Smartphone-based Healthcare Technology Adoption in Malaysian Public Healthcare Services

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Abstract

The present study attempts to examine the impact of smartphone-based healthcare technology (SHT) adoption in public healthcare services. System dynamics is used to understand the substantial impact of SHT adoption among patients and doctors would improve the discharge rate and patient’s medical costs. The results show that the changes in the proportion of SHT adoption among patients seem to be significant to the perceived medical expenses and the patient discharge rate from public hospitals. This is due to the fact that the increase in the proportion of patient using SHT would reduce the proportion of basic medical expenses incurred by patients and increase inpatient discharge rate as well. On the other hand, the proportion of both medical doctors and patients adoption of SHT for medical consultation is found to be vital to improve the number of patients being discharged from hospital wards. This impact is implicitly shown from the model through the effectiveness of health consultation using common available social networking apps. In conclusion, the findings of this work are hoped to provide an apprehension to the hospital management’s decision makers and doctors that smartphone devices are considered vital to improve healthcare delivery in Malaysian government hospital and to reduce the burden of medical costs.

Key words: Smartphone, adoption, Malaysian healthcare, technology, system dynamics

1. Introduction

A steadily increasing healthcare expenditures, an aging population and many other health challenges in many countries around the world have probed the attention of the government, researchers and policy decision makers. These pressing issues have called for the implementation of health-based information and communication technologies (ICT) to address the burden of the national budget and the unsolved problems of the high health care costs as well as the inefficient quality of healthcare services. According to Marschollek et al. [1], the ICT usage in healthcare would benefit patients by providing a more cost-effective healthcare via online consultation with their physicians from home. Medical care inputs such as doctors, nurses, beds, medical equipment and technology are the other indispensable determinants of one’s health [2]. Over the past couple of years, there has been a surge of mobile devices such as tablets, smart phones and other wearable devices on the market to ease people’s lives. Surprisingly, today’s healthcare providers are also utilising mobiles as it allows healthcare practitioners to execute multiple recurring tasks.

Mobile health devices have apparently become an increasing trend as a recent survey recorded an escalation of smartphone ownership. Meaning that a large number of mobile users presumably utilise online communication and social network tools such as email, Skype and Facebook to consult with experienced health consultants for preventive care, and sick patients seek to engage with their physicians and nurses regarding their health condition [3]. Mobile devices help patients and healthcare providers to access resources and information from anywhere and at any time of the day. However, this usage is still a niche in the healthcare industry, particularly in Malaysia. Accordingly, this study attempts to examine the impact of smartphone-based healthcare technology (SHT) adoption in public healthcare services. The aim of the study attempts to answer the following research question: How does smartphone adoption among patient and doctor would improve healthcare service delivery and medical cost incurred by patients?

The remainder of the paper is organised as follows. In the next section, the literature review is presented. Then, section 3 describes a brief description of the system dynamics and qualitative analysis through the model conceptualization to visualize how interrelated the elements of each sub-sectors affect each other. Section 4 discusses the quantitative analysis of smartphone-based healthcare technology adoption model. Section 5 shows the results of model testing. Section 6 shows the results of scenario analysis and the discussion of the results. Conclusion is summarised in section 7 which includes the limitation of the current study.

2. Review of Literatures

Research on the interaction between technology devices and healthcare has received a great attention and interest
around the world. Studies from Malaysia are also not left behind. Many researchers attempted to identify the factors influencing the adoption, acceptance and usage of this technology on health and healthcare which is done by Zahra e et al. [4]. Haenssgen and Ariana [5], for example, examined the relationship between mobile phone and healthcare access behaviour among rural elder people in low-middle income countries without specifically considering the phone-based healthcare intervention. However, the mobile use in healthcare implications is complex and time-consuming. Yet, they emphasised that the study of healthcare resulting from mobile phone usage among patients remains limited and suggested that a causal link underlying the relationship needs to be established in future studies. Varabyova et al. [6] asserted that the analysis of medical technology adoption determinants often requires laborious data collection surveys and case studies, as these data are usually not readily available. The failure to account for the interactions between the innovation and the characteristics of the adopter and the environments has been cited as one of the main limitations of the literature on determinants. The interaction occurs in a complex and non-generalizable manner and it is difficult to be translated into statistical models or in quantitative terms. Therefore, they suggested that more detailed qualitative studies are needed to include the complexity of the surrounding settings into the analysis of the determinants.

