical, in which they are viewed as derived demands for "good health". The theoretical model paid more attention on the concept of health and health investment, providing us a profound comprehension on the significant role of several factors such as the individual's age, education level, level of health status, and income level in the production of health via the demand for health capital (Hassan, et al., 2016). His model attempted to find a solution for the following question that had been raised:

> *"How do a person's age, education, health condition, and income level impact on the production of health via the demand for health capital?"*
>
> (The Concept of Health Capital and Demand for Health, Grossman, 1972)

Human capital theory delineates that an individual usually attempts to invest their productivity through getting education, training and taking care of health to increase their income earnings (Folland, et al, 2007). Furthermore, Grossman provides us with the difference between the concept of health demand with traditional demand theory for other products and services or concept of human capital that has been found in many economic textbooks for an ordinary individual, like the following:

i) The stock of knowledge and health would impact upon its engage in the market or non-market activity. He explained in regard to health-improving efforts, where peoples do not merely buy health directly from the market, but they also need to produce by allocating their time and efforts on working to earn money in order to purchase medical inputs. This means that an individual's health status and education level represent the number of time they can utilise in producing income and goods. Health is produced in the amalgamating of both time and buying medical inputs.

ii) People's demand for medical care is not a service per se, albeit to producing good health. In other words, medical care is defined as the derived demand for health, where medical care is an input of the production of health output. Therefore, people will demand medical care inputs such as visiting health services, physicians, nurse, equipment, and both modern and alternative medicines in order to gain better health output that refers to a healthy life.

iii) People's health lasts for over than one period. Meaning, health does not depreciate instantly, and hence, it is assumed or described as capital good.

iv) Health also assumed or treated as an endogenous variable in which people could improve their health through the consumption and investment of goods. Health is viewed as the consumption of goods that specify the level of health desired because it will cause people to feel better. On the other hand, health is viewed as a good investment because good health would increase the number of healthy days, thus enabling an individual to work and earn income.

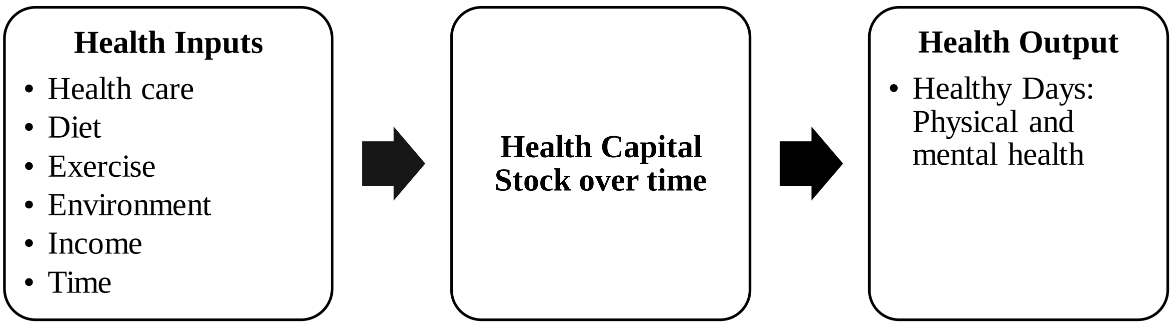


Figure 2.1: The process of investing in health

Source: Adapted from Folland, et al. (2007)

Figure 2.1 above depicts the process of investment in producing health. Folland, et al. (2007) explained the concept of the consumer as a health producer based on Grossman's view of the demand for health capital. In traditional economic theory, a production function simplifies the links between inputs and outputs. In the concept of health as a good, health output production is a function of inputs of health such as health care, diet, environment, income, and other input factors together with the stock of health capital over time. Depending on an individual's age, diseases or morbidity, health capital stocks that supply health output will probably grow, decrease or remain constant over time. Health also viewed as a capital stock because it is influenced by time and the individual's age, as it will depreciate once people get older (Hassan, et al., 2016). Grossman's health model in producing health and other inputs are mathematically viewed as the concept of the consumer utility function for other goods in traditional microeconomic theory. As laid out in the original Grossman's health model (1972) in producing health and other home goods, the utility function of health for one person can be mathematically modelled following Equations 2.1 to 2.4. Basically, these modelling equations are known as, "model of time spent in producing health capital and other consumer goods."

$$\boldsymbol{U} = \boldsymbol{U}\,(\delta_t H_0, \ldots, \delta_t H_t, B_0, \ldots, B_t) \tag{2.1}$$

where,

H_0 is the inherited stock of health,

H_t is the stock of health in the *t*he period,

δ_t is the service flow per unit stock,

$\delta_t H_t$ is the total consumption of health services,

B_t is the total consumption of other goods and services besides health in the *t*th period.

An intertemporal utility function, the length of life is considered does not change and acted as an endogenous variable. Thus, length of life is influenced by the amounts of inherited stock of health (H_0) to maximize the utility subject to production constrained. Therefore, net investment in the stock of health is calculated as the difference between gross investment and depreciation:

$$H_{t+1} – H_t = IH_t - £_tH_t \tag{2.2}$$

$$IH_t = IH_t\,(M_t, TH_t, E_t) \tag{2.3}$$

$$B_t = B_t\,(X_t,\ TB_t,\ E_t) \tag{2.4}$$

where,

IH_t is the gross investment on health,

$£_t$ is the rate of depreciation during the tth period. The rates of depreciation are assumed to be exogenous and vary with the age of the individual. This rate also might be a negative function of stock of health.

M_t is the medical care which can be referred market health inputs such medical technology, general practitioners, drugs, and many health inputs

TH_t is time spent in the production to improve health

E_t is the stock of human capital

B_t is other goods produced such as reading, playing, working, sleeping and many other home goods

X_t is the other good input in the production of the commodity B_i

TB_t is time used in producing other goods

In principle, medical care inputs are not merely the market good in the gross investment production function as shown in equation 2.3, but inputs such as housing, diet, physical activity, individual's self-behaviour like smoking and alcohol consumption are also impacts on individual's health. However, in the paper of "The Concept of Health Capital and Demand for

Health", Grossman emphasize medical care inputs as the key factors of his health model and treated as the most valuable market good in the gross investment function. The model also assumed that all production functions are homogeneous of degree 1 in the goods and time inputs. Therefore, the gross investment production function for health can be re-written as:

$$IH_t = M_t\, g\ (\phi_t;\ E_t) \qquad (2.5)$$

$$\phi_t = TH_t / M_t. \qquad (2.6)$$

2.2.2 The concept of productivity of health care

The version of the aforementioned traditional Grossman's health consumption theory has been widely simplified by the other prominent health economist, Adam Wagstaff (1986), who has redeveloped far beyond the concept of demand for healthcare in the early 1920s by Koç (2004). The paper has provided a theoretical analysis of health care productivity and identified the necessary and sufficient conditions for the relation between the effect of medical technology and health care demand elasticity. In addition, he also offers a broader group of production functions such as schooling, health production efficiency, and technology effects, in comparison to the previous Grossman's theory, which is expected to be useful for future empirical research of health production functions. In his model, a person's health is influenced by the health production function, whereby the direct inputs considered here are the quantity of health care, food, diet, eating habit, and many more. The mathematical equation of the basic utility function is a function of health and consumption can be expressed as follows:

$$U\ (c, H) \qquad (2.7)$$

where,

U is the quasiconcave utility function;

H is health

c is consumption

Whilst, health production is a function of the quantity of health care (*m*) and the productivity of health care (*s*) as shown in the following mathematical equation:

$$H\ (m, s) \tag{2.8}$$

Where, the quantity of health care herein is defined as health care services, for instances, the number of specialist visits or the length of stay in the hospital. Thus, the herein conceptual motivation of this research is based on Grossman's demand for health capital theory and Wagstaff's productivity of health care as discussed above. The state of health is based on the form of human capital and medical care inputs represent as health resources and services available such as medical expenditure, a number of doctor and number of beds are the key inputs into person's health.

On the other hand, the supply of health care facilities depends on internal and external factors. The internal factors are the availability of funds, government subsidy and encouragement, the existence of medical personnel and drugs, et cetera. The external factors are the demand for health care, the existence of pharmaceutical companies, laboratories, blood banks, et cetera. As the demand for health care services is inelastic, the supply of health care services is also inelastic. In general, the production function is a function of the labour, capital and intermediate inputs. In health care service sectors like a hospital, the production function of the hospital would comprise the following elements:

i. The labour in a hospital includes doctors, medical specialists, nurses, technicians, administrative staff, and many other types of health care workers;
ii. The capital stock of hospitals would be hospital beds and any diagnostic tools and machines;
iii. Intermediate inputs in a hospital include medicine or any raw material;

iv. Technological advances in the production of health care outputs comprise both the product and process innovation. For example, advanced machinery that is used in health care facilities.

Some health care suppliers have significant market power, which presumes that firms seek to make as much profit as possible in accordance with the standard economic theory. However, for some health care suppliers such as government-controlled hospitals or non-profit health care institutions, profit maximisation may not be their goal. Therefore, the price of health care services is not certainly determined by the demand and supply of health care market, where the health care prices are set up by the government of one's country. Accordingly, the demand for health care service is an inelastic demand, as the quantity demanded does not respond to the changes in health care price, which is the characteristic of health care as a public or necessity good. Health care as a necessity good is applied when we are sick and in need of treatment; it will be likely that the ill and sick will purchase health care service at almost any health care cost. Though the intention to purchase medical care is ultimately constrained by an individual's income, we are likely to trade off on medical care over other consumer goods.

2.2.3 New Product and Technology Diffusion Model

Diffusion of new products and services in a potential market has been greatly studied in the former literature. The diffusion model estimated the number of adopters of new products or services. One of the prominent adoption models was introduced by Bass Model (1969), who has broadened the innovation diffusion theory by Rogers (1962). The Bass Model is based on the behavioural assumption that the probability for a new product or services being adopted in the period, *t*, is a linear function to the number of previous adopters, A_{t-1}.

$$\mathbf{P}(\boldsymbol{a}_{\mathbf{t}}) = \boldsymbol{p} + \boldsymbol{q}\,\frac{\mathbf{A}_{\boldsymbol{t-1}}}{\boldsymbol{M}} \tag{2.9}$$

The probability is constituted of two influences; the first influence is on the rate of innovators, *p*, who adopt the product independent from the number of previous adopters; the second is indicated by the rate of imitator, *q*, whose adoption is dependent on the share of past adopters by the total market size, *M*. The share has been described as a probability of contagion or word-of-mouth from adopters to non-adopters.

2.3 Review of Empirical Literatures

Numerous research studies have shown interest in the field of public health, health economics and health care management. Different types of methodologies have been applied such as econometrics, system dynamic simulation model and other simulations to solve the obscurity of this field. The study reviews published and unpublished reports on the interaction demand and supply of health care provision. In the prior sections, the concept of health and health care, or sometimes referred to as "medical care", has been applied more theoretically than empirically. The number of theoretical works on the uncertainty of the capital stock of health has surpassed the number of empirical studies. In particular, there is a lack of literature in relation to the health care demand, supply and technology interaction in developing countries than in developed economies, including Malaysia. Their findings are reviewed in this section.

2.3.1 Health care demand-side drivers

The study of demand for health care has a long history. An important starting point for much of the subsequent work was the framework suggested by Grossman (1972). His model took into account some of the special characteristics of health, which were both the consumption and capital goods, and that it was in part a derived demand (McPake, et al., 2013b). The wide reports of previous works on the drivers of demand for health and health care such as ageing population, improvement in socioeconomic conditions, one's health status, technological advances, health system characteristics, and many other factors. Health care is composed of myriad products and services that sustain, ameliorate and rehabilitate a person's health. The individual's state of health has caused them to demand health care, where sicker people tend to attend medical facilities to seek treatment in an attempt to increase the overall stock of health. Fuchs and Frank (2002) discover a high utilisation of medical care, both in outpatient and inpatient care among residents who live in highly polluted urban areas in the United States. The demand for health care projected had risen substantially with the swift growth and ageing population (Wren et al., 2017). According to Trellevik (2008), a larger proportion of the population exerts increased pressure on the health care system in Bergen. The ageing population is the pronounced challenge confronted by health policy makers since chronic diseases are most prevalent amongst old people aged around 65 and above. They are, in particular, the largest contributor to hospital admission *(*Ng, et al., 2011*)*.

2.3.2 Health care supply-side drivers

Health is one of the crucial factors to determine the economic development of one's country, as a healthier person is more productive and robust than a sick individual. They can earn higher monthly salaries than those who are absent from work due to sickness. Therefore, healthier citizens provide more economic advantages to their country (Bloom, et al., 2004; Taskaya & Demirkiran, 2016). In this regard, many policymakers of countries attempt to assure the population achieve good health by increasing the investment in health care systems (Imoughele & Ismaila, 2015). Consequently, health expenditures in countries all over the world are seen to have been proliferating substantially. Health expenditures primarily include all expenses for improving health status (Martín et al., 2011; Rengin, 2012). According to Hassan & Minato (2017), public health financing allocated by the government of one's country is vital to improve the population's health status through health care facilities and resources.

Human resources for health are the other indicator that influences health expenditures. A number of doctors play a key role in health services' demand and supply, which in turn lead to the rise in health expenditures due to higher human resources investment on health (Taskaya & Demirkiran, 2016). Another driver that impacts the health expenditure of one's country is the hospital bed. Increasing hospital beds have driven the increment of health expenditure. Giannoni & Hitiris, (2002) found that the number of hospital beds has a positive contribution to the expenditure on health care in their empirical study. However, technology is a prominent supply-side driver of health spending. Recent studies estimated that advanced technology applied in medical care has contributed to USA's health expenditure growth between 27 to 48 per cent since 1960 (Smith, et al., 2009).

The health status of a country also relies on access to the quality of health care. Retzlaff-Roberts et al. (2004) argued that advances in health care and the extension of access to quality care have expanded the quality and years of healthy life of the population in many advanced economies. They modelled access to medical care, physician services and proportion GDP allotted to health care as inputs to the production of health using the DEA approach. In line with other studies by Grubaugh & Santerre (1994) and Smith, et al. (2009), physicians and inpatient beds as major medical inputs are represented as access to health care. Hospitals are the main resources of health care in the health sector for patients to seek preventive and curative care. Hospital congestion is a serious issue that would threaten the patient quality and the bottling line of the country's health system. It was brought on by increased demand for public health care services. The demand for health services and resources has risen via the patient attendance, which then turns to impact on the health care budget to increase the health care resources to meet these needs (Ng, et al., 2011).

A negative view holds that the supply side is largely resultant from financial incentives deriving from consumer behaviour; this means that the supply-side is the dependent variable

(Berham, 1999). He states that a health care provider is a recognised legal or administrative entity that organises and manages the production of health care services. Health care providers can range from simple to very complex entities. They can be categorised as individual practitioners who work out of their homes with less complex inputs, to large entity hospitals with thousand employees and capacities. In other words, health care providers may be individuals or organisations. A "provider" can be defined as both a direct producer of health care and governance that carries out activities and controls certain critical functions, which would enable this direct production of health care services. Health care comprises a diverse set of products, which is probably catered in diverse settings. Broadly-defined health care provision analyses will pick up a variety type of providers. Therefore, policies that address the supply issues to improve health care are often focused on a specific type of services (Berham, 1999).

2.3.3 Interaction demand-side and supply-side drivers

Health care demand in many countries is greatly increased by the rapid growth ageing population along with decreasing of fertility rate, changes in socio-demographic status, rising of non-communicable disease due to lifestyle, advances in medical technologies and many other drivers that would trigger people to seek for treatment. According to Trellevik (2008), a larger proportion of the population exerts increased pressure on the health care system in Bergen. The abundance of research has probed the critical role of health financing in improving the health status of individuals. It is proven that expanding the financing in health has had a positive significant impact on the mortality rate reduction and improving life expectancy rate (Berger and Messer, 2002; Grosskopf, Self and Zaim, 2006; Gani, 2009; Besstremyannaya, 2009). Increased health financing generates a reduction in mortality rates, as better and additional health services are supplied such as insurance coverage scheme. That being said, a rise in the health expenditure would probably increase the mortality rates if the health resources were operated inefficiently. Health financing governances should be concurrently invented and a wide-range issue concerning to governance has to be addressed before health financing mechanisms, for example, public hospital funding, medical care options, and out-of-pocket expenditure can be weighed up for implementation (Butler, 2010). In contrast, increase of health care spending from an individual's out-of-pocket would cause financial stress on their monthly incomes, consequently, bring about poverty prevalence among the poorest group of the society in a country, which can be particularly seen from what is happening in many low-income nations (Hamid, et al., 2014).

According to Hassan & Minato (2017), the study of the financing of healthcare is crucial as it is an important component in a healthcare system that would help to reduce the financial risks of individuals and thus improve their health outcomes. Most of the emerging economies including Malaysia are confronting several typical challenges to achieving universal healthcare coverage (UHC), namely: financial constraints, limited in doctor and bed supply and last but not least is the happening epidemiological transition such as infectious diseases and increasing non-communicable diseases. Therefore, financial risk protection like medical insurance and social insurance would prevent sick individuals and their family member from being pushed into poverty as they doubt either to pay for the treatment of care or to spend on other goods from their own pockets.

According to Grosskopf et al (2006), even developed countries have performed better than less or least-developed countries in utilising public health expenditure; it does not certainly mean that as a consequence of depending on a larger share of public health care funding. While out-of-pocket health financing has negatively impacted the health outcome, a curtailment in public health care spending will affect the well-being of an individual's health status and coerce them to pay for the health care services from their own pockets. World Health Report (2010) explained the risk and uncertainty of health care that have daunted people from seeking preventive care, albeit, they prefer to expend their pocket money on curative care. Human resources for health like the number of physicians and nurses, for example, are the vital resources to determine health expenditure. The number of health workers causes to improve health outcomes and have a minimal negative impact on health conditions. The number of physicians and specialists plays the critical role of the demand and supply side of health services. However, these changes need more investment in labour resources in the health care sector (Amiri and Gerdtham, 2013). The rising of human resources for health care leads to escalating health spending. Traditionally public health care service owned the physical resources to supply service. The number of doctor per 1,000 population was positively affected by health expenditures (Taskaya and Demirkiran, 2016).

2.3.4 Technological devices adoption in Health care Settings

Study on the important role of technology to health care sectors has been widely discoursed and received great attention in many countries around the world, especially in recent years, in developing countries. Discussion on this matter in Malaysia has also not been left behind. Many Malaysian policy stakeholders and researchers attempt to recognise the significant role of technology devices and information of technology to adopt in the health sector. For example, Zahra, et al. (2016) attempted to identify the influence factors of utilisation for mobile health applications for chronic diseases. Non-specifically account for a device of mobile-based health care technology, Haenssgen & Ariana (2017) investigated the interaction between mobile phone adoption and the behaviour of rural elderly people in low-middle income nations to access to health care. They argued that the use of mobile device for medical care purposes sounds complex and a dynamically time-consuming behaviour. Yet, they underlined that the health care researches on the adoption of mobile devices are still relatively limited and incomplete. They also recommended that future health care studies should consider the causal links addressing the relationships between both aspects. In the same year, research by Varabyova, et al. (2017) has had a similar point of views that examining the factors of medical technology adoption often demands for laborious time and effort for data gathering through surveys and case studies. Usually, the data for this kind of study is not readily available or accessible.

The negligence to elucidate the interrelations between the innovation and the behaviour of adopters and their environments has been reported as one of the major limitations of prior literature. Typically, the interaction between the elements eventuate in a complex system and non-generalisable process, thus, it is problematic to analyse in the statistical model or in quantitative ways. Accordingly, they strongly urged future related studies to conduct a more detailed qualitative analysis, in which it would consider the complexity of environmental factors into the analysis of factor adoption. The qualitative analysis would take into account the dynamic interactions among the adoption factors and the impact of technology on medical expenditures.

2.4 Review of System Dynamics Literature

Complex problems mean a variety of elements and interdependence, non-linearity, inability to understand, and uncontrollability, in which the solutions would cause other problems and unintended consequences. Many health care literature reviews addressed the added value of simulation methods to be applied in health care issues. Simulation modelling is explained as the process of developing a model of the real-world system, performing experiments on the built model to understand the behaviour of the system and assess the different strategies for the performance of the system (Shannon, 1998). Simulation approaches are rapidly growing in the application of health care systems (Jun, Ward, et al., 2009). For instance, Broyles, et al., (2010) analyse hospital inpatient inventory using Markov model to reduce delay in waiting for service, service delivery, reduce operating costs, and for ineffective chronic illness management. In the following section, the current research proposes the literature review of system dynamic that has been widely employed in health care settings and has discussed some of the reasons behind the usefulness of using modelling tools in this sector. Health care system can be contemplated as wide-ranging complex systems that incorporate many interconnected elements. The organisation needs to be well-operated to perform the desired value of its stakeholders, namely, patients, medical workforces and any health care business industries (Khudyakov, et al., 2013).

2.4.1 System Dynamics Model applied in Public Health Policy

Practically, the system dynamics model has been broadly used in a varied background of social and public policy studies, including food security and biofuel challenge in Ghana (I. Ansah, 2014), and dynamic population (Krejčí, et al., 2011; Sutrisno & Handel, 2011; J. P. Ansah, et al., 2015). However, the eruption in the adoption of system dynamics modelling for public health planning settings is also available in a wide range since the past decade. According to Homer & Hirsch (2006), the methodology has been effectively used in many developed countries since the 1970s for public health and social policy areas. An ever broader in public health challenge due to a variety of emerging chronic diseases problems caused many health researchers attempted to use simulation model such as system dynamics technique. For instance, they were trying to evaluate possible interventions to improve cardiovascular health prevalence among the societies. The importance and potential capability of system dynamics model in guiding policy successfully for public health issues have been recognised (Homer et al., 2009; Kenealy, et al., 2012; Mahamoud, et al., 2013; Guariguata, et al., 2016). Homer et al., (2009) provides nineteen plausible interventions for local leaders national allies such as suggesting to lower the CVD risks without increasing the total consequences cost[2], intervention to improve the utilisation of primary care, reduce smoking, and improving the indoor and outdoor air quality are identified to have the capability of saving lives considerably quick.

The usefulness of system dynamics methodology has been supported by Kenealy et al., (2012); Mahamoud, Roche, & Homer (2013), and Zainal Abidin et al. (2014) asserted that system dynamics has been widely applied in an excellent way for health policy planning and development in tackling chronic diseases problems in many high-income country contexts. However, the utilisation of the methodology in developing markets as an aid to policy decision-making has not been widely applied yet (Guariguata et al., 2016). Guariguata et al. (2016) designed a system dynamics model for developing effective policy guidance on the prevention and control of diabetes in the Caribbean.

Their study is recognised as the first study to use system dynamics methodology in related to non-communicable disease in developing countries, where the developed model for the Caribbean can be implemented for guiding policy in another middle-income region. The study assessed the system dynamics in health of the finite resources context for middle-income countries. In addition to their studies for the developing countries, Meisel et al. (2018) provided a novel model for analysing nutritional transitions of Colombian peoples that were disaggregated based on their age and socioeconomic status. The motivational conducting of the study was raised due to the widespread phenomena of the obesity epidemic in many low- and middle-income countries, including Colombia.

[2] Total consequence costs defined as the medical and productivity costs generated by three type of intervention consequences addressed in their study (J. Homer et al., 2009).

Table 2.1 Several SD literature of public health issues

Author (Year)	Country	Issues
J. Homer, et al. (2009)	USA	Assessing multiple interventions to prevent and improve cardiovascular risks among US adults
Pedamallu, et al. (2012)	USA	Using cross-impact analysis in system dynamics model to examine the intentional transmission of HIV
Kenealy, et al. (2012)	New Zealand	Model cardiovascular diseases
Mahamoud, et al. (2013)	Canada	Model for social determinants of health
Zainal Abidin, et al. (2014)	UK	SD optimization for combating obesity epidemic among British children
Guariguata, et al. (2016)	North America	SDM for guiding policy on diabetes
Meisel, et al. (2018)	Colombia	Assessing nutritional stages by age and socioeconomic status for tackling obesity problems

Besides that, the study of the usage system dynamics in public health issues is not limited to merely tackling non-communicable diseases problems, albeit the several studies of the epidemic and communicable diseases outbreak have also adopted system dynamics model to provide intervention policies to epidemic diseases problems in one’s country. Pedamallu, Ozdamar, Kropat, & Weber (2012) developed a cross-impact model using system dynamic approach to investigate the situation of intentional transmission of HIV/AIDS by non-disclosure. A brief description of the several kinds of literature on public health-based system dynamics methodology can be seen in Table 2.1.

2.4.2 System Dynamics applied in Malaysian Public Health and Health Care Systems

Though the methodology has been discovered over the past fifty years, the application of the methodology is still considerably new and not widely used in Malaysia, particularly in public health and health care management policy (Abidin, et al., 2017). This section of the study illustrated several limited kinds of literature in the field of health care and public health in Malaysia. Most of those researches are still at an early stage, which is merely discussed in the qualitative framework. Even though system dynamics involves both qualitative and quantitative approaches, a qualitative method was only conducted for health care in Malaysia (Sumari, et al, n.d.). A qualitative method in system dynamics is used to gain a clear understanding the situation to be addressed in the study, including an interview related to the stakeholders of the model, collection of data, determination of the variables to be used in the model, and drafting of the conceptual model.

In the study of the medical emergency centre for a public hospital in Johor Bahru, Sumari, et al. (n.d.) have conducted the first stage of qualitative system dynamics that involves discussion of thematic analysis, including data familiarisation, coding, searching for a theme, and identifying the variables. Similarly, research by Noraida, et al., (2010) also offers a preliminary stage of system dynamics for addressing the complex problems of the emergency department in Penang government hospitals. Their research aimed to develop system dynamics by incorporating the flow of patients through the emergency service centre, applying the concept of theory of constraints in health capacity and delays in decision making. The concept of managing constraints in adopted as a complement to the SD model to be built for understanding the problems and identifying the solutions for health care capacity (Davies & Davies, 1994). On the other hand, Halim, et al., (2016) are the other researchers who developed a qualitative stage, for tackling one of the public health issues in Malaysia, where they proposed a hypothetical model for control smoking prevalence among Malaysian adults.

On the other side, several public health and health care studies in Malaysia also have been found to use both qualitative and quantitative aspects of the system dynamics approach. Meaning that these researches have completely developed a simulation model for tackling their research issues. For instance, Abidin, et al. (2017) provided system dynamics optimisation for solving obesity prevalence through the interventions in physical activity behaviour to accomplish the country's desired weight target among the population by 60 kg in 2020. Furthermore, the complex system dynamics simulation model has been constructed with regard to the health capacity management issues. For instance, Abas, et al. (2017) have evaluated the projection of nurse workforce supply. On the other hand, Ahmad, et al. (2013) used a combination of two different simulation modellings, namely, discrete event simulation and system dynamics model to explore the potential effects of a patient increase to the performance of government emergency department. Lacking in visualising the whole system approach, system dynamics is used as the second approach for assisting discrete event simulation method to capture the relationship of emergency department with a unit of health services such as ambulance, laboratory and hospital wards.

Similar to other health problems, dental health is also an important issue to public health problems with dental caries problems that would affect a person's health, physically and psychologically, and it is estimated to cause the prevalence in other morbidity and disease problems (WHO, 2010). Samah et al. (2014) used the system dynamic simulation model for projecting the supply of dental workforce in both public and private health services, as statistically recorded that Malaysia has challenges in dental manpower (The Star, 2013). The dentist supply simulation model was disaggregated based on age and gender categories. The summary of System Dynamics literature applied in Malaysian public health and health care system can be found in Table 2.2 below.

Table 2.2 Several SD literature applied in healthcare issues in Malaysia

Authors (Year)	**Case studies**	**Analysis**
Sumari et al. (n.d.)	Medical emergency coordination centre in public hospital around Johor Bahru	Implemented a qualitative method of system dynamics for understanding the complex system of health organizations
Noraida et al., (2010)	Emergency Department, Penang Government hospitals	Proposed a framework for solving health capacity planning using system dynamics and Theory of Constraints (TOC)
Ahmad et al. (2013)	Government Emergency department	To explore the potential effect of increasing patient flow to the performance of the emergency department
Samah et al. (2014)	Dentists in Malaysian public and private health sectors	To project the dental workforce supply
Halim, et al. (2016)	Aggregate Malaysian population	The dynamic hypothesis of tobacco control model as an attempt to overcome smoking prevalence among Malaysian
Abas et al. (2017)	Registered nurse workforce in Malaysia	Well-developed qualitative and quantitative SD model for the supply of nurse workforce projection

Abidin et al. (2017)	Aggregate Malaysian population	Proposed the optimization framework for obesity problems related to physical and eating behaviour

2.4.3 Modelling health care demand and supply in health services

While various studies have analysed the health production function approach concerning the medical inputs, health care expenditures and health care systems as determinants of health outcomes, more recent research has extended the analysis of health care system delivery with emphasis on the application simulation model. The relevance of adopting system dynamics in health care aroused from the holistic worldview and interconnected features of the methodology. This is because of the basic principles of the method is the demonstration of a complex and dynamic system that relies on the intrinsic structure of its model, in which the multiple variables interact and effect in each other within one system will create a dynamic behaviour (Forrester, 1985; Sterman, 2000; and Elf et al., 2007). The list of several related studies that have employed system dynamics for evaluating patient demand and the respective health care resources can be found in Table 2.3.

Principally, an application of system dynamics approaches for modelling the feedback interaction between demand and supply health care resources, widely designed in western and developed countries European, UK and US health care system. For instance, Rohleder, et al. (2007) developed system dynamics as an alternative of their previous discrete event simulation model for predicting unintended increases in demand for patient service centres (PSC) than their expectation. They tried to explore the several potential behavioural consequences of implementing new PCS to improve resource utilisation and reduce demand variability. As stated by Young (2005), system dynamics was used as a suitable method for improving health care management and was adopted in health care environments for seeking policies of ongoing operations, for instance, in emergency departments (Brailsford, et al., 2004; Lane, et al., 2000; Taylor & Dangerfield, 2005) used system dynamics to clarify the potential effects of alternative policies of services improvement for UK cardiac catheterisation services. Trellevik (2008) developed a simulation for projecting several future scenarios of Geriatric Healthcare[3] in the city of Bergen. His experimental simulation model bears a close resemblance to many healthcare demand modelling representing the population, geriatric nurses, clients and infrastructure sub-models. Unlike many other healthcare demand studies, the model includes the effects of establishing the private sector for geriatric services. The finding revealed the private opportunity may relief a load of public geriatric care, in turn, to reduce the demand for the public sector of geriatric health services. Research from Australia by Burnett et al. (2010) applied system dynamics model for Garrison Health services including the wide-ranging interaction of six sub-sectors such as medical staff, dependency, service delivery, service demand, costing and budget for health. In line with their study, Ng, et al. (2011) developed a system dynamics modelling to study the affordability and accessibility of health care in Singapore. Their simulation model considered the demand for hospital services and the significant several of health care resources (doctors, nurse and bed) and their respective health care spending.

However, several pieces of research concerning health care-based system dynamic approach can be found for developing countries like India, China and Iran (Mehrjerdi, 2012; Chaudhary, 2015; Yu, et al., 2015; Wang, et al., 2015; Zhang, et al., 2017; Li, et al., 2018; Khanmohammadi, et al., 2018). The constructed simulation model by Chaudhary (2015) was originally inspired by Ng, et al., (2011) and applied it to India health care system for analysing

[3] Geriatric Healthcare or medicine is sometimes known as “medical gerontology” refers to a field of medical care that focusing on treating, preventing the disease occurring among elderly people.

health affordability challenges in India. Both studies constructed the causal interaction between demand and supply of health care resources in the health care system with regard to the affordability of health care. System dynamics model is developed to elucidate complexities in health care systems with regard to affordability, where they assumed that the demand for health care is derived from the total population in one’s country. As the population keeps rising, the demand for health care services is also expected to increase, which will impact the health care resources such as bed facilities, doctor and nurse availability, and health care expenditure. Their models illustrated how national health system behaved and it can be understood and done to improve its health care affordability. Correspondingly, Zhang, et al. (2017) also provided the feedback relation between patient’s demand, service utilisation in both hospital and community health services, as well as two main resource constraints consisting of capital and human resources.

Instead of evaluating the feedback interaction of patient volume to health care resources, Yu et al., (2015) attempt to explore the impact of health policies on the actual proportion of the patients not seeking for medical treatment in order to increase the potential medical demand. Accessibility to medical services and health insurance compensation are the main drivers of the potential medical demand. Besides that, a beneficial of system dynamics has been recognised by a recent study from Iran researcher by Khanmohammadi et al. (2018). They developed a system dynamics model of five major components of hospital conditions to handle a leap of demand in the aftermath of earthquakes. Many hospital resources like hospital building, staff, medicine, technical systems, and equipment are all affected by the earthquake and they need to recover in an effective manner to serve and treat the casualty patients due to this disaster. Differently to research by Wang, et al. (2015) constructed system dynamics simulation model to analyse the relationship between the different types of financial indicators for the Liaoning province such as public expenditure, total health expenditure, government health expenditure, social health expenditure, and out-of-pocket expenditure.

A study of addressing neonatal healthcare problems in Uganda by Semwanga, et al., (2016) proposed to use system dynamics approach for providing an integrated view of the neonatal health system and exploring policy alternatives with the best impact factor to improve its healthcare service delivery. In yet other system dynamics studies were established to project the future need and demand for health workforces in various types of health services such as paediatric workforce supply by Wu, et al. (2017), clinical physician and OB/GYN specialists in Japan by Ishikawa, et al. (2013), medical specialists in Spain by Barber & López-Valcárcel, (2010), nurse workforce supply in Malaysia by Abas et al. (2017) and many more the other related studies.

2.4.4 Technology adoption in the health care system

Various methodologies comprising of longitudinal studies, statistical models, econometric analysis, and other approaches, have been employed to analyse and understand problems associated with healthcare systems. Mostly those methods applying linear approaches or focusing on a portion of the problems. Howbeit, it has been increasingly acknowledged studies that consider the intricate complexities of healthcare system problems is urgently necessary. Linear methods that producing technical solutions are not ample to intensify effective ways, as the adoption and diffusion of innovations that justify reactions to health problems are affected by the dynamics of health systems (Atun, 2012).

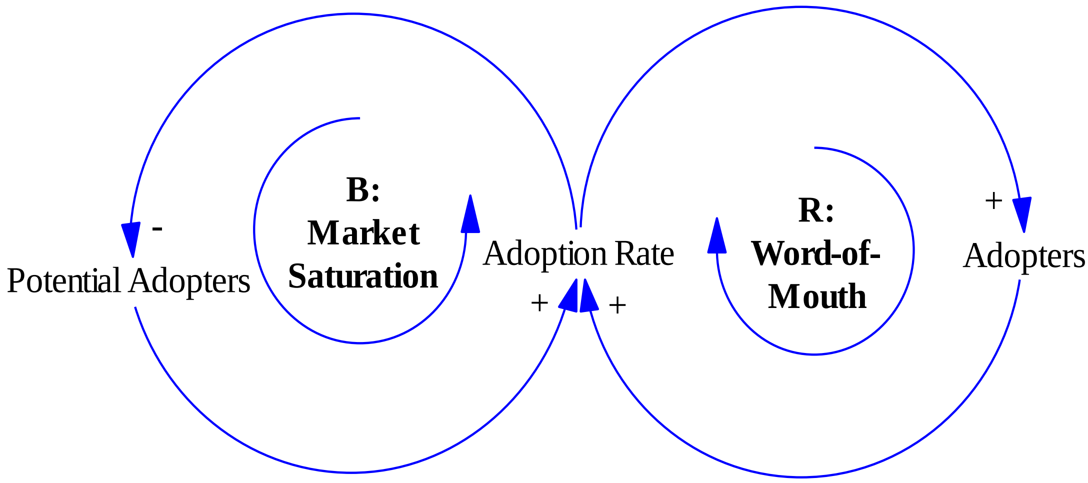


Figure 2.2 Basic causal loop structure for the diffusion and adoption model

Despite the myriad of suggestions stemming from statistical approaches that studies adoption of ICT-based health has been studied, the available research evaluating the adoption of technology-related health care dynamics, as a complex system is limited to developing countries. According to Sharif & Ramanathan (1984), system dynamics should be used to ease the mathematical and computational complexity in designing a diffusion model. On the other hand, Mutingi & Matope (2013) upheld that a profound comprehension of the natural dynamics in technology for the success of policy and developing the strategy, for instance, Renewable Energy Technology (RET) used in their study. They investigate the dynamic behaviour of RET adoption employing system dynamics. Besides that, those available research from developed countries, particularly studies from the United States, can widely be found.

