UNDERSTANDING THE ROLE OF FAMILY DOCTORS USING SYSTEM DYNAMICS MODELING

by

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This is to certify that I have examined this copy of a master's thesis by

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To my family

ABSTRACT

In this study, a two-tier health service system is modeled using system dynamics methodology with the objective of understanding the impact of operational factors on people's choice of first contact to get medical care. This two-tier health service system is motivated by the transformation of the primary care system to family practice in Turkey. Interviews are conducted with health officers in Düzce to develop a model for patient and doctor flows. The general practitioner is the primary health care provider, whereas state and private hospitals are secondary health care providers in the two-tier health service system. The main principle behind family practice in primary care is to provide a family doctor for every individual in order to improve preventative and curative care and to alleviate hospital workloads. However, current system allows patients to choose hospitals as a first contact for even the simplest conditions. As a barrier for this, a regulation which imposed general practitioners as gate-keepers in the system was implemented, but it remained effective for only seven months. In this study, we explore the dynamics of patient flows in the system using system dynamics modeling. One objective is to understand the reasons for failure of this gatekeeping policy. Operational factors are determined as service quality, trust and waiting time; which are studied in different scenarios to understand dominant factors in the system. Further, we explore implications of changing certain policy parameters on the system performance measures such as daily demand and waiting times for general practitioners and hospitals.

ÖZET

Bu çalışmada, insanların tedavi olabilmek amacıyla gittikleri ilk sağlık merkezini hangi dinamik faktörlerden etkilenerek seçtiklerini anlayabilmek için sistem dinamiği metodu kullanarak iki-kademeli bir sağlık servis sistemi modelledik. Bu iki kademeli sağlık sistemi, Türkiye'deki birinci basamak sağlık hizmetine aile hekimliğinin getirilmesi sonucunda oluşturuldu. Modeldeki hasta ve doktor akışlarının oluşturulabilmesi için de Düzce'de çalışan sağlık memurlarıyla karşılıklı görüşmeler yapıldı. Böylece aile hekimleri iki kademeli sağlık sisteminin birinci basamağını, devlet ve özel hastaneler de ikinci basamağını oluşturdu. Birinci basamağa aile hekimliğinin getirilmesindeki asıl amaç, sistemdeki herkesin bir aile hekimi tarafından tedavi edilerek koruyucu ve tedavi edici sağlık hizmetlerinin geliştirilmesi ve aynı zamanda hastanelerin yükünün hafifletilmesidir. Fakat şimdiki sistem hastaların en basit rahatsızlıklarında bile hastaneyi seçmesine izin vermektedir. Bunu engellemek için aile hekimlerden sevk alma zorunluluğu getirilmiş olup bu düzenleme de sadece yedi ay boyunca etkili olabilmiştir. Biz bu çalışmada, sistemdeki hasta akışlarının dinamiklerini sistem dinamiği modellemesi kullanarak araştırdık. Öncellikle, zorunlu hale getirilen sevk zincirinin başarısız olma nedenlerini anlamaya çalıştık. Sistemdeki dinamik etkileri servis kalitesi, güven ve bekleme süresi olarak belirleyerek, farklı senaryolar altında hangi etkinin daha baskın olduğunu anlamaya çalıştık. Bunlara ek olarak da, sistemdeki parametreleri değiştirerek, bunların günlük başvuru oranları, aile hekimliği ile hastanedeki bekleme süreleri gibi sistem performanslarına olan etkilerini araştırdık.

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Chapter 1

INTRODUCTION

The health system in Turkey faces many challenges and performs inferior to countries with similar income levels based on infant and adult mortality measures [1]. Primary care services provide the first point of contact for people with healthcare needs. Primary care is the most important lever to improve the health of the population in an efficient way, by emphasizing disease prevention and health promotion. Therefore, recent efforts to improve the health system in Turkey have focused on the primary care system. This thesis focuses on the transformation of primary health care system in Turkey. Our broad objective is to understand operational factors that may have an effect on the performance of the system.