In probing the questions raised in section 1, system dynamics modelling is adopted for this study. The method is useful and provides a better comprehension of the complicated healthcare problems [7]. Many researchers from Western countries applied system dynamics methodology in the healthcare management field. For instance, in the analysis of the bed blockage problem due to a delayed discharge in the Irish healthcare system by Rashwan et al. [8]. They also designed the dynamic flow of elderly patients. In Malaysia, Ahmad et al. [9] simulated the effect of patient volume on the emergency department in government hospitals by using a combination method of system dynamics and discrete event simulation. According to Sharif and Ramanathan [10], system dynamics should be used to ease the mathematical and computational complexity in designing a diffusion model. Several prior works of diffusion and adoption models in healthcare technology such as telehealth, Early Health Technology Assessment (eHTA), and electronic health records (EHR) have utilized a system dynamics methodology [11-16].

In regard to the literature gaps, the present paper seeks to employ the system dynamics methodology to elucidate the complexities brought about by multiple interrelated elements of healthcare demand, supply, medical costs and technology sub-models into one diagram.

### 3. Methodology

#### 3.1 System Dynamics Modeling

Initially, the method was applied in the field of Industrial Dynamics published by the prominent founder of this methodology named Jay Forrester in the late of 1950’s. Presently, the method has been applied widely in the field of public health. In the light of the complexity of healthcare problems, a system dynamics simulation modelling is a computer-aided application that uses a method to encapsulate the feedback relationships between variables in the healthcare system. In general, the system dynamics have both distinct characteristics: qualitative and quantitative. The qualitative side depends on the construction of the causal loop diagram as a simple map to define the dynamic relationship between various factors. It allows these adjustments to be implemented by fine-tuning the parameters.

Figure 1 below presents the basic representation of stock and flow diagram in a Vensim software consisting of five graphical icons such as stock, flow, valve, cloud and arrow connectors. In this diagram, the stock is graphically represented by rectangular-shaped icons or boxes which accumulate or deplete over time. It is controlled by a flow. Both inflows and outflows are represented by arrows with a double trace cut by a triangle which are the icons resembling pipe and faucet assemblies that fill or drain the quantitative value of the state (stock) over a period of time. Flows are mechanisms that will increase and decrease the value of the stock. The cloud at the tail of one of the arrows represents the sources and sinks. The single line arrows indicate the information link or the connector between variables in the system.

![Figure 1 Basic structure of stock and flow model](image)

Mathematically, a state of stock (S) in the system dynamic models can be expressed as an integration of the difference between inflow and outflow over a specified interval of time. The transition is driven from the equation below:

\[
\text{Stock} (T) = \int_{t_0}^{T} (\text{Inflow} - \text{Outflow}) \, dt + \text{Stock} (t_0)
\]  

(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 discrete time (t), which is its net rate of change as expressed in equation (2):

\[
\text{Net Flow} = \text{inflow} - \text{outflow} \text{ or } \frac{\text{d}S}{\text{d}t}
\]  

(2)
3.2 Model Conceptualization
Proliferating a large portion of the GDP as allotted by the Malaysian government to healthcare over the years has triggered a positive feedback from the public to highly subsidized government hospital [19]. Increasing the patient’s visiting hour over limited resources and capacity have received the attention from healthcare stakeholders to seek for an implementation of technology devices usage in healthcare delivery. This study applied the implication of the adoption of smartphone device among doctors and patients at public healthcare services in Malaysia. Figure 2 depicts a generic conceptual model of the interrelationships between elements in the system. The model analysis of the Smartphone-based Healthcare Technology (SHT) adoption among doctors and patients consists of four sub-models. As indicated by the arrows, the sector of the model is connected to one another on the multiple levels. The qualitative aspect in figure 2 cannot be determined solely by analyzing the generic structure. Specific and detailed variables need to be quantified and a quantitative modelling known as stock and flow diagram is further carried out and explained in the next section.