The generic model of Figure 2.2 is a characterization of the Bass (1969) diffusion model applying system dynamics methodology. The model incorporating two types of loops, that is, reinforcing and balancing feedback loops. The reinforcing feedback loop is primarily driven by the word-of-mouth process, in which the adopters influence and persuade potential adopters to take up the product or technology. On the other hand, the balancing or negative feedback loop produces from market stagnation based on the size of the total market. Bass concludes that p values are much less than q (Bass, 1969). The relationship between an element of the model can be parameterized as indicated in the following equation:

$$AR\ (T) = p\big(N - A\ (T)\big) + \frac{q}{N}\ A\ (T)\ (N - \ A\ (T)) \tag{2.10}$$

$$A\ (T) = N\ \times\ \left(\frac{1 - e^{-\,(p+q)t}}{1 + \frac{p}{q}\,e^{-\,(p+q)t}}\right) \tag{2.11}$$

where,

AR (T) is adoption rate at the time (t) indicating the size of adoption to the potential adopters.

A (T) is the number of adopters

N indicates the size of the potential market.

N – A (T) indicates the number of potential adopters at the time (t)

p represents the coefficient of the innovation process. At this phase, the potential adopter attempts to adopt the product resulting from the influence of advertisement or exploration about the specific product of interest by themselves.

q represents the coefficient of the imitative adoption process. This process indicating when adoption of certain product or technology is basically influenced by peers or family members who already adopted the product or technology. The innovative process, p drove from advertisement and individual investigation are not sufficiently able to stimulate potential adopters to adopt that specific product or technology.

Table 2.3 Several SD literature applied in healthcare demand and supply

Authors (Year)	Country	Issues	Model Stage
Taylor & Dangerfield (2005)	UK	Patient flow model of two cases of shifting services in UK cardiac catheterization services.	Qualitative
Elf, et al. (2007)	Sweden	A dynamic causal loop diagrams of the care planning process	Qualitative
Trellevik (2008)	Bergen	Simulation model healthcare planning for Geriatric patients	Qualitative and Quantitative
Burnett, et al. (2010)	Australia	An applied system dynamics as a tool for Garrison Health Modeling	Qualitative and Quantitative
Cooke, et al. (2010)	Canada	A dynamic model for identifying causes of treatment delay	Qualitative
Ng, et al. (2011)	Singapore	Modelling healthcare utilization and supply of healthcare workforces, hospital capacity and respective costs	Qualitative and Quantitative
Yu, et al. (2015)	China	Modelling potential medical demand and access to medical service for hospitals and community health systems (CHSs)	Qualitative and Quantitative

Wang, et al. (2015)	China	Analysis of total health expenditure to improve the equity of financing for healthcare	Qualitative and Quantitative
Semwanga, et al. (2016)	Uganda	Develop Neonatal Healthcare Simulation Model consisting health of mothers and neonates, demand and operation services	Qualitative and Quantitative
Zhang, et al. (2017)	China	Modelling patient demand, utilization, human resources and capital supply for community primary health care and hospitals	Qualitative and Quantitative
Khanmohammadi, et al., 2018)	Iran	Modelling five components of the hospital's recovery process affected by earthquake disaster namely hospital building, staff, medicine inventory, technical systems and clinical equipment	Qualitative and Quantitative

However, those former studies applied several different types of technologies used for the health care system. For example, the adoption of electronic health records (Erdil & Emerson., 2009; Otto & Nevo, 2013), telecare (Bayer, et al., 2007), health information exchange adoption (Edaibat, et al., 2017), health care robot adoption (Lin & Chen, 2012; Rojas-Cordova, et al., 2016), medical technology such as full body x-ray machine (Van Der Watt, et al., 2016), home telehealth (Serdar Kilinc & Bennett Milburn, 2016), and mobile health application by recent study (Pai & Alathur, 2018). Moreover, those available research the models focused on identifying the factors adoption of respective technology among health stakeholders based on the concept of Innovation Diffusion Theory (Rogers, 1962) and Technology Acceptance Theory (Davis, 1989). This means that fewer studies have empirically tested the usefulness of those respective technologies in improving the health care service delivery.

Table 2.4 Several SD literatures of healthcare technology adoption

Authors (Year)	**Types of Technology**	**Model Emphasis**
Erdil & Emerson (2009)	Electronic Health Record (EHR)	EHR adoption model for analysing the efficiency interventions in the US healthcare system
Shu-Ping Lin & Jeng-Shyong Chen (2012)	Healthcare Robot System (HCRS)	Developed model of user behaviour for healthcare robots among elderly people based on Technology Acceptance Theory
Adriaan et al. (2016)	Full Body X-Ray Machine	Simulation Model of Innovation Decision Process
Pai & Alathur (2018)	Mobile Health Applications	Constructs qualitative model of the perception and use of mobile health applications among the people

2.5 Research Gaps

In this research, I attempt to highlight two aspects of the research gap that have been found from former studies, as intensely described in previous sections.

i. In relation to the application of system dynamics simulation approach in the health care management in Malaysia, most of those researches are still at an early stage. The availability of health care management had empirically evaluated on the projection of workforce supplies such as nurse and dentist supplies. Studies on the wide-view of the whole health care system such as interaction demand and supply are still under the qualitative aspect of system dynamics. Besides that, they also attempt to focus research framework on specific health services such as on the emergency department and in the state's hospital.

ii. In relation to the application of technology-based health care studies that used system dynamic methodology as a tool for analysis. Aforementioned in prior sections, the research has been widely studied in developed countries. To the best of my knowledge, there has been a limitation on the related study from developing countries including Malaysia. Besides that, the types of technology used in their studies are relatively different from each other and less likely to be used in evaluating the usefulness of that technology to health care services. Those researches tended to focus on the acceptance and adoption determinants of user behaviour rather than how technology tool or devices could positively or negatively to healthcare delivery.

2.6 Originality

Based on the aforementioned research gaps, this research attempts to fill those two gaps. The original contributions of this research can be described as:

i. To present a wide-ranging view and amalgamates the feedback relationship between the health care demand and the supply of three major types of health care resources in Malaysian government hospitals into one whole system.

ii. Incorporating the sub-model intervention of smart-health technology adoption in order to explore the possible behaviours to improve patients' medical expenses and health service performance through patient discharge.

CHAPTER 3: METHODOLOGY

3.1 Overview of the chapter

This chapter provides a detailed description of the system dynamics modelling as a methodology adopted in this study. System Dynamics (SD) is a simulation technique that would assist decision makers to have a better comprehension of the behaviour of complex systems over time and the implication of system intervention. In this chapter, I first introduce the fundamental concepts and underlying the methodology of System Dynamics. I then delineate the essential stages of model development, such as problem articulation, dynamic hypothesis, model formulation, model testing and the implementation of the model analysis in the following section of this chapter.

3.2 Introduction to System Dynamics Modelling

System dynamics is a computer-based simulation technique as a method for managers to analyse complex problems (Porter, 1962). Initially, it was inaugurated by the prominent founder of this methodology named Jay Forrester, at the Massachusetts Institute of Technology (MIT) in the late 1950's. In the past, it is originally employed to study a non-linear system and feedback control in engineering and science fields. Since the 1960's, the methodology has been widely applied in many areas of the studies, including public health and health care management field. Today, the method has been applied widely in health systems as it offers diverse advantages over simple spreadsheet programs. It allows these adjustments to be implemented by fine-tuning the parameters. The method is utilised to construct models of a real world and to understand how the model's structure create dynamic behaviour over time (Forrester, 1985 and Sterman, 2000). In general, it is a combination of both qualitative and quantitative aspects to convey the complex ideas.

In view of the complex problems, a system dynamics methodology is an invaluable method to solve and capture the feedback relationships between variables during a particular period. System dynamics is the application of feedback control systems principles and techniques to managerial, organisational and socioeconomic problems (Roberts, 1978). He added the methodology's philosophy rests on a belief that the behaviour of time of an organisation is principally generated from the organization's structure. Such a structural framework consists of sources of amplification, time lags, and information feedback similar to those found in complex engineering systems. Borrowing from signal-flow graphs of electrical engineering, cause-and-effect arrow diagramming was developed to portray visually the underlying managerial situation. The term "dynamics" indicates continuous change, and so, dynamic systems mean that the system changes continuously over time. This means that the current state is different to the state of the past period, and the future state would be changed from the state of the current time (Khudyakov et al., 2013). System dynamics provides the ability to view both drastic changes of events and patterns of behaviour over time, rather than mainly focusing on the day-to-day events; the system structure is illustrated by a chain of causal links.

System dynamics model has formed a methodology for engaging with many stakeholders and policymakers to enable wider thinking on the complex problems of the related issues to be addressed. The activities include an interview with stakeholders and conduct group model building workshop to construct and clarify qualitative conceptual model and quantitative simulation model. "Games" or "flight-simulators" has sometimes been used for assessing the potential effect of different policy designs for policy decision-making. In comparison with other simulation models, a system dynamics model and discrete event simulation model can provide a long-term decision framework. The model is capable of coping with the internal feedback loops and time delays that impact the behaviour of the whole system (Khudyakov et al., 2013).

3.3 Stages of the Model Development

Figure 3.1 shows an overview of the developing process for a system dynamics simulation model. Fabricating a system dynamics model is not a rigidly linear process, albeit it has a continuance process denoted by repetition, review, and feedback at each stage in the development process (Guariguata et al., 2016). The figure illustrates the essential steps of modelling in system dynamics. The process has been explained thoroughly in the following sub-section.

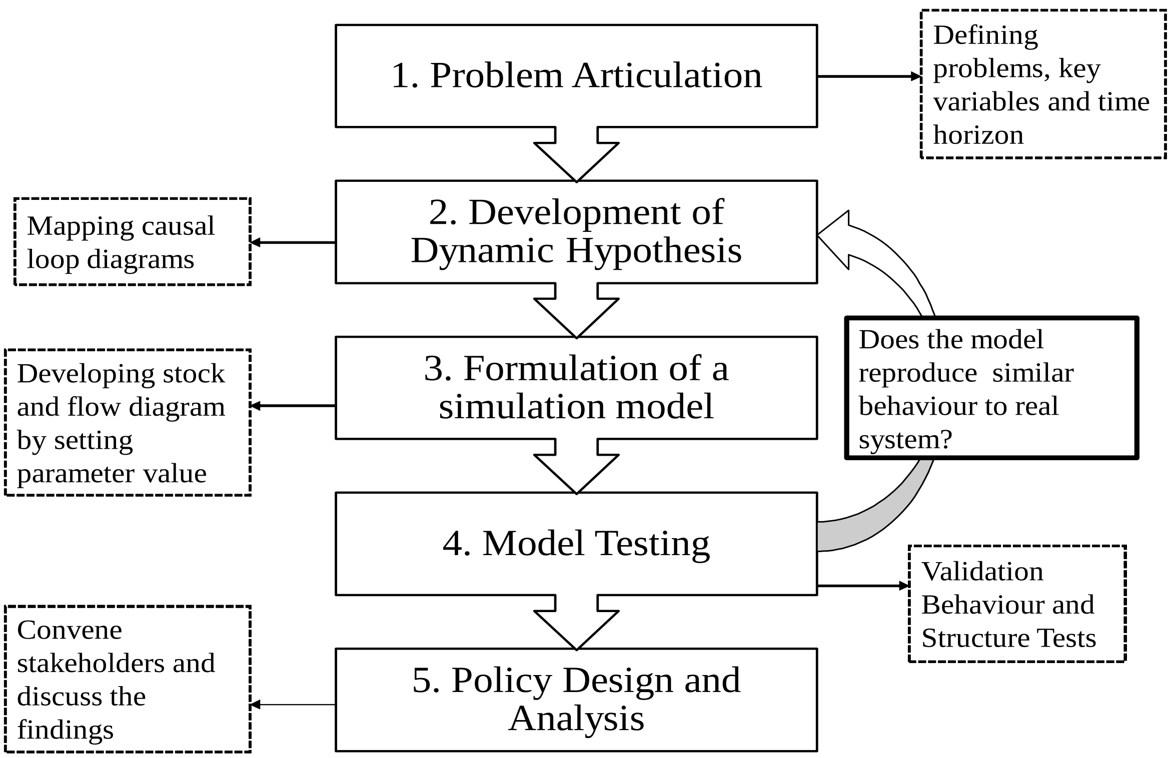


Figure 3.1 Model Building Process of System Dynamics Methodology

Source: Adapted from Business Dynamics, John Sterman (2000)

Note: Elbow arrow connector indicates perform iterations

3.3.1 Problem Articulation

Problem articulation is the foremost stage of the model building. At this stage, the model purpose and specific problems of the study should be clearly stated. Thenceforth, the necessary variables that should be included in the model are identified. In system dynamics, the variables are divided into three types such as endogenous, exogenous and excluded. An endogenous variable is the variable emerge within the boundary of the system. In other words, it is defined within the scope of the model. The exogenous variable is the variables derived from outside of the system. When the exogenous are entered, the model is capable of generating the behaviour of endogenous variables over time by relating the variables to one another as defined by the model equations. It is including the input parameters that are constant over time or input variables that are dynamic over time. The excluded variable is then defined as the variable that outside of the scope the model which would not take into the model. Collected data of the key variables can be used to develop the reference mode which would able to elicit the problem and generalize the dynamic hypothesis.

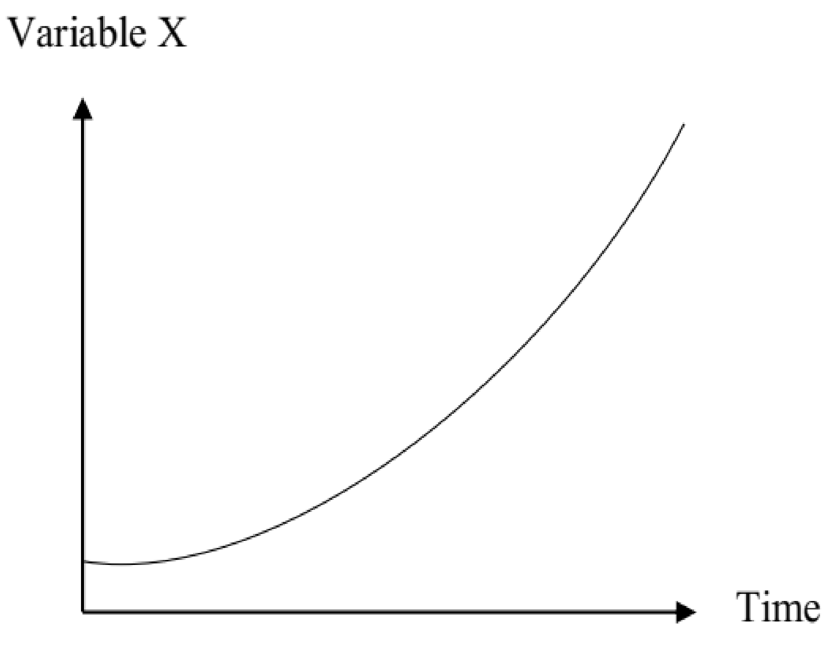


Figure 3.2 The behaviour of exponential growth

Sternman (2000) has defined reference mode as a set of graphs that produced the behaviour of variables over time. The time variable is plotted on the horizontal axis against an important variable (Variable X) plotted on the vertical axis, as shown in Figure 3.2. This figure shows the behaviour of exponential growth as one of the fundamental modes of behaviour in the dynamic systems. Another type of modes of behaviour is goal-seeking, s-shaped growth, oscillation, growth with overshoot, and overshoot and collapses (Sterman, 2000).

3.3.1.1 Sources of Information for Modelling

The complex nature of health systems brings about its significance for health system models to draw upon the massive data about the health care systems being built. Jay W. Forrester (1994) highlighted the three types of data sources that system dynamics modeller should tap into in building a complex social systems, namely, mental base, written base and numerical base (Jantsch, 1994; Ansah, 2014).

i. Data source from mental base:

The mental base comprises the related data about the system that is being modelled, which lay on the minds of knowledgeable persons with professional experiences on the issues of the system. In constructing model conceptualisation, the mental base would provide guidance about the trend and pattern behaviour of the key variables in detail, as well as being useful for the building the confidence of simulation model (Morecroft, 2015). Therefore, it is important to collect information from informal discussions with experienced individuals in health care systems and system dynamics methodology, as these mental base source will be used to build a generic model framework of the study.

ii. Written base:

This type of data and source of information engaged in collecting data and theories from published and unpublished studies such as peer-reviewed articles, country and world organisation reports. This database can be used as additional information for constructing a simulation model, obtaining the necessary variables, estimating model equations, inserting initial parameter values, and validating the model structure.

iii. Numerical base:

This database covers secondary data sources comprising of short- and long-term time series data employed in this study to initialise and parameterise the structure of the model.

3.3.2 Development of Dynamic Hypothesis

The dynamic hypothesis is a conceptual model typically consisting of a causal loop diagram (or called an influence diagram) and sub-system diagram that analysing the system qualitatively. Principally, system dynamics depends on the causal loop diagram (CLD) as a simple mind map to describes the dynamic relationship amongst multiple factors. It is capable to present the effect of each variable on the other ones simultaneously. On the other hand, sub-system diagrams generalize the overall architecture of the system which does not contain too much detail of the variables in the system compare than CLD. This research constructs sub-system diagram to elucidate the overall picture of the public healthcare system in Malaysia. However, both qualitative model then should be transformed into quantitative model namely stock and flow diagram.

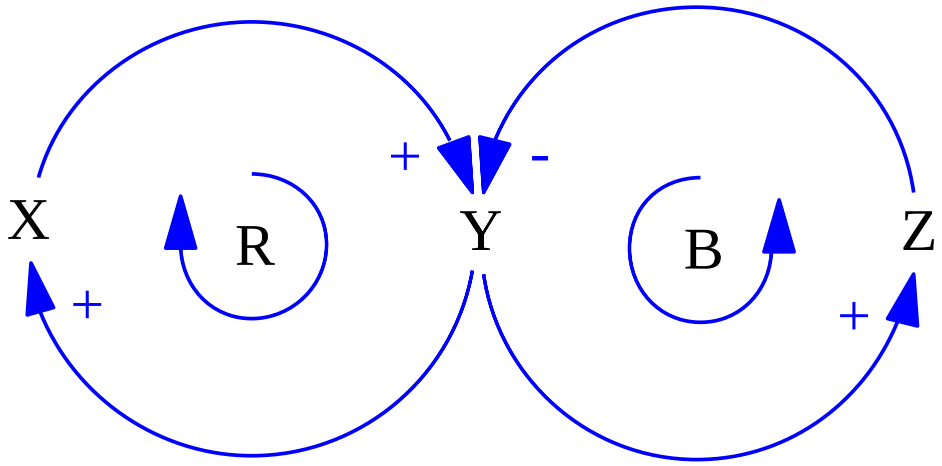


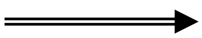
Figure 3.3 Generic structure of causal loop diagram

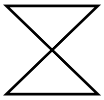
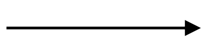
Figure 3.3 depicts an example of a causal loop diagram notation applied in system dynamics. A causal diagram comprises of variables: X, Y and Z linked by arrows indicating the causal influences among variables. The diagram is drawn using Vensim software. The figure explains how variable X and Z effect on variable Y and vice versa. Each causal link is assigned a polarity, either positive or negative to define the changes in the independent variable will change the dependent variable (Sterman, 2000). Meaning that a causal effect relationship between variable can alter the behaviour of the variable in the same direction that designated as a plus or in the opposite direction that designated as a minus. For example, the positive causal link between variable X (Z) and Y is interpreted as when variable X (Z) increases, it would increase (decrease) the variable Y, while the other variable keeps constant. In this case, variable Y is accumulated by variable X and Z. A loop identifier written as R indicates reinforcing (positive) loop. While loop identifier written as B is balancing (negative) loop.

3.3.3 Formulation of the Simulation Model

Once the dynamic hypothesis model is built in the second stage of the system dynamic model building process, the model will be converted into stock and flow diagram to allow the model to be investigated quantitatively.

Table 3.1 Diagramming notations of stock and flow diagram

Graphical Icons	**Variables**	**Description & Function**
	Stock (or level)	• Stock represents the state of the system. • A variable which accumulates or depletes over time by inflows and outflows • For examples: inventories (of goods or ideas), balances of funds, pools of employees
	Flow (or rate)	• Flow is the variable that will change the value of the stock. • The inflow (the arrowhead directed into the stock variable) acts to increase the stock • The outflow is the arrow directed out from the stock variable which acted to decrease the value of the stock. • Includes all activities within the system such as the flow of effort, the streams of information, the payment for expenses

	Valve	• Controls the inflow and outflow that alter the quantitative value of the stock over the course of time that drawn in the middle of the flow
	Cloud	• Cloud indicates the source and sink
	Connector	• The arrow connector represents the cause-and-effect links between elements in the model structure

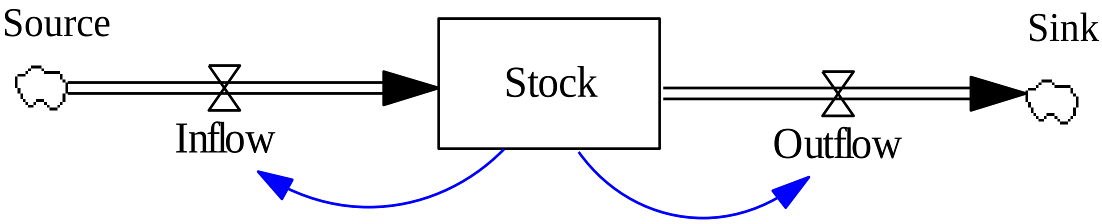


Figure 3.4 Basic structure of stock and flow model

Figure 3.4 presents the basic representation of stock and flow diagram in Vensim software consists of five graphical icons such as stock, flow, valve cloud and arrow connectors. This simulation model can be constructed using various types of computer simulation software that offers system dynamics features such Vensim, STELLA, Powersim, Analogic, Simulink and many other of simulation software. In system dynamics, dynamic behaviour is viewed arisen from the principle of accumulation, where the dynamic behaviour of the system state occurs when the flows accumulate in a stock variable. A stock, where, extensively exemplified by a bathtub, while, the flows represented as a faucet and a pipe to fill in and drains the state of stock. Herein, the flow fills in and drains the stock are called inflow and outflow respectively. The stock flows, and arrow links comprise of interrelations of the set of differential and integration equations constructed from a wide range of reliable empirical data (J. B. Homer & Hirsch, 2006) in which a guidance to understand the interrelationships among included variables in model structure. A detailed explanation of the icons is described in table 3.1. Once the graphical simulation model is built as shown as a sample in figure 3.4, the parameter values and equations are inserted for each variable. The numerical value for each parameter typically obtained from former literature related to the field of research and publicly available data sources. 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. The transition is given by the equation below:

$$\mathrm{Stock}\ (\mathrm{T}) = \int_{\mathrm{t}_0}^{\mathrm{T}} (\mathrm{Inflows} - \mathrm{Outflow})(\mathrm{t}))\mathrm{dt} + \mathrm{Stock}\ (\mathrm{t}_0) \qquad (3.1)$$

Whereas, the flows typically are measured over a certain interval of time. Mathematically, a flow can be viewed as the derivative of the stock with respect to the time, which is its net rate of change as expressed below:

$$\mathrm{Net\ Flow} = \mathrm{inflow} - \mathrm{outflow\ or\ Net\ flow} = \frac{\mathrm{dS}}{\mathrm{dt}} \qquad (3.2)$$

3.3.4 Model Testing

In the model testing, the simulation model has been trained to reproduce the behaviour seen in the real world. It is also conducted to uncover the model’s defect and to increase the model confidence in terms of its structure and behaviour. There are several tests available to validate the model structure such as structure-verification test, dimensional consistency, extreme conditions, behaviour sensitivity and behaviour reproduction test. Model testing will involve sensitivity analyses for the incorporated parameters and extreme case testing to evaluate the plausibility of the simulation model (Barlas, 1996).

In regard to structure validation tests of the model, this validation test is a fundamental part of most system dynamics model has been addressed by many system dynamics professionals such as Forrester (1978), J. Sterman (2002), Magistrale et al. (2016). Accordingly, the structure of the current model is rigidly rooted in existing knowledge and empirical evidence on the feedback interactions between elements in each sub-diagrams. Principally, the idea of the model is to formulate policy test to foster comprehensions for health policymaking. Furthermore, the parameter values inserted as initial values and parameterizing the model are should be acquired from the reliable data sources.

3.3.5 Implementation

The reason for applying model testing is to check whether the built model is appropriate to conduct important insights for policy analyses. Thereupon model testing, the simulated model can be applied for policy designation. Engagement with policy makers is crucial for supporting simulation results to be further applied in alternative policy scenarios (Oliver, et al., 2014).

CHAPTER 4: MODEL CONCEPTUALIZATION

4.1 Overview of the chapter

This chapter begins with a discussion of the data gathering process and information of the variables to be used in constructing both qualitative and quantitative model that will be discussed in this chapter and the following chapter. This chapter is then provided with the generic model overview demonstrating the main feedback interactions between model sectors. The subsystem diagram presented herein illustrates a simplified diagram of the interaction between healthcare demand, supply and smartphone adoption. There are five major sub-diagrams of the entire model: healthcare demand, doctor supply, bed capacity, healthcare financing and smartphone-based technology adoption. The following section will explain one of the common diagramming tools applied in the system dynamics approach. Description of the system dynamics typically begins with causal loop diagramming as a mental model of a modeller for visualising and assessing complex system structures. This leads to a discussion of the positive and negative feedback loops pictured by the causal loop diagrams, of the prototype behaviours generated by these loop structures.

4.2 Data Sources and Variables

The data for the variables used in the modelling process were obtained from the publicly available data sources literature reviews and authors' assumption. There have few methods for collecting data and information for the variables and parameters that will be used in this research.

4.2.1 Review of existing qualitative data and health researcher

The interview and review novel literature have been used to garner qualitative data and parameters selection from literature and health researches on their perspective concerning the

Malaysian health service system, challenges happening in a government hospital, and the public response on their health care and service. The model construction will be an iterative task with each stage apprising the other, thus revising the model. This will assign a supplementary process of nurturing critical reflection of the model structure through the grasping of the essence and result of any variations. The study conducted in-depth interviews with system dynamics expert from System Dynamics conference in many countries, and interview with health researchers like a Malaysian doctor, and students studying in Japan and Malaysia. These interviews were intended to gain their views regarding health issues in its attempt to be addressed in this study. The study had undertaken a qualitative analysis using data obtained from the interview data and made a connection to elements in the health system in Malaysia, particularly to the upstream factors of patient flow to hospital services. These qualitative interviews are conducted simultaneously to assist in the construction of the model. For instance, the number of patients and total health expenditure will be utilised as the principal result measure of interest, in which in system dynamics is indicated as the "reference mode" for analysing policy intervention. The initial concept of the current model has been utilised to engage with those with expertise in the system dynamics and promote health system situation during the in-depth interviews.

4.2.2 Review of quantitative evidence

A methodical literature review will give authentication of the quantitative relationships between the elements in the model. The existing empirical data will be utilised to calibrate the developed simulation model. A methodical review is being carried out to evaluate patient flow model to health services (e.g., emergency department, acute care, ambulance care), utilisation of bed capacity, impact on health workforces (e.g., nurses and doctors), country's spending on health care system, technology adoption model in diverse sectors, technology diffusion theory, and variety of simulation models applied corresponding to the issues of the present study. In addition, dataset information had also been inquired by stakeholders during the interviews. For the unavailability of adequate quantitative data for a relationship within the model, data from other countries can be applied for calibration purposes (Guariguata et al., 2016).

A necessary caution will be given to using those data emulating to Malaysia's health system environment as closely as possible. Despite the policy of interests for the analysis of this study that distinct from those of the existing adoption model, the core health system structure must be followed, in which it is comprehensive and will be adopted as the starting point for model re-development. Thus, the study will be based on a literature review on the available evidence and consultation sessions with researchers in health policy and medical doctors that serve in Malaysian hospitals and inquired regarding the current challenges in Malaysian public health services. A conceptual model will be constructed in the next section for Malaysia health system using input and data obtained from stakeholders and evidence review, as well as received opinions from system dynamics experts concerning the constructed model built.

4.2.3 Electronic Secondary Data

This study obtained data from publicly online publication data from Ministry of Health, Department of Statistics and Malaysian Communications and Multimedia Commission (MCMC), and from published researches. The list of key parameters used for the modelling process and its information sources are listed in Appendix A.

4.3 Subsystem Diagrams

The conceptual model is the first stage of modelling the healthcare demand and smartphone-based technology adoption model with system dynamics. The fundamental system components are all demonstrated: the alternative for the policy maker, external drivers which cannot be altered and the influences of these drivers to the system and the applicable criteria. System dynamics modelling, in which the grounded of the theory of dynamical system tackling with long-term behaviour quantitatively for a dynamical system that represented in mathematical equations. This method is employed as the main tool for analysing healthcare system from a strategic perspective in this research.

The model hypothesis of this research is illustrated in Figure 4.1. The sub-system diagrams, which is reconstructed from Hassan & Minato (2018) is adopted to model the causal loop structure and quantitative simulation model required to solve the research questions of the current study. At this stage, the dynamic conceptual can be utilised as a framework to get insights on the knowledge of the hypothetical dynamic interaction of diverse variables within the model to the quality of the health care delivery process. The model identifies the linkage that is well comprehended, and those variables are required for building the quantitate simulation model for a further stage of the research. It is the aim of the study to further develop the model and validate the variables and its links.

It is widely acknowledged that health care service in Malaysia has been recognised by robust public attention to the government hospital and clinics as this public health care sector acted as primary care and government have spent a large portion of its GDP to the health care sector. This exponentially proliferating in health care expenditure over the years has triggered a better expectation from citizens that government service provided better quality or service to them and they only need to spend their pocket money in a very small amount to receive a medical treatment Accordingly, this large population of the ill will increase strain on health care workers and overcrowd the public health care facilities. Therefore, an approach to utilise smartphone device among patients, health professionals and hospital providers have enabled the improvement of health care service delivery that works effectively and reduces the burden of the medical cost covered by providers for visiting patients.

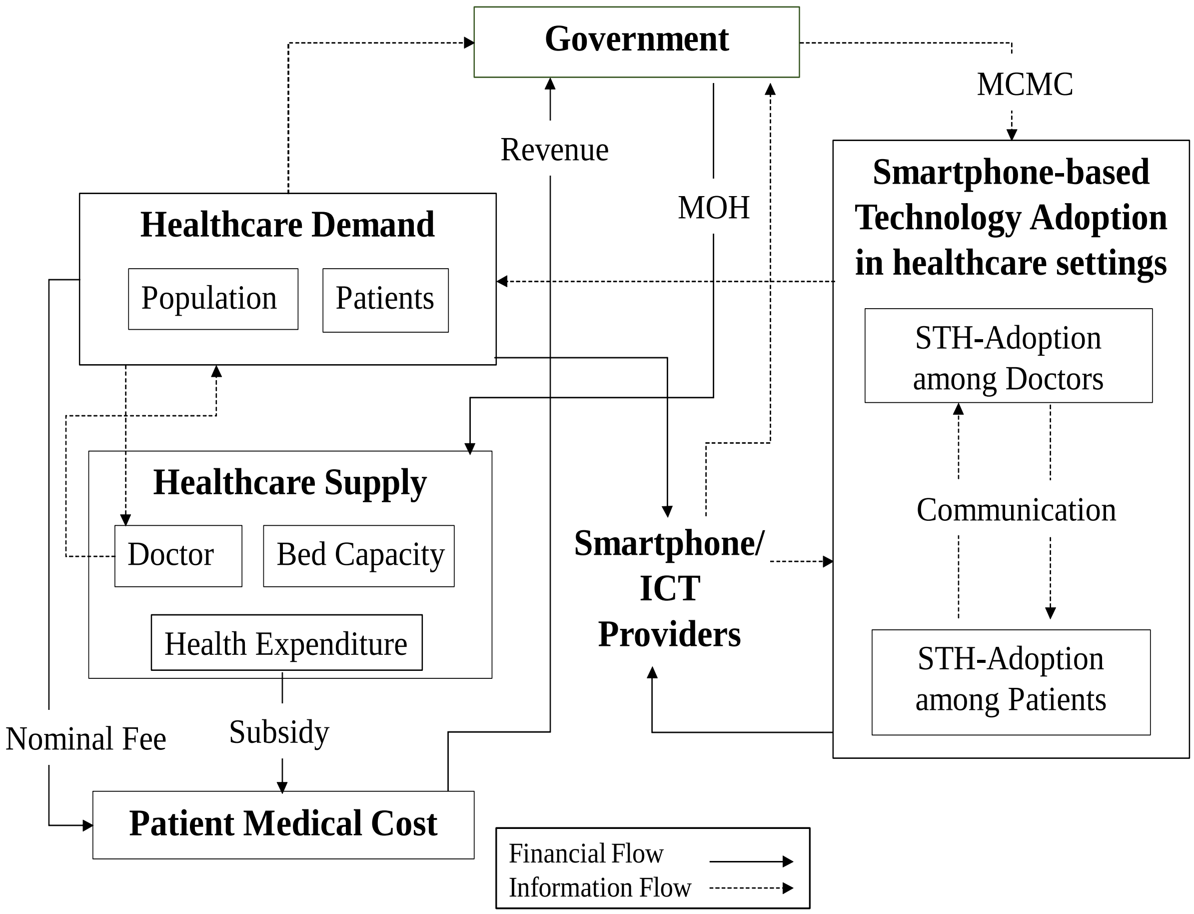


Figure 4.1 Model Overview of Smartphone-based Technology Adoption for Healthcare [4]

Figure 4.1 shows the general architecture model of the mutual connection between sub-sectors in the system for building a simulation model. The model can be divided into five subsystems: healthcare demand, medical practitioners, bed capacity, financing borne by both healthcare providers and patients, as well as smartphone-based technology adoption subsystems. The interrelation flows of each prime subsystems of the population, patients, workforce resources, bed facilities, and financial resources to one another are linked by two

[4] Smartphone-based Technology for Healthcare (STH) refers to the smartphone used for medical purpose by health stakeholders, in which doctors and patients for current research. The acronym STH will be widely found in this paper.

types of flows: Information and Financial Flows. Information flow is indicated by the dashed line, meanwhile, financial flow is indicated by the solid line respectively. Based on the figure, there has six financial flows and nine information flows. A detailed elucidation of these is clarified in Table 4.1 below.

Table 4.1 Description of Financial and Information Flows

Types of Flow	**Fluxes between sub-sectors**	**Descriptions**
Financial	Government to Healthcare supply	Government allocates its government expenditure for healthcare, in which the Ministry of Health (MOH) as a primary source of finance
	Health expenditure on patient medical cost	The proportion of the healthcare budget is subsidized to medical costs for visiting patients
	Healthcare Demand to Patient medical services	Patient and Population pay nominal fee to consume treatment either preventive or curative care at public hospitals
	Patient medical cost to the government	The medical fee paid by the patient for treatment received as revenue for hospital and government financial budget
	Healthcare demand to smartphone/ICT providers	Population/Patients buy a smartphone to access health information or communication

	ST adopters to smartphone/ICT providers	They paid for the monthly bills or additional downloaded apps
Information	Healthcare Demand to Government	It is a government responsibility to know the condition of its citizens. Besides that, citizens who working as government servants will provide their condition either financially or health status to the superior in the government sector
	Healthcare Demand to Doctor	Citizens provide information about their health status to medical practitioners while attending to hospitals
	Doctor to Healthcare demand	The doctor provides medical consultation to a sick population
	Smartphone/ICT providers to Government	Smartphone/ICT provides information on the beneficial use of a smartphone for tackling healthcare issues to government
	Government to Smartphone adopters in healthcare settings	Government through the ministry of multimedia and communication (MCMC) encourages doctors and patients to use a smartphone as a medium of communication or health consultation
	Smartphone/ICT providers to ST adopters (Doctors and Patients)	Several ICT providers give information directly to health stakeholders

	STH adoption among doctors and patients	Both doctors and patients communicate using a smartphone

4.4 Causal Loop Diagrams

In system dynamics, causal loop diagram or known as "influence diagram" is also one of the effective ways to graphically depict the feedback relationship between the elements within each sub-system. In comparison to model conceptualisation, the causal loop diagram enabled us to recognise the variables that will be used in the simulation model in more details. The model will then be finalised using a quantitative aspect of simulation model called stock and flow diagram in the system dynamics. At this stage, the parameters and variables will be incorporated and estimated based on the collective data and parameters compilation. Wholly, the model structure consists of four sub-system diagrams interacting with each other during the simulation exercises, namely, health care demand, workforce and capacity supply, health care financing, and smartphone adoption sub-diagrams. Some parts of the model such as the population sub-model are based on the common existing model. However, the assumptions and brainstorming of ideas in the building of the remaining sub-models came from the prior work by Ng et al. (2011) in modelling affordability health care in Singapore and Chaudhary (2015) in modelling affordability healthcare in Singapore and India respectively.