In 2004, World Bank funded "Transformation in Health" project to "improve the governance, efficiency, user and provider satisfaction and long term sustainability of the healthcare system" [2]. This transformation in Turkish health system was put in action with the implementation of the family practice system. Before this transformation, health posts and health centers are the primary health care units at the village level, since the introduction of the socialization law in 1961 [3]. Health posts can serve 2500-3000 people in one village or more; however health centers can serve between 5000-10000 people in rural areas and up to 50000 people in urban areas with the purpose of providing services to whole population, especially to rural areas. In this system, basic preventative and curative services are provided by health centers and patients can be referred to upper-level health service. In addition, mother and child health, family planning centers and tuberculosis dispensaries also provide primary healthcare while hospitals provide secondary and tertiary care in the health system [1]. Hospitals can be grouped as State Hospitals, Private Hospitals and University and

Research Hospitals for secondary and tertiary care in the system.

After transition to family practice, primary care has two main providers which are family doctors (general practitioners) and public health centers [2]. General practitioners are responsible for individual care of 3000 or 4000 patients and they can refer patients to secondary and tertiary care if there is a necessity for detailed medical treatment at hospital. Public health centers are only responsible for the public health duties. Hospitals still provide health services as secondary and tertiary care after transformation. Thus, it is planned to have better health status by providing a general practitioner for every individuals in the system. Additionally, preventative and curative healthcare can be convenient for every individual and also the system will be rendered more efficient by decreasing the workloads of hospitals.

Düzce has been selected as pilot city for this project and the project started on 15$^{\text{th}}$ September 2005 [4]. Düzce is the 45th of 81 cities in Turkey when cities are ranked according to their socioeconomic development. It is located in the earthquake zone which experienced earthquake disasters seriously affecting the region in 1999. Application of using general practitioners in the health system has taken the role of in social therapy of the city since 2005 for the damages emerging after 1999 eartquake disasters. However, it has been observed from on implementation of this transformation to Düzce that there are significant deficiencies in the model. These deficiencies are defined and reported by The Turkish Medical Association [5] and Practitioner Association [6]. First of all, based on their reports, this model brings a division among the practitioners since practitioners working in the Public Health Centers are not satisfied with their job. They feel like being punished because of their lower salaries than that of family doctors and also they are acting like being as candidates when there is a problem with family doctors. At the same time, specialists are against the family doctors' (general practitioners) salaries since they earn more than specialist.

Secondly, individuals are not aware of the significance of family doctors since they are not registering and contacting with their family doctors in Düzce. They just feel that, in pre-transformation period, they could take the service by each practitioner in health services, while in transformation period, with this new model, health service can be provided to each patient by a fix family doctor. Individuals have the opportunity to change their doctors but the time to change is 6 months later. Yet, this implementation prevents general practitioners to follow their patients' health status since they cannot conduct their mobile services due to the long distances.

Finally, these reports ([5], [6]) state that hospital workloads are still high after transformation. This is most probably due to behaviour of individuals, i.e. patients and doctors. Savas et al. [1] indicate that due to the inadequacy of health centers and health posts, people are forced to go the hospitals as the first contact in urban and rural areas before transformation. Also, there is not any referral system in Turkey which encourages patients to choose health centers as the first contact. There should be two main elements in an effective referral system. One of them is a single primary care doctor who takes the responsibility of a particular patient for the treatment. The other is hospitals which do not accept the self-referred patients except for emergency situations. Because of absence of these elements in pre-transformation period, referral systems failed in Turkish health system before transformation. Although family doctors are introduced to the health system, The Turkish Medical Association [5] and Practitioner Association [6] state that this historical behaviour of individuals have not been changed and still they would prefer to get services from hospitals for even the simplest conditions. Government brings a regulation for the referral system and patients which is forcing to go to general practitioners before secondary care in the model. However, it is seen that general practitioners have increased their referral fractions at the same time with demand increases and workloads at hospitals have not been changed because of this high fraction. Also, general practitioners need to get feedbacks from hospitals about their individuals after their referrals. However, the system cannot allow this implementation because of lack of communication between primary and secondary health care. As a result, referral system was implemented only for seven months between June 2006 and January 2007 and patient still would prefer to go to the secondary care as the first contact.

In this thesis, our aim is to model the health service system in Düzce using the system dynamics methodology in order to to understand the role of operational factors which affect patients' decision to choose their primary health care as the first contact. For this purpose, we first conducted interviews with health officers in Düzce city and decided to model patients' choice based on trust, service quality and waiting time factors. From these interviews, we also defined our mental model as "a two- tier health services". Since, we group general practitioners and hospitals as single servers in the model. We compared these services based on the number of their outpatients. Therefore, this model represents only the subsystem of the actual health system; the outpatient care system.