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1 Smartphone-based Healthcare Technology (SHT) is a term used to define the utilisation of smartphone for medical and healthcare treatment purposes

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

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4 Model Formulation

For the quantitative aspect of this methodology, the built conceptual model (figure 2) has been converted into the stock and flow diagram where the variables in the system are calculated. The system dynamics software allows a variety of techniques to be produced, ranging from mathematical relationships to graphical functions. The model considers a simulation of time horizon from 2010 to 2030 since smartphones started to launch around the year of 2010. The year 2010 is employed as a base year in the whole model. A quantitative analysis of the stock and flow diagram was constructed and presented using the Vensim Personal Learning Edition (PLE) software.

4.1 Patient-flow submodel

It is constructive to develop a core model of healthcare demand in this study which has been amended from the authors’ prior work [19]. Basically, the patient-flow into the hospital represents the healthcare demand of a country. In this work, we focus on the patients’ visit to a government hospital run by the Ministry of Health (MOH). An aging chain demand model comprises two stocks, namely outpatient and inpatients stock that simulates the flow of patients through the visiting rate and admission to inpatients care.

In this study, we merely assume that patients enter government hospital by attending a general practitioner (GP) at outpatient department (OPD). Based on the GP instructions, outpatients may thereupon receive a diagnosis and prescription of drugs or they would be consulted to be admitted into the hospital as “inpatients” for some special cases. The number of inpatients flows into wards is determined by the admission rate. This inpatient stock is reduced by the proportion of death at the public hospital, patients who get out from the hospital after receiving a treatment (discharge) and untreated patients who do not receive medical care. In order to improve public healthcare resources, this current work attempts to seek the impact of smartphone usage among major healthcare stakeholders: patients and doctors in healthcare delivery. From figure 3, variables (self-management and effectiveness of health consultation) were connected to the discharge. Hypothetically, these variables would improve the excess healthcare demand in government through improvement in discharge rate.

4.2 Basic Medical Costs submodel

Figure 4 shows the model structure of expected basic medical cost incurred by a patient who attends public hospital in Malaysia. The elements in this submodel can be calculated as follows:

\[ MC(T) = \int_{t_0}^{T} C(t) \, dt + MC(t_0) \]  

MC is the total cost incurred by patients. Present medical cost is increased by its initial state and inflow (C). C is increasing in cost. \( C \) is the accumulated average costs from outpatient (OPD) and inpatient department (IPD) of a patient incurred.

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3 Smartphone-based Healthcare Technology Model has been revised from authors’ original model for the conference paper presented at International Conference of Business & Information, Aichi, Japan, October 2017.
Incurred cost at OPD is obtained from the first-time visit charge to outpatient department and cost of follow-up by referral from government medical officer. Meanwhile, the costs of hospital admission is determined by the admission fee and the daily medical charges for the following days of staying in the hospital. Basically, the basic charges of outpatient visits in all Malaysian government hospital are very low and affordable to the patient as it is charged at MYR1 (about 0.26USD) without the classification on the income level. While, the cost will be a little bit higher when the patients need to visit a specialist for some cases and pay MYR5 for any types of follow-up visit that are classified into three types: referral from government medical officer, a referral from a private sector and follow-up cases after discharge from hospital ward [25]. Following the equation (4) expressing the medical cost incurred by patients who adopt the SHT (MC\textsubscript{SHT}) to benefit themselves. \textit{A} \textsubscript{P} represents the patients’ adoption of SHT.