4.4.1 Healthcare Demand

According to Mardiah & Basri (2013), 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. As in many health care demand models from prior system dynamics model, the current research also assumed the patient flows into government hospital is an indicator of the citizen demand for health care. Specifically, the current model includes new links and information in comparison to the existing health care demand model, namely the budget spent on health care in which also one of the key variables for this study. On the demand side, the patient visiting the hospital is determined by medical demand and medical need. A basic understanding of the likely demand for public health care service is increasing in medical need and positive expectation from citizens from public sector budget allotted to health care. Figure 4.2 below depicts the causal loop diagram for patient flow to a Malaysian government hospital. Principally, this model contains five negative feedback loops. Each loop will be described in the following table.

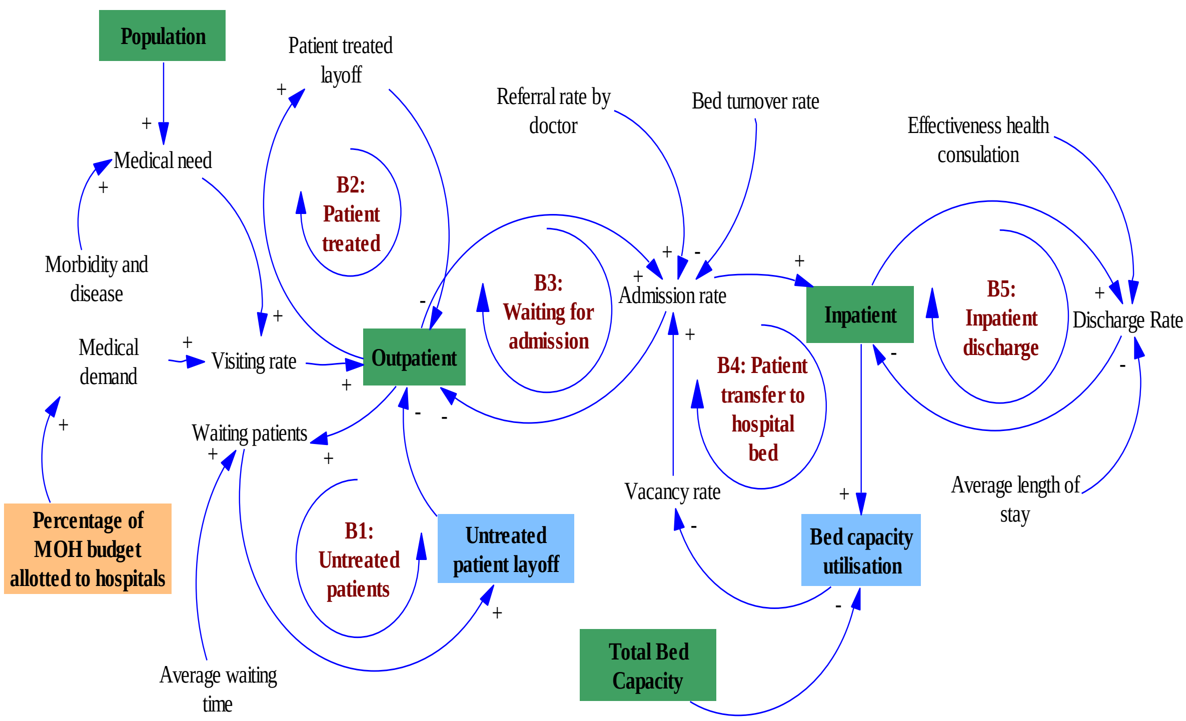


Figure 4.2 Causal loop diagram of patient flows

Notes: Green coloured variables indicate stock variables, blue coloured variables indicate variables that connected to some of the other sub-models, and peach coloured variables indicates the vital variable of the study

Table 4.2 Description of the patient flow linkages

Loops	Descriptions
B1: Untreated patient loop	• This loop indicates untreated patients leave government hospital due to long waiting time • Increase in the number of patient in outpatient visits lead to increase the number of waiting lists, in which turn to increase untreated patient to leave the hospital, eventually decrease the number of outpatients.
B2: Patient treated loop	• This loop indicates the proportion of patients successfully receive treatment and return to home. • Increase number of outpatient will be expected an increase in the proportion of treated patients
B3: Waiting for admission loop	• This loop indicates patients have to wait for admission depends on the available bed and turnover bed to be returned available
B4: Patient transfer to a hospital bed	• This loop indicates patients eventually transfer to a hospital bed as an “inpatient” • When admission rate increase, many inpatients in the hospital has increased the utilisation of bed capacity, in turn, to cause vacant bed decrease. However, once the proportion of bed vacant increase, it turned to increase admission rate again.
B5: Inpatient discharge	• This loop indicated the proportion of patient discharge after receiving treatment

	• Increase in the number of admitted patient will increase the number of discharge rate. Oppositely, increase the proportion of discharge patients will reduce the current number of inpatient in a hospital

4.4.2 Doctor Capacity

Rising demand for physical and human resources such as space, facilities, bed capacity, doctors, and other medical staffs lessen their availability over-consumption. Doctors are the key input of the production of health care and they are arguable as a second best choice for measuring health care resources. In this thesis, doctor workforce capacity and bed capacity are merely considered. Following Table 4.3 indicate the description of causal links between elements in the doctor supply model and its causal loop diagram is shown in Figure 4.3.

Table 4.3 Description of the doctor supply linkages

Loops	**Descriptions**
B6: Increase doctor capacity	• This loop shows that the rate to increase health workforce capacity relied on the budget spent on health care • Increase in government budget for health care will increase the number of doctors to be recruited based on the desired quota of the health workforce to increase. As the availability of a number of doctors increase, the discrepancy between the desired and actual amount will be closer.
R1: Doctor leaving the hospital	• This loop shows the percentage of the expected amount of doctor to leave their service in the government sector

	• As the doctor utilisation rate increase due to the increased number of patients, it will then put the burden of workload to doctors. Eventually, some doctors decided to layoff and cause to decrease the number of a doctor in the hospital.
B7: Retirement rate	• This loop shows the proportion of retire doctors depending on the retirement age. • When the retirement period is set by the government is longer, retire doctor will reduce. Meanwhile, when more doctor is retired, doctor availability in the hospital will reduce.

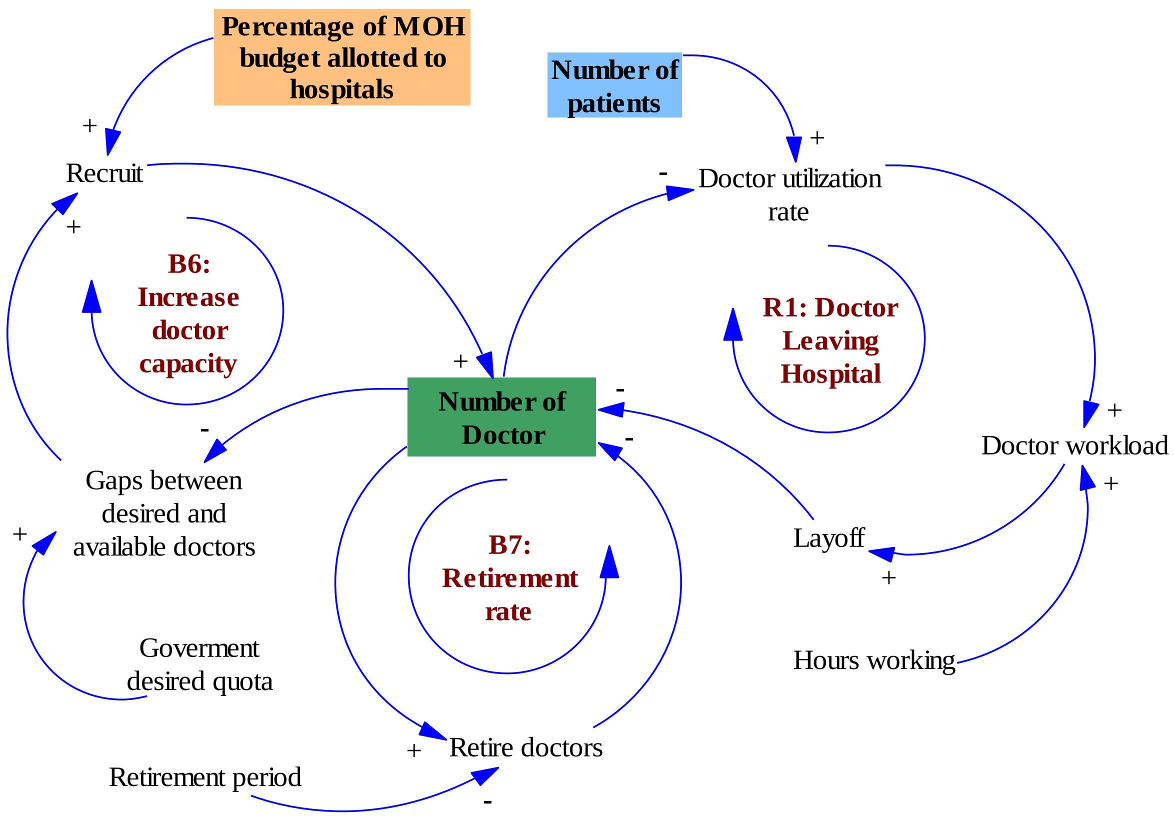


Figure 4.3 Causal loop diagram of doctor supply

Notes: Green coloured variables indicate stock variables, blue coloured variables indicate variables that connected to some of the other sub-models, and peach coloured variables indicates the vital variable of the study

4.4.3 Bed Capacity

Patient attendance at the hospital has also influenced the bed capacity availability. Once the outpatient is converted into inpatient based on the doctor's prescription for admitting into the hospital, bed capacity utilisation will then increase. Therefore, as the health workforce supply, the budget for health care is also necessary to supply more beds to the hospital. The rising number of available beds will reduce the gaps between the desired bed (shown as bed capacity utilisation) and available bed. This connection can be seen from the loop B8 of bed accumulation in Figure 4.4.

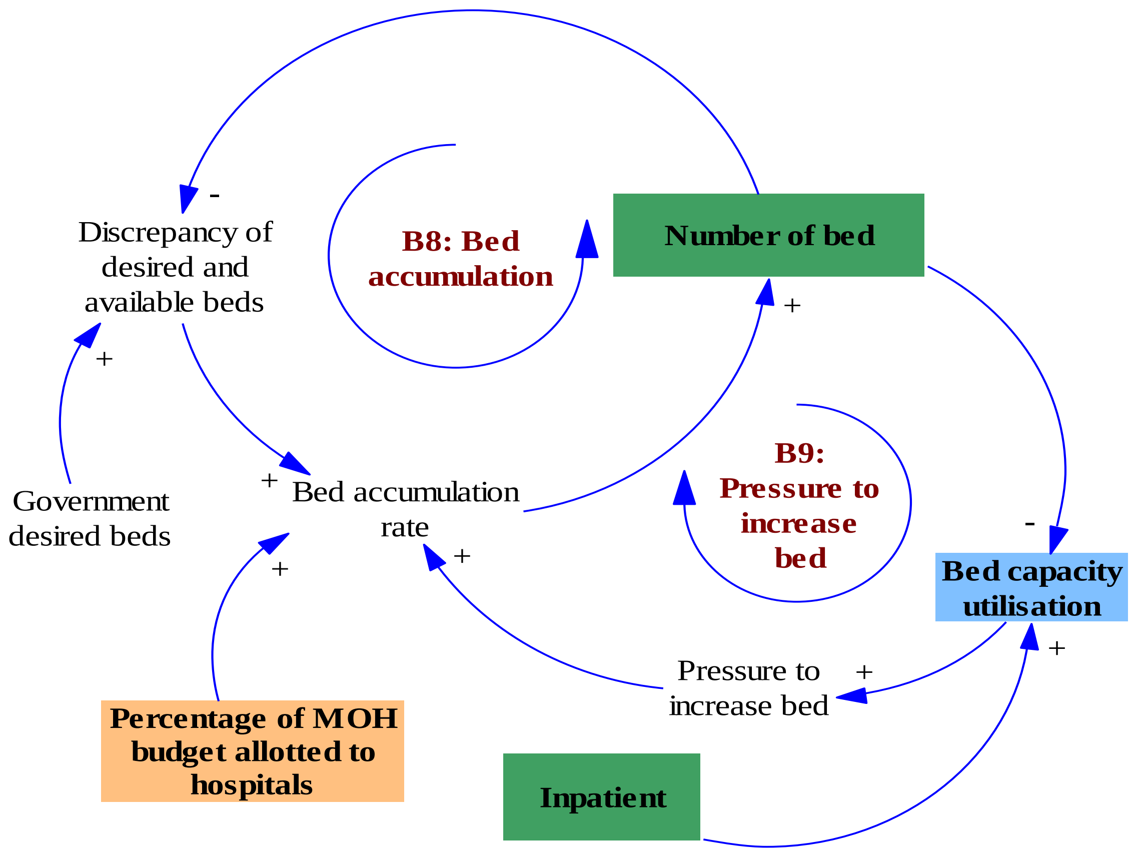


Figure 4.4 Causal loop diagram of bed supply

Notes: Green coloured variables indicate stock variables, blue coloured variables indicate variables that connected to some of the other sub-models, and peach coloured variables indicates the vital variable of the study

4.4.4 *Financial Resources*

Over the years, healthcare providers retaliate to the availability constraints by earning more resources, thus, raising the cost of healthcare. Malaysian government enormously subsidises the public health sector, where patients only need to pay a nominal sum for receiving a treatment. On the other side, treatment fee used in the private sector will be paid either fully by the patient themselves, or by their employers and insurance providers that they applied in. government health services, in particular, financed by taxes from citizen and other public revenues have achieved awesome coverage for primary healthcare. In line with prior research by Ng, et al. (2011), this research also assume the allocation of healthcare budget corresponds with economic growth that is specified as a national gross domestic product (GDP). Figure 4.5 depicts the causal loop diagram of health financing sub-model.

Principally, this financing health diagram comprises both the financing from the health providers-side and financing from the patient-side. Loop R2 indicates the reinforcing loop of financial spent for government hospital that is authorised by the Ministry of Health (MOH). The polarity of this loop begins when the national income or GDP is assumed to increase, resulting in the increase in total health expenditure allotted of the percentage GDP in the same way. Increase in total health expenditure then encouraged MOH authority to allocate budget for the government sector, in which it has led to the budget expansion for the hospital. An increase in the budget allocation to the hospital by the government can also act as an indicator that the medical cost to patients borne by these providers has also increased, and in turn, increased the health expenditure. On the patient's financing side, average medical costs borne by patients for each visit to the hospital will return as a revenue to the hospital. Meanwhile, if the medical cost per patient visit, either outpatient or inpatient, borne by the provider increases, it is expected that the demand in private sectors will reduce. Untreated patient layoff due to long waiting time in hospital has also caused an increase in attending private sector.

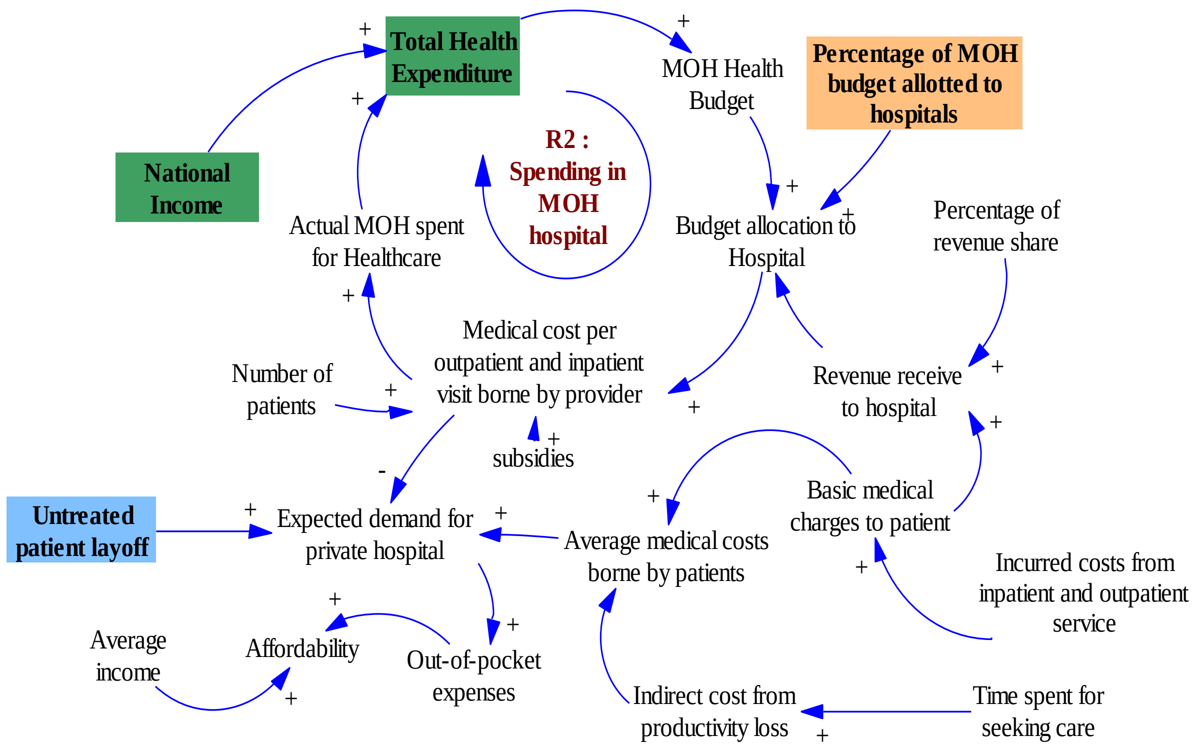


Figure 4.5 Causal loop diagram of Health Financing

Notes: Green coloured variables indicate stock variables, blue coloured variables indicate variables that connected to some of the other sub-models, and peach coloured variables indicates the vital variable of the study

4.4.5 Smartphone-based Technology Adoption

Undoubtedly moving toward modern technologies is indisputable for many organizations. Before transforming the technology into the organisation, analysing the conditions precisely of the entrance these technologies using technology acceptance model are required (Abbasi, et al., 2016). In the present day, many service sectors particularly education and banking industries used mobile technology system to attracts more customers for instance. This technology also recognises that would reduce communication costs and increased the efficiency of the service process for banking sector using e-banking.

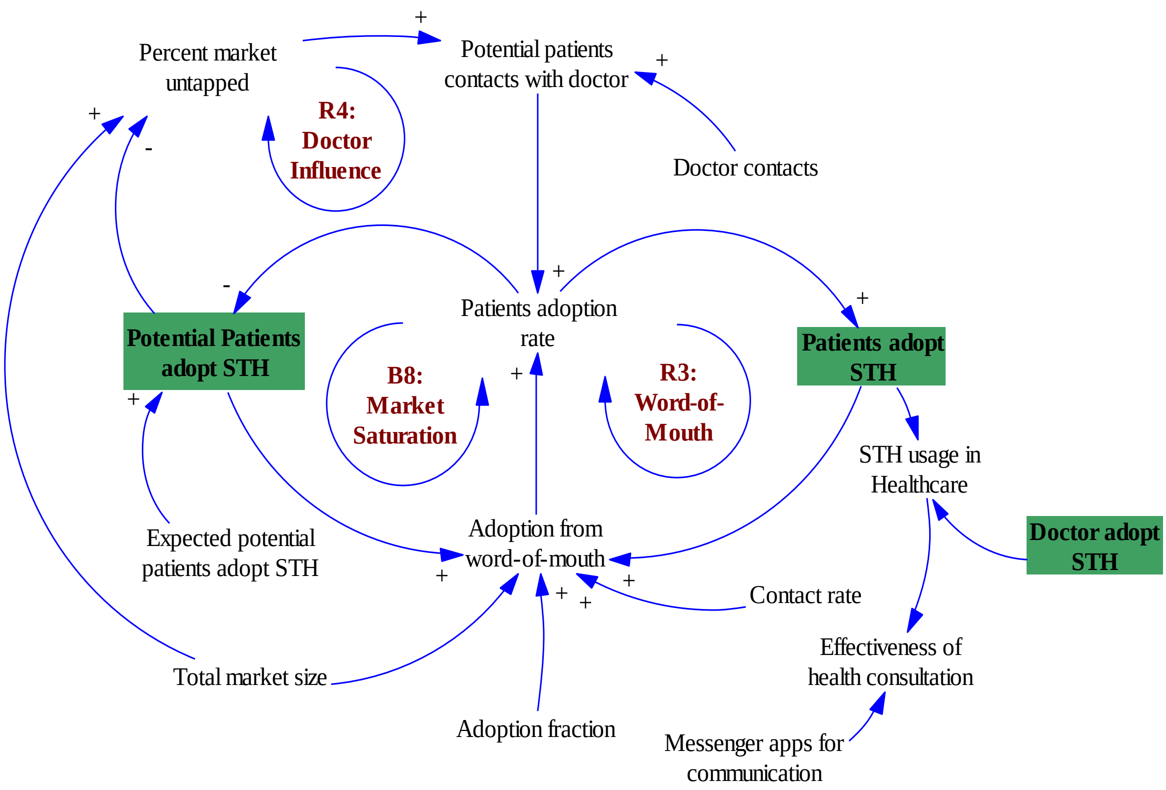


Figure 4.6 Causal loop diagram of smartphone-based technology adoption

Notes: Green coloured variables indicate stock variables

Figure 4.6 shows the basic diagram of the technology adoption model based on system dynamics simulation model. In applying related issues of the study, I extend the model to include the "expected potential patients adopt STH" based on several factors influencing to increase new potential adopters. For example, the rate of disease, mobile penetration, mobile health availability, smartphone penetration and messenger apps used for communication between stakeholders. In similar to the above figure, smart-health adoption model for doctor also produce the same way.

Table 4.4 Description of the smart-health adoption linkages

Loops	Descriptions
B8: Market Saturation	• This loop indicates the negative feedback loop of the market saturation process that limiting the imitative process to the actual market capacity that is number of patients (doctor) • The more potential patient adopt smart-health based on the factors driving to increase potential adopters among patients and doctors towards smart-health, the greater the imitative adoption rate in turn to increase more adopters, and consequently, the potential adopters will be less.
R3: Word-of-mouth	• This loop indicates the positive feedback loop that fuels the dynamics of imitative adoption process among patients and other population. • As the number of adopters among patients (or doctors) to adopt smart-health, the products potentially spreading through this interaction.
R4: Doctor influence	• This loop indicates the positive feedback loop that fuels the dynamics of imitative adoption process that influenced through contact with doctors. • When patients often contact with adopted doctors to STH, STH adoption rate among doctors will increase, this will reduce potential patient adopts STH.

CHAPTER 5: MODEL FORMULATION

5.1 Overview of the chapter

This section presents the stock and flow structure of the entire simulation model of smartphone-based technology adoption. Quantitative aspects of system dynamics are presented on differentiating stock and flow variables in a system simulation representation. Herein, the thorough model categorised into five groups of sub-models: healthcare demand, workforce and capacity supply, health financing, and smartphone-based technology adoption for healthcare among two main health stakeholders: doctors and patients. These sub-models encompass stocks, flows, and causal links that flows into flow variables, as has been explained in chapter three. The structure of these block models are formulated based on the causal loop diagram explained in the prior chapter. The built model will be attempted and reproduced the trends of real behaviour for the period 2010 to 2016 through conducting model behaviour reproduction test that will be presented in the section thereafter simulation model. This paper uses Vensim PLE software for building, validating, testing and analyzing the stock and flow diagrams. The initial values of each parameter can be found in Appendices at the end of this thesis. Thus, the detailed frameworks of the stock and flow diagrams are demonstrated below.

5.1.1 Health care demand sub-model

For health care demand sub-model, it is more constructive to develop a common core model of population and patients' structure in this study. Basically, this common population model has been extensively applied in prior studies. In this model, the population in one country grows dynamically from the births that determined by a constant percentage rate of births and depleted by death rate. The population sector comprises basic components of population change drivers, namely, birth and death rates, as widely developed in many prior studies of the population dynamics structure (Ansah, 2014; Krejčí et al., 2011). The population sub-model shows the essential interdependency of demographic factors in the population sector. Both births and deaths are assumed to influence the state of the current population. As the population model is not the focus of the study, the other likely drivers such as emigration and immigration variables are excluded in the model. A high number of births lead to a rise in population, which in turn increase many more births. In system dynamics, this is called as reinforcing feedback loop (Sterman, 2000). On the other hand, increase in population also leads to more number of deaths, in which high in death rate lead to a decrease in the total population in a country. The opposite direction between population and deaths is known as implicit goal seeking or balancing feedback loops (Sterman, 2000). The population model can be mathematically explained as following:

$$\mathrm{POP\ (T)} = \int_{\mathrm{t_0}}^{\mathrm{T}} (\mathrm{BR} - \mathrm{DR})\, dt + \mathrm{POP\ (t_0)} \qquad (5.1)$$

Where,

POP (T) is the state of current total population

POP (t_0) is the initial total population at the time (t)

BR is births at the time (t);

DR is the deaths at the time (t)

Equation 5.1 indicates the mathematical equation for the population stock, where the current population is the integration of the flow of birth and death plus the initial state of population stock. Whilst, births and deaths equation can be determined by birth rate (CBR) or death rate

(DR)[5] and the current state of the population as indicated in equation 5.2 and equation 5.3 respectively. In stock and flow terms, births and deaths are calculated as inflow and outflow of the population stock respectively.

$$BR = CBR \times POP(T) \quad (5.2)$$

$$DR = CDR \times POP\ (T) \quad (5.3)$$

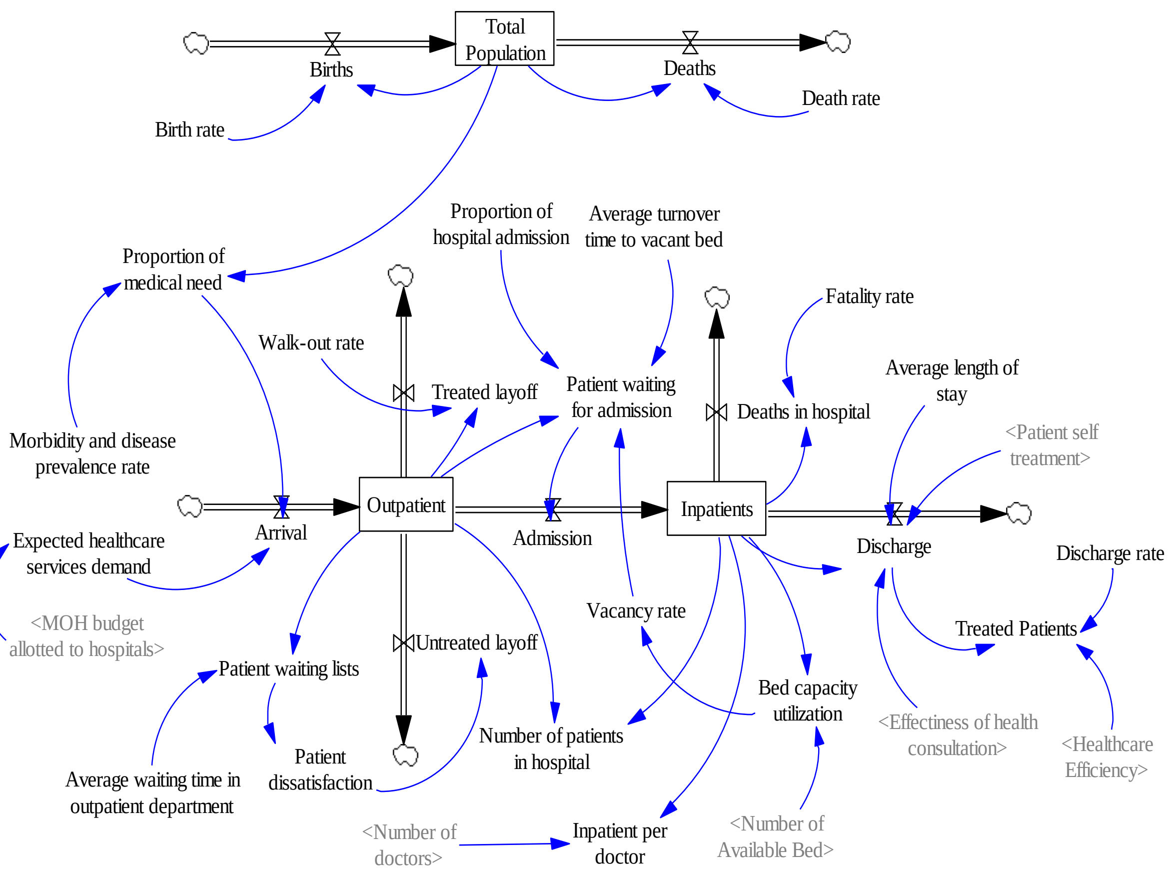


Figure 5.1 Patient pathways through public hospitals

[5] The crude birth and death rate are the number of live birth and death occurring in a certain period of time.

Figure 5.1 shows the structure of health care demand model. As discussed in prior causal loop diagrams in the previous chapter, the health care demand can be seen from the journey of the patient into the public hospital. These sub-models have highlighted the three main stock variables, namely, total population, outpatient and inpatient. The patient sub-model in this paper is a simplification of the complex micro-level flow of patients as published in previous studies of the comprehensive health care system. An original patient model by Hassan & Minato (2017) of the current study has been revised by classifying factors that influence the hospital visiting rate into two, namely, medical demand and medical need drivers. As the population increases along with prevalence morbidity and diseases, visiting rate to the hospital is postulated to increase. The health care demand sector projects the patient flows into the public hospital as the demand for public health resources.

For the purpose of this model, expected medical demand is assumed to be influenced by the proportion of budget allocation only. Meaning, the number of patients in public hospital is estimated to recruit from the total population in Malaysia, as we assumed Malaysian citizens have a better expectation towards the government health care and thus, inducing the demand for a public hospital. Ageing chain patient sub-model has been broken into two stocks, that is the outpatient and inpatients stocks that simulate the flow of patients through the outpatient visits and inpatients care. Based on the figure, patients flow into the hospital begins when patients enter a public hospital by visiting a doctor at the primary outpatient clinic. Based on the doctor's prescriptions, outpatients may thereupon be able to receive a further diagnosis and prescription of drugs, thus may depart from hospitals. These treated outpatients are shown flowing out from the stock of "outpatient" as a treated layoff. The mathematical equations of these elements are expressed as following equation 5.4 to 5.8.

$$\text{OUP (T)} = \int_{t_0}^{T} (\text{Arrival} - \text{Treated layoff} - \text{Untreated layoff} - \text{Admission})\,dt + \text{OUP}(t_0) \quad (5.4)$$

$$\text{Arrival} = \text{Proportion of medical need} \times \text{expected healthcare services demand} \quad (5.5)$$

$$\text{The proportion of medical need} = \text{MDPR} \times \text{POP} \quad (5.6)$$

$$\text{Expected healthcare services demand} = \text{MOH budget allotted to hospitals} \quad (5.7)$$

$$\text{Treated layoff} = \text{WOR} \times \text{OUP (T)} \quad (5.8)$$

where,

OUP (T) is the state of current outpatient

OUP (t_0)is the initial outpatient at the time (t)

Arrival is patient arrival rate at the time (t);

The treated layoff is patient leaving the hospital after receiving treatment at the outpatient department at the time (t);

The untreated layoff is untreated patient leaving hospital who have not received treatment at the time (t);

Admission is the proportion of patients to be admitted into hospital bed at the time (t)

WOR walks out rate of patients from the outpatient department at the time (t)

Patient arrival indicated in equation 5.5 is the rate of accumulation of both medical need by population and medical demand expectation from the budget spent to healthcare. The proportion of medical need is calculated by multiplication of morbidity and disease prevalence rate and total population as represented in equation 5.6. Equation 5.7 indicates expected healthcare services demand is equal to MOH budget allotted to hospitals. This equation means that budget allotted to the hospital by MOH will increase expectation of citizens to demand medical services at public hospitals. Equation 5.8 explains the number of treated patients leaving from outpatient departments is equal to the multiplication of the currents stock of outpatient and walk-out rate (WOR) at the time (t).

However, due to overcrowding phenomenon facing by most of the public hospitals in many countries, some attending patients to outpatient might be a tendency to stop waiting for care and decide to leave off the hospital before receiving the medical consultations from medical doctors. A number of people on waiting lists are often been focused by policymakers in the planning of healthcare (Van Der Sanden, et al., 2006). They explained that long waiting lists for dementia care will cause people stay at home where they prefer to remain self-supplying. Over the years, waiting lists continue increasing as capacity cannot be expanded immediately as planning and investment on it are consuming several years. Based on the above patient flow sub-model, untreated patients leave the outpatient department due to the dissatisfaction of prolonged waiting time. This prolonged waiting time is caused by the long listed of patients waiting for treatment at waiting area. The elements can be seen from mathematical equations expressed in following equation 5.9 to 5.11. Patient waiting lists are calculated by multiple of the current state of an outpatient with average waiting time in the outpatient department (OPD).

$$\text{Untreated layoff} = \text{Patient dissatisfaction} \tag{5.9}$$

$$\text{Patient dissatisfaction} = \text{Patient waiting lists} \tag{5.10}$$

$$\text{Patient waiting lists} = \text{OUP (T)} \times \text{Average waiting time in OPD} \tag{5.11}$$

For some special cases, patients who successfully able to meet medical doctors are sometimes prescribed to be admitted into further treatment and care at hospital. Equation 5.12 and 5.13 expressed mathematical equations for the flux of outpatients from the outpatient department into waiting area for admission as inpatients, where waiting for admission means the proportion of patient waiting to be admitted to hospital. This variable influenced by the number of outpatients, average turnover time to vacant bed (BTR), the proportion of admission rate by doctor's referral and vacant rate of bed supply (VR).

$$\text{Admission} = \text{Waiting for admission} \tag{5.12}$$

$$\text{Patient waiting for admission} = \text{OUP (T)} \times \text{BTR} \times \text{Admission rate} \times \text{VR} \tag{5.13}$$

$$\text{INP (T)} = \int_{t_0}^{T} (\text{Admission} - \text{Deaths} - \text{Discharge})\,dt + \text{INP}(t_0) \tag{5.14}$$

$$\text{Deaths in hospital} = \text{Fatality rate} \times \text{INP} \tag{5.15}$$

$$\text{Discharge} = \left(\frac{\text{INP}}{\text{ALOS}}\right) \times \text{self treatment} \times \text{Effectiveness of health consultation} \tag{5.16}$$

$$\text{Treated Patient} = \text{Discharge} \times \text{Discharge rate} \times \text{Efficiency} \tag{5.17}$$

Equation 5.14 indicates the mathematical equation for the inpatient stock, where current inpatient is the integration of the flow of admission, deaths in hospital and discharge rate plus the initial state of inpatient stock. While deaths variable is determined by fatality rate and stock of inpatient. Hospital discharge is determined by the number of patients in the hospital and the average length of stay (ALOS) of patients. It is important to note that delays represent as the average length of stay are part of the structure. According to OECD (2018), the variable ALOS is frequently used as a proxy of healthcare efficiency. This indicator explains the average number of days that patient stays in hospitals. It is usually calculated as a total number of spent days by the sum of inpatients for a year divided by the number of admissions or discharges. Self-treatment and effectiveness of health consultations are two intervention variables used to improve discharge rate in hospital. Average hospital length of stays differs across OECD countries, for instance, 4 to 5 days in Israel, Denmark and Turkey, but 34 days in Japan. The efficiency of the hospitals is negatively associated with average length of stay (Varabyova & Schreyögg, 2013). The following Table 5.1 indicates a description of the selected parameters for the modelling process are based on former studies and reported facts in regard to Malaysia situation.

Table 5.1 Description of several parameter settings for healthcare demand model

Parameters	Reasons
The proportion of medical need	Patient attending to the public hospital is increased by the prevalence of morbidity and disease among the population. According to NoorAni et al., (2018) the prevalence of chronic disease and ageing population poses a greater impact on health care utilization (outpatient and inpatient) in Malaysia.
Patient dissatisfaction	As waiting time increase, patient satisfaction decreases, or ceteris paribus where, patients care to the aspect of access to care service, as such length of time to wait. The increasing in waiting time due to an increase in patient visits to service centres (Rohleder et al., 2007).
Expected healthcare demand	Malaysia public healthcare provides rock-bottom healthcare prices to the citizen, where its budget allotted roughly over 95% to cover medical costs per patient visits (including outpatient and inpatient). This coverage has increased growing demand to a public hospital.
Waiting time	Waiting time is widely known as a service performance indicator. In the health sector, the performance indicator of health services can be measured via patient’s waiting time where it is triggered by an increasing number of patients attending to service which in turn to lead decreasing in resource capacity (Ahmad et al., 2013).