In next chapter, we first conduct a literature review to understand the methodology of system dynamic. Also, we review relevant papers in the literature on health service systems using this modeling method. Similar to previous studies, we work on our model with the perspective of patient flows and model the factors as multiplicative effects.

Chapter 3 describes model development in two parts as: causal loop diagrams and stock-flow maps which are based on interviews in the city. In causal loop diagrams, we build the model qualitatively with the perspective of demand side and supply side. In demand side we determine the effects of trust, service quality and waiting time factors on patients' first contact decisions and we try to understand the behaviour of model based on these factors individually. In supply side, we study doctor flows and we try to determine the factors which affect the number of necessary general practitioners based on the demand side. In stock flow map of the model, we study quantitatively and formulate the mental model to get numerical results.

Chapter 4 describes the model testing and validation of the system which includes the sensitivity analysis in addition to extreme condition tests, behavior reproduction tests and parameter assessments. The aim of this chapter is to understand the behaviour of the model by defining the flaws and boundaries. Therefore, necessary interventions can be applied to the model to overcome these problems.

In Chapter 5, we use our model first by simulating the current system in order to understand which of these operational factors dominates, and what kind of system configurations would encourage people to choose the general practitioners as the first contact. For this purpose, we derive scenarios based on capacity problems and service qualities. We also simulate policies to control the behavior under these scenarios.

Chapter 6 concludes with a summary of the results and policies by including our insights that we get from our mental model. Although it is a subsystem of reality, policy parameters in the model can be used to improve the primary care system in Turkey. Also, possible further researches based on the limitations of the model are discussed in this chapter.

Chapter 2

LITERATURE REVIEW

In this chapter, we perform a literature survey to model a two-tier health service system in Düzce to understand its behavior due to the dynamics in the real world. For this purpose, we first choose appropriate simulation method and then we study on its implementation to the real world systems.

2.1 Introduction to System Dynamics

System dynamics and discrete-event simulation are computer simulation methods to model real world dynamics. Both of them try to explain the various interrelated factors in real world. System dynamic is used to understand the internal feedback structures of the system, however discrete-event simulation focuses on external and internal variation [7]. In our study, as mentioned above, we try to explain the structural behavior and so we decide to use system dynamics methodology.

Barlas [8] states that system dynamic methodology is used to approach long-term policy problems as national economic problems, supply chains, project management, educational problems, energy systems, health care and many other areas. The purpose of the methodology is to understand dynamics of these feedback loops and to develop necessary policies to solve problems and to improve system performance.

Coyle [9] determines that these loops can be goal-seeking (negative) or growth-producing (positive). Goal-seeking loops try to achieve its goal when there is a discrepancy between the actual and desired level and they balance the system; however positive loops acts a growth generating mechanism. These positive and negative loops form the influence diagram of the system which creates the dynamic behavior of the model. In Figure 2.1, example for

Population changes can be seen as negative and positive loops. These influence diagrams are also called as qualitative system dynamics.

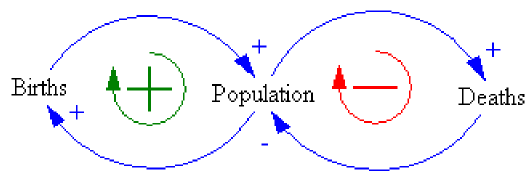


Figure 2.1: Influence Diagram of Population Model

As seen in Figure 2.1, raise in *Births* rate increases the value of *Population* and also *Population* increases the *Births* rate in the positive loop; in the negative loop, rise in *Population* increases *Deaths* rate however *Deaths* rate decreases the value of *Population*.

In quantitative system dynamics, these loops are represented with equations. These equations are modeled inside the stock-flow maps of the system. Barlas [8] states that there are two main variables in the model. These are stocks and flows. Stocks accumulate over time and represent the state of the system at time t. Rectangle is symbolic shape of stocks in literature. Also there flows in the model, which changes the value of stocks in time t. Arrow shows the way of flows in the model and valve is the symbolic shape of the flow. If flow increases the accumulation of stock then it is called inflow; however if it decreases the value of stock then it is called outflow. Vennix [10] shows the stock-flow map of Population example in Figure 2.2.