\[
MC_{SHT} = \frac{MC\textsubscript{SHT}}{A\textsubscript{P}}
\] (4)

4.3 Smartphone-based Healthcare Adoption

This study attempts to reproduce a classical Bass Diffusion Model [17] which was implemented in Susceptible Infectious disease model [18] and other related studies of technology adoption model that uses the System Dynamics approach [11-15]. Generic adoption model assumes that there are two types of new product consumers: Current and potential consumers that interact with each other in the market during the adoption process. Figure 5 and 6 show the processes that bring about the adoption among non-adopters of SHT (PA) and those who adopt SHT (A) for both doctors and patients. The adoption model in this study assumes once the initial adopters are converted to the technology, these adopters influence the other potential adopters through the word of mouth interactions and the social pressures to adopt the technology as well. Mathematically, the underlying elements of the healthcare adoption model can be expressed as follows:

\[
PA\textsubscript{P}(T) = \int_{t_0}^{T}(IPA\textsubscript{P} - AR\textsubscript{P})dt + PA\textsubscript{P}(t_0)
\] (5)

Where \textit{PA}\textsubscript{P} is the potential patient adoption of SHT, IPA\textsubscript{P} is the increase in potential adopter, described as patients potentially adopting SHT, and \textit{AR}\textsubscript{P} is patient adoption rate. Meaning that the state of potential adopter among patients is increased and decreased by new potential adopter and patient adoption rate. In this study, we assume patients potential adoption of SHT 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.

In our model, the adoption rate for both doctors and patients indicate the number of doctors or patients adopting the SHT products per time unit, which is per year for the case of 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). \textit{AR} is increased by patient adoption rate (\textit{AR}\textsubscript{P}). The adoption rate expression indicated by the equation (9) defines that the adoption rate consists of two sources namely adoption from the interaction among patients (WOM\textsubscript{P}) and adoption based on doctor recommendation to use SHT for medical consultation (DR). The equation for 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:

\[
A\textsubscript{P}(T) = \int_{t_0}^{T}(AR\textsubscript{P})dt + A\textsubscript{P}(t_0)
\] (6)

\[
\frac{d(PA\textsubscript{P})}{dt} = -AR\textsubscript{P}
\] (7)

\[
\frac{d(A\textsubscript{P})}{dt} = AR\textsubscript{P}
\] (8)

\[
AR\textsubscript{P} = WOM\textsubscript{P} + DR
\] (9)

\[
WOM\textsubscript{P} = CR\textsubscript{P} \times A\textsubscript{P} \times AF\textsubscript{P} \times \left(\frac{PA\textsubscript{P}}{N\textsubscript{P}}\right)
\] (10)

\textit{CR}\textsubscript{P} is patient contact rate, \textit{AF}\textsubscript{P} is patient adoption fraction and \textit{N}\textsubscript{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 like Facebook, Twitter and WhatsApp to discuss patient’s health improvement. They also connect with their peers in the effort of sharing and exchanging knowledge related to self-management. The equations (7) and (8) are differential equations defining how the stock values of potential adopters and adopters change over time.
5 Model Testing

The model testing is conducted to uncover the model’s defect and to increase the model confidence in terms of its structure and behaviour. In the simulation process, we train our model to calibrate the real-world behaviour. In order to reproduce the model with historical behaviour, we employ the limited availability of recorded time-series data. Therefore, our entire model run from 2010 as the number of smartphone users started to be widely available in 2010 particularly in Malaysia [21]. Figure 7 depicts the trend behavior of simulation and historical data for the number of patients. Intuitively, we can say that the structure of behavior of the simulation model almost fits the real data. The value of R-squared: 99% is greatly high which also means an absolute percentage error (MAPE): 0.34% is considerably small allowing us to affirm the reliability of the model.
6 Results

Once the model has been validated, the model parameters have been changed and the model is re-run for different future scenarios. The effects of possible interventions on the parameter of adoption fraction among doctors and patients were explored. The entire findings of the impact of an intervention demonstrated a simulation behaviour over the course of 21 years from 2010 to 2030.