Admission to hospital	Patient admitted to hospital is determined by the expected number of patient waiting to be hospitalized. Expected patient waiting for the hospital is influenced by vacancy bed and how long bed is turnover to new patients from old patients (Wael Rashwan, 2013). Average bed turnover in Malaysia is 2.1 days (Ministry of Health Malaysia, 2011b)

5.1.2 Doctor workforce supply sub-model

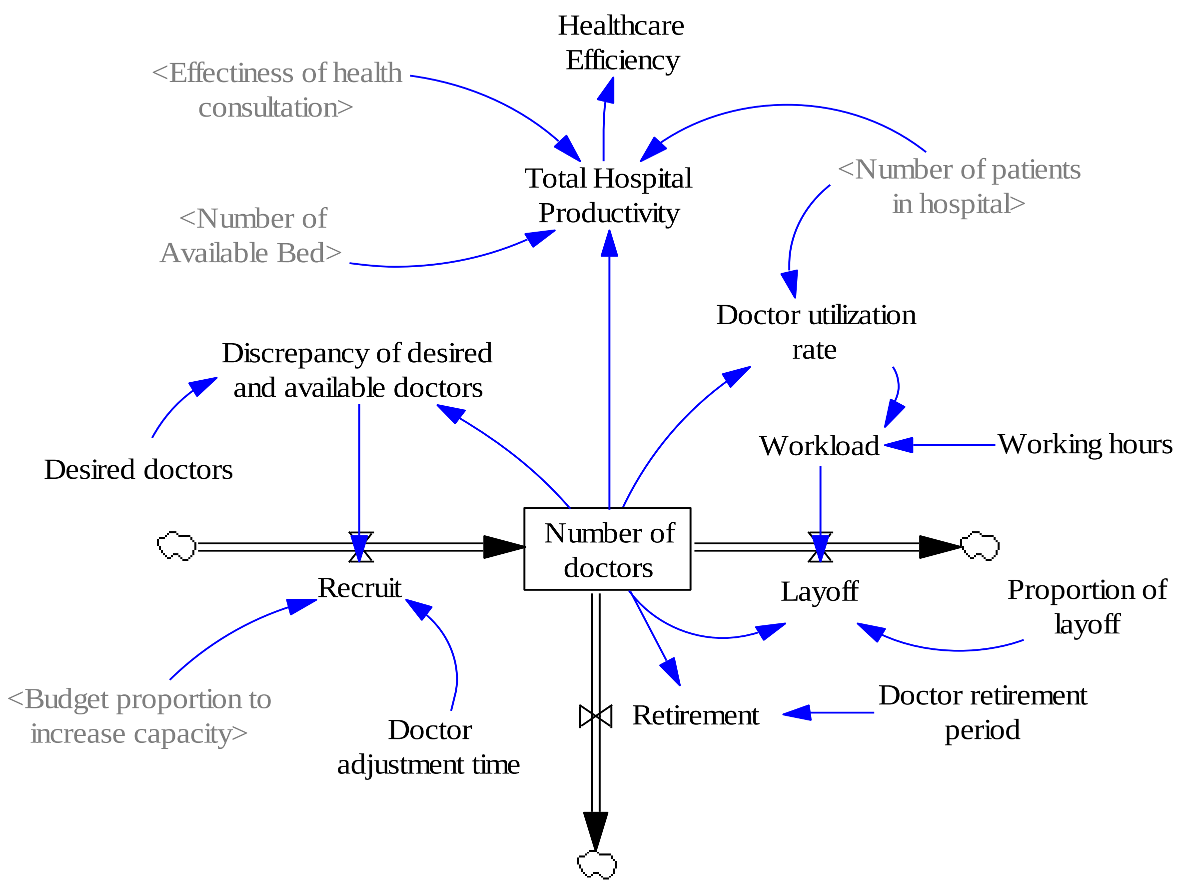


Figure 5.2 Healthcare workforce supply

In general, health production capital is defined as physical and human capital invested for the state of health, comprising medical doctors, bed facilities, medical equipment, hospital buildings, and many more factors. For brevity of the current study, the structure of the medical workforce and bed capacity provisions show the process of increasing the supply, as there is an accumulation in the number of patients and inpatients to the sector. The structures of the medical doctor and bed capacity supply are depicted in Figure 5.2 and 5.3 respectively. Meanwhile, doctor as the main component of the health care workforce supply is considered in this study. The medical officer sub-model is changed by the flow of recruiting adds into doctor cohort, in turn, they are depleted by layoff and recruitment. Measuring hospital efficiency also means estimating the performance of the productive unit, where it can be gauged as the ratio of output and inputs. For instance, commonly adopted by economists to measure the ratio of cost and production as included in the doctor's subsystem. The mathematical equation for medical doctor sub-model is expressed as:

$$\text{Doctor (T)} = \int_{t_0}^{T} (\text{Recruit} - \text{layoff} - \text{retirement})\,dt + \text{Doctor}\,(t_0) \quad (5.18)$$

$$\text{Recruit} = \text{Budget to increase capacity} \times \text{doctor'discrepancy} \times \text{AT} \quad (5.19)$$

$$\text{Doctor's discrepancy} = \text{Desired doctors} - \text{Doctor (T)} \quad (5.20)$$

$$\text{Layoff} = \text{Doctor} \times \%\,\text{layoff} \times \text{workload} \quad (5.21)$$

$$\text{Workload} = \text{Doctor utilization rate} \times \text{Working hours} \quad (5.22)$$

$$\text{Retirement} = \frac{\text{Doctor (T)}}{\text{Retirement period}} \quad (5.23)$$

$$\text{THP} = \left(\frac{\text{NP}}{\text{Bed+Doctors}}\right) \times \text{Effectiveness of health consultation} \quad (5.24)$$

Equation 5.18 indicates the mathematical equation for the number of the doctor as a stock, where current doctor capacity, Doctor (T). is integration of the recruit, layoff and retirement plus the initial state of doctor stock $\text{Doctor}\ (\text{t}_0)$. The flow variable of recruit is increased by the percentage to increase capacity connected from budget spent for the hospital, doctor's discrepancy between desired and actual capacity, and adjustment time (AT) to increase it. Whilst, a layoff is risen by the initial state of a doctor, percentage of doctor to layoff (% layoff) and workload based on hours of working. Rising doctor workload indicated by doctor utilization would cause a doctor to lay off from a government hospital. In a certain period, senior a doctor expected to retire. This retirement rate is calculated by the number of doctors divided the period for retirement in government health services which is at 58 years old. In line with Taskaya & Demirkiran (2016), a number of the doctor was affected by the health expenditure.

5.1.3 Bed capacity supply sub-model

Bed capacity is vital for facilitating patients who are prescribed by their doctors to be admitted into hospitals. The number of hospital beds is measured as resources for providing capacities to inpatients in hospitals. This means that patients' admission to the hospital for further treatment relies on the availability of a bed. As the vacancy for bed rises, the hospitals are able to take in more patients who are waiting in the waiting room. The number of bed capacity to meet the number of inpatients admitted to the hospital depends on how long it takes for the bed capacity to be provided by the hospital, which is represented by the "adjustment time to accumulate bed". Similar to the doctor supply, in order to supply more bed to public hospitals, financial budget from public health providers is required. Figure 5.3 depicts the structured stock and flow model of bed capacity. The mathematical equation for bed capacity sub-model is expressed as:

$$\text{Bed (T)} = \int_{\text{t}_0}^{\text{T}} (\text{ Bed accumulated})dt + \text{Bed}\ (\text{t}_0) \tag{5.25}$$

$$\text{Bed accumulated}_t = \text{Budget to increase bed capacity} \times \text{Bed capacity utilization} \times \text{Bed's discrepancy} \times \text{AT} \quad (5.26)$$

$$\text{Bed's discrepancy} = \text{Desired bed} - \text{Bed (T)} \quad (5.27)$$

$$\text{Bed capacity utilization} = \frac{\text{INP}}{\text{Bed (T)}} \quad (5.28)$$

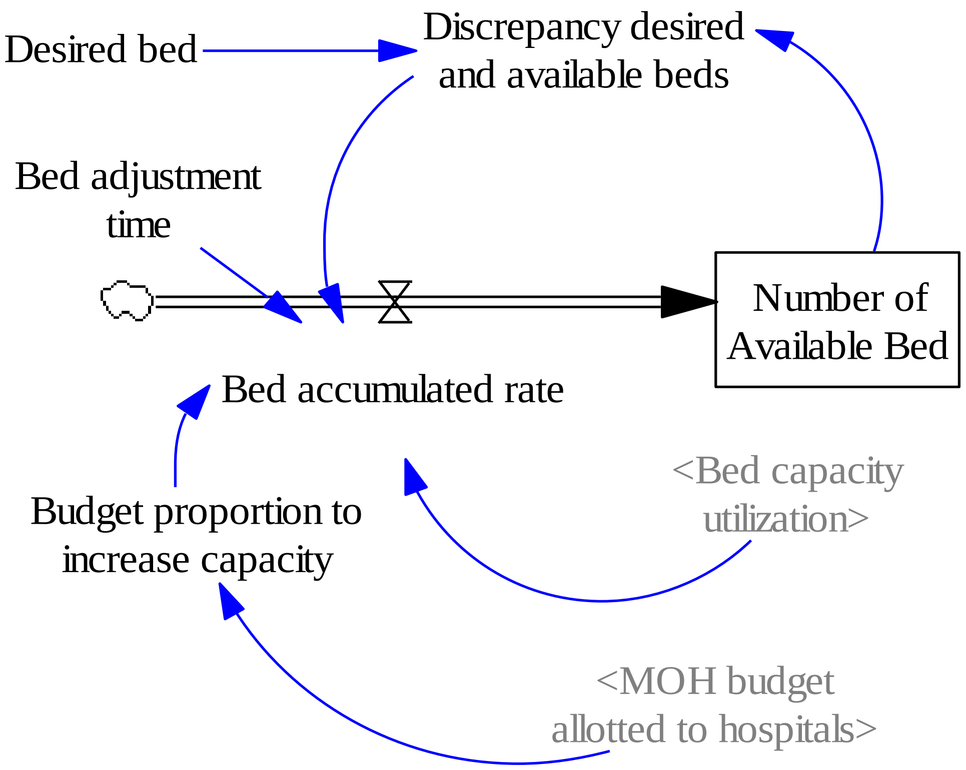


Figure 5.3 Bed capacity supply sub-model

5.1.4 Financial Resources sub-model

Economic development and an ageing population are the reasons for the substantial increase in health spending (Anderson, et al., 2003). GDP allocated to health care has explained a measure of a country's preference for health care (Retzlaff-Roberts, et al., 2004). It measures the proportion of a country's resources spent to health care or the relative support made by a country to the health care sector. Per capita health care expenditure is found to be related to a health system efficiency of several countries (Evans, et al., 2001). The number of patients in public hospital has induced the desired health expenditure, which in turn had increased the percentage allocation on public health expenditure so as to close the gap with current public health spending availability. In other words, the increment in allocated health care budget and the way it is spent is resultant from the health status of the citizen and their consumption in the health care system. In this study, we solely assume that the population's health care consumption is the demand for a public hospital. The mathematical equation for the main components of health financing sub-model is expressed as:

$$\text{GDP (T)} = \int_{\text{t}_0}^{\text{T}} (\text{ GDP change})dt + \text{GDP } (\text{t}_0) \quad (5.29)$$

$$\text{GDP changed}_{\text{t}} = \text{GDP (T)} \times \text{GDP growth} \quad (5.30)$$

$$\text{THE (T)} = \int_{\text{t}_0}^{\text{T}} (\text{ THE increased})dt + \text{THE } (\text{t}_0) \quad (5.31)$$

$$\text{THE increased} = \text{MOH Health Expenditure} \times \text{AT} \times \text{Gap} \quad (5.32)$$

$$\text{Gap} = \text{Target by WHO} - \text{\% of GDP allotted to THE} \quad (5.33)$$

$$\text{\% of GDP allotted to THE} = \frac{\text{Total Health Expenditure}}{\text{Total GDP}} \quad (5.34)$$

Equation 5.29 and 5.31 indicates the mathematical equation for the total GDP and total health expenditure as a stock, where current total GDP and health expenditure is the integration of the proportion to increase their volumes plus the initial state of their stock GDP (t_0) and THE (t_0). The flow variable of increased the capacity of GDP is changed by the GDP growth rate and the initial state of the GDP. Meanwhile, the flow variable to increase the capacity of Total Health Expenditure (THE) is changed by MOH actual health expenditure, adjustment time (AT) and the gaps between desired and actual volume of total health expenditure.

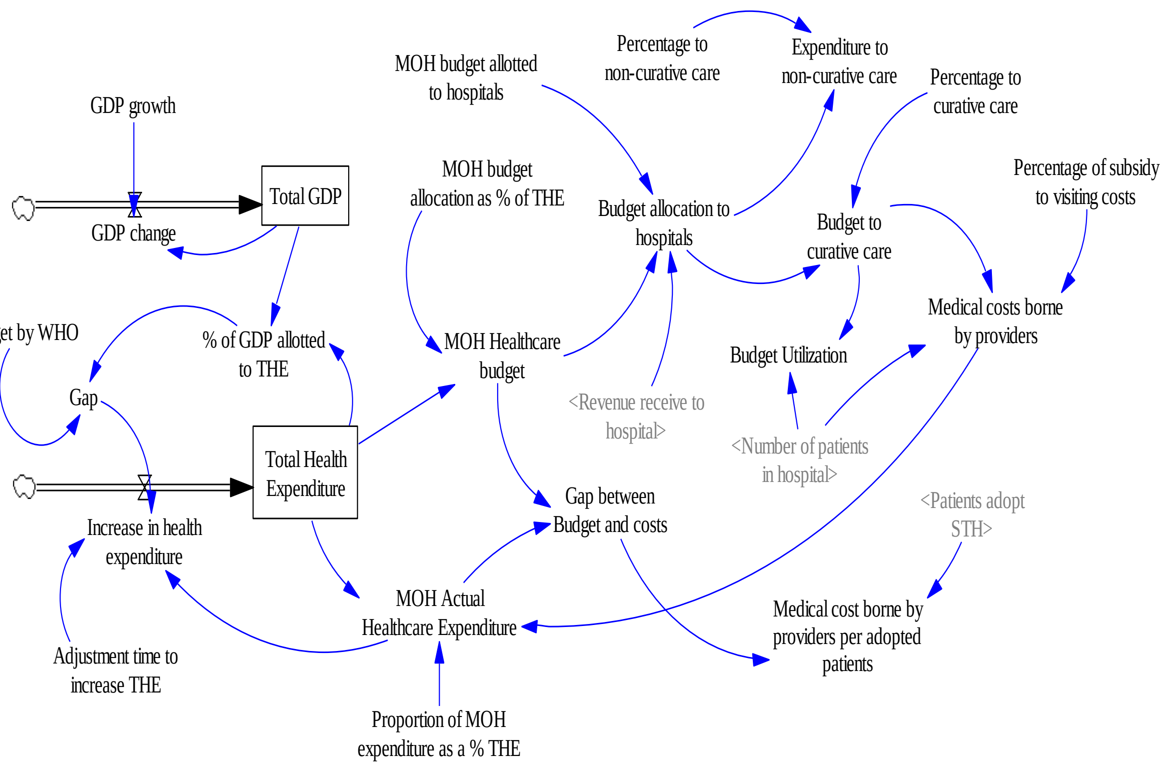


Figure 5.4 Financial resources borne by healthcare providers

On the other hand, Figure 5.5 indicates the financing cost incurred by the patient at minimal cost as revenue received by the hospital when patients visit the hospital. The figure also explains the expectation for consuming in the private sector should the patient has to wait for too long at the hospital, thus forcing them to layoff from the hospital before receiving the treatment. The cost of treatment incurred was considerably sizeable when compared to the average national income per capita (GDP per capita) and the mean annual health expenditure per Malaysian. The average admission cost per patient was 9 per cent of the country's GDP per capita and was double of the average health spending per person annually (Quek, 2009). The subsequent costs of annual treatment were either: (1) lower than the first-time visit if patients do not require surgery and patients would just remain at home or do several follow-up visits, or (2) the cost could be higher if patients require surgery and complex rehabilitative treatment.

Different types of diseases, for example, medical and surgical diseases produced different results of the relationship between the IT investment and patient-level costs, where cost related to medical diseases has a substantial impact rather than that of surgical diseases (Lee & Dowd, 2009).

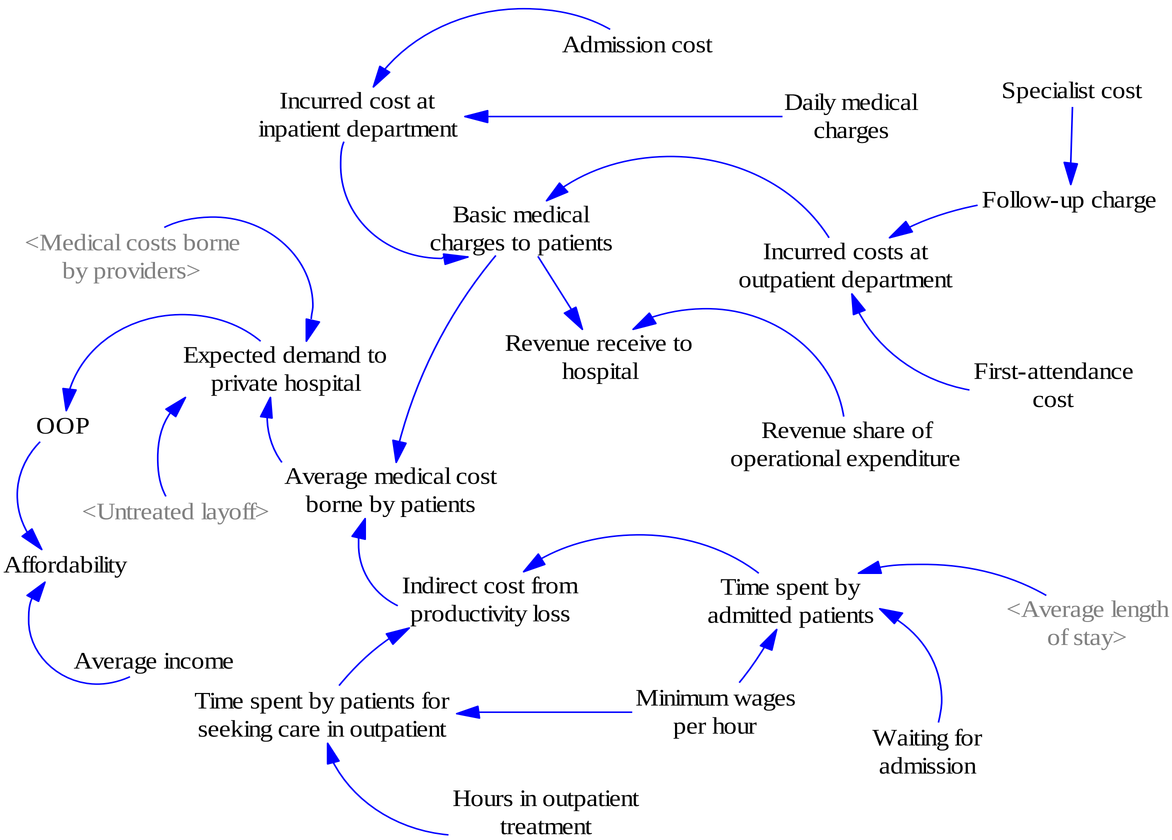


Figure 5.5 Financing cost borne by patients

5.1.5 Smartphone-based Technology Adoption

Several significant variables have been discovered from the literature review and interviews with experts in system dynamics, healthcare management, and public health fields. While the impact of the diffusion technology adoption on healthcare is difficult to quantify and even more strenuous to predict. Valuable insights and better analysis could, however, be quantified using system dynamic model. This sub-section provides a quantitative model of smartphone-based technology adoption for healthcare settings. Current research remodels a generic diffusion model (Bass, 1969) which was implemented in Susceptible Infectious disease model (Sterman, 2000) and other related studies of technology adoption model that applies the System Dynamics model. A basic adoption model developed by Hassan & Minato (2018) assumes that there are two types of new product and technology adopters: Actual adopters and potential adopters that interact with each other in the market during the adoption process. Figure 5.6 represents the processes that convert the adoption among non-adopters of STH indicating as PA and those who adopt STH, noted as A for both doctors and patients. The adoption model in this study assumes once the initial adopters are adopted to the technology, these adopters persuades the other potential adopters through the word of mouth effects and the social pressures to adopt the technology as well. The underlying elements of the smartphone-based technology adoption model for patients can be expressed as follows:

$$\mathrm{PA_P(T)} = \int_{\mathrm{t_0}}^{\mathrm{T}} (\mathrm{IPA_P} - \mathrm{AR_P})dt + \mathrm{PA_P(t_0)} \tag{5.35}$$

where PA_P is the potential patient adoption of STH, IPA_P is the increase in potential adopter, described as patients potentially adopting STH, and AR_P is patient adoption rate. That means the state of potential adopter among patients is risen and reduces by new potential adopter of patient and patient adoption rate. In this thesis, the model assumes patients potential adoption of STH is influenced by the percentage of internet usage among the patients, smartphone penetration among patients, availability of mobile health apps and the relative advantage of smartphone features indicated as new potential patients adopt STH is the rate at which new possible patients adopt STH.

In current model, the adoption rate for both doctors and patients indicate the number of doctors or patients adopting the STH products per time unit, which is per year for the case of the present study. Marketing effects are excluded from the model as it is out of the scope of the current study. The adoption rate is driven only by the contacts between the healthcare stakeholders (doctors and patients). A_P is increased by patient adoption rate (AR_P). The adoption rate expression indicated by the equation (5.40) defines that the adoption rate consists of two sources namely adoption from the interaction among patients (WOM_p) and adoption based on doctor recommendation to use STH for medical consultation (DR). The equation for the adoption rate by word-of-mouth is ordinary for any diffusion model such as infectious diseases, and new product in the market. Mathematically it can be expressed as follows:

$$A_P(T) = \int_{t_0}^{T} (AR_P)dt + A_P(t_0) \tag{5.36}$$

$$\frac{d\,(PA_p)}{dt} = -AR_P \tag{5.37}$$

$$\frac{d\,(A_p)}{dt} = AR_P \tag{5.38}$$

$$AR_p = WOM_p + DR \tag{5.40}$$

$$WOM_P = CR_P \times A_p \times AF_p \times \left(\frac{PA_p}{N_p}\right) \tag{5.41}$$

Where, CR_P is patient contact rate, AF_P is patient adoption fraction and N_P is the number of patients. Patients are assumed to come into contact at a certain rate. If adopters contact potential adopters, the latter will make up their mind to adopt with a certain constant probability known as adoption fraction. Contract rate among doctors and patients are vital to inform the matters of health and healthcare. For example, doctors and patients can use available social media such as Facebook, Skypes, personal email and WhatsApp to consult a patient’s health improvement. They also connect with their peers in the effort of sharing and exchanging knowledge related to self-management. The equations (5.37) and (5.38) are differential equations defining how the stock values of potential adopters and adopters change over time. Adoption from the interaction is the product of the rate at which potential adopters have contact with other individuals and the probability contact with an adopter. The above mathematical equation 5.35 to 5.41 for patient's adoption submodel applied the same way for doctor's adoption submodel. The developed adoption model is basically generated similar structure from various types of technology and new product adoption model in former studies (Medvechi, 2011; Eva-Maria, 2007, Mariana, 2011)

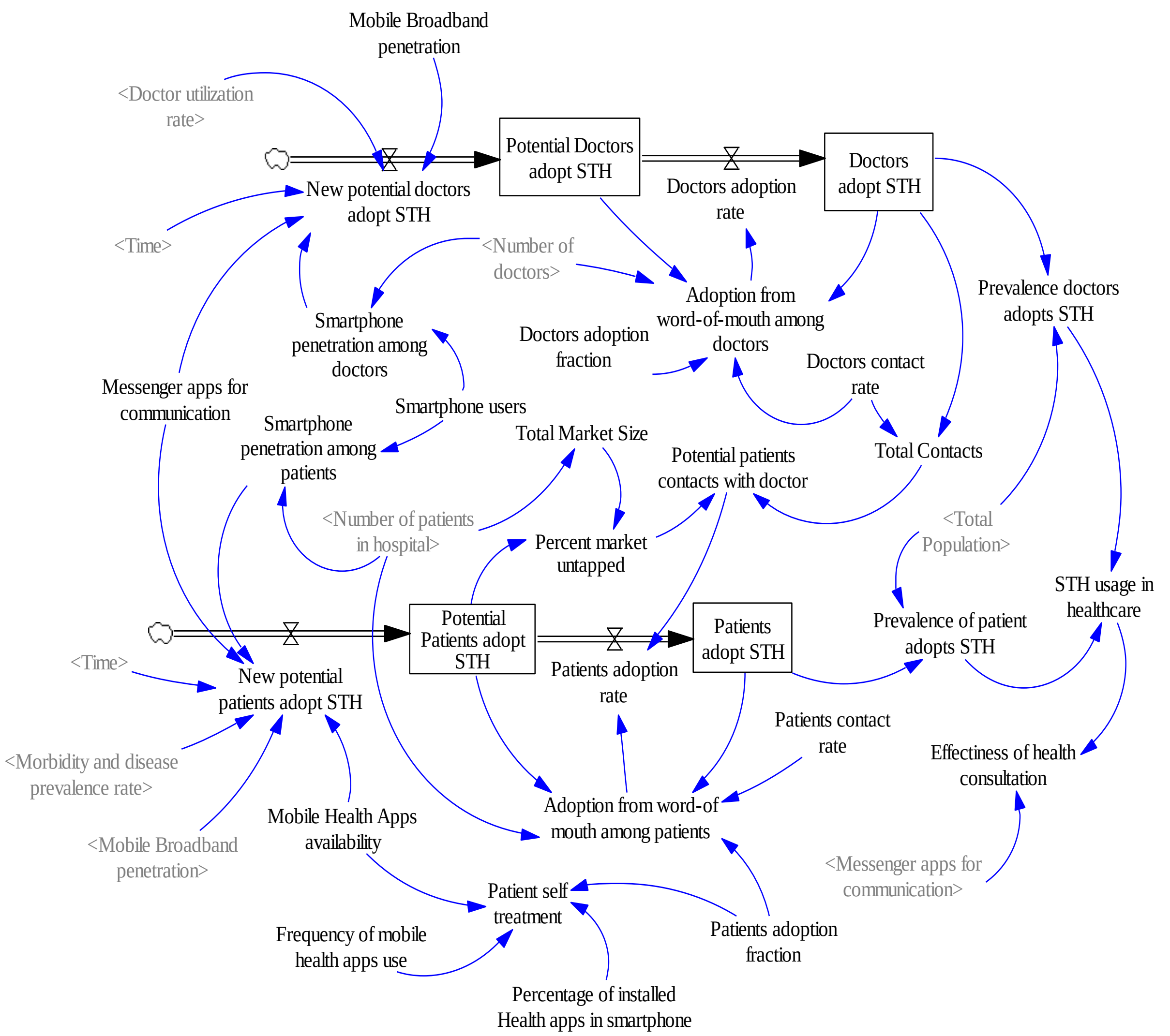


Figure 5.6 Smart-Health Technology Adoption sub-model

5.2 Model Validation Tests

Once the stock and flow model has completely developed, the developed model then used for calibration to fit the real data. There are a number of suggested validation tests in system dynamics to build confidence in the model structure (Sterman, 2002). For brevity, this study demonstrates two major tests for validating of model fitting for research purpose. I used statistical data to populate the model. Parameter values in the simulated model were calibrated using publicly available Malaysian health statistics, an annual publication in the Ministry of Health website. In this paper, the year 2010 was chosen as the base year as smartphone data available at this year, and hence will be utilized for all initial values in the baseline simulation model. The model begins in 2010 and simulates them continuously through 2030.

5.2.1 Validation of Structure and Behaviour

This test to validate the compatibility level of model behaviour determined by the behaviour of reference variables. Figure 5.7 to 5.13 illustrate the comparisons of simulated behaviours of key variables (population, outpatients, inpatients, doctors, bed capacity, GDP and total health expenditure) with time series data. From the illustrated perspective of those figures, both trends favourably look very similar pattern of behaviour. The simulated trend is displayed smoother than the real data. The small discrepancies between two trends can be seen as a defect. In other words, the behaviour tests' results clearly indicate the historical and default behaviour of simulated model harmonize appropriately, where simulated model considerably fit real time series data. The solid and dotted lines are the behaviour of interpolated historical data and the default behaviour of the built model respectively. The diagrams show the behaviour of seven variables for over the period 2010 to 2016.