Barlas [8] shows the equation for this example as:

$$\begin{aligned} Population(t+dt) &= Population(t) + (Births - Deaths)dt \\ Births &= Population \times Birth\ rate \\ Deaths &= Population \times Death\ rate \end{aligned}$$

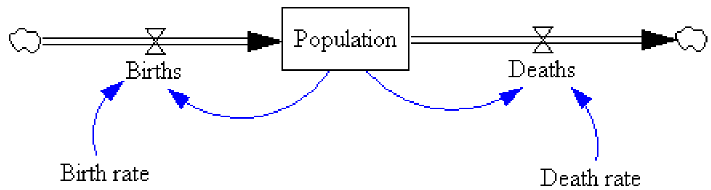


Figure 2.2: Flow Diagram of Population Model

2.2 System Dynamics Applications in Health Care System

System dynamics methodology helps to test healthcare systems without any risk. Wolstenholme [11] studied on National Health Service (NHS) in U.K. health using system dynamics where resource allocation problems were analyzed with the perspective of patient flows in his model. These resource allocations problems are defined as two problems: growing waiting lists for elective surgery and growing-rate of non-elective hospital admissions. His model includes national-level and quantitative patient flows and develops national policies from the interventions on the flows.

Wolstenholme et al. [12] also studied coping policies which causes unintended consequences. These policies have been applied when local health and social care organization have insufficient supply capacity to meet the demand. Therefore, they cause discrepancies between the observed data and works of organizations. System dynamic helps to explain these discrepancies in the system and sustainable solutions can be obtained from the model. This study shows that policies in the model has significant role on the behavior of the model output.

Van Ackere and Smith [13] also study NHS in the U.K however they just focus on the waiting list of the system. Their model differentiates from Wolstenholme's [12] model since they consider the whole system as a single server with a single queue to use the queuing theory with Poisson arrivals and exponential service times. Therefore, they group the model in the perspective of supplier side and demand side. Supplier side includes hospitals and general practitioners where general practitioners acts like gatekeeper in the model and refers patients to hospital for surgery and demand side represents the patient flows in the model. Therefore, the supply side with service capacity μ and demand side with arrival rate λ determine the system dynamic model for waiting list. Also perceived waiting time has been modeled as a stock in the demand side to associate with waiting lists. Because of the lack of quantitative data, they cannot generate a policy for the NHS waiting list but they note the important dynamics of the model.

Taylor and Dangerfield [14] also build a system dynamics model for the U.K however they build a model for cardiac catheterization. They describe a system where there is an existence of referral chains from the general practitioner (primary care) to district general hospitals (secondary care) and from there to more specialized hospital-based centers (tertiary care). This referral chain is modeled with five base referral multipliers which are waiting time, knowledge of patients (word of mouth) and skills of care providers as endogenous variables and capacity losses and other factors on referral as exogenous variables. Due to the inadequate data, they estimate the parameter by constructing functions or using estimations based on preliminary simulation runs in the model.

As mentioned above, Taylor and Dangerfield [14] conduct general practitioners as a gatekeeper in their model and this gatekeeping system should be implemented to especially new industrialized countries' health care systems. Rauner [15] supports this idea by giving Latvia example where the existence of infectious and chronically diseases and alcoholism rates are higher than Western European countries. She suggests the health level in Latvia can be defined with the method of using general practitioner as gatekeeper to record all data and be responsible for certain number of patients. Western European countries can also differ in general practitioner's role in the system as British National Health Service and the Spanish Servicio Nacional de Salud are using gatekeeping system but German and Belgium are not [16].

Different from the referral rate model of Taylor and Dangerfield [14], Mariñosa and

Jelovac [16] consider the fact that payments of general practitioner affect the referral rate when there is a gatekeeping system in the health care. Lurås [17] supports this idea by claiming that this increase in referral rate is the result of general practitioner's income due to the general practitioner's patient list. Therefore, when general practitioner's patient list is high they can earn more. This situation encourages them to treat more patients in order to be able to serve more patients and therefore general practitioners increase their referral rate.

In our study, we build system dynamic models to understand the behavior of the two-tier health service system in Düzce. We model the system under the two subsystems; as demand side and supplier side. In demand system we build the model with the perspective of patient flow and our stocks represent the health service providers. Services are built with the perspective of doctor flow under the supply side of the model. We consider general practitioners and hospitals as multi-server queue and we use well-known result of Little's Law from queueing theory. Different from Taylor and Dangerfield's model [14], we consider the waiting time effect for the attractiveness of services in the model and in addition to that, we model service quality and trust effect.