6.1 Baseline Behaviour

In the system dynamics methodology, the behavioural pattern produced in the model is a crucial consideration instead of the data of variables because some variables in 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. Figure 8 demonstrates the curve of the SHT adopters among patient which is produced by the S-shaped behaviour over 21 time-span. This is a consequence of the interaction between the two feedback loops namely reinforcing and balancing loops as clarified in the system dynamics.

![Figure 8 Behavior of SHT adoption among patients over time](image)

In the beginning, the reinforcing of word-of-mouth among patients causes the exponential growth while the number of patients as the size of the market is still large. Ultimately, as the market approaches to a limit growth or market saturation, the balancing loops begin to dominate. This negative feedback loop brings the system to a state of equilibrium. This stagnation is assumed as every patient (or doctor) who might ever want smartphones to have an access to health-benefit has actually bought one and adopt it, then causing the SHT product adoption rate to reach zero. In this model, we assume that as the potential patients (or doctors) adopt the products, they stop being the potential patients (or doctors) and this variable also becomes zero. The adoption rate is the derivative of the SHT adopters which generates a bell-shaped curve. Similar to many cases, this is true in explaining most of the dynamic behaviour of technology adoption. From the figures, the simulated model has been validated and produced similar behaviour with the basic Bass adoption model [17] and revised new product diffusion model by Sterman [18]. Most adoption or diffusion process follows an S-shaped curve of percent adoption over time [11-15].

6.2 Differentiating of Basic Medical costs per patient

![Figure 9 Behaviour of medical costs per patient based on different levels of hospital wards](image)

In the beginning, the reinforcing of word-of-mouth among patients causes the exponential growth while the number of patients as the size of the market is still large. Ultimately, as the market approaches to a limit growth or market saturation, the balancing loops begin to dominate. This negative feedback loop brings the system to a state of equilibrium. This stagnation is assumed as every patient (or doctor) who might ever want smartphones to have an access to health-benefit has actually bought one and adopt it, then causing the SHT product adoption rate to reach zero. In this model, we assume that as the potential patients (or doctors) adopt the products, they stop being the potential patients (or doctors) and this variable also becomes zero. The adoption rate is the derivative of the SHT adopters which generates a bell-shaped curve. Similar to many cases, this is true in explaining most of the dynamic behaviour of technology adoption. From the figures, the simulated model has been validated and produced similar behaviour with the basic Bass adoption model [17] and revised new product diffusion model by Sterman [18]. Most adoption or diffusion process follows an S-shaped curve of percent adoption over time [11-15].

6.3 Intervention on patient adoption fraction

This work attempts to identify whether a technology device would reduce the medical cost per patient. Figure 10 demonstrates the intervention of the changes in adoption fraction of the patient to the proportion of
medical cost as the percentage of SHT adoption among patient.

6.4 Scenario analysis of doctor adoption fraction and contact rate

Figure 12 Scenario analysis of doctor adopt SHT

Figure 12 illustrates the different behavior of doctor adoption of SHT through the changes in their adoption fraction and contact rate. From the figure, we can observe that the changes in the doctor contact rate give out a substantial impact rather than an adoption fraction. An increase in the contact rate has also increased doctor adoption of SHT. Doctor contact rate refers to the frequency of the doctors coming into contact with somebody at a certain rate. In this model, we assume a doctor contacts 40 people per time unit. Through this meeting, an adopter doctor would influence a non-adopter doctor in the healthcare community to adopt this SHT product. In a business environment, word-of-mouth plays a crucial role in minimizing risk and uncertainty to buy a certain product.