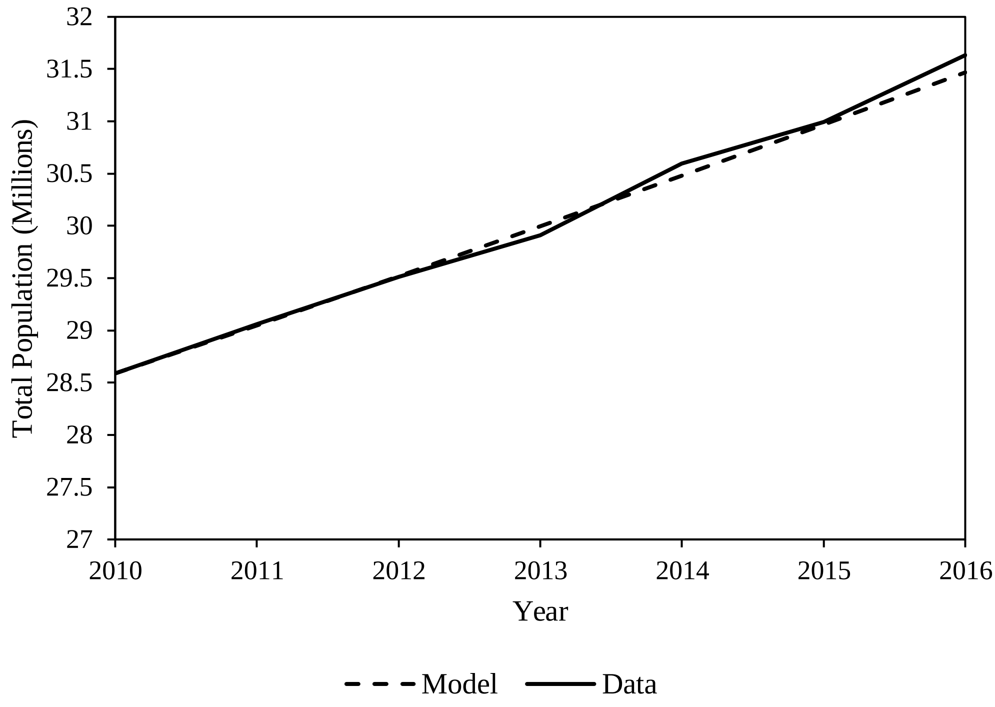


Figure 5.7 Historical and simulated behaviour of total population

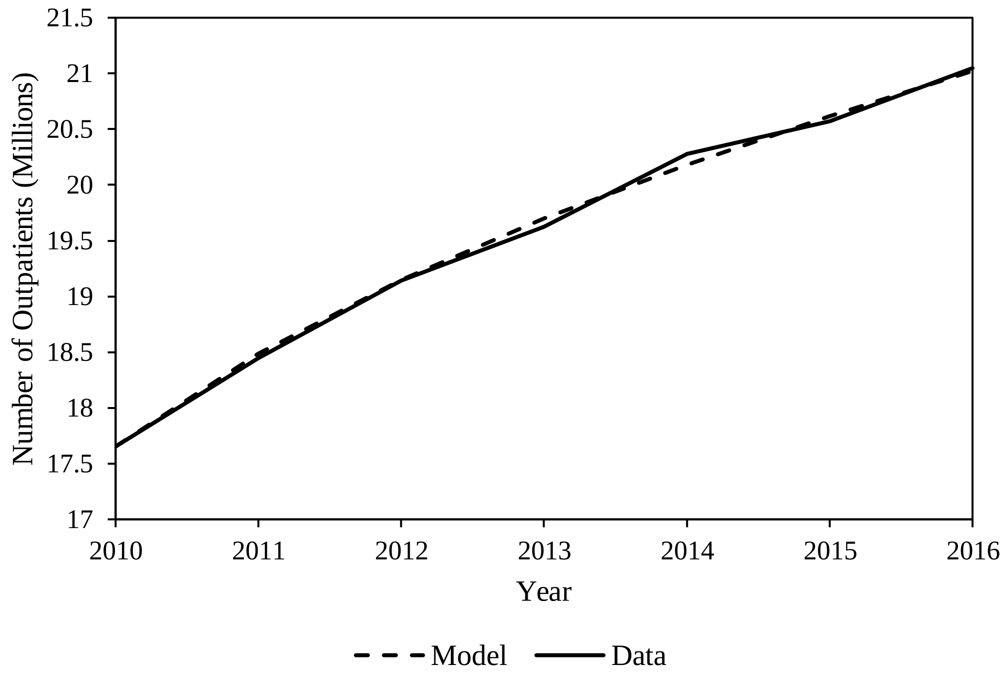


Figure 5.8 Historical and simulated behaviour of a number of outpatients

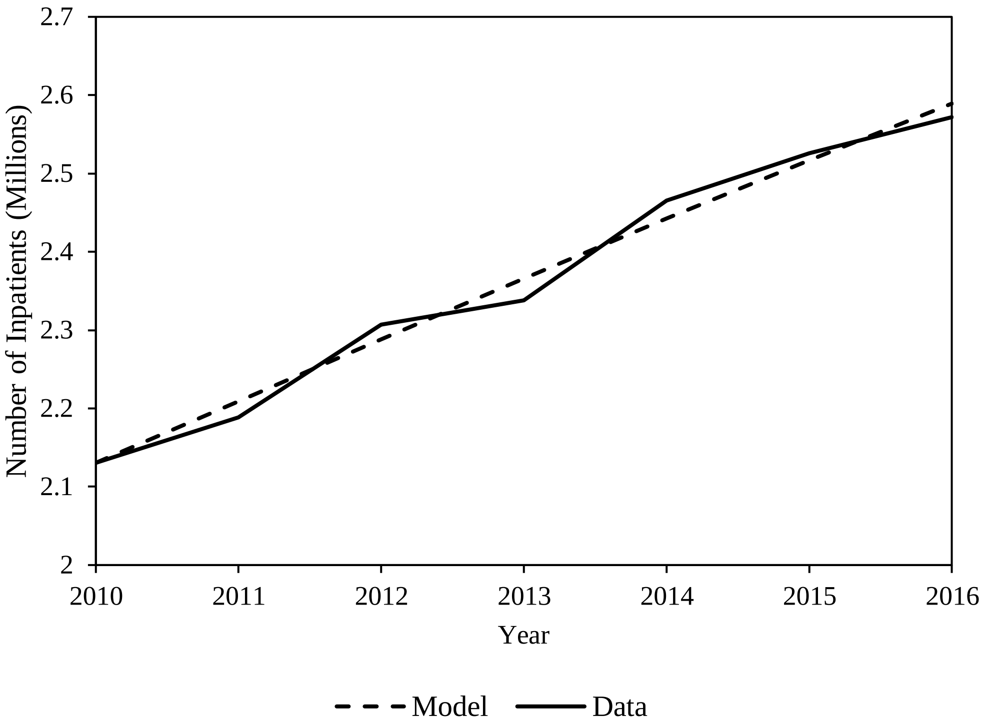


Figure 5.9 Historical and simulated behaviour of a number of inpatients

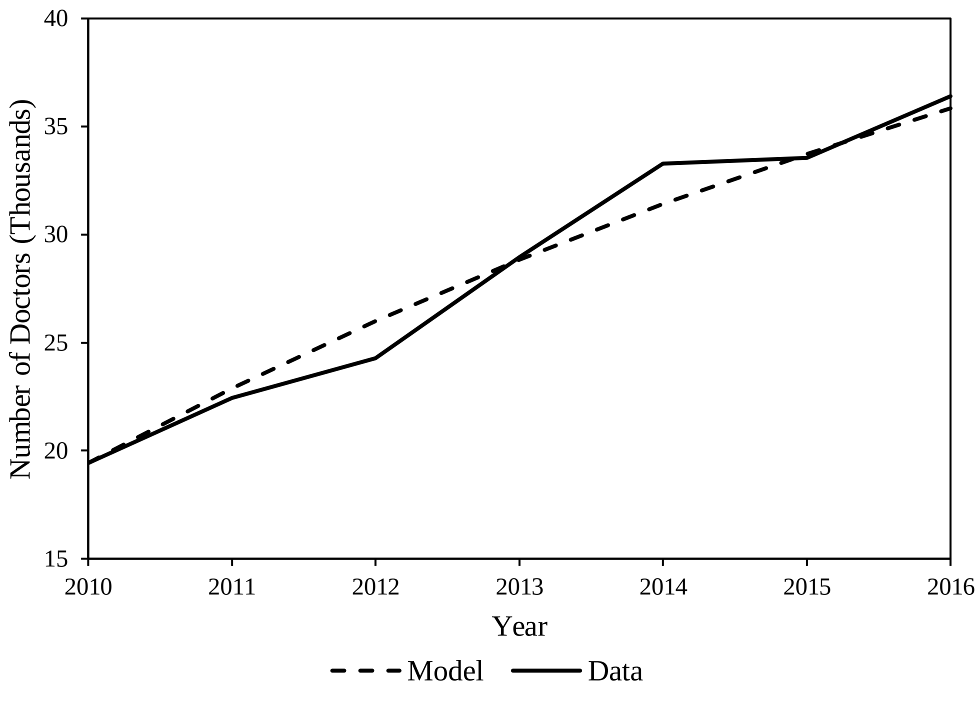


Figure 5.10 Historical and simulated behaviour of medical doctor supply

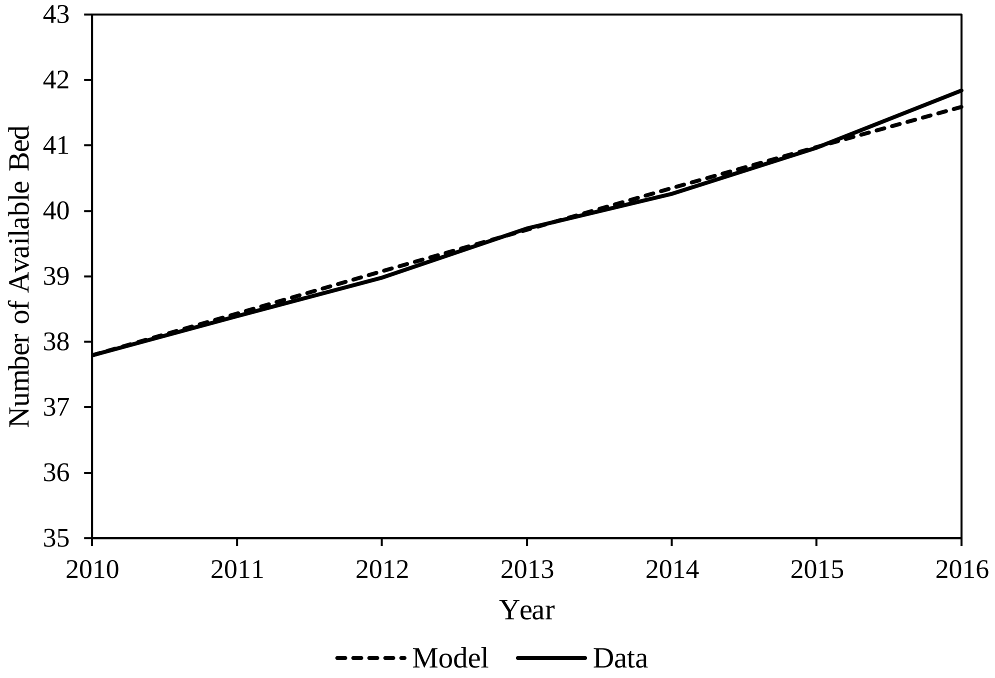


Figure 5.11 Historical and simulated behaviour of bed capacity supply

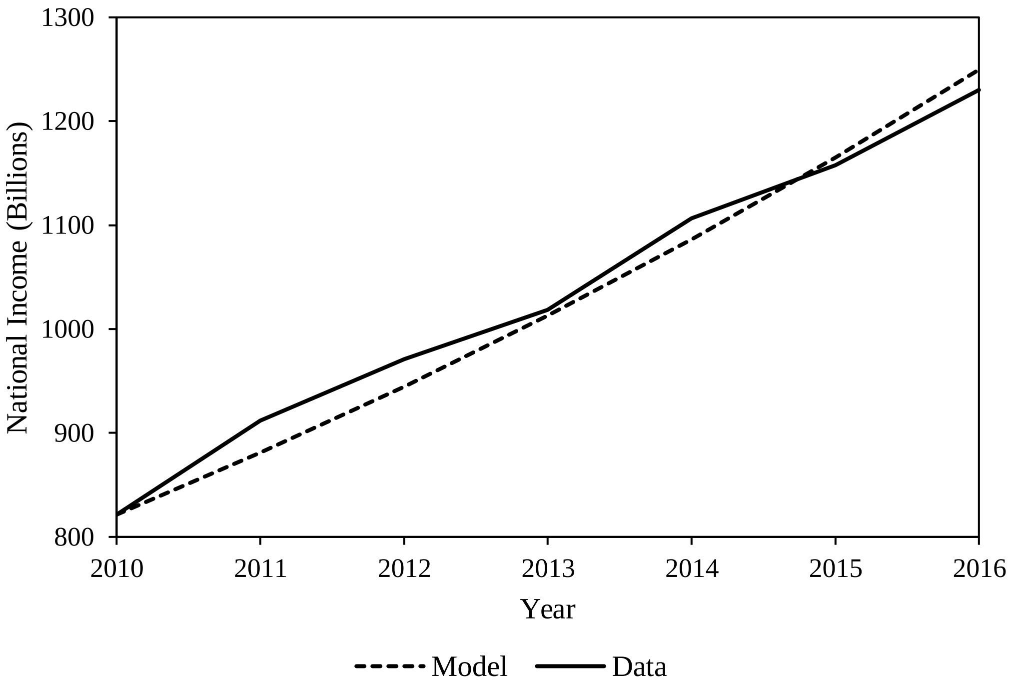


Figure 5.12 Historical and simulated behaviour of national income (GDP)

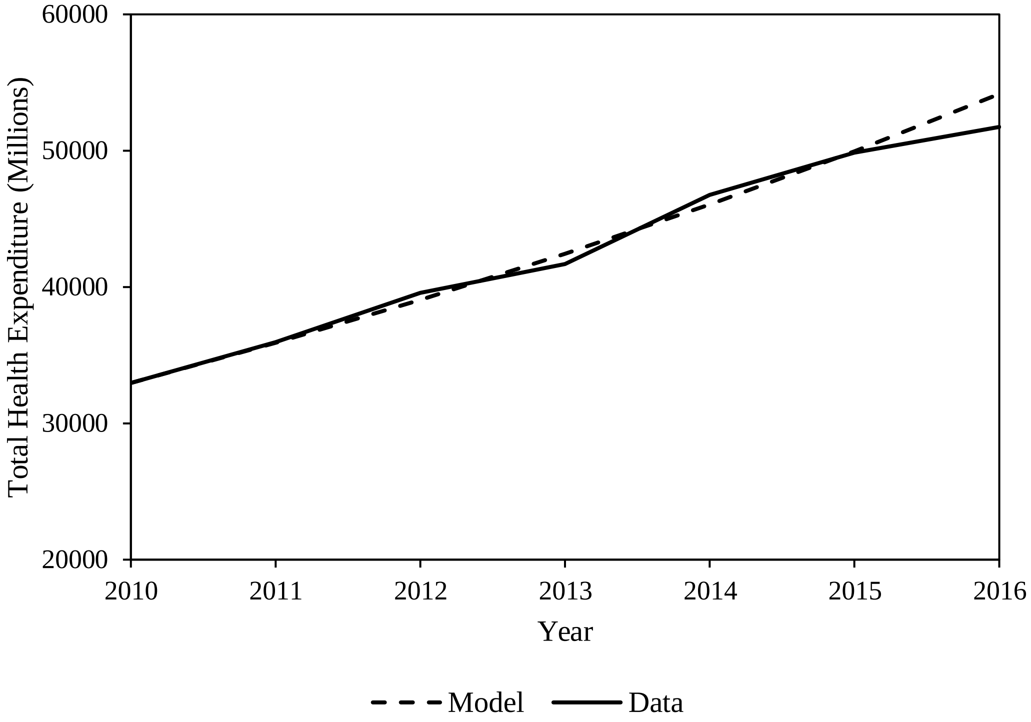


Figure 5.13 Historical and simulated behaviour of total health expenditure

In addition, the model validation is also employed to examine the structure of the model whether it is fit to the real behaviour. For the more valuable answer of the resemblance between simulated and real behaviour, the statistical comparative measurement of seven stock variables namely the coefficient of determination r-squared (R^2), and the mean absolute percentage error (MAPE) have been applied in this study.

$$R^2 = r^2 = \frac{1}{n}\sum\frac{(X_d - \overline{X_d})}{s_d}\frac{(X_m - \overline{X_m})}{s_m} \tag{5.42}$$

$$\text{MARE} = \frac{1}{\text{n}}\sum_{\text{t}=1}^{\text{n}}\frac{|X_m - X_d|}{X_d} \tag{5.43}$$

where, X_m and X_d indicate the output of the model and the historical data respectively.

The statistical coefficients of R-squared results shown in Table 5.1 present the fitting value of the simulated model is more than 0.9 and MAPE value considerably low, indicating that the model structure replicates actual historical data reasonably very well.

Table 5.2 Error Analysis of key variables, 2010 – 2016

Variables	**MAPE (%)**	**R-squared**
Total Population	0.302	0.996
Outpatients	0.205	0.998
Inpatients	0.705	0.986
Medical Doctors	2.456	0.976
Beds capacity	0.177	0.995
Gross Domestic Product	1.526	0.99
Total Health Expenditure	1.392	0.985

Note: MAPE is mean absolute of percentage error

5.2.2 Dimensional Consistency Test

Dimensional consistency test is applied to validate whether the units and equations parameterized in the model are consistent and inserted in correct manner, as well as corresponding to the concepts of the real world (Sterman, 2000). Figure 5.14 shows the output result of the unit checking test produced by Vensim PLE software.

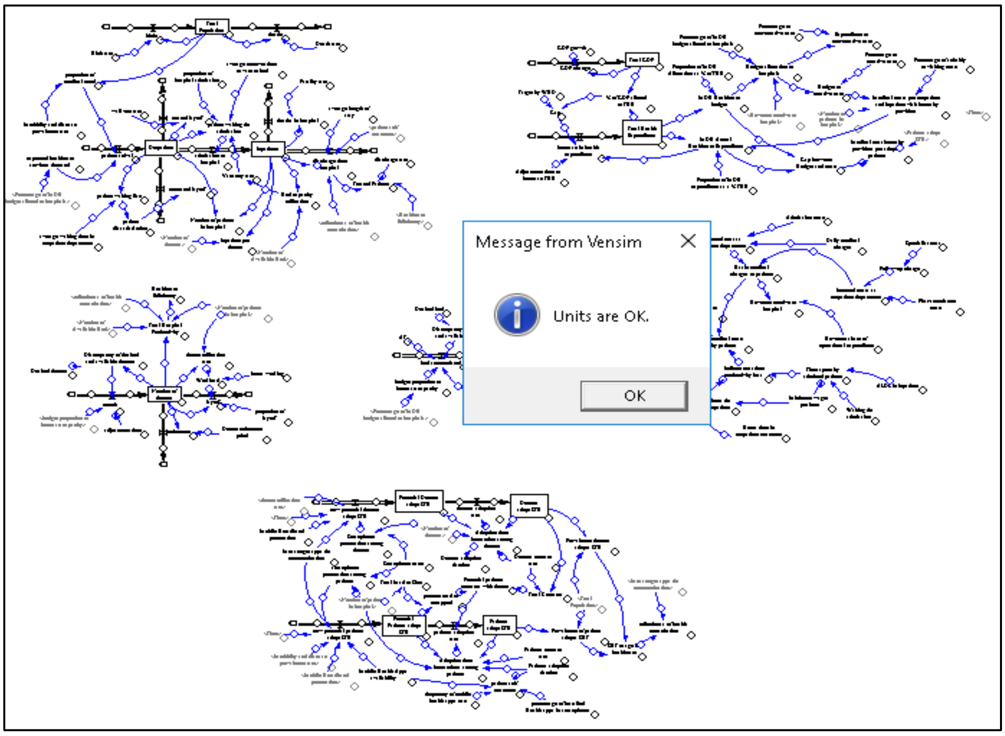


Figure 5.14 Result of dimensional unit testing

CHAPTER 6: ANALYSIS OF HEALTHCARE DEMAND AND SUPPLY

6.1 Overview of the Chapter

Once the model has been validated in prior chapters, in the end, the structured simulation model will be utilised for different scenarios and intervention analysis testing. The sensitivity analysis of parameter values examines how the certain variable changes with different estimated parameter values. The entire findings of the impact of an intervention demonstrated a simulation behaviour over the course of 21 years from 2010 to 2030. The baseline simulation behaviour is compared with simulation behaviour under different scenarios. This analysis attempts to seek the behaviour prompted to a fact of the global demand for health care supply persistently to grow faster than the availability of health care supply. The policy intervention and scenario analysis of healthcare demand and supply are investigated in order to address the first research question raised in this study:

"How does growing patient attendance at the public hospitals affect healthcare provisions?"

6.2 Baseline Behaviour

In this section, the baseline behaviour of the simulation model under the condition that structural and parameter values do not change. Figure 6.1 illustrates the trend behaviour of a number of doctors and the average amount of patients a doctor has to handle in Malaysia annually over the course of 21 years from 2010 to 2030. From this figure, the number of doctors and doctor utilization rate are labelled at left-side of y-axis and right-side of the y-axis, while on the x-axis is represented by the annual period. As we can see that the solid line behaviour of the number of doctors is projected to increase from 19,429 in 2010 to 50,992 in 2030.

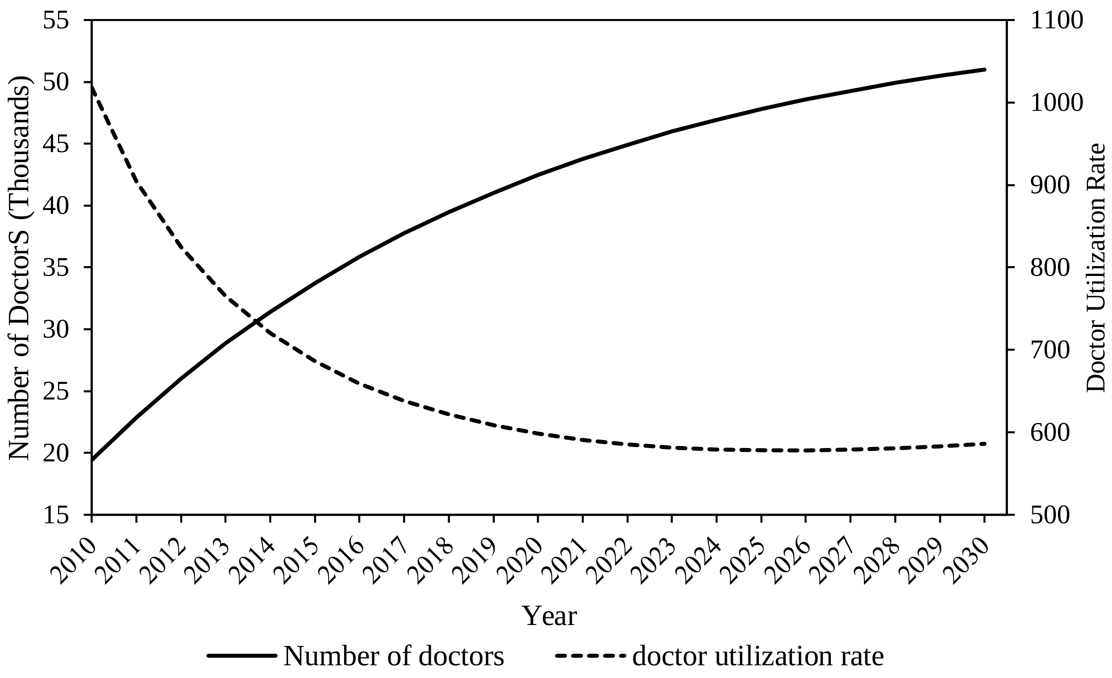


Figure 6.1 Projecting behaviour of Doctors and Doctors Utilization

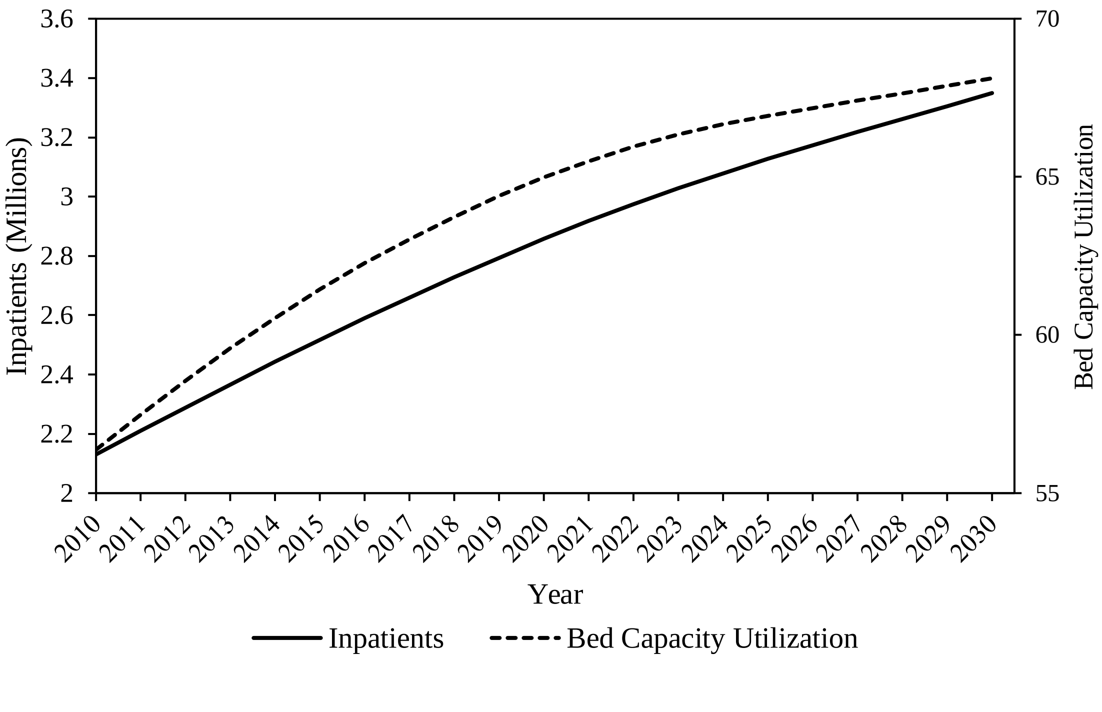


Figure 6.2 Projecting behaviour of Inpatients and Bed Capacity Utilization

Meanwhile, the average number of patients for each medical doctors to prescribe and treat the patients is indicated by the doctor utilization rate shown as the dotted line produces exponential at a decreasing rate. Further, Figure 6.2 depicts the output graphs indicating the projected number of admitted patients and bed capacity utilization from the period 2010 until 2030. Both variables are shown an increasing trend of behaviour.

6.3 Policy Intervention Analysis of Healthcare Demand and Supply

The results of the analysis of various simulation via pessimistic and optimistic interventions that set a 10% increase or decrease from the baseline value are profoundly discussed in this section.

6.3.1 Impact of Budget Allotted to Hospitals

Many studies assert the importance of budget spends to health care for providing a better quality of health care. Hassan & Minato (2017), public health financing allocated 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 their GDP on health care (Savedoff, 2007). However, this increasing budget allocation has increased citizen's expectation of public hospital.

This analysis is attempted to evaluate the parameter value of the health care budget to health care utilisation. Budget allocation to health care is the main factors that increase citizen's expectation to receive treatment in a government hospital. These interventions will impact the two main components of health care supply, namely, doctor utilisation rate and bed utilisation rate. The results found that continuance increase is not the best solution to improve access to health care service. Figures 6.3 and 6.4 show how the changes in budget allocation would change the behaviour of bed utilisation and doctor utilisation. Similar to the prevalence of morbidity and diseases, as people have a better expectation on the public sector, they attempt to seek for treatment in a government hospital in compare to the private sector that is more expensive. Consequently, increasing this expectation will increase number of patients in the hospital and in turn, will impact the health workforce and bed capacity.

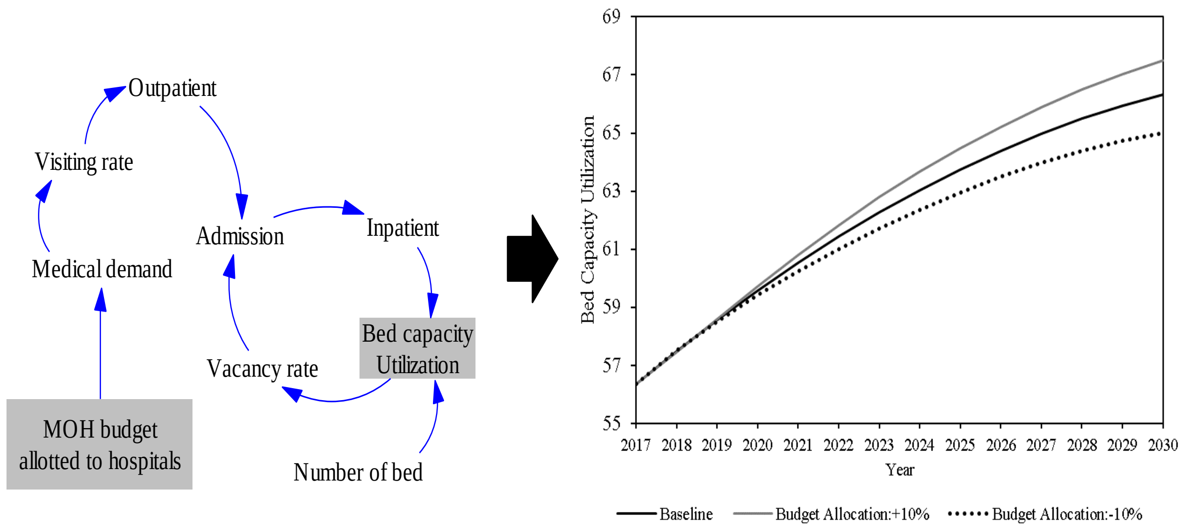


Figure 6.3 The impact of budget allocation on bed utilisation

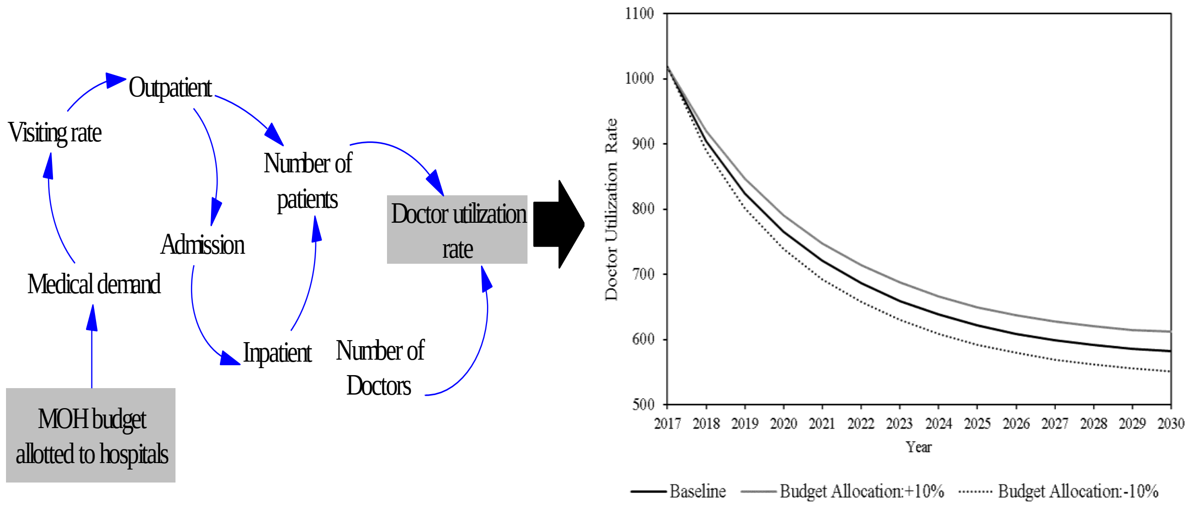


Figure 6.4 The impact of budget allocation on doctor utilization

6.3.2 *Impact of Morbidity and Disease Prevalence (MDPR)*

Patient attending to the public hospital is increased by the prevalence of morbidity and disease among the population. The impact of growing patient attendance can be seen from the influence of the medical need of the sick population. This analysis attempts to evaluate the impact of morbidity and disease prevalence rate (MDPR) on health care utilisation, where the parameter values of MDPR are changed by 10 per cent increase and decrease from the baseline value. Figures 6.5 to 6.7 depict the results found that an increase in the prevalence of the disease is contributed to the increased probability of utilising available bed, doctor and healthcare budget, respectively. The dotted line indicates the simulated behaviour of three components of healthcare supply for a 10% decreased of MDPR parameter value from the year 2017 until 2030. Meanwhile, the solid line shows the default mode behaviour and the grey line shows that those three components of healthcare utilization are higher than expected if MDPR is increased by 10%.

Specifically, Figure 6.5 indicates the impact of MDPR on bed capacity utilisation. This impact can be seen from the causal model at the left side of Figure 6.3 when the patient begins to attend hospital due to the prevalence of disease or morbidity. Some proportion of outpatient needs to be transferred as inpatient based on the doctor’s referral. As those patients need to stay in the hospital for a few days or even a few months depending on the type of diseases, the availability of bed plays an important role to facilitate those patients. Therefore, once the patient has been successfully admitted to a hospital bed, the available bed becomes “bed utilisation”. Based on Figure 6.5, an increase in the prevalence of diseases among the population is expected to increase the proportion of bed utilisation by inpatients, in which it shows the upward movement from the baseline behaviour. Oppositely, if the prevalence rate of disease is lower, there will be more bed available in hospitals, in which it will be indicated by the decrease in bed utilisation.

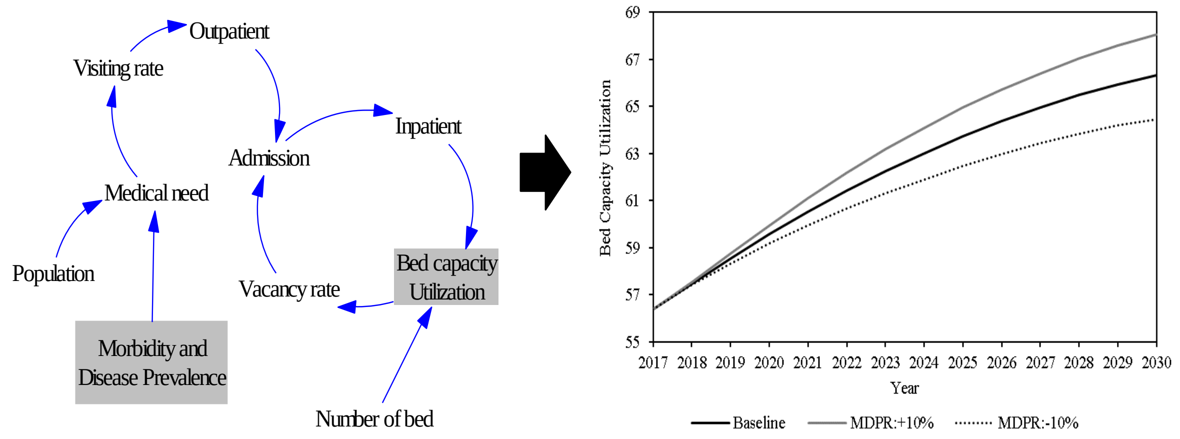


Figure 6.5 The impact disease prevalence on the utilization of bed capacity

Additionally, the other important variable that has been affected by the prevalence of diseases and morbidity among patients is doctor utilisation rate, where the reason why patients visit the hospital is to seek for a treatment for the available doctor. However, overloading of the patient has utilised a limited number of available doctors, causing the burdening of workload to doctors hence, the need for them to work for more hours. Similar to the prior research, a current study expected that doctors would probably leave the government hospital and seek another alternative medical institution as the workload and working hour increase.

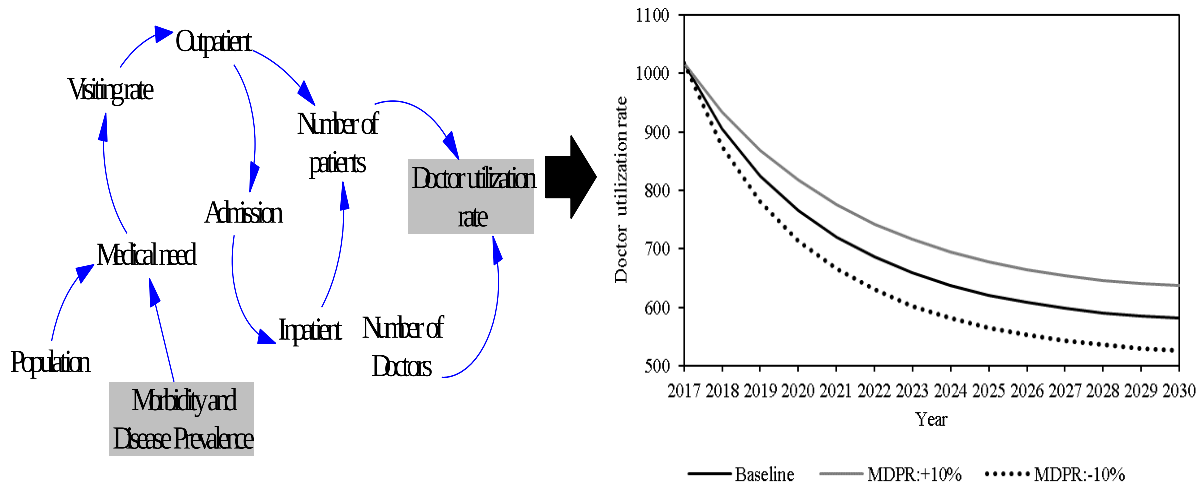


Figure 6.6 The impact of disease prevalence on the utilization of doctor capacity

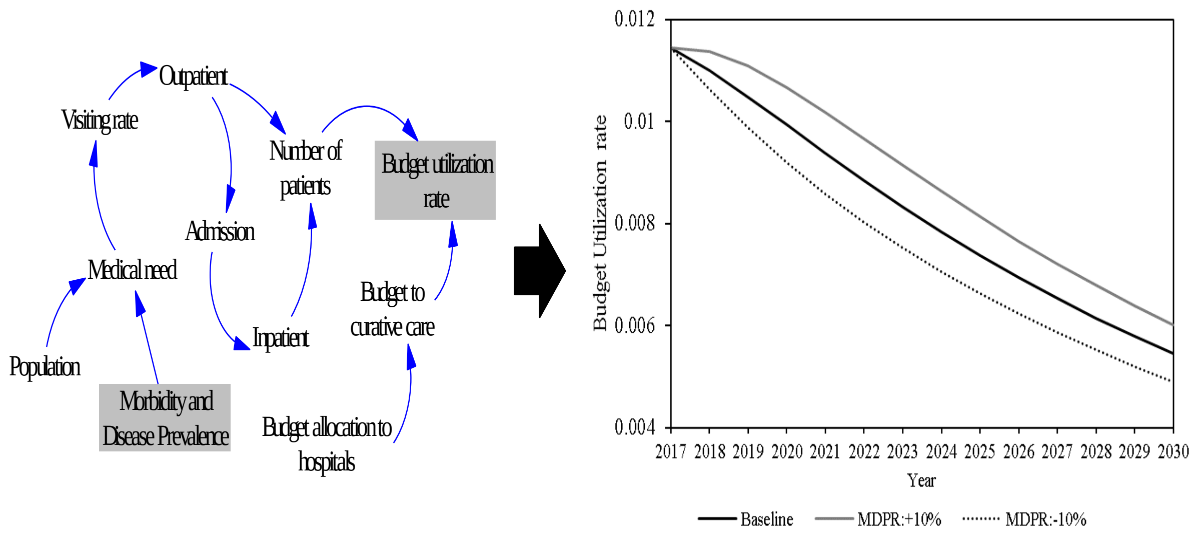


Figure 6.7 The impact disease prevalence on the utilization of health spending

Yasmin Ramlan, (2018) reported that doctors in government service will move to the private sector as they have to work long hours and have to deal with many patients in a current government hospital. In line with prior studies, NoorAni et al. (2018) stated that the prevalence of chronic disease and ageing population poses a greater impact on health care utilisation (outpatient and inpatient) in Malaysia. As verified in the figure, changes in MDPR do no produce different behaviours of the capacity utilisation. The results are shown different, only in numerical values. Figure 6.7 shows the behaviour of an upward movement from the baseline behaviour that explains the increase of doctor utilisation rate due to an increase in the prevalence of disease. Meanwhile, the movement to the bottom of the baseline behaviour indicates the opposite.

Figure 6.7 indicates the impact of diseases prevalence on the utilisation of the health care budget. Increase in patient attendance to the public hospital not only merely impacts the utilisation of its capacity but also to the financial aspect. Figure 6.5 above demonstrates the behaviour budget per patient as more patients attend to the hospital, consequently, more budget will be allotted and covered to those patients, as the Malaysian government covers above 95 per cent of the actual patient's cost. The upward movement to the right from the baseline line behaviour indicates that budget per patient increased, as more patients suffer from diseases and morbidity.

6.4 Scenario Analyses of Healthcare Demand and Supply

This study established six types of scenarios as indicated in Table 6.1. Business as usual (BAU) scenario is a baseline scenario without additional changes to the current model and in accordance with the current health care situation. This alternative analysis was performed to identify the significant parameters and to explore in which scenarios are the most impacts on the certain variables in the system with different estimated values were set of 10% increase or decrease for both MDPR and budget allocation as discussed above. Scenario 1 indicates when all other else equal, the parameter value of MDPR is set to increase by 10% from the baseline value: 0.563. Meanwhile, the parameter value of budget allocation is set to increase by10% for scenario 2, when all the other variables of the model remain constant. These parameter changes are then extended of three more comprehensive policy (CP) scenarios. Comprehensive policy scenarios representing scenario 4, 5 and 6 where both parameter values of MDPR and budget allocation are changed simultaneously. Both parameter value of MDPR and budget allocation are increased by 10% for exploring scenario 4. Scenario 5 is conducted to explore the behaviour of affected variables when medical need represented is increased by 10%, but budget allocation by the government is decreased by 10%. Contrary to scenario 4, budget allocation is increased by 10%, while MDPR is decreased by 10% for scenario 5.

Figure 6.8 indicates an analysis of the impact of different types of scenario on the behaviour of admission to hospitals drawn on the vertical axis for over 14 years. Based on the result of analysis shown in the above figure, the impact of budget allocation to hospitals is more pronounced in compare to morbidity and disease prevalence, when all else being equal. The solid grey line of scenario 2 is shown above than the dotted grey line of scenario 1.

Table 6.1 Parameter changes of medical demand and need scenarios

Scenario Testing	**Parameter changes**	
	Morbidity and Disease Prevalence Rate (MDPR)	**Budget allocation**
BAU (Baseline)	0.563	0.511
Scenario 1	0.619 (+ 10%)	-
Scenario 2	-	0.562 (+ 10%)
Scenario 3	0.619 (+ 10%)	0.562 (+ 10%)
Scenario 4	0.619 (+ 10%)	0.46 (-10%)
Scenario 5	0.507 (-10%)	0.562 (+ 10%)

It can be said that most of the citizens that seeking treatment to public hospitals are because of the better expectation of public health services due to an increase of government budget subsidized to public hospitals. Disease prevalence is less pronounced to a patient admitted to the hospital probably due to the severity of the patient’s condition. These scenarios in line with scenario 4 and 5 where, where for scenario 5, when budget allocation to hospital increase, but MDPR decrease, more patients will be admitted to hospitals. In contrast, admitted patients are reduced when budget allocation to the hospital is reduced and the prevalence rate of disease and morbidity is going to increase. This behaviour explains that the ill patients might be left off outpatient department after receiving consultation and would like to have further treatment at non-public hospitals either, self-treating or admitting to private hospitals. As expected, admission to the hospital will increase more when both MDPR and budget allocation to hospital increase as indicated by the trend behaviour of scenario 3 in Figure 6.8.

On the other hand, Figure 6.9and 6.10 illustrated the scenario analyses of the bed capacity utilization and doctor utilization rate respectively. In connection to previous scenario analysis of admission to hospitals demonstrated in Figure 6.8, changes in both MDPR and budget allocation will also impact to bed capacity utilization. The increase of financial health care allocated to public hospitals will certainly increase more available resources of medical care such as bed capacity and medical doctors. Sufficiency of medical resources available will able to improve the quality of health care as represented by doctor and bed capacity utilization. Scenarios of increasing budget allocation to public health services can be seen from the behaviour of scenario 2, 3 and 5, where the rate of both bed and doctor capacity utilization is lower than rising of the proportion for morbidity and disease prevalence. This scenario results supported previous literature' hypotheses and proved that when budget allocation is spent more on health care, more doctors and bed capacity can be expanded to facilitate attending patients, in turn, to reduce the strains and workload of both capacities.