Gatekeeping is not a valid policy nowadays in Düzce. Therefore, we build the model for the two cases; when gatekeeping exists or not in the system. In our model, general practitioners' salaries affect the model at supplier side by influencing the attractiveness of general practitioner job. Referral rates of general practitioners are also influenced from these referral rates.

Our contribution to the literature is using multiplicative effects for people's choices of first contact to get medical treatment and we determine these factors as: waiting time, service quality and trust. In order to see the impact of these factors on behaviour, we model a two-tier health service system with the perspectives of patient flow as demand side and doctor flow as supply side.

Chapter 3

MODEL BUILDING

In this chapter, we introduce the model development process in two parts. Causal loop diagrams are introduced in the first part, which is followed by the stock and flow maps.

3.1 Causal Loop Diagrams

In this chapter, we will build the model qualitatively and quantitatively as mentioned in previous chapter. We will build the model from two perspectives; demand side and supply side [13]. Demand side consists of patient flows, and supply side focuses on the doctor flows in the model.

3.1.1 Demand Model

A causal loop diagram of healthcare system in Düzce case has been developed by the help of interviews with health officers in the city. Using these interviews, it is validated that general practitioners, state hospitals, private hospitals and research (university) hospitals take the role of health service centers as a first contact for the patients at treatment period in the city. For the sake of simplicity and generalization, these three kind of hospitals have been grouped under the title of "hospital" which makes the system a two-tier health service system with respect to the first contact with general practitioner and hospital. Here we focus on the demand for these two health service providers, namely the general practitioners and hospitals.

Demand side of influence diagram explains main variables and dynamics on patient flow in the system and this patient flow represents the movements of people from being healthy until treatment in the system. We assume that all people (population) in the model are healthy at the beginning and they start to become unhealthy in time. The number of unhealthy people not only increases at the same time with population growth but also reduces the number of healthy people. This behaviour causes a negative loop (balancing loop) in the system which can be seen in Figure 3.1.

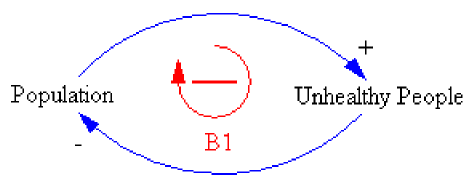


Figure 3.1: Sickness Loop

Unhealthy people generate a demand for healthcare in which behaviour of demand for healthcare will be the same with behaviour of unhealthy people in the system. This demand can be both for general practitioners or hospitals and at this point patients have to decide whether to go to general practitioner or hospitals as a first contact for their treatment. This decision can be seen in Figure 3.2.

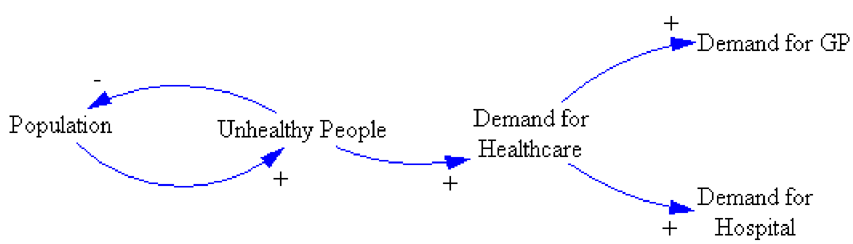


Figure 3.2: Patients Decisions

This decision has been affected by various dynamics which defines the behaviour of patients. Among these dynamics, we focus on patients' choice for the first point of contact in the health system and try to model these dynamics. From our interviews in Düzce, the dynamic factors that affect attractiveness are defined as trust effect, service quality effect, waiting time effect, gatekeeping policy effect, laboratory existence effect at general practitioner and distance effect. In the following, we discuss these effects in detail first and after that we discuss how these interact to determine the patients' choice.