6.5 Scenario analysis adoption fraction among doctors and patients

A high number of patients being admitted to the hospital does not only merely create challenges to medical doctors and other clinical staffs, but it would cause a strain to other stakeholders in hospital management department. Figure 13 shows the scenario behaviour of the effectiveness of health consultation through the interventions on the proportion of SHT adoption among doctors and patients by 10%. Both parties attempt to adopt SHT for online consultation using the commonly used social network in Malaysia. Improving the quality of health consultation would increase the proportion of discharge rate as shown in figure 14, which in turn improves hospital capacity such as the availability of beds for needy acute patients. A doctor can prescribe the treatment and monitor their patient’s vitality from his or her office while the patients remain at home.
In conclusion, the findings of this work are hoped to provide an apprehension to the hospital management’s decision makers and health practitioners that smartphone devices are considered significant to improve healthcare delivery in Malaysian government hospital and to reduce the burden of medical costs per patient who cannot afford it. This study strongly suggests the need for an 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 previous studies aforementioned in the beginning of section 1. Marschollek et al. [1] assert that information technology is a more cost-effective healthcare 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 [11]. Significantly, the constructed SHTAM to help future researchers and healthcare management understand the system complexities of smartphone usage in healthcare. Through the application of system dynamics technique, we can observe how utilisation of digital devices optimise the current state of our healthcare delivery in a whole system, rather than the mere individual aspects.

### 7 Conclusion

As the world becomes interconnected with each other, these technology devices become one of the essential aspects of both our lives and economy. Besides that, it 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 healthcare workers as well due to the ever rising patients’ admission to the hospital every year. In response to this situation, The present study attempts to examine the impact of smartphone-based healthcare technology (SHT) adoption in public healthcare services. System dynamics application to understand the substantial impact of SHT adoption among patients and doctors would improve the discharge rate and patient’s medical costs. Based on the scenario results, the changes in the proportion of SHT adoption among patients seem to be significant to the perceived medical expenses and the patient discharge rate from public hospitals. This is due to the fact that the increase in the proportion of patient using SHT would reduce the proportion of basic medical expenses incurred by patients and vice versa. Additionally, an increase in the patient adoption fraction would develop as a self-treatment mechanism using mobile health apps among patient. Accordingly, improving hospital utilisation affect the patients discharged from hospital as they are able to monitor their vitality on their own. On the otherhand, the proportion of both medical doctors and patients adoption of SHT for medical consultation is found to be vital to improve the number of patients being discharged from hospital wards, as the doctor-patient communication increase. This impact is implicitly shown from the model through the effectiveness of health consultation using common available social networking apps.

In conclusion, the findings of this work are hoped to provide an apprehension to the hospital management’s decision makers and health practitioners that smartphone devices are considered significant to improve healthcare delivery in Malaysian government hospital and to reduce the burden of medical costs per patient who cannot afford it. This study strongly suggests the need for an 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 previous studies aforementioned in the beginning of section 1. Marschollek et al. [1] assert that information technology is a more cost-effective healthcare 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 [11]. Significantly, the constructed SHTAM to help future researchers and healthcare management understand the system complexities of smartphone usage in healthcare. Through the application of system dynamics technique, we can observe how utilisation of digital devices optimise the current state of our healthcare delivery in a whole system, rather than the mere individual aspects.

#### 7.1 Limitation

There are several limitations in the present paper that could be considered in future studies. (1) This simulation merely involved patients who attend public hospital which are among those of low and average income level. The awareness to use technology device for seeking healthcare probably is still low among these patients. (2) The paper focused on smartphone devices, different type of technologies might produce different results. Therefore, the model is not applicable to all types of technology-based healthcare. The specific factor that influences Malaysian doctor and patients to use a smartphone or any technology devices should be taken into account for adoption and diffusion studies. (3) Age-specific groups should be considered as the country has an aging population and older people less likely to adopt or put their trust on new technology, and the difficulty faced while using this device might discourage them of further use.

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