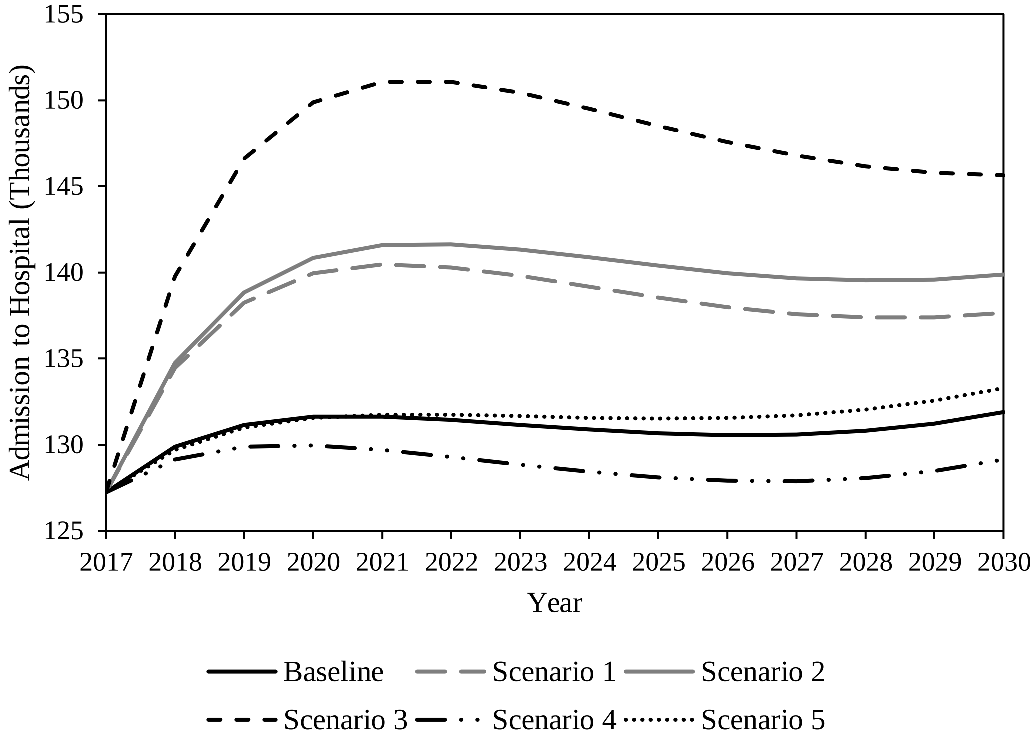


Figure 6.8 Scenario analysis of admission to hospitals

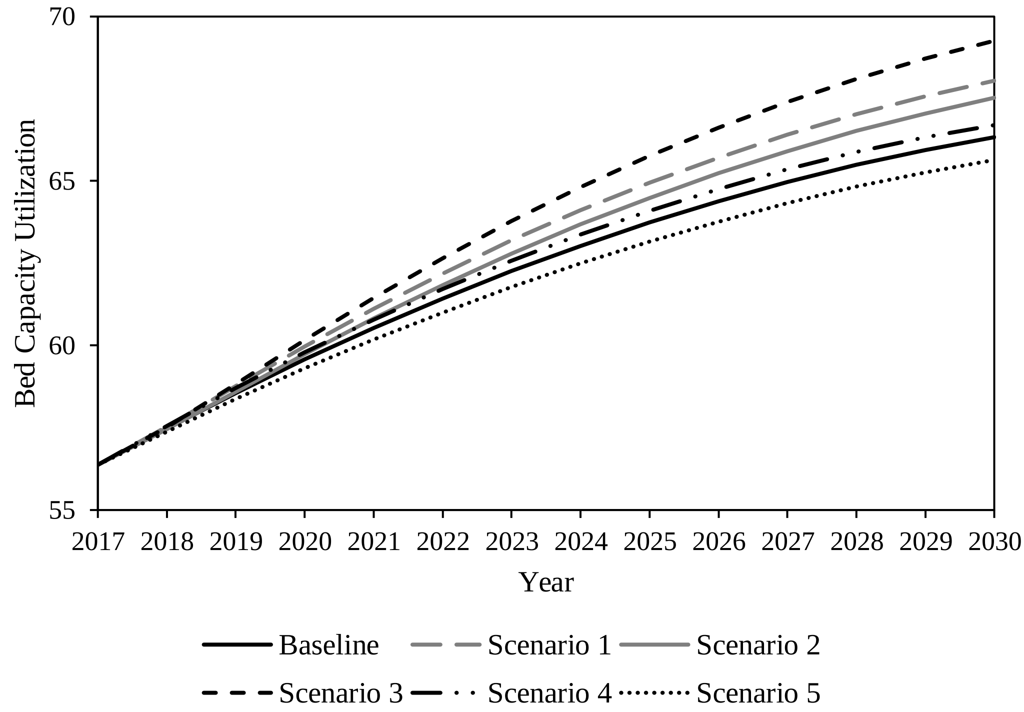


Figure 6.9 Scenario analysis of bed capacity utilization

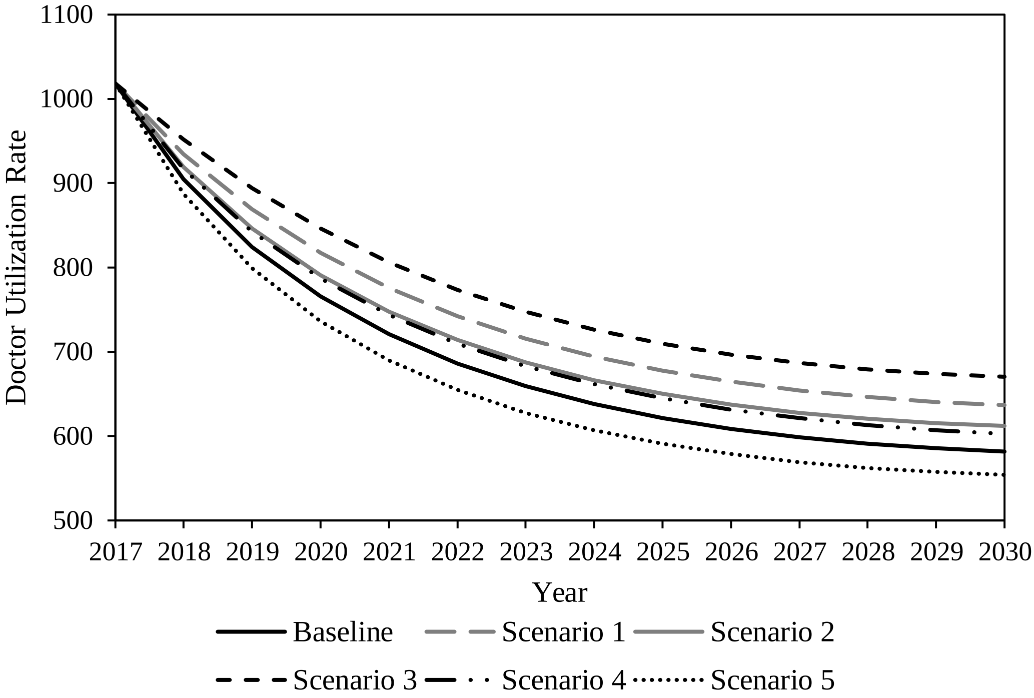


Figure 6.10 Scenario analysis of doctor utilization rate

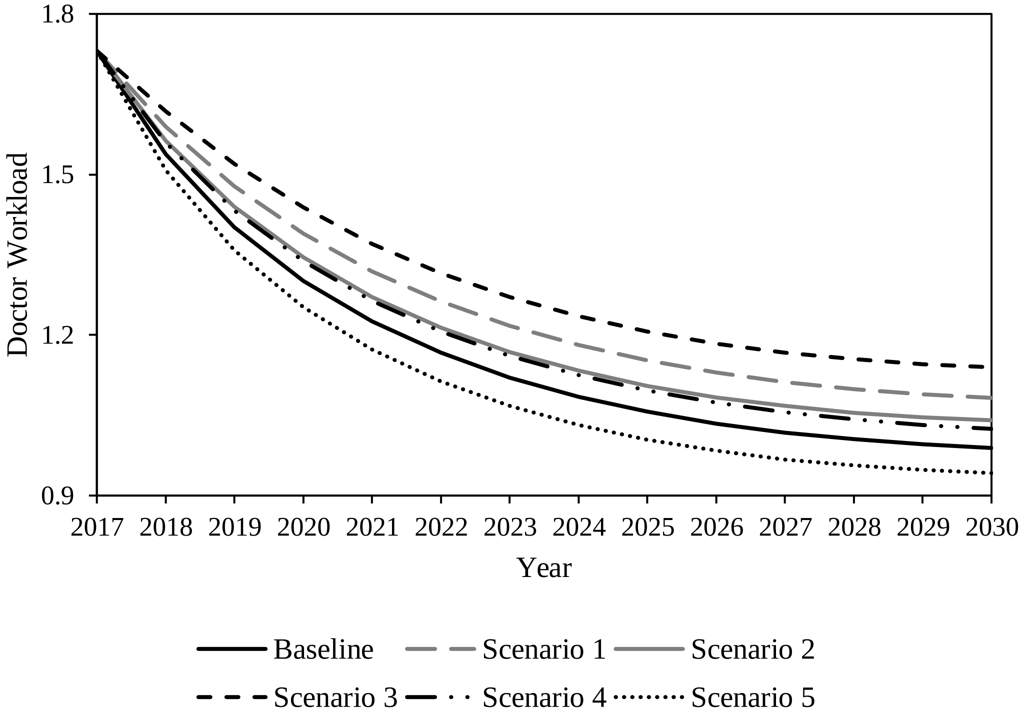


Figure 6.11 Scenario analysis of doctor workload

This Figure 6.11 demonstrates the comparison behaviour of business as usual scenario and the other five different scenarios for doctor workload as a result of several parameter changes of MDPR and budget spent for public health services. In relation to previous Figure 6.10 of doctor utilization rate. As discussed in the previous chapter, the doctor's workload is measured by doctor utilization rate multiply by the working hours of a doctor. The current study assumed doctor's working hour per day is 15 hours based on the source from M. Lee (2017). Scenario 1 of both doctor utilization and workload of doctors explain that when MDPR is expanded by 10% when all the other else are equal, doctor utilization and their workload simultaneously will be increased than business as usual scenario. This can be seen from the figure, the move upward trend of scenario 1 line above than the baseline line. However, the experiment of the parameter values for public health spending find that they are a strong impact on the health care utilization rate in comparison to the prevalence rate of morbidity and disease among citizens.

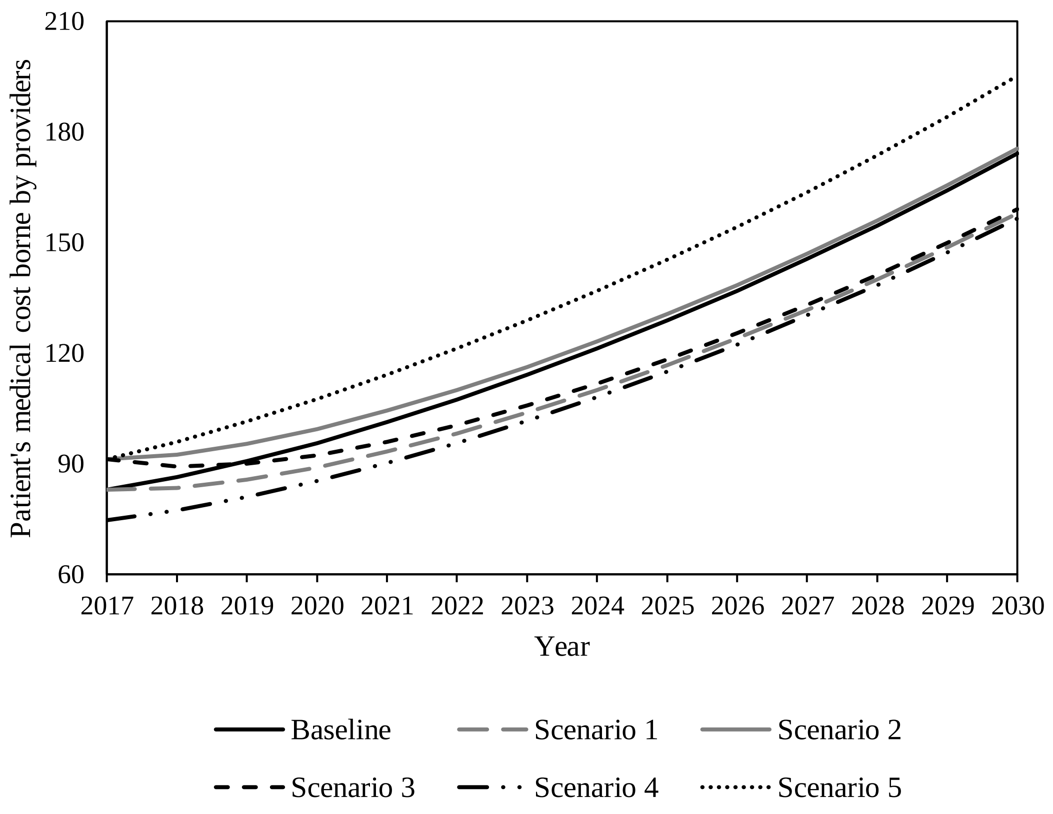


Figure 6.12 Patient's medical cost borne by health care providers

According to Zainal & Mahat (2014), the current's medical cost for each outpatient and inpatient visits are subsidizing by the Ministry of Health (MOH) amounting over 95 per cent of the actual cost. This means, patients attending to public hospital merely need to pay lower than 5 per cent of the real medical costs. As expected, patient's medical cost incurred by health providers per patient visit hospital slightly rises than baseline scenario shown by scenario 2 and 5, when the budget allocated for health care is inflated.

CHAPTER 7: ANALYSIS OF SMARTPHONE-BASED TECHNOLOGY ADOPTION FOR HEALTH CARE

7.1 Overview of the chapter

This chapter provides findings of the analysis of smartphone-based technology adoption for health care in order to answer the following second research question raised in this thesis:

How does smart-health adoption among healthcare stakeholders would impact on healthcare service and medical expenses?

The effects of possible interventions on the parameter of contact rate and adoption fraction of patients were explored. The comprehensive results of the possible impacts of intervention and scenario analysis illustrated a simulation behaviour over the course of 14 years from 2017 until 2030. In the same way as analysis provided in chapter 6, the simulation period is extended from 2017 to 2030 for the policy analysis of the smartphone-based technology analysis. The analyses are conducted to seek for various alternative scenarios for achieving the relevant objectives of the current research. The following section will first explain the baseline behaviour of smartphone adoption for both doctors and patients.

7.2 Baseline Behaviour of Smartphone-based Technology Adoption

In this thesis, the analysis of smartphone-based technology adoption is based on a system dynamics application for the product diffusion model initiated by Frank Bass in 1969. His generic diffusion model incorporating two different characteristics of the adoption process, namely innovative and imitative adoption. The smartphone-based technology adoption sub-system of the current re-developed and expanded the original Bass model by incorporating several additional elements in accordance with the issue to be addressed in this research. This sub-model has been presented and profoundly discussed in chapter 5. After running the STH adoption simulation model, then the results of simulation adoption model for both doctors and patients produce the fundamental trend of key variables: potential adopters, adoption rate and adopters as shown in Figure 7.1 and 7.2 respectively. These behaviours confirm the similar behaviour as the Bass diffusion model. Principally, the behaviour of potential adopter and adopter reveal a reverse S-shaped and S-shaped sigmoid curves respectively. While bell-shaped behaviour graph intuitively represented for the adoption rate.

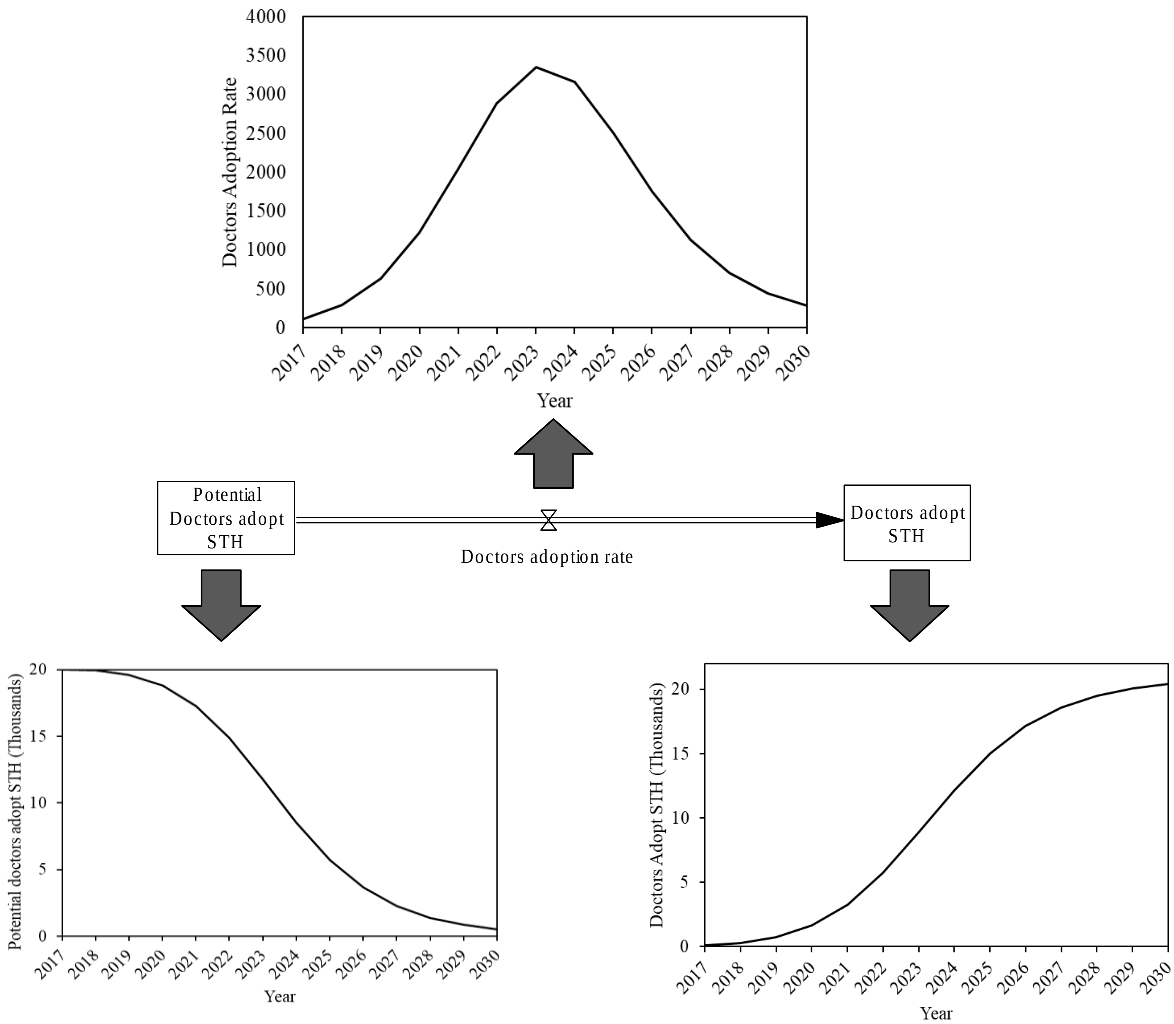


Figure 7.1 Simulation behaviour of STH adoption among doctors

Figure 7.1 precisely reveals the output behaviour of three major components of smartphone-based technology adoption. The figure integrates the basic structure of the system dynamic model for the diffusion model and the model behaviour generated for these three fundamental variables: potential adopter of doctors, doctor adopters, and doctor adoption rate. Each adoption characteristics (innovative and imitative process) provides in the momentous process to the whole adoption pattern. For example, the occurrence, period of time, the speed of a technology take-off is wholly connected to the dynamics of adoption, in which cause to the massive spreading of adoption via word-of-mouth. Innovative adoption stage plays a significant role in the diffusion process of technology or new product. Sterman (2000) has adapted Bass model for system dynamic methodology in which not merely applied for new product diffusion phenomenon, but also for the epidemic issues. The S-shaped adoption curve and the bell-shaped curve of adoption rate represent the cycle of three major adoption process, namely technology take-off, market maturity and saturation stages as shown in both Figure 7.1 and 7.2.

Figure 7.1 and 7.2 depict the curve of the STH adopters among doctors and patients respectively, in which generated by the s-curved behaviour over 14 time-span from 2017 until 2030 of the simulation period. The "S-shaped curve" is a well-accepted behaviour to evaluate the dynamics of new products diffusion and technologies adoption as postulated by innovation diffusion theory (Rogers, 1962). Indeed, many market products and technologies like telephone, electricity, microwave ovens, Facebook social networking apps, DVD players and many more, those go through S-curve life cycles. In system dynamics methodology, the generated s-curve behaviour usually arises from the interaction between the two different types of feedback loops namely reinforcing feedbacks that generate growth and balancing feedback as the products or technologies ultimately being adopted by all peoples in the market. The graph of adopters and potential adopters among doctors and patients in Figure 7.1 and 7.2 are plotted on a vertical axis ranged from zero to twenty thousands of doctors and zero to one million patients respectively.

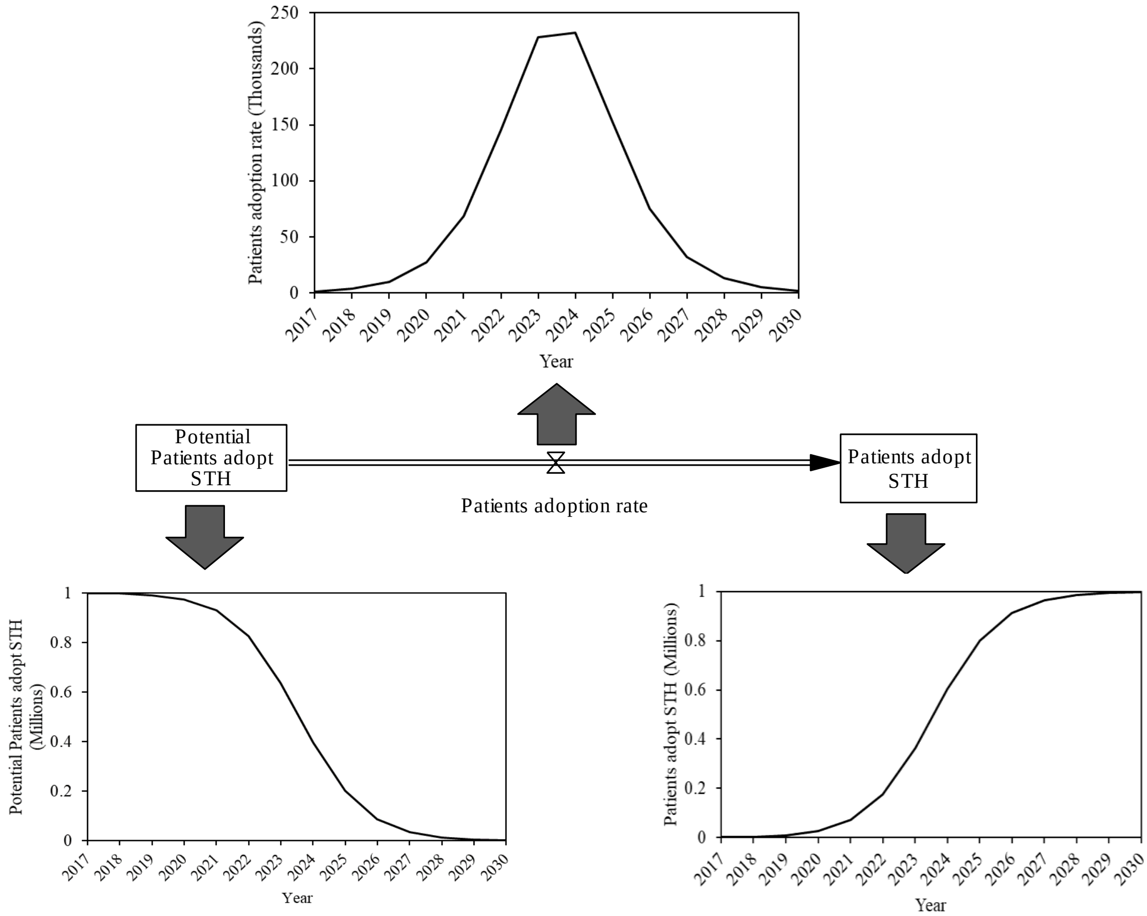


Figure 7.2 Simulation behaviour of STH adoption among patients

In the beginning, the model assumed there are only 100 adopters of the number of doctors and 1000 adopters of the number of patients. While the size of the market is relatively still large at the start of smartphone introduction, the reinforcing feedback of the interaction or spreading words of the adoption phase triggers the exponential growth. The number of doctors and patients are assumed as the size of the market. As both adopters gradually start to grow, the potential adopters of both doctors and patients also expected a turn to moderately drop to nearly zero in the year of 2030 as shown at the bottom of the stock and flow diagram. In smartphone-based technology adoption simulation model, the current research assumes that as the potential doctors and patients adopt the smartphone, they stop being the potential adopters and this is the reason of potential adopters of both doctors and patients become zero at the end of the simulation period. A slow increasing behaviour is said as the nature of social contagion (Morecroft, 2015). Eventually, as the market approaches to limit growth or market saturation, the balancing loops begin to dwarfed by the total of market size. This negative feedback loop brings the system to a state of equilibrium or stagnate. This stagnation is expected that the doctors and patients who might ever want having smartphones for accessing health information and medical purpose has ultimately bought and adopt it (Hassan & Minato, 2018).

Accordingly, the adoption rate of smartphone-based technology for healthcare (STH) to reach closely zero for both doctors and patients. In other words, as the system goes on through the time period, the adoption rate would create a normal distribution curve, in which the adoption rate initially increased and then turn to decreased after the certain period, once the market is saturated. As shown in the figure, as the potential adopters decreased, perceptibly the adopters will increase. This is logically justified that system behaviour of the constructed model. In a mathematical expression, the adoption rate refers to the derivative of the STH adopters which produces a bell-curved behaviour as shown at the upper of the stock and flow diagram in both Figure 7.1 and 7.2. Thus, the dynamic behaviour of smartphone-based technology adoption as discussed above substantiates the current model in accordance with the previous findings of study new product and technology adoption process (Bass, 1969; Sterman, 2000; Mutingi & Matope, 2013). Due to the limitation of available historical data, the research depends strongly on the resemblance of technology adoption structure from the prior case studies and input from experts and literature review (Abidin et al., 2017).

7.3 Policy Intervention Analysis of Smartphone-based Technology Adoption

In this section, the simulation model's parameter values are then changed in various conditions to obtain the dynamic characteristics of the model system. Respectively, the basic simulation model produces the system behaviour and the different trends of key variables. On the other hand, the establishment of sensitivity analysis divulges the actual consequence of the system.

7.3.1 Impact of Patient Adoption

Theoretically, technological innovation can reduce costs as often does for various kinds of good and services. This thesis attempts to conduct "what-if" analysis of the impact smartphone-based technology on the medical cost borne by the health care provider for each visiting patient.

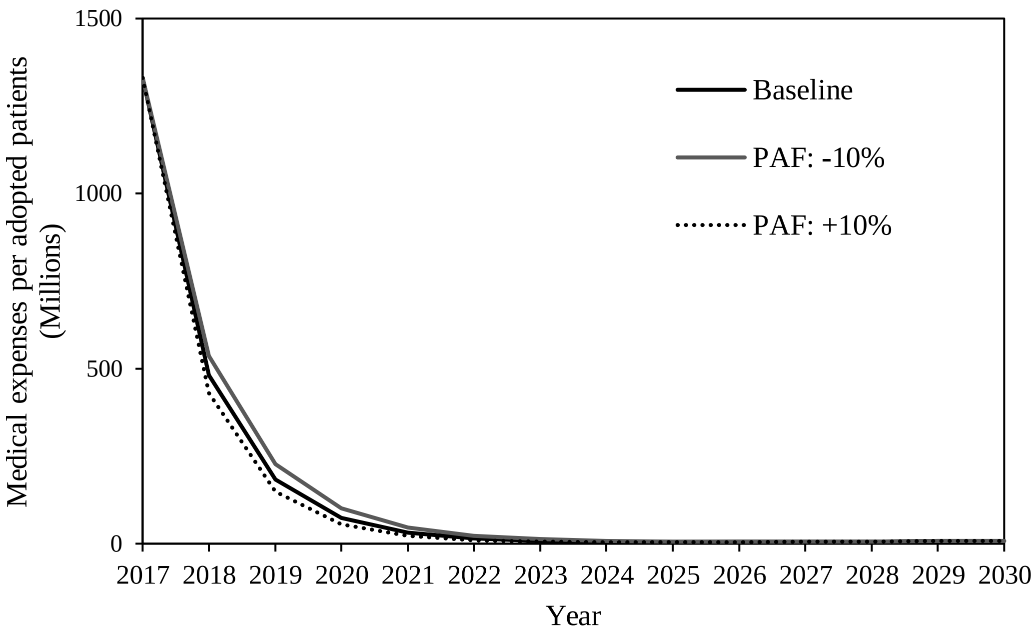


Figure 7.3 Analysis of medical expenses per STH adopted patients

Figure 7.3 represents the possible intervention of the changes in the parameter value of patients' adoption fraction by 10% increase or decrease to the medical expenses incurred by the government as a crucial provider per adopted STH-patients. Increase the patient adoption towards smartphone-based technology via the changes in the parameter value of adoption fraction by 10% probably would reduce medical cost borne by healthcare providers illustrating slightly move below than baseline behaviour. The exponential curve of the cost of medical incurred by healthcare providers has shifted towards the left. This movement explaining an impressive cost saving to the health service providers (Hassan & Minato, 2018).

This reduction is expected to be a consequence of persistent of self-monitoring care during attending at the hospital as their health personnel are having a workload. Malaysian doctors' workloads have become heavier and exhaustion in recent years due to more patients attending to public hospitals where a doctor sometimes has to examine and take care of over 500 patients (Nadirah H. Rodzi, 2017). Self-monitoring using smartphone gives patients' awareness of taking care of their vitals. Consequently, it then leads patients to discharge from hospital as they expect they can consult their doctors via smartphone. Consequently, more patient's discharge indicating an improvement in health service performance and reduce the utilization of health care resources. The analysis of inpatient being discharged from the hospital can be observed from Figure 7.4.

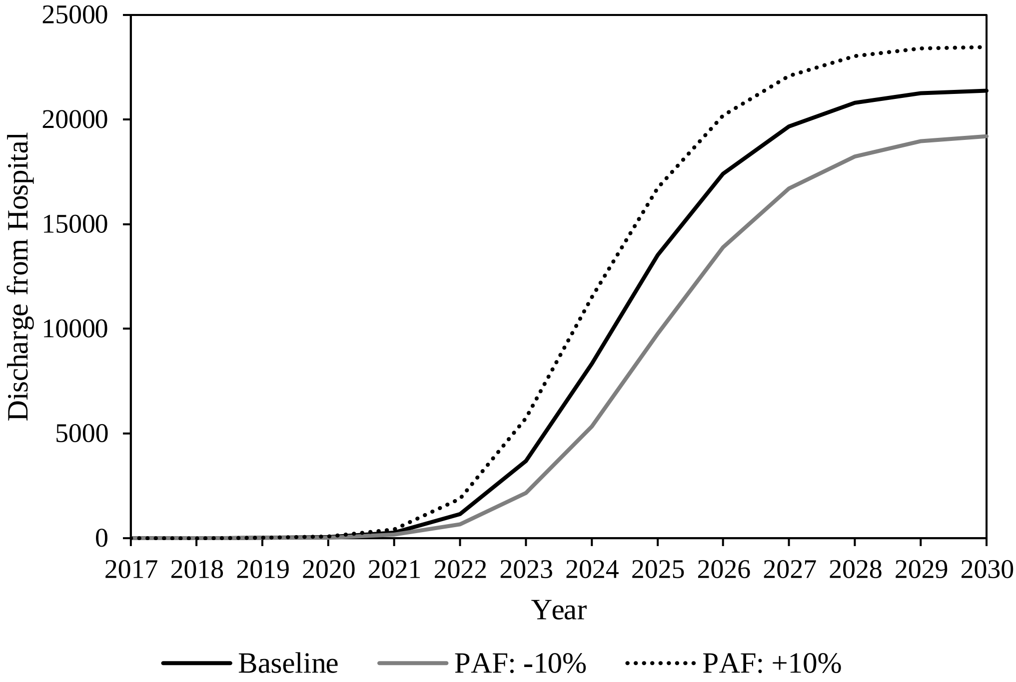


Figure 7.4 Analysis of adoption fraction to inpatient discharge

This research finding is collateral with previous studies found that health information technology (IT) would reduce hospital costs in many ways including reduction of hospital stays, medical tests redundancy, errors, and administrative expenses. Health information technology adoption was negatively impacted on medical costs (Adhikari, et al. 2005; Lee & Dowd, 2009). Lee & Dowd (2009) examined the impacts of health IT expenditure on cost borne by patients using fixed effect regressions analysis. Their results found the quadratic relationships between expenditure on health information technology and patient costs. Their result on the quadratic relationship was consistent with the economic theory of the marginal effect. This theory implies that at beginning spending more on IT systems will increase their cost savings, however, at a certain period, investing more on health IT will eventually reduce their costs. Their findings were found compatible with several related studies that health IT adoption caused a reduction in costs (Borzekowski, 2009; Jha et al., 2009; Furukawa, et al., 2010)

7.3.2 Impact of patient interaction rate

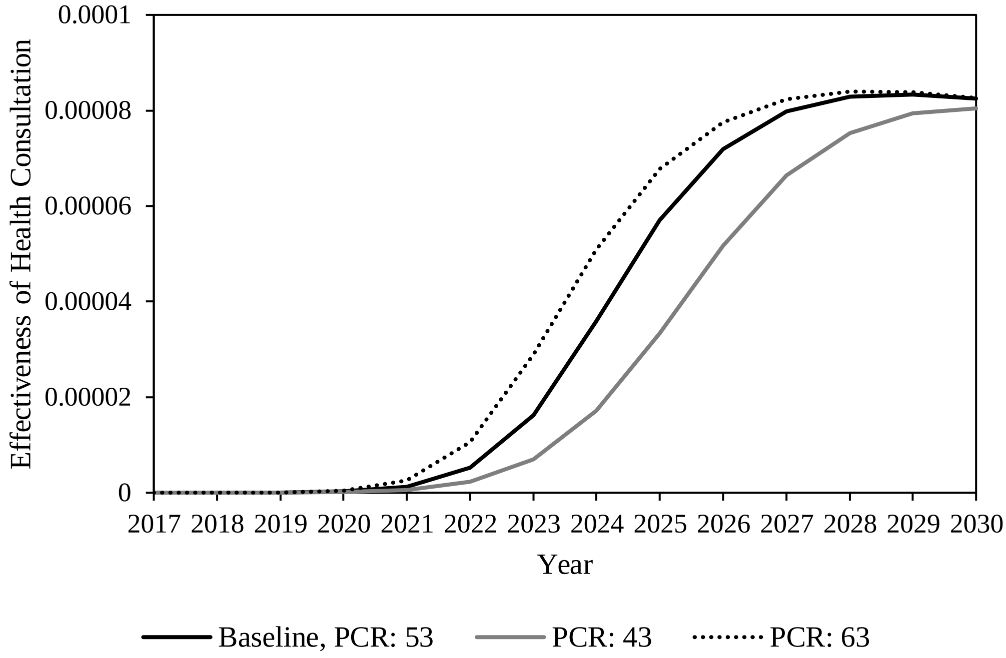


Figure 7.5 Impact of patient interaction intervention to a health consultation

This thesis tried to explore the advantages of smartphone-based healthcare for health care providers via the performance of health care service delivery. Figure 7.5 demonstrates the intervention of the changes in contact interaction of the patient to the effectiveness of health consultation. From the behaviour in Figure 7.5 and 7.6, the impact of patient adoption on healthcare service via changes in patient contact rate (PCR). As it was predictable, we can see that as the percentage of interaction rate between adopted and non-adopting STH patients increase from the baseline value: 20 to 30 persons, the expected of the effectiveness of the health consultation and discharge patients will increase. The value for contact rate determines the speed of adopting the smart-health technology. For example, higher values generally signify that a product is more contagious where indicated curve moves to the left for both figures. When more patient to adopt STH at a faster rate than current baseline value, healthcare service would be also be improved at a faster rate in the future. This is because patients can consult with their doctor easier, in turn, to improve more the number of patients to discharge from the hospital. Inpatient days and patient discharges are common intermediate variables to represent health gain of individual patients and measured as the output of hospital care (Varabyova & Schreyögg, 2013; Linna, et al., 2006)

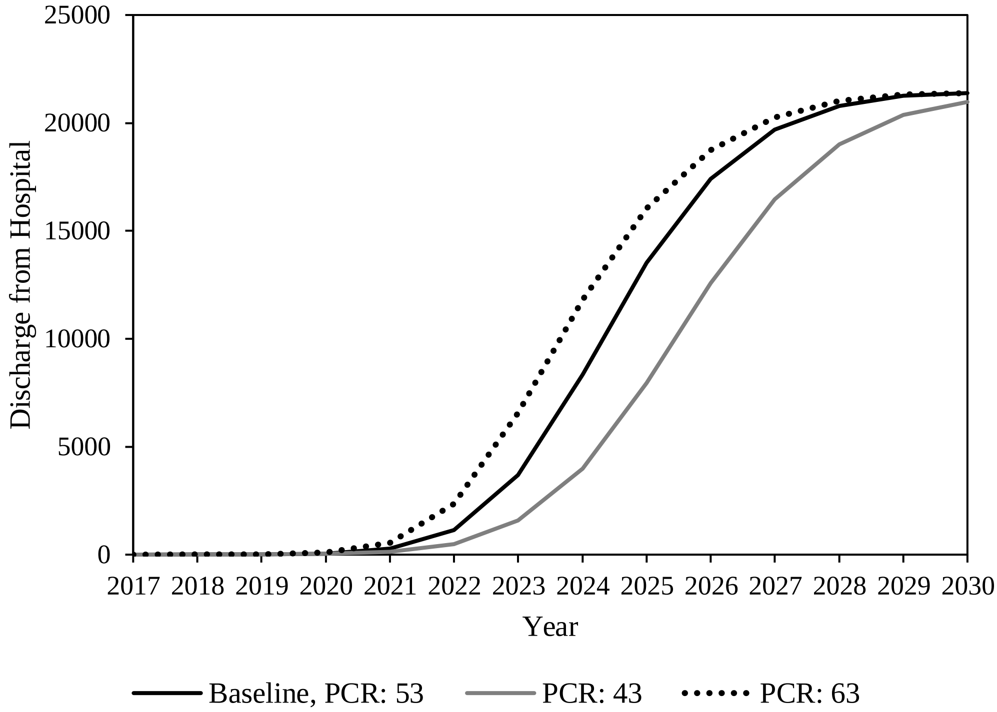


Figure 7.6 Impact of patient interaction intervention to discharge rate

7.4 Scenario Analyses of Smartphone-based Technology Adoption

This thesis established five different types of scenarios analyses of smartphone-based technology adoption as indicated in Table 7.1. Business as usual (BAU) scenario is a baseline scenario without additional changes to the current model.