3.1.1.1 Trust Effect on Attractiveness

First factor is patients' confidences to general practitioners and hospitals. In the system, when patients decide to visit general practitioners at least twice that means they have confidences from their previous treatment. This confidence increases the number of visits to general practitioner and they will decide to choose the general practitioner as a first contact. In addition, satisfied patient can influence other patients by their experience from health centers. This is similar to a "word-of-mouth effect" which defines the trust effect in our system. Same situation also exists for patients' trust to hospital. When patients prefer to go hospital instead of general practitioner, that means their previous treatment was successful or they are influenced from other patients. In both health centers, more demand causes more trust to health center in which trust increases the attractiveness for relevant health center. Higher attractiveness increases the probability of choosing relevant health center which also increases the demand for relevant health center. These loops for general practitioners and hospitals cause an exponential growth behaviour for demands and they can be seen in Figure 3.3. In the figure, R1 determines reinforcing loop (positive loop) for general practitioners and R2 determines for hospital.

3.1.1.2 Service Quality Effect on Attractiveness

Second factor is the service quality effect on attractiveness of general practitioners and hospitals. Service time has a significant role to define the quality of treatment at health center since it is the average time that doctors at hospital or general practitioners spend to diagnose a patient. If service time is higher than average service time, quality of treat-

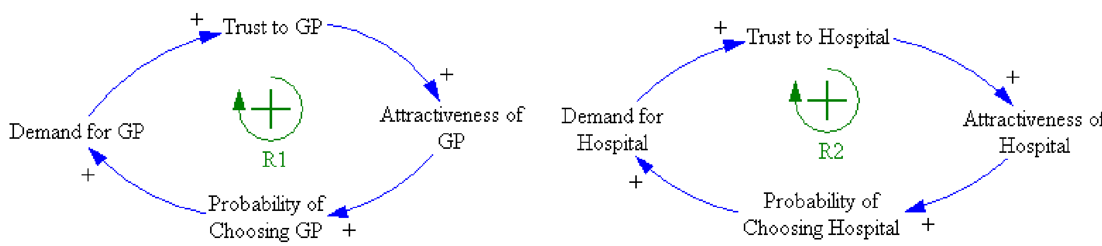


Figure 3.3: Trust Effect on Attractiveness

ment will be increased since doctor could spend more time and attention on the patient. However, if the service time is less than normal service time, probability of incorrect treatment may increase which decreases the service quality. Therefore, service time influences attractiveness positively. This service time is also influenced directly from the number of general practitioners, hospital doctors and daily treatment demand for health centers, since they althogether determine how much time is available for a patient. Here we make the observation that when the demand is very high, then doctors inevitably reduce their service time. On the other han, if there is not many people waiting, they tend to be more attentive to their patients. However, we will also assume that there is a limit to this adjustment.

Behavior of service time is same with number of general practitioner or hospital doctors since higher number of doctor means less daily demand per doctor which increases service time in the center. Additionally, daily demand has an inverse relationship with service time since increasing the demand at health center causes less service time per patient at the relevant health center. Figure 3.4 shows these balancing loops (negative loops) of service quality on attractiveness at general practitioner as B2 loop and at hospital as B3 loop.

3.1.1.3 Waiting Time Effect on Attractiveness

Waiting time effect on attractiveness at health centers is the third dynamic factor in the system. Waiting time is the average time that patients have to spend during waiting in

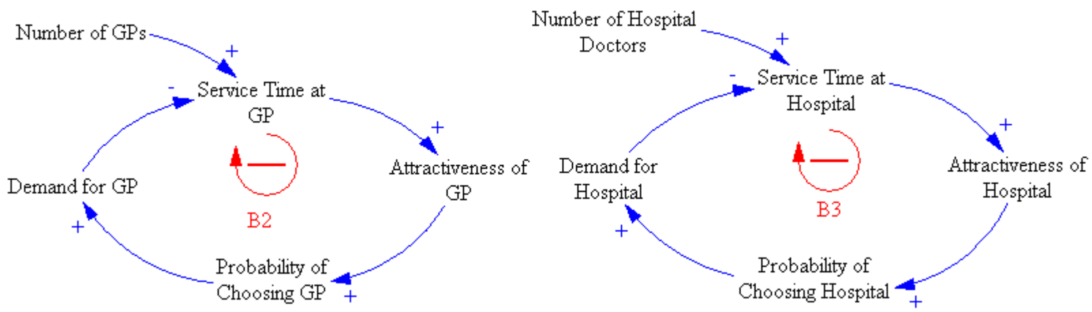


Figure 3.4: Service Quality Effect on Attractiveness

general practitioners' offices or hospitals for treatment. Waiting time has a negative effect on attractiveness since patients always prefer less waiting time and longer waiting time decreases attractiveness of health centers. We know from queuing theory that waiting time can be affected from both daily demand for healthcare, service time and number of doctors which refers arrival rate, λ, service rate, μ and number of servers, c in the classical queuing model. If service time is long, it causes congestion at health centers which increases the waiting time; therefore service time and waiting time have a negative relation. In addition to this, waiting time at general practitioners' office or hospital decreases when the relevant number of doctors increases in the system. To conclude, waiting time increases with daily demand. These influences and balancing loops of general practitioner (B4) and hospital (B6) can be seen in Figure 3.5.

3.1.1.4 Gatekeeping, Laboratory and Distance Effect

Gatekeeping policy, laboratory and distance effects are the final factors which influence the attractiveness of general practitioner and hospital without causing any dynamic loop. By the help of interviews from Düzce, it has been seen that introducing gatekeeping policy for general practitioner increases the demand for general practitioner treatment. When there's a gatekeeping policy, although patients need secondary primary care in hospital because of

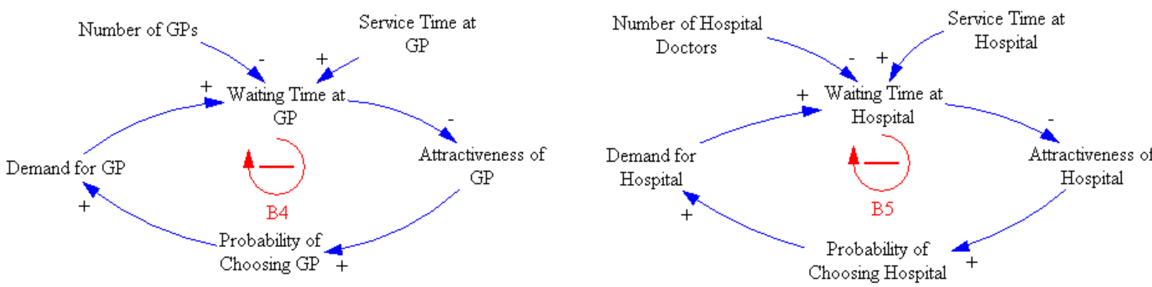


Figure 3.5: Waiting Time Effect on Attractiveness

some diseases, they have to take referral from general practitioners to go hospital. Because of this obligation, significantly more people prefer to go to general practitioner as their first contact. To model this, we assumed a gatekeeping policy parameter in the system which increases attractiveness of general practitioner. Therefore, if gatekeeping policy exists in the system attractiveness of general practitioner will automatically increase, if not it will have no effect on attractiveness.

In addition to gatekeeping policy, laboratory existence in the general practitioner office has positive effect on attractiveness of general practitioner. In that case, patients do not have to go to hospital for their blood test. Therefore, if laboratory exists in the general pracitioner's office attractiveness of general practitioner will automatically increase, if not it will have no effect on attractiveness.

Distance to the health centers is the final dynamic effect on attractiveness in the system. Patients generally prefer to go to the closest health center for their treatment which makes the distance factor to have significant role on attractiveness. When the distance between the patient and health center increases, attractiveness of relevant health center decreases which means distance and attractiveness have an inverse relationship. In Figure 3.6 influences of gatekeeping policy, laboratory existence at general practitioner and distance effect can be seen.

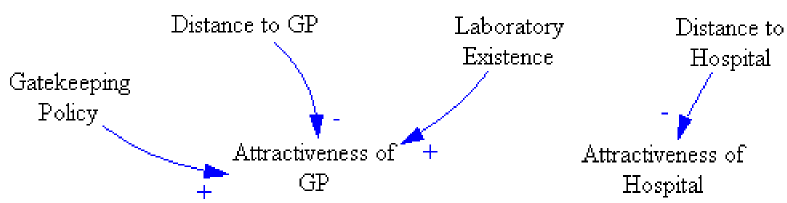


Figure 3.6: Gatekeeping, Laboratory and Distance Effect on Attractiveness

3.1.1.5 Model of Choice Probability

Final relation in the influence diagram is effects of attractiveness of general practitioner and hospital on the choice probability. As mentioned above, attractiveness of health center increases the probability of choosing relevant health center, while it decreases the probability of choosing other health center at the same time. Therefore, attractiveness of general practitioner affects the probability of choosing hospital negatively and attractiveness of hospital influences the probability of choosing general practitioner negatively. These relations have been showed in Figure 3.7 as follows.