Table 7.1 Parameter changes of adoption scenarios

Scenario Testing	**Parameter changes of Adoption Fraction**	
	Doctor	**Patient**
BAU (Baseline)	0.287	0.438
Scenario 1	0.316 (+ 10%)	-
Scenario 2	-	0.482 (+ 10%)
Scenario 3	0.258 (- 10%)	0.394(- 10%)
Scenario 4	0.316 (+ 10%)	0.482 (+10%)

This scenario analysis was conducted to explore the significant parameters and to identify the most impact scenarios on the certain variables in the system with different estimated values were set of 10% increase or decrease for both doctor and patient adoption fraction. Scenario 1 indicates when all other else equal, parameter value of doctor adoption fraction (DAF) is set to increase by 10% from the baseline value: 0.287. Meanwhile, the parameter value of patient adoption fraction (PAF) is set to increase by10% from the baseline value of 0.438 for scenario 2, when all the other variables of the model remain constant. These parameter changes are then extended of comprehensive optimistic and pessimistic scenario analyses for both DAF and PAF simultaneously showing as scenario 3 and 4. Both parameter value of DAF and PAF are decreased by 10% for exploring scenario 3. Differently, scenario 4 is conducted to explore the behaviour of affected variables when both DAF and PAF increased by 10% from the baseline value.

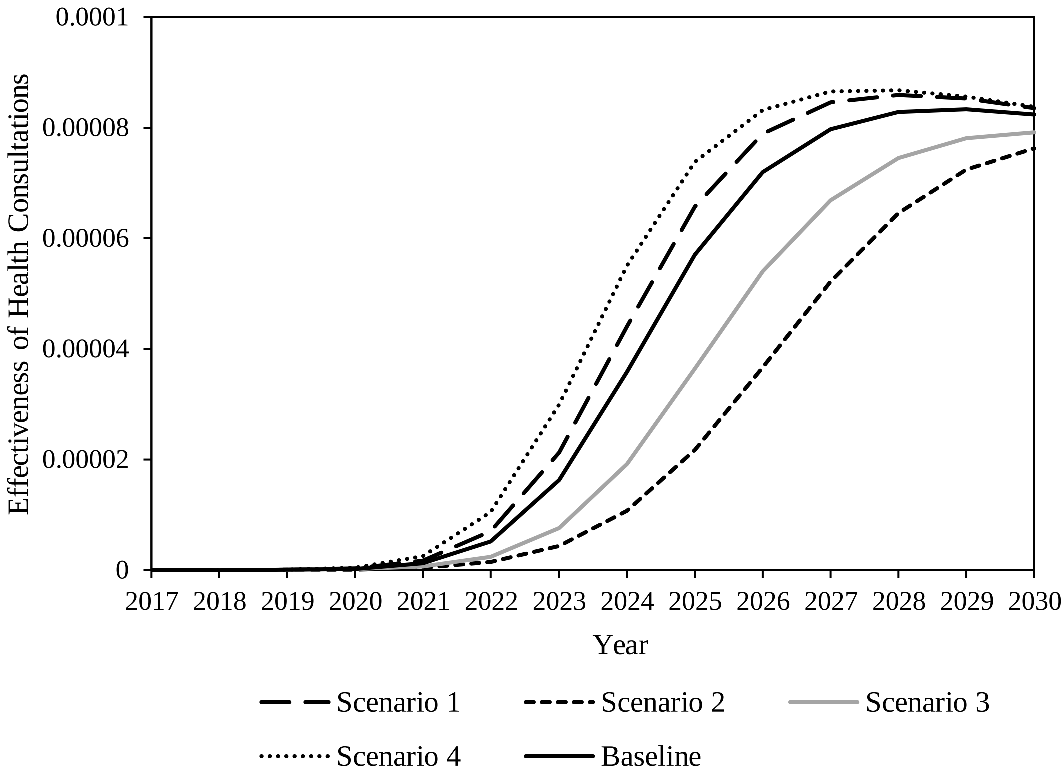


Figure 7.7 Scenario analysis of the effectiveness of health consultation

A rising number of patients being hospitalized does not only cause pressures to medical doctors and other clinical workforces, though it would cause challenges to hospital administrators and managers to efficiently manage health services delivery. Donabedian (1988) believed that improvement in patients' health status can be achieved through the health services provisions received during hospitalisation. Goldstein & Spiegelhalter (1996), agreed that changes in patients' health status were mainly affected by patients' characteristics, where the patient's health status per se and the procedure of hospitals. Therefore, the current study attempts to explore the implementation of smartphone adoption for improvement in healthcare service, in turn, would impact on patient's health status. Figure 7.7 and 7.8 represent the output results of scenario analysis of the smartphone-based adoption fraction for both on the health care service performance. The health care service performance can be measured through the improvement of patient discharge from hospitals. Patient discharge is an indicator of activity-based measures, where the more patients being treated means the more efficient health services is, while all else being equal (Jacobs, et al., 2006). The rising number of patient discharge from hospital is assumed to be a result of the effectiveness of health consultation as both doctors and patients attempt to use a smartphone for medical purpose.

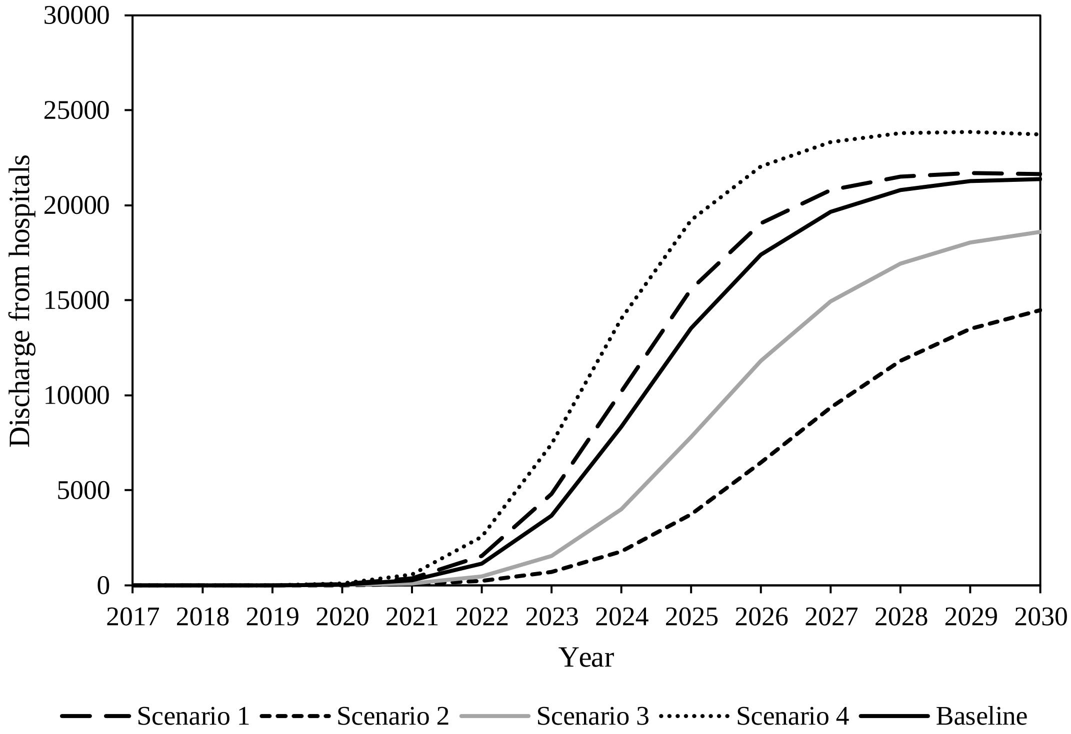


Figure 7.8 Scenario analysis of discharge rate

CHAPTER 8: CONCLUSION AND LIMITATIONS

8.1 Overview of the chapter

The Smartphone-based Technology for Healthcare Model (STHM) was successfully constructed with the hoped to provide profound insights into the interactions of health care demand, the supply of resources and smartphone-based technology. This chapter concludes the analysis of health care demand, supply and smartphone-based technology adoption for Malaysian public hospitals in the following section. The final section will assign the limitations of the current research and providing several recommendations for future studies.

8.2 Conclusion

Healthcare systems around the world confront continuous challenges as healthcare expenditure surpasses actual national budget allocated for healthcare. Rapidly growing health expenditure is believed resulting from the global demand for health care services, where expected to continuously increase in the future due to demographic shifts. Since the beginning of the 21st century, information technology and wireless devices have changed many aspects of people's lives. These devices such as smartphone, tablets and so on are acknowledged capacitate high value for healthcare delivery to solve the proliferating of health care costs. Hassan & Minato, (2018) substantiate that smartphone device has been acknowledged as a powerful tool to address the growing burden of medical expenses around the world. Moreover, it is able to release the burden of health care workers as well due to the ever-rising patients' admission to the hospital every year (Hassan & Minato, 2018).

In response to this situation, The present study attempts to: (1) present a dynamic interaction between the demand and supply of health care provisions; and (2) probe the substantial impact of smart-health technology adoption among health care stakeholders (patients and doctors) on health care service utilisation and medical expenses using a system dynamics simulation model. The System Dynamics approach is employed for three reasons: (1) to present the causal interactions between health care demand and supply, (2) to construct a model of smartphone-based technology adoption process in applied for health care purpose among medical practitioners and patients, and (3) to examine the substantial impact of this adoption on health care service delivery and medical expenses borne by providers. Based on the intervention results for the first objectives, changes in proportion rate of morbidity and disease prevalence has impacted on three main components of health supply utilisation, namely, bed, doctor and financing, in the same direction. This means that an increase in disease prevalence will increase the utilisation of those health supplies. Meanwhile, the changes in budget allocation have increased citizens' expectation in demanding for health, which in turn impacts both the bed and doctor utilisations in the same direction. These budget allocation has proved empirically impacted on two main components of healthcare supply. However, these results find that continuance increase is not the best solution to improve access to healthcare. These findings also supported by other researchers during my model and findings consultation with them. They agreed that continuance rising of supply is not the best way to improve health care service. Instead, they recommended utilising appropriate technology. One of the researchers in healthcare technology claimed as the following quotation:

> *"One of the challenges that might be faced when adopting technology for healthcare is to ensure that all patients have equal opportunity to access this technology and get benefit from it. Therefore, it is important for all parties like government, health human resource and technology provider companies to work together for making this technology accessible to all. A solid policy in adopting this technology should be carefully formulated in order to ensure it is beneficial to all".* -Ts. Dr Zuraida

On the other hand, a second analysis of the impact of smartphone adoption to health services and medical cost borne by providers is to answer the second objective. The analysis intervention of interaction rate through the changes in contact rate variable has proved that when more patients adopt STH, health consultation becomes more effective and in turn, increases the number of patients discharged from public hospitals. Medical consultation is found to be vital to improve the number of patients being discharged from hospital wards, as the doctor-patient communication increases. This impact is implicitly shown from the model through the effectiveness of health consultation using common available social networking applications. Moreover, the changes in the proportion of STH adoption patients seemed to be significant to the perceived medical expenses borne by providers and the patient discharge rate from public hospitals, as an increase in the patient adoption fraction would be developed as a self-treatment mechanism using mobile health applications among patients. Accordingly, improving hospital utilisation affects the number of patients discharged from the hospital, as they are able to monitor their vitality on their own.

In conclusion, the results of this research are hoped to provide a comprehension to the hospital management's decision makers, public health practitioners and medical practitioners that smartphone devices are considered significant to improve the health care delivery in Malaysian government hospitals and to reduce the burden of medical costs per patient who cannot afford it. This study strongly suggests the need for increasing awareness among patients and doctors to appropriately use this device in this service sector. The results of the present study are in line with the former research, as aforementioned at the beginning of chapter one, whereby Marschollek et al. (2007) asserted that the information technology is more cost-effective health care, where patients and doctors can actively communicate with each other from anywhere and at any time. The use of home telehealth has reduced the hospital utilisation service such as acute care services.

8.3 Research contributions

Significantly, the STHM is constructed to assist future researchers and health care management understand the system complexities of smartphone usage in health care. The model enables us to visualise the interactions between demand and supply of health care resources that would assist the health care management to understand resource capacity and the bottlenecking of the health care system, thus, making a decision to improve the health care service.

8.3.1 *Contribution to Academia*

The findings of this research offer a starting point for future research in the healthcare, technology management and system dynamic fields in Malaysia particularly. Through the application of system dynamics technique, we can observe how the utilisation of digital devices optimises the current state of our health care delivery in the whole system, rather than for mere individual aspects. Besides that, system dynamics enables the current study to investigate the adoption process of a smartphone technology from a holistic point of view, in turn, to provide the empirical evidence with the usefulness of the smartphone technology to health care services. Rohleder et al. (2007) assert the usefulness of developing the full dynamic model as it would assist in exploring possible side effects 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.

8.3.2 Contribution to the Management Practice

The development of the Smartphone-based Technology for Healthcare Model (STHM) is to visualise the interactions between the demand and supply of healthcare resources. This would assist healthcare management to understand resource capacity and the bottleneck of the healthcare system and thus make a decision to improve the healthcare service. Precisely, the findings of the research provide implication to both public health and healthcare management. In regard to the findings of the analysis demand and supply for healthcare, an implication goes to public health management, where the findings give guidance to practitioners to take an initiative controlling disease prevalence and public health finance of a country. The results of this study are expected to provide important information on how policymakers should formulate the availability of health care resources when planning their limited resources. Thus, expecting the supply of health care to address future health challenges is a pivotal, but complex task for policymakers. Indeed, the smartphone is substantiated as a helpful tool to improve health care management in terms of medical costs and the performance of health care service delivery. Therefore, hospital management should encourage patients and doctors to appropriately adopts this device in this sector.

8.4 Limitations

There are several limitations that have been acknowledged in this research, which could be considered for improvement in future studies, whether in terms of the models, or issues that have been raised. Limitations and suggestions provided here also included several feedbacks and suggestions on my research findings for future improvement.

First, the current model only covers the basic medical charges of outpatient and inpatient borne by patients, which is relatively low. Based on the first limitation addressed above, specifically examining the common occurrence disease and its health care costs can be considered for the future study, for example, the prevalence of diabetes and its costs. Depending on the severity level of hypertension, a research by Alefan, et al., (2009) have found that the total indirect cost covered by patients was much higher for seeking hypertension care, which made up 73–84 per cent of the total cost, more specifically ranging between MYR 6,655–8,079 (equivalent to $1598.43–1940.45[6]). Meanwhile, the direct cost of treating hypertension patients reported was merely made up between MYR 1,612–2,178 (equivalent to $388.86–523.12). In contrast, a recent study found that the average cost of stroke care for each hospitalised patients was MYR 36,969, where human resources composed of as the largest cost component, in which it was 36% from the total cost (Nor Azlin, at al., 2012). This reflects the vast difference between the cost borne by the provider and patients due to the loss of productivity for the different types of diseases. This suggestion has been supported by a researcher in healthcare technology, as she suggested future research should analyse a detail disease burden.

Other than that, the current research's analysis concentrates on smartphone-based technology devices for medical treatment purposes. Thus, a different type of technology tool, innovative device and medical equipment will probably produce different results, depending on the factor of adoption and objective of analysis of the study. However, the basic structure of the model is applicable to all types of technology-based health care by expanding and including more important elements. The current model should include the probability of people discard of this technology, as every technology becomes obsolete and has its own average life period to sustain in the market. For that reason, the adopters will be converted back into being potential adopters. The specific factor that influences Malaysian doctors and patients to use a smartphone or any technology devices should be taken into account for adoption and diffusion studies.

On the other hand, considering the level of average income as lower average income citizens tend to visit the public hospitals more and are the higher number of being outpatients, this reflects the utilisation of the public hospitals, which can be viewed as an inferior good

[6] At currency exchange rate MYR 1 equivalent to $ 0.24, € 0.21 and £0.19

rather than a normal good. This is due to richer patients that opt to seek treatment at private hospitals rather than going to public hospitals in order to circumvent from longer waiting times and meet their expectation for better services. Nadirah H. Rodzi, (2017) reported that the rising cost of living is the reason patients opting to go seek treatment at public hospitals.

Furthermore, the population cohort model should be specifically constructed where age-specific groups should be considered, as the country has an ageing population. The elderly are probably more vulnerable to chronic health problems and they are also less likely to adopt the use of smartphone-based technology due to the difficulty faced while using this device, which in turn, might discourage them from further use. This idea has been supported by other Malaysia researcher who worked on a similar area of current study where she provides her suggestion for the idea of disaggregate age-specific groups for the future model as following:

> *"I love this idea, but the modeller might need to consider the range of age for older people that have awareness on the technology. I believe that the range of age have a big influence to model outcome especially when we talk about technology. Try to look into a few factors like the economic background for each population in Malaysia because all can have the technology but not everyone knows how to use it in the right way. Besides that, there have few things to ponder. In Malaysia, most patients in government hospitals are older citizens whereby they are not interested to use any technology. Therefore, how can we relate to the use of technology".*
>
> -Suliza Sumari

In contrast to above opinion, one of the technologist who working on the health care technology field in collaboration with Ministry of Health (MOH), she provides her views on the implementation of technology usage in health care services as the following quotation. Her statements are based on the provided questions (see Appendix D) in regard to current research results.

"Smartphone will be a helpful tool in health care services. Specifically, in preventive care. However, it should be noted that this technology tool will be fully beneficial when the infrastructure of the whole system is fully ready, complete and comprehensive. The readiness of both the healthcare service provider and the patient is also a must in order to ensure that the tools work well. I can see somehow our healthcare provider will adopt this technology. It can be seen that the rest of the world is now adopting it. There is much other technologies that will be used such as cloud technology (I heard that there will be cloud hospital for Malaysia) and blockchain technology in medical area in Malaysia perhaps. As a researcher and technology provider, I think we have to look into how the technology can be used as a tool to the healthcare services in Malaysia. However, it must be noted that technology is only a tool, we could never replace the health care provider (the human)". -Ts. Dr Zuraida

Additionally, during working on this research, a number of problems occurred which make using system dynamics in this situation more difficult. First of all, there was a problem with the collection of the data needed for running the model. The use of system dynamics needs a different kind of data then the data currently collected (which is needed for the current planning methods). This meant that a number of uncertain assumptions had to be made while filling the model with data. The validity tests showed that despite these uncertain assumptions there is the reason for some confidence in the results of the model. However, to make the use of system dynamics easier in the future the researchers recommend a change in the sort of data that is collected. This will further increase the trust put into the constructed models. In corresponding to the argument made by Rohleder et al., (2007), system dynamics was used as a qualitative learning tool and forecasting potential outcomes even there was no data available at the time of implementation of the new facility design for patient service centres. Not all data was obtainable electronically. Some of the data obtained manually from the literature. Several qualitative techniques have been conducted such interviews and questionnaire are required. Ahmad et al., (2013) also performed interviews with stakeholders to their studies in order to fully understand the patient arrival process and observe the main aspects in the patient service department that are needed to be included in my model. Therefore, in system dynamics methodology, the behavioural pattern produced in the model is a crucial consideration instead of the data of variables because some variables in the certain system are restrained by the scarcity of available data. Those variables are probably still needed in the model of account as they may have an important bearing for a comprehensive result.

REFERENCES

Abas, Z. A., Ramli, M. R., Desa, M. I., Saleh, N., Hanafiah, A. N., Aziz, N., … Musa, H. (2017). A supply model for nurse workforce projection in Malaysia. *Health Care Management Science*, 1–14. https://doi.org/10.1007/s10729-017-9413-7

Abbasi, E., Bastan, M., & Ahmadvand, A. M. (2016). A system dynamics model for mobile banking adoption. *2016 12th International Conference on Industrial Engineering (ICIE)*, (January), 1–9. https://doi.org/10.1109/INDUSENG.2016.7519341

Abidin, N. Z., Zulkepli, J. H., & Zaibidi, N. Z. (2017). A system dynamics optimization framework to achieve population desired of average weight target. *AIP Conference Proceedings*, *1905*. https://doi.org/10.1063/1.5012189

Achampong, E. K. (2012). The State of Information and Communication Technology and Health Informatics in Ghana. *Online Journal of Public Health Informatics*, *4*(2), 1–13. https://doi.org/10.5210/ojphi.v4i2.4191

Adhikari, N. K. J., Beyene, J., Sam, J., & Haynes, R. B. (2005). Effects of Computerized Clinical Decision Support Systems on Practitioner Performance. *Journal of American Medican Association*, *293*(10), 1223–1238. https://doi.org/10.1001/jama.293.10.1223

Ahmad, N., Ghani, N. A., Abdulbasah Kamil, A., & Tahar, R. M. (2013). Simulating the Impact of an Increase in Patient Volume on a Government Emergency Department in Malaysia. *World Applied Sciences Journal*, *63*(16). https://doi.org/10.7763/IPEDR

Alefan, Q., Izham, M., Ibrahim, M., Razak, T. A., & Ayub, A. (2009). *COST OF TREATING HYPERTENSION IN MALAYSIA*. *Asian Journal of Pharmaceutical and Clinical Research* (Vol. 2). Retrieved from http://irep.iium.edu.my/11019/1/cost_of_treating_hypertension_in_Malaysia.pdf

Anderson, G. F., Hurst, J., Hussey, P. S., & Jee-Hughes, M. (2000). Health spending and outcomes: Trends in OECD countries, 1960-1998. *Health Affairs*, *19*(3), 150–157. https://doi.org/10.1377/hlthaff.19.3.150

Ansah, I. (2014). Biofuel and Food Security : Insights from a System Dynamics Model . The Case of Ghana Thesis Submitted in Partial Fulfillment of the Requirement for the Degree of Master of Philosophy in System Dynamics Supervisor : Professor Erling Moxnes System Dynamics.

Ansah, J. P., Riley, C. M., Thompson, J. P., & Matchar, D. B. (2015). The impact of population dynamics and foreign labour policy on dependency: the case of Singapore. *Journal of Population Research*, *32*(2), 115–138. https://doi.org/10.1007/s12546-015-9145-9

Atun, R. (2012). Health systems, systems thinking and innovation. *Health Policy and Planning*, *27*(SUPPL. 4), 4–8. https://doi.org/10.1093/heapol/czs088

Barber, P., & López-Valcárcel, B. G. (2010). Forecasting the need for medical specialists in Spain: application of a system dynamics model. *Human Resources for Health*, *8*(1), 24. https://doi.org/10.1186/1478-4491-8-24

Barlas, Y. (1996). Formal aspects of model validity and validation in system dynamics, *12*(3), 183–210.

Bass, F. M. (1969). A New Product Growth for Model Consumer Durables Author (s): Frank M . Bass Source : Management Science , Vol . 15 , No . 5 , Theory Series (Jan ., 1969), pp . 215-227 Published by : INFORMS Stable URL : http://www.jstor.org/stable/2628128. *Management Science*, *15*(5), 215–227.

Bayer, S., Barlow, J., & Curry, R. (2007). Telecare 61 Published online in Wiley InterScience (Syst. *Dyn. Rev*, *23*, 61–80. https://doi.org/10.1002/sdr

Bloom, D. E., Canning, D., & Sevilla, J. (2004). The Effect of Health on Economic Growth : A Production Function Approach, *32*(1), 1–13.

https://doi.org/10.1016/j.worlddev.2003.07.002

Borzekowski, R. (2009). Measuring the cost impact of hospital information systems: 1987-1994. *Journal of Health Economics*, *28*, 938–949. https://doi.org/10.1016/j.jhealeco.2009.06.004

Brailsford, S. C., Lattimer, V. A., Tarnaras, P., & Turnbull, J. C. (2004). Emergency and on-demand health care: modelling a large complex system. *Journal of the Operational Research Society*, *55*(February), 34–42. https://doi.org/10.2307/4101825

Broyles, J. R., Cochran, J. K., & Montgomery, D. C. (2010). A statistical Markov chain approximation of transient hospital inpatient inventory q. *European Journal of Operational Research*, *207*, 1645–1657. https://doi.org/10.1016/j.ejor.2010.06.021

Burnett, M., Clifford, K., & Durant-Law, G. (2010). Use of System Dynamics Techniques in the Garrison Health Modelling Tool. *Joint Operations Division Defence Science and Technology Organisation*, 23. Retrieved from http://oai.dtic.mil/oai/oai?verb=getRecord&metadataPrefix=html&identifier=ADA542407

Chaudhary, A. S. M. M. I. of T. (2015). System dynamics approach to healthcare affordability in India. Retrieved from https://dspace.mit.edu/handle/1721.1/105305

Chua, H., & Cheah, J. (2012). Financing Universal Coverage in Malaysia: a case study. *BMC Public Health*, *12*(Suppl 1), S7. https://doi.org/10.1186/1471-2458-12-S1-S7

Cooke, D., Rohleder, T., & Rogers, P. (2010). A dynamic model of the systemic causes for patient treatment delays in emergency departments. *Journal of Modelling in Management*, *5*(3), 287–301. https://doi.org/10.1108/17465661011092650

Davies, R., & Davies, H. (1994). Modelling patient flows and resource provision in health systems. *Omega*, *22*(2), 123–131. https://doi.org/10.1016/0305-0483(94)90073-6

Davis, F. D. (1989). Perceived Usefulness, Perceived Ease of Use, and User Acceptance of

Information Technology. *MIS Quarterly*, *13*(3), 319. https://doi.org/10.2307/249008

Department of Statistics Malaysia Official Portal. (2018a). Department of Statistics Malaysia Official Portal. Retrieved December 14, 2018, from https://www.dosm.gov.my/v1/index.php?r=column/ctwoByCat&parent_id=115&menu_id=L0pheU43NWJwRWVSZklWdzQ4TlhUUT09

Department of Statistics Malaysia Official Portal. (2018b). Department of Statistics Malaysia Official Portal.

Donabedian, A. (1988). The Quality of Care. *JAMA*, *260*(12), 1743. https://doi.org/10.1001/jama.1988.03410120089033

Edaibat, E. A., Dever, J., & Stuban, S. M. F. (2017). System dynamics simulation modeling of health information exchange (HIE) adoption and policy intervention: A case study in the State of Maryland. *Operations Research for Health Care*, *12*, 60–70. https://doi.org/10.1016/j.orhc.2017.02.001

Elf, M., Poutilova, M., & Öhrn, K. (2007). A dynamic conceptual model of care planning. *Scandinavian Journal of Caring Sciences*, *21*(4), 530–538. https://doi.org/10.1111/j.1471-6712.2007.00493.x

Elizabeth Armstrong Moore. (2015). How can we improve access to healthcare in emerging countries? | World Economic Forum. Retrieved November 11, 2018, from https://www.weforum.org/agenda/2015/11/how-can-we-improve-access-to-healthcare-in-emerging-countries/

Erdil, N., & Emerson, C. R. (2009). Simulation Modeling of Electronic Health Records Adoption in the U.S. Healthcare System . *Proceedings of the 27th International Conference of the System Dynamics Society*, (July), 1–16.

Evans, D. B., Tandon, A., Murray, C. J. L., & Lauer, J. A. (2001). Comparative efficiency of national health systems: cross national econometric analysis. *BMJ*, *323*(307).

https://doi.org/10.1136/bmj.323.7308.307

Folland, S., Goodman, A. C., & Stano, M. (2007). *The economics of health and health care*. Pearson Prentice Hall. Retrieved from https://books.google.co.jp/books/about/The_Economics_of_Health_and_Health_Care.html?id=txwoAQAAIAAJ&redir_esc=y

Forrester, J. W. (1978). Tests for Building Confidence in System Dynamics Models - Jay Wright Forrester - Google Books. Retrieved November 18, 2018, from https://books.google.co.jp/books/about/Tests_for_Building_Confidence_in_System.html?id=emCaHAAACAAJ&redir_esc=y

Furukawa, M. F., Raghu, T. S., & Shao, B. B. M. (2010). Electronic medical records, nurse staffing, and nurse-sensitive patient outcomes: Evidence from California Hospitals, 1998-2007. *Health Services Research*, *45*(4), 941–962. https://doi.org/10.1111/j.1475-6773.2010.01110.x

Giannoni, M., & Hitiris, T. (2002). The regional impact of health care expenditure: The case of Italy. *Applied Economics*, *34*(14), 1829–1836. https://doi.org/10.1080/00036840210126809

Goldstein, H., & Spiegelhalter, D. J. (1996). *League Tables and Their Limitations: Statistical Issues in Comparisons of Institutional*. *Source: Journal of the Royal Statistical Society. Series A (Statistics in Society)* (Vol. 159). Retrieved from https://www.jstor.org/stable/pdf/2983325.pdf?refreqid=excelsior%3A788e17f31c94aff5598d8726fb98f29d

Grossman, M. (1972). *On the Concept of Health Capital and the Demand for*. *Source: Journal of Political Economy* (Vol. 80). Retrieved from https://www.jstor.org/stable/pdf/1830580.pdf?refreqid=excelsior%3A4c5f1403f5a84dbbe73ec9056c256937

Grubaugh, S. G., & Santerre, R. E. (1994). Comparing the Performance of Health Care Systems: An Alternative Approach. *Southern Economic Journal*, *60*(4), 1030–1042. https://doi.org/10.2307/1060439

Guariguata, L., Guell, C., Samuels, T. A., Rouwette, E. A. J. A., Woodcock, J., Hambleton, I. R., & Unwin, N. (2016). Systems Science for Caribbean Health: The development and piloting of a model for guiding policy on diabetes in the Caribbean. *Health Research Policy and Systems*, *14*(1), 1–7. https://doi.org/10.1186/s12961-016-0150-z

Haenssgen, M. J., & Ariana, P. (2017). The Social Implications of Technology Diffusion: Uncovering the Unintended Consequences of People's Health-Related Mobile Phone Use in Rural India and China. *World Development*, *94*, 286–304. https://doi.org/10.1016/j.worlddev.2017.01.014

Halim, T. F. A., Sapiri, H., & Abidin, N. Z. (2016). A Dynamic Modelling Framework towards the Solution of Reduction in Smoking Prevalence. *The 4th International Conference on Quantitative Sciences and Its Applications (ICOQSIA2016)*, *040006*, 6–13. https://doi.org/10.1063/1.4966073

Hassan, F. A., & Minato, N. (2017). A System Dynamics Analysis of Malaysian Healthcare Resources, *9*(1), 61–69.

Hassan, F. A., & Minato, N. (2018). Smartphone-based Healthcare Technology Adoption in Malaysian Public Healthcare Services. *International Journal of Japan Association for Management Systems*, *10*(1), 95–104.

Hassan, F. A., Minato, N., Ishida, S., & Mohamed Nor, N. (2016). Social Environment Determinants of Life Expectancy in Developing Countries: A Panel Data Analysis. *Global Journal of Health Science*, *9*(5), 105. https://doi.org/10.5539/gjhs.v9n5p105

Homer, J. B., & Hirsch, G. B. (2006). System dynamics modeling for public health: background and opportunities. *American Journal of Public Health*, *96*(3), 452–458.

Homer, J., Milstein, B., Labarthe, D., Orenstein, D., Wile, K., Trogdon, J., & Huang, P. (2009). Simulating and Evaluating Local Interventions to Improve Cardiovascular Health. *Preventing Chronic Disease*, *7*(1), A18. https://doi.org/A18 [pii]

How Many Hours Do Housemen In Malaysia Actually Work? (n.d.). Retrieved December 18, 2018, from http://www.rojakdaily.com/lifestyle/feature-how-many-hours-do-Malaysian-houseman-work.aspx

Imoughele, L. E., & Ismaila, M. (2015). Determinants of Public Health Care Expenditure in Nigeria: An Error Correction Mechanism Approach (1981-2014). *Journal of Economic and Sustainable Development*, *6*(24), 7–19.

Ishikawa, T., Ohba, H., Yokooka, Y., Nakamura, K., & Ogasawara, K. (2013). Forecasting the absolute and relative shortage of physicians in Japan using a system dynamics model approach. *Human Resources for Health*, *11*, 41. https://doi.org/10.1186/1478-4491-11-41

Jacobs, R., Smith, P. C., & Street, A. (2006). *Measuring Efficiency in Health Care*. Cambridge: Cambridge University Press. https://doi.org/10.1017/CBO9780511617492

Jantsch, E. (1994). *World Dynamics*. Retrieved from https://ac.els-cdn.com/0016328771900383/1-s2.0-0016328771900383-main.pdf?_tid=f9bcf9ee-dafb-46e1-bc14-ffa2e3e55959&acdnat=1542452657_037d2706a9ea2529b2a15ec48ecfc6d8

Jha, A. K., DesRoches, C. M., Campbell, E. G., Donelan, K., Rao, S. R., Ferris, T. G., … Blumenthal, D. (2009). Use of Electronic Health Records in U.S. Hospitals. *N Engl J Med*, *360*, 1628–1666. https://doi.org/10.1056/NEJMsa0900592

Jun, G. T., Ward, J., Morris, Z., & Clarkson, J. (2009). Health care process modelling: which method when? *International Journal for Quality in Health Care*, *21*(3), 214–224. https://doi.org/10.1093/intqhc/mzp016

Kenealy, T., Rees, D., Sheridan, N., Moffitt, A., Tibby, S., & Homer, J. (2012). A “whole of system" approach to compare options for CVD interventions in Counties Manukau. *Australian and New Zealand Journal of Public Health*, *36*(3), 263–268. https://doi.org/10.1111/j.1753-6405.2011.00812.x

Khanmohammadi, S., Farahmand, H., & Kashani, H. (2018). A system dynamics approach to the seismic resilience enhancement of hospitals. *International Journal of Disaster Risk Reduction*, *31*(October 2017), 220–233. https://doi.org/10.1016/j.ijdrr.2018.05.006

Khudyakov, A., Jean, C., Stal-Le Cardinal, J., Jankovic, M., & Bocquet, J.-C. (2013). *Simulation methods in the healthcare systems*. Retrieved from https://hal.archives-ouvertes.fr/hal-00871615

Koç, C. (2004). The productivity of health care and health production functions. *Health Economics*, *13*(8), 739–47. https://doi.org/10.1002/hec.855

Krejčí, I., Kvasnička, R., & Švasta, J. (2011). Dynamic aging chain of the Czech Republic population. *Acta Universitatis Agriculturae et Silviculturae Mendelianae Brunensis*, *59*(7), 209–216. https://doi.org/10.11118/actaun201159070209

Lane, D. C., Monefeldt, C., & Rosenhead, J. V. (2000). Looking in the wrong place for healthcare improvements: A system dynamics study of an accident and emergency department. *Journal of the Operational Research Society*, *51*(5), 518–531. https://doi.org/10.1057/palgrave.jors.2600892

Lee, J., & Dowd, B. (2009). Effect of Health Information Technology Expenditure on Patient Level Cost Corresponding Author. *The Health Information Technol-Healthc Inform Res*, *19*(3), 215–221. https://doi.org/10.4258/hir.2013.19.3.215

Li, M., Zhang, Y., Lu, Y., Yu, W., Nong, X., & Zhang, L. (2018). Factors influencing two-way referral between hospitals and the community in China: A system dynamics simulation model. *Simulation*, *94*(9), 765–782. https://doi.org/10.1177/0037549717741349

Lin, S.-P., & Chen, J.-S. (2012). Acceptance and Usage of Innovative Healthcare Service for the Elderly People : A System Dynamics Modeling Approach, *36*, 57–61.

Linna, M., Häkkinen, U., & Magnussen, J. (2006). Comparing hospital cost efficiency between Norway and Finland. *Health Policy*, *77*, 268–278. https://doi.org/10.1016/j.healthpol.2005.07.019

Magistrale, L., Qem, I., Aranda, L. G., Longbin, Z., Melas, C. D., Zampetakis, L. A., … Okunade, A. A. (2016). How to do structural validity of a system dynamics type simulation model: The case of an energy policy model. *PLoS ONE*, *6*(1), 1–16. https://doi.org/10.1016/j.enpol.2009.12.009

Mahamoud, A., Roche, B., & Homer, J. (2013). Social Science & Medicine Modelling the social determinants of health and simulating short-term and long-term intervention impacts for the city of Toronto , Canada. *Social Science & Medicine*, *93*, 247–255. https://doi.org/10.1016/j.socscimed.2012.06.036

Mardiah, F. P., & Basri, M. H. (2013). The Analysis of Appointment System t o Reduce Outpatient Waiting Time at Indonesia's Public Hospital. *Human Resource Management Research*, *3*(1), 27–33. https://doi.org/10.5923/j.hrmr.20130301.06

Marschollek, M., Mix, S., Wolf, K.-H., Effertz, B., Haux, R., & Steinhagen-Thiessen, E. (2007a). Medical Informatics and the Internet in Medicine ICT-based health information services for elderly people: Past experiences, current trends, and future strategies ICT-based health information services for elderly people: Past experiences, current trends,. *Medical Informatics and the Internet in Medicine ISSN:*, *32*(4), 251–261. https://doi.org/10.1080/14639230701692736

Marschollek, M., Mix, S., Wolf, K.-H., Effertz, B., Haux, R., & Steinhagen-Thiessen, E. (2007b). Medical Informatics and the Internet in Medicine ICT-based health information services for elderly people: Past experiences, current trends, and future strategies ICT-based health information services for elderly people: Past experiences, current trends,. *Medical Informatics and the Internet in Medicine ISSN:*, *32*(4), 251–261. https://doi.org/10.1080/14639230701692736

Martín, J. J. M., del Amo Gonzalez, M. P. L., & Dolores Cano Garcia, M. (2011). Review of the literature on the determinants of healthcare expenditure. *Applied Economics*, *43*(1), 19–46. https://doi.org/10.1080/00036841003689754

McPake, B., Normand, C. E. M., & Smith, S. (n.d.). *Health economics : an international perspective*. Retrieved from https://www.esri.ie/publications/health-economics-an-international-perspective/

McPake, B., Normand, C. E. M., & Smith, S. (2013a). *Health economics : an international perspective*. Retrieved from https://www.esri.ie/publications/health-economics-an-international-perspective/

McPake, B., Normand, C. E. M., & Smith, S. (2013b). *Health economics : an international perspective*.

Mehrjerdi, Y. Z. (2012). *A System Dynamics Approach to Healthcare Cost Control*. Retrieved from https://pdfs.semanticscholar.org/9ad1/eb115ac544cc92c270ed21afa3f5c9f77546.pdf

Meisel, J. D., Sarmiento, O. L., Olaya, C., Lemoine, P. D., Valdivia, J. A., & Zarama, R. (2018). Towards a novel model for studying the nutritional stage dynamics of the Colombian population by age and socioeconomic status. *PLoS ONE*, *13*(2), 1–22. https://doi.org/10.1371/journal.pone.0191929

Ministry of Health Malaysia. (2011a). Health Facts 2010. *Health Informatics Centre, Planning and Development Division*, *11*(August), 5–6. Retrieved from http://www.moh.gov.my/images/gallery/stats/heal_fact/health_facts_2010.pdf

Ministry of Health Malaysia. (2011b). Health Indicators 2010, *91*, 399–404.

Morecroft, J. D. W. (John D. W. (2015). *Strategic modelling and business dynamics : a feedback systems approach*. Retrieved from https://www.wiley.com/en-us/Strategic+Modelling+and+Business+Dynamics%3A+A+feedback+systems+approach%2C+%2B+Website%2C+2nd+Edition-p-9781118844687

Mushkin, S. J. (1962). *Health as an Investment*. *Journal of Political Economy* (Vol. 70). https://doi.org/10.1086/258730

Mutingi, M., & Matope, S. (2013). System dynamics of renewable energy technology adoption. *2013 IEEE International Conference on Industrial Technology (ICIT)*, 1512–1516. https://doi.org/10.1109/ICIT.2013.6505896

Nadirah H. Rodzi. (2017). Overwork taking a toll on Malaysian doctors, SE Asia News & Top Stories - The Straits Times. Retrieved December 19, 2018, from https://www.straitstimes.com/asia/se-asia/overwork-taking-a-toll-on-malaysian-doctors

Ng, A., Sy, C., & Li, J. (2011). A system dynamics model of Singapore healthcare affordability. *Proceedings - Winter Simulation Conference*, (Sterman 2004), 1325–1332. https://doi.org/10.1109/WSC.2011.6147853

NoorAni, A., Rajini, S., Balkish, M. N., Noraida, M. K., SMaria, A., Fadhli, M. Y., … Tahir, A. (2018). Morbidity patterns and healthcare utilisation among older people in Malaysia: 1996–2015. *Public Health*, *163*, 105–112. https://doi.org/10.1016/j.puhe.2018.06.018

Nor Azlin, M. N., Syed Aljunid, S. J., Noor Azahz, A., Amrizal, M. N., & Saperi, S. (2012). *Direct Medical Cost of Stroke: Findings from a Tertiary Hospital in Malaysia*. Retrieved from http://www.e-mjm.org/2012/v67n5/direct-medical-cost-of-stroke.pdf

Noraida, N. A., Ghani, A., & Kamil, A. A. (2010). *A Framework For Emergency Department Capacity Planning Using System Dynamics Approach And The Theory Of Constraints Philosophies*. 24th European Conference on Modelling and Simulation. Retrieved from http://www.scs-europe.net/conf/ecms2010/2010 accepted papers/ibs_ECMS2010_0013.pdf

OECD. (n.d.). *Health at a Glance 2011: OECD Indicators*. https://doi.org/10.1787/health_glance-2011-en

Oliver, K., Innvar, S., Lorenc, T., Woodman, J., & Thomas, J. (2014). A systematic review of barriers to and facilitators of the use of evidence by policymakers. *BMC Health Services Research*, *14*. https://doi.org/10.1186/1472-6963-14-2

Otto, P., & Nevo, D. (2013). Journal of Enterprise Information Management Electronic health records: A simulation model to measure the adoption rate from policy interventions Article information. *Journal of Enterprise Information Management*, *26*(2), 165–182. https://doi.org/10.1108/17410391311289613

Pai, R. R., & Alathur, S. (2018). Assessing mobile health applications with twitter analytics. *International Journal of Medical Informatics*, *113*(February), 72–84. https://doi.org/10.1016/j.ijmedinf.2018.02.016

Pedamallu, C. S., Ozdamar, L., Kropat, E., & Weber, G. W. (2012). A system dynamics model for intentional transmission of HIV/AIDS using cross impact analysis. *Central European Journal of Operations Research*, *20*(2), 319–336. https://doi.org/10.1007/s10100-010-0183-2

Porter, D. E. (1962). Industrial Dynamics. Jay Forrester. M.I.T. Press, Cambridge, Mass.; Wiley, New York, 1961. xv + 464 pp. Illus. $18. *Science*, *135*(3502), 426–427. https://doi.org/10.1126/science.135.3502.426-a

Quek, D. (2009). The Malaysian Health Care System : A Review. *Intensive Workshop on Health Systems in Transition*, (July).

Reinhardt, U. E., Hussey, P. S., & Anderson, G. F. (2002). Cross-national comparisons of health systems using OECD data, 1999. *Health Affairs*, *21*(3), 169–181. https://doi.org/10.1377/hlthaff.21.3.169

Rengin, A. K. (2012). The Relationship between Health Expenditures and Economic Growth: Turkish Case. *International Journal of Business Management & Economic Research*, *3*(1), 404–409. Retrieved from http://search.ebscohost.com/login.aspx?direct=true&db=buh&AN=82584750&site=ehost-live

Retzlaff-Roberts, D., Chang, C. F., & Rubin, R. M. (2004). Technical efficiency in the use of health care resources: A comparison of OECD countries. *Health Policy*, *69*(1), 55–72. https://doi.org/10.1016/j.healthpol.2003.12.002

Rizzo, J. A., & Han, M. (2012). The Health Returns to Medical Expenditures : Does Age Matter ? *HEC Montreal*, 38. Retrieved from http://www.hec.ca/en/governance_departments/index_services/index.html

Roberts, E. B. (1978). *Managerial applications of system dynamics*. Productivity Press. Retrieved from https://books.google.co.jp/books/about/Managerial_applications_of_system_dynami.html?id=2pwSAQAAMAAJ&redir_esc=y

Rogers, E. M. (1962). *DIFFUSION OF INNOVATIONS Third Edition*. Retrieved from https://teddykw2.files.wordpress.com/2012/07/everett-m-rogers-diffusion-of-innovations.pdf

Rohleder, T. R., Bischak, D. P., & Baskin, L. B. (2007). Modeling patient service centers with simulation and system dynamics. *Health Care Management Science*, *10*(1), 1–12. https://doi.org/10.1007/s10729-006-9001-8

Rojas-Cordova, A., Baghaei-Lakeh, A., Zhang, H., Wernz, C., Rahmandad, H., Slonim, A. D., & Caroline, A. (2016). Improving technology investment decisions at hospitals through system dynamics and decision analysis. *Proceedings of the Annual Hawaii International Conference on System Sciences*, *2016–March*(April), 1517–1526.

https://doi.org/10.1109/HICSS.2016.192

Samah, A. A., Wah, L. K., Desa, M. I., Majid, H. A., Azmi, N. F. M., Salleh, N., … Manual, A. (2014a). Decision Support System Using System Dynamics Simulation Modelling for Projection of Dentist Supply. In *2014 International Conference on Computer Assisted System in Health* (pp. 22–25). IEEE. https://doi.org/10.1109/CASH.2014.18

Samah, A. A., Wah, L. K., Desa, M. I., Majid, H. A., Azmi, N. F. M., Salleh, N., … Manual, A. (2014b). Decision Support System Using System Dynamics Simulation Modelling for Projection of Dentist Supply. *2014 International Conference on Computer Assisted System in Health*, 22–25. https://doi.org/10.1109/CASH.2014.18

Samuelson, P. A. (Paul A., & Nordhaus, W. D. (1998). *Economics*. Irwin/McGraw-Hill. Retrieved from https://trove.nla.gov.au/work/6792576?q&sort=holdings+desc&_=1541833106890&versionId=208135313

Savedoff, W. D. (2007). What Should A Country Spend On Health Care? *Health Affairs*, *26*(4), 962–970. https://doi.org/10.1377/hlthaff.26.4.962

Semwanga, A. R., Nakubulwa, S., & Adam, T. (2016). Applying a system dynamics modelling approach to explore policy options for improving neonatal health in Uganda. *Health Research Policy and Systems*, *14*(1), 35. https://doi.org/10.1186/s12961-016-0101-8

Serdar Kilinc, M., & Bennett Milburn, A. (2016). A study of home telehealth diffusion among US home healthcare agencies using system dynamics A study of home telehealth diffusion among US home healthcare agencies using system dynamics. *IIE Transactions on Healthcare Systems Engineering*. https://doi.org/10.1080/19488300.2016.1195461

Shannon, R. E. (1998). *INTRODUCTION TO THE ART AND SCIENCE OF SIMULATION*. Retrieved from http://delivery.acm.org/10.1145/300000/293175/p7-

shannon.pdf?ip=133.19.169.3&id=293175&acc=ACTIVE SERVICE&key=D2341B890AD12BFE.E7C6D16F16E10784.4D4702B0C3E38B35.4D4702B0C3E38B35&__acm__=1542373031_e59a90377fd5ed0a761b7faa0a8392e8

Sharif, M. N., & Ramanathan, K. (1984). Temporal models of innovation diffusion. *IEEE Transactions on Engineering Management*, *EM-31*(2), 76–86. https://doi.org/10.1109/TEM.1984.6447569

Smith, S., Newhouse, J. P., & Freeland, M. S. (2009). Income, insurance, and technology: Why does health spending outpace economic growth? *Health Affairs*, *28*(5), 1276–1284. https://doi.org/10.1377/hlthaff.28.5.1276

Sterman, J. (2000). *Business dynamics : systems thinking and modeling for a complex world*. Irwin/McGraw-Hill. Retrieved from https://dl.acm.org/citation.cfm?id=540759

Sterman, J. (2002). System Dynamics: Systems Thinking and Modeling for a Complex World. Retrieved from https://dspace.mit.edu/handle/1721.1/102741

Sumari, S., Ibrahim, R., & Zakaria, N. H. (n.d.). Qualitative Analysis in System Dynamics for Health Care System. Retrieved from http://seminar.utmspace.edu.my/jisri/

Sutrisno, A., & Handel, O. (2011). Dynamic Aging Population in Germany : A case study about demographic change by Dynamic Aging Population in Germany :, (November).

TASKAYA, S., & DEMIRKIRAN, M. (2016). The Causality between Healthcare Resources and Health Expenditures in Turkey. A Granger Causality Method. *International Journal of Academic Research in Accounting, Finance and Management Sciences*, *6*(2), 98–103. https://doi.org/10.6007/IJARAFMS/v6-i2/2075

Taylor, K., & Dangerfield, B. (2005). Modelling the feedback effects of reconfiguring health services. *Journal of the Operational Research Society*, *56*(6), 659–675. https://doi.org/10.1057/palgrave.jors.2601862

The Star. (2013). Malaysia still in need of over 5,000 dentists, says Subra - Nation | The Star

Online. Retrieved November 25, 2018, from https://www.thestar.com.my/news/nation/2013/10/07/malaysia-still-in-need-of-over-5000-dentists-says-subra/

The State of Healthcare in South East Asia. (2013). Retrieved November 14, 2018, from https://www.slideshare.net/EdelmanInsights/the-state-of-healthcare-in-south-east-asia

Trellevik, L. K. . (2008). Planning for an elderly boom; A System Dynamics Approach to strategic healthcare planning in Bergen, Norway, 195.

Van Der Sanden, R., Everwijn, H., Rouwette, E., & Gubbels, J. (2006). *Balancing supply and demand for dementia care in the Netherlands*. Retrieved from https://www.systemdynamics.org/assets/conferences/2005/proceed/papers/ROUWE303.pdf

Van Der Watt, A. J., Pretorius, M., & Pretorius, L. (2016). Adoption of health technology in healthcare facilities: A case study. *IAMOT 2016 - 25th International Association for Management of Technology Conference, Proceedings: Technology - Future Thinking*, 308–318.

Varabyova, Y., Blankart, C. R., Greer, A. L., & Schreyögg, J. (2017). The determinants of medical technology adoption in different decisional systems: A systematic literature review. *Health Policy*, *121*(3), 230–242. https://doi.org/10.1016/j.healthpol.2017.01.005

Varabyova, Y., & Schreyögg, J. (2013). International comparisons of the technical efficiency of the hospital sector: Panel data analysis of OECD countries using parametric and non-parametric approaches. *Health Policy*, *112*(1–2), 70–79. https://doi.org/10.1016/j.healthpol.2013.03.003

Wael Rashwan, M. A. R. (2013). Bed Blockage in Irish Hospitals: System Dynamics Methodology. *Proceedings of the 2013 Winter Simulation Conference, 53*(9), 1689–1699. https://doi.org/10.1017/CBO9781107415324.004

Wagstaff, A. (1986). > 0 < 0., 1–3.

Wang, X., Sun, Y., Mu, X., Guan, L., & Li, J. (2015). How to improve the equity of health financial sources? - Simulation and analysis of total health expenditure of one Chinese province on system dynamics. *International Journal for Equity in Health*, *14*, 1–10. https://doi.org/10.1186/s12939-015-0203-x

WHO | What is the burden of oral disease? (2010). *Who*. Retrieved from http://www.who.int/oral_health/disease_burden/global/en/

WHO, W. H. O. (2007). *E V E R Y B O D Y ' S B U S I N E S S ST R E NGT H E N I NG H E A LT H SYST E MS TO I M PROV E H E A LT H OU TCOM E S W HO'S F R A M E WOR K FOR AC T ION*. Retrieved from https://www.who.int/healthsystems/strategy/everybodys_business.pdf

Wren, M.-A., Keegan, C., Walsh, B., Bergin, A., Eighan, J., Brick, A., … Banks, J. (2017). *Projections of Demand for Healthcare in Ireland, 2015-2030 First Report From the Hippocrates Model*. Retrieved from http://www.esri.ie/pubs/RS67.pdf

Wu, M., Yu, J., & Huang, C. (2017). Theoretical System Dynamics Modeling for Taiwan Pediatric Workforce in an Era of National Health Insurance and Low Birth Rates. *Pediatrics and Neonatology*, *54*(6), 389–396. https://doi.org/10.1016/j.pedneo.2013.04.010

Yasmin Ramlan. (2018). More money, less stress reasons for government doctors' move to private sector | The Malaysian Insight. Retrieved December 19, 2018, from https://www.themalaysianinsight.com/s/33256

Young, T. (2005). An Agenda for Healthcare and Information Simulation. *Health Care Management Science*, *8*(3), 189–196. https://doi.org/10.1007/s10729-005-2008-8

Yu, W., Li, M., Ge, Y., Li, L., Zhang, Y., Liu, Y., & Zhang, L. (2015). Transformation of potential medical demand in China: A system dynamics simulation model. *Journal of*

Biomedical Informatics, *57*, 399–414. https://doi.org/10.1016/j.jbi.2015.08.015

Zahra, F., Hussain, A., & Mohd, H. (2016). Usability factors of mobile health application for chronic diseases (p. 020108). https://doi.org/10.1063/1.4960948

Zainal Abidin, N., Mamat, M., Dangerfield, B., Zulkepli, J. H., Baten, M. A., & Wibowo, A. (2014). Combating Obesity through Healthy Eating Behavior: A Call for System Dynamics Optimization. *PLoS ONE*, *9*(12), e114135. https://doi.org/10.1371/journal.pone.0114135

Zainal, R., & Mahat, M. (2014a). Estimating The Costs Of Specialist Out-Patient Services In A Public Hospital. *Value in Health*, *17*(7), A790. https://doi.org/10.1016/J.JVAL.2014.08.431

Zainal, R., & Mahat, M. (2014b). Estimating The Costs Of Specialist Out-Patient Services In A Public Hospital. *Value in Health*, *17*(7), A790. https://doi.org/10.1016/J.JVAL.2014.08.431

Zhang, H., Liu, Y., Yang, Q., Gu, S., Zhen, X., Xia, Y., … Dong, H. (2017). A System Dynamics Simulation Model of Hierarchical Medical Care System Reform in China. *Journal of Health & Medical Informatics*, *08*(02). https://doi.org/10.4172/2157-7420.1000253

APPENDICES

Appendix A: List of baseline value of the key variables and the source of data

Parameters	Value	Unit	Data Source
Admission cost	0	MYR	Ministry of Health Malaysia (2011)
Average Length of Stay (ALOS)	0.0115	Year	Ministry of Health Malaysia (2011)
Average turnover time to vacant bed	0.0059	%	Ministry of Health Malaysia (2011)
Birth Rate	0.02	%	Ministry of Health Malaysia (2011)
Daily medical charges	3	MYR	Ministry of Health Malaysia, (2011)
Death Rate	0.004	%	Ministry of Health Malaysia (2011)
Desired bed	65754	Volume	Author's calculation
Desired doctors	71471.5	People	Author's calculation
Discharge rate	0.9778	%	Ministry of Health Malaysia (2011)
Doctor adoption fraction	0.287	%	MC
Doctor contact rate	4	People	MC
Doctor retirement period	58	Year	DOS

Fatality rate	0.023	%	Ministry of Health Malaysia (2011)
First attendance cost	1	MYR	Ministry of Health Malaysia (2011)
GDP	821,434,000,000	MYR	Ministry of Health Malaysia (2011)
Hours in outpatient treatment	0.000114	Hour per year	Author's calculation
Hours working	0.0017	Hour per year	Author's calculation
Inpatients	2,130,560	People	Ministry of Health Malaysia (2011)
Messenger apps[7]	5	Volume	MC
Minimum wages per hour	4.33	Hour per year	Author's calculation
MOH budget allotted to hospitals	0.511	%	Ministry of Health Malaysia (2011)
Morbidity and disease prevalence rate	0.563	%	Ministry of Health Malaysia (2011)
Number of available bed	37,793	Volume	Ministry of Health Malaysia (2011)
Number of doctor	19,429	People	Ministry of Health Malaysia (2011)

[7] In Malaysia, there are five common apps actively used for communication such as Facebook, WhatsApp, Twitter, Email, and Skype.

Outpatients	17,653,500	People	Ministry of Health Malaysia (2011)
Patient Adoption Fraction	0.438	%	MC
Patient contact rate	53	People	MC
Percentage of subsidy to visiting costs	0.95	%	Zainal & Mahat (2014)
Percentage to curative care	0.9291	%	Ministry of Health Malaysia (2011)
Percentage to non-curative care	0.0709	%	Ministry of Health Malaysia (2011)
Smartphone users	4,002,400	People	MCMC
Specialist Cost	5	MYR	Ministry of Health Malaysia (2011)
Target by WHO	0.05	%	Chua & Cheah (2012)
Total Health Expenditure	32,962,000,000	MYR	Ministry of Health Malaysia (2011)
Total Population	28,588,600	People	Ministry of Health Malaysia (2011)

Note: MYR is Malaysia Ringgit, and WHO is world health organization. The term MC indicates the parameter value is based on the model calibration during simulation process using SyntheSim tool in Vensim software

Appendix B: Output of parameter values and equations from Vensim PLE

1. "% of GDP allotted to THE"= Total Health Expenditure/Total GDP

   Units: 1

2. Adjustment time to increase THE= 0.215

   Units: 1/year

3. Admission costs= 0

   Units: Dmnl

4. Admission to hospital= Patient waiting for admission

   Units: Unit/year

5. Adoption from Interaction among doctors=

   Doctors adoption fraction*Doctors contact rate*Doctors adopt STH*

   (Potential Doctors adopt STH/Number of doctors)

   Units: Unit/year

6. Adoption from Interactions among patients=

   Patients adoption fraction*Patients contact rate*Patients adopt STH*

   (Potential Patients adopt STH/Number of patients in hospital)

   Units: Unit/year

7. Affordability=average income/OOP

   Units: 1/Unit

8. Average income=1000

   Units: 1/year

9. Average length of stay=0.0115

   Units: year

10. Average medical costs borne by patients=Basic medical charges to patients

+Indirect cost from productivity loss

Units: Dmnl

11. Average turnover time to vacant bed=0.0059

    Units: Dmnl

12. Average waiting time in outpatient department=0.000114

    Units: 1/year

13. Basic medical charges to patients=

    Incurred cost at inpatient department+Incurred costs at outpatient department

    Units: Dmnl

14. Bed accumulated=Bed adjustment time*Bed capacity utilization*

    Discrepancy desired and available beds*Budget proportion to increase capacity

    Units: Unit/year

15. Bed adjustment time=0.0008

    Units: Dmnl

16. Bed capacity utilization=Inpatients/Number of Available Bed

    Units: 1

17. Birth rate=0.02

    Units: 1/year

18. Births=Birth rate*Total Population

    Units: Unit/year

19. Budget allocation to hospitals=MOH Healthcare budget*

    MOH budget allotted to hospitals*Revenue receive to hospital

    Units: Unit/year

20. Budget proportion to increase capacity=MOH budget allotted to hospitals

    Units: 1/year

21. Budget to curative care=Budget allocation to hospitals*

    Percentage to curative care

    Units: Unit

22. Budget Utilization=Number of patients in hospital/Budget to curative care

    Units: 1

23. Daily medical charges=3

    Units: Dmnl

24. Death rate=0.004

    Units: 1/year

25. Deaths=Death rate*Total Population

    Units: Unit/year

26. Deaths in hospital=Fatality rate*Inpatients

    Units: Unit/year

27. Desired bed=65754

    Units: Unit

28. Desired doctors=71471.5

    Units: Unit

29. Discharge from hospital=(Inpatients/Average length of stay)*

    Patient self-treatment*Effectiness of health consultation

    Units: Unit/year

30. Discharge rate=0.9778

    Units: 1

31. Discrepancy desired and available beds=Desired bed-Number of Available Bed

    Units: Unit

32. Discrepancy of desired and available doctors=Desired doctors-Number of doctors

Units: Unit

33. Doctor adjustment time=0.155

    Units: Dmnl

34. Doctor retirement period=58

    Units: year

35. Doctor utilization rate=(Number of patients in hospital/Number of doctors)

    Units: 1

36. Doctors adopt STH= INTEG (Doctors adoption rate,100)

    Units: Unit

37. Doctors adoption fraction=0.287

    Units: Dmnl

38. Doctors adoption rate=Adoption from Interaction among doctors

    Units: Unit/year

39. Doctors contact rate=4

    Units: 1/year

40. Effectiness of health consultation=Messenger apps for communication*

    STH usage in healthcare

    Units: Dmnl

41. Expected demand to private hospital=

    (Average medical costs borne by patients/Medical costs borne by providers)

    *Untreated layoff

    Units: Unit/year

42. Expected healthcare services demand=MOH budget allotted to hospitals

    Units: 1/year

43. "Expenditure to non-curative care"=Budget allocation to hospitals

44. *"Percentage to non-curative care"

    Units: Unit/year

45. Fatality rate=0.023

    Units: 1/year

46. "First-attendance costs"=1

    Units: Dmnl

47. "Follow-up charge"=Specialist cost

    Units: Dmnl

48. Frequency of mobile health apps use=0.025

    Units: Dmnl

49. Gap=Target by WHO-"% of GDP allotted to THE"

    Units: 1

50. Gap between Budget and costs=

    (MOH Actual Healthcare Expenditure-MOH Healthcare budget)

    Units: Unit

51. GDP change=GDP growth*Total GDP

    Units: Unit/year

52. GDP growth=0.07

    Units: 1/year

53. Healthcare Efficiency=Total Hospital Productivity

    Units: Dmnl

54. Hours in outpatient treatment=0.000114

    Units: Dmnl

55. Hours working=0.0017

Units: 1

56. Increase in health expenditure=Gap*Adjustment time to increase THE

*MOH Actual Healthcare Expenditure

Units: Unit/year

57. Incurred cost at inpatient department=Admission costs+Daily medical charges

Units: Dmnl

58. Incurred costs at outpatient department="First-attendance costs"+

"Follow-up charge"

Units: Dmnl

59. Indirect cost from productivity loss=

Time spent by patients for seeking care in outpatient

+Time spent by admitted patients

Units: Dmnl

60. Inpatient per doctor=Inpatients/Number of doctors

Units: Dmnl

61. Inpatients= INTEG (Admission to hospital-Deaths in hospital-

Discharge from hospital,2.13056e+06)

Units: Unit

62. Layoff=Number of doctors*Proportion of layoff*Workload

Units: Unit/year

63. Medical cost borne by providers per adopted patients=

(Gap between Budget and costs/Patients adopt STH)

Units: 1

64. Medical costs borne by providers=(Budget to curative care/

Number of patients in hospital)*Percentage of subsidy to visiting costs

Units: 1

65. Messenger apps for communication=5

    Units: Dmnl

66. Minimum wages per hour=4.33

    Units: Dmnl

67. Mobile Broadband penetration=0.3247

    Units: Unit

68. Mobile Health Apps availability=100

    Units: Dmnl

69. MOH Actual Healthcare Expenditure=

    (Total Health Expenditure*"Proportion of MOH expenditure as a % THE")

    *Medical costs borne by providers

    Units: Unit

70. MOH budget allotted to hospitals=0.511

    Units: 1/year

71. MOH Healthcare budget=

    "Proportion of MOH Allocation as % of THE"*Total Health Expenditure

    Units: Unit

72. Morbidity and disease prevalence rate=0.563

    Units: 1

73. New potential doctors adopt STH=Doctor utilization rate*

    Mobile Broadband penetration*Smartphone penetration among doctors

    *Messenger apps for communication/Time

    Units: Unit/year

74. New potential patients adopt STH=Mobile Broadband penetration*

Mobile Health Apps availability*Morbidity and disease prevalence rate

*Smartphone penetration among patients*Messenger apps for communication/Time

Units: Unit/year

75. Number of Available Bed= INTEG (Bed accumulated,37793)

    Units: Unit

76. Number of doctors= INTEG (Recruit-Layoff-Retirement,19429)

    Units: Unit

77. Number of patients in hospital=Outpatient+Inpatients

    Units: Unit

78. OOP=Expected demand to private hospital

    Unit: Unit/year

79. Outpatient= INTEG (Patient arrival-"Treated walk-out"-

    Admission to hospital-Untreated layoff,1.76535e+07)

    Units: Unit

80. Patient arrival=Expected healthcare services demand*Proportion of medical need

    Units: Unit/year

81. Patient dissatisfaction=Patient waiting lists

    Units: Unit/year

82. Patient self treatment=Mobile Health Apps availability*

    Percentage of installed Health apps in smartphone*

    Patients adoption fraction*Frequency of mobile health apps use

    Units: Dmnl

83. Patient waiting for admission=Average turnover time to vacant bed*

84. Outpatient*Proportion of hospital admission*Vacancy rate

    Units: Unit/year

85. Patient waiting lists=Outpatient*Average waiting time in the outpatient department

Units: Unit/year

86. Patients adopt STH= INTEG (Patients adoption rate,1000)

Units: Unit

87. Patients adoption fraction=0.438

Units: Dmnl

88. Patients adoption rate=Adoption from Interactions among patients+ Potential patients contacts with doctor

Units: Unit/year

89. Patients contact rate=53

Units: 1/year

90. Percent market untapped=Potential Patients adopt STH/Total Market Size

Units: 1

91. Percentage of installed Health apps in smartphone=0.92

Units: Dmnl

92. Percentage of subsidy to visiting costs=0.95

Units: 1

93. Percentage to curative care=0.9291

Units: year

94. "Percentage to non-curative care"=0.0709

Units: 1

95. Potential Doctors adopt STH= INTEG (New potential doctors adopt STH-Doctors adoption rate,20000)

Units: Unit

96. Potential Patients adopt STH= INTEG (New potential patients adopt STH-

Patients adoption rate,1e+06)

Units: Unit

97. Potential patients contacts with doctor=Percent market untapped*

Total Contacts

Units: Unit/year

98. Prevalence doctors adopts STH=Doctors adopt STH/Total Population

Units: 1

99. Prevalence of patient adopts STH=Patients adopt STH/Total Population

Units: 1

100. Proportion of hospital admission=0.028

Units: 1/yea r

101. Proportion of layoff=0.005

Units: 1/year

102. Proportion of medical need=Morbidity and disease prevalence rate*

Total Population

Units: Unit

103. "Proportion of MOH Allocation as % of THE"=0.511

Units: 1

104. "Proportion of MOH expenditure as a % THE"=0.493

Units: 1

105. Recruit=Doctor adjustment time*Discrepancy of desired and available doctors

*Budget proportion to increase capacity

Units: Unit/year

106. Retirement=Number of doctors /Doctor retirement period

Units: Unit/year

107. Revenue receive to hospital=Basic medical charges to patients*

Revenue share of operational expenditure

Units: Dmnl

108. Revenue share of operational expenditure=0.024

Units: Dmnl

109. STH usage in healthcare=Prevalence doctors adopts STH*

Prevalence of patient adopts STH

Units: 1

110. Smartphone penetration among doctors= Smartphone users/Number of doctors

Units: 1

111. Smartphone penetration among patients= Smartphone users/

Number of patients in hospital

Units: 1

112. Smartphone users=4.0024e+06

Units: Unit

113. Specialist cost=5

Units: Dmnl

114. Target by WHO=0.05

Units: 1

115. Time spent by admitted patients= (Waiting for admission+

ALOS in inpatient*365) * Minimum wages per hour

Units: 1

116. Time spent by patients for seeking care in outpatient=

(Hours in outpatient treatment*365) * Minimum wages per hour

Units: 1

117. Total Contacts=Doctors adopt STH*Doctors contact rate

Units: Unit/year

118. Total GDP= INTEG (GDP change,8.21434e+11)

Units: Unit

119. Total Health Expenditure= INTEG (Increase in health expenditure,3.2962e+10)

Units: Unit

120. Total Hospital Productivity=(Number of patients in hospital/

(Number of Available Bed+Number of doctors))*Effectiness of health consultation

Units: 1

121. Total Market Size=Number of patients in hospital

Units: Unit

122. Total Population= INTEG (Births-Deaths, 2.85886e+07)

Units: Unit

123. Treated Patients=Discharge from hospital*Discharge rate*Healthcare Efficiency

Units: Unit/year

124. "Treated walk-out"="Walk-out rate"*Outpatient

Units: Unit/year

125. Untreated layoff=Patient dissatisfaction

Units: Unit/year

126. Vacancy rate=100-Bed capacity utilization

Units: Dmnl

127. Waiting for admission=0.0059

Units: Dmnl

128. "Walk-out rate"=0.405

Units: 1/year

129. Workload=Doctor utilization rate*Hours working

Units: 1

Appendix C: Model Output and Historical Data

Total Population		
Year	**Model**	**Data**
2010	28588600	28588600
2011	29049600	29062000
2012	29518000	29510000
2013	29994000	29912300
2014	30477600	30598000
2015	30969000	30995700
2016	31468400	31633500

Inpatients			Outpatient		
Year	**Model**	**Data**	**Year**	**Model**	**Data**
2010	2130560	2130560	2010	17653500	17653500
2011	2209320	2188600	2011	18484500	18446300
2012	2288160	2307000	2012	19146200	19139600
2013	2366010	2338000	2013	19697900	19621300
2014	2442300	2465160	2014	20178800	20275600
2015	2516730	2526210	2015	20614500	20572400
2016	2589180	2571880	2016	21022300	21048200

Number of Available Bed			Number of doctors		
Year	**Model**	**Data**	**Year**	**Model**	**Data**
2010	37793	37793	2010	19429	19429.00
2011	38436	38394	2011	22880	22437.00
2012	39077	38978	2012	26007	24277.00
2013	39713	39728	2013	28840	28949.00
2014	40345	40260	2014	31407	33275.00
2015	40971	40960	2015	33734	33545.00
2016	41590	41840	2016	35843	36403.00

Total GDP			Total Health Expenditure		
Year	**Model**	**Data**	**Year**	**Model**	**Data**
2010	821434000000	821434000000	2010	32962000000	32962000000
2011	880927000000	911733000000	2011	35905000000	35965000000
2012	944730000000	971252000000	2012	39044900000	39586000000
2013	1013150000000	1018610000000	2013	42416000000	41671000000
2014	1086530000000	1106440000000	2014	46044900000	46756000000
2015	1165230000000	1157720000000	2015	49953000000	49838000000
2016	1249620000000	1230120000000	2016	54158900000	51742000000

Appendix D: Questions about research findings

1.	What do you think about the addressed issues in this research to the real situation in Malaysia? Do my results collateral with the current public health management problems?
2.	Do you think the smartphone will be a helpful tool to be used in health care services?
3.	Do you have any comments about the constructed model, may be should I include several variables?
4.	Will our government, hospital staffs, doctors or patients adopt this kind of technology?
5.	Besides my findings, do you have any suggestions for further improvement ? in terms of issues to be included, important variables, either implementation of national insurance, instead of technology adoption or both?