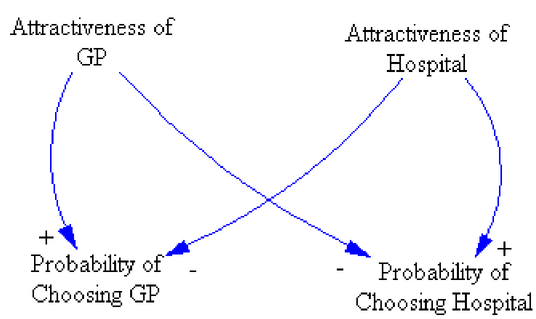


Figure 3.7: Effects of Attractiveness on Probabilities

Finally, demand side of the influence diagram can be seen in Figure 3.8 when all loops and variables are combined with each other. As seen in the figure, all loops have relations with each other which mean behavior of the model depends on the dominance of these loops. Dominant loop in the model will change the decisions of patients for their first contact by affecting attractiveness of health centers.

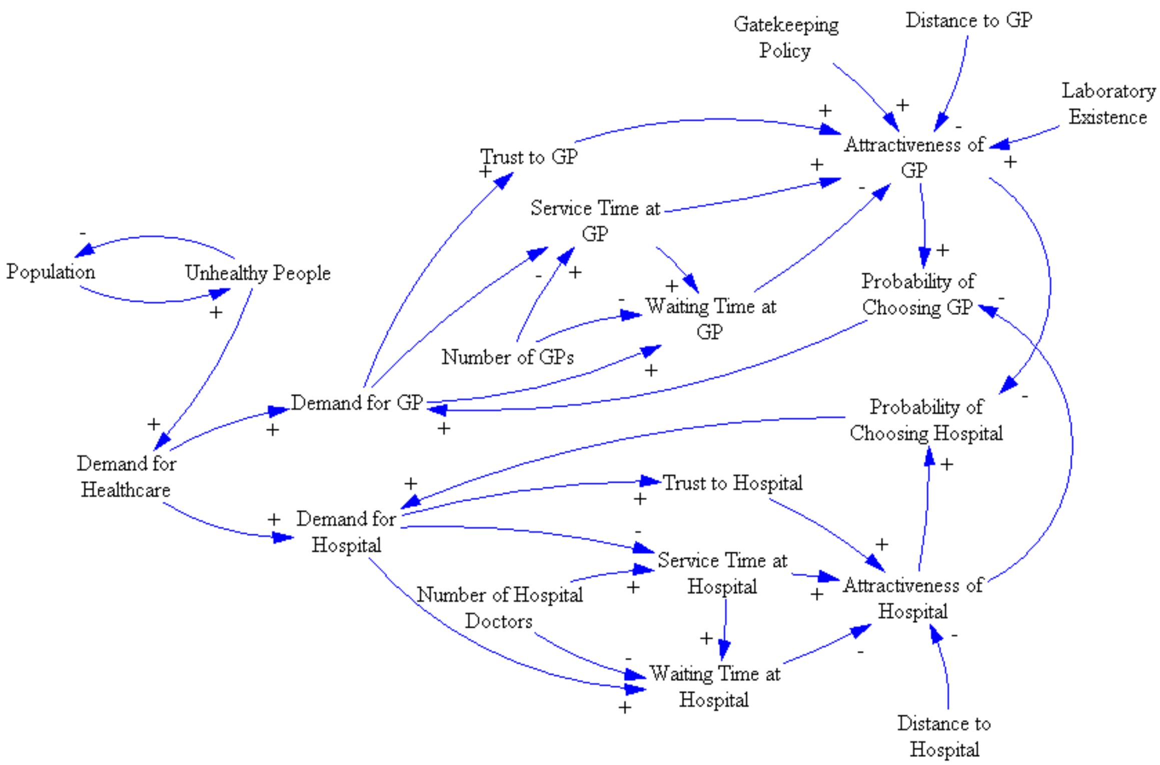


Figure 3.8: Causal Loop Diagram of Demand Side

3.1.2 Supply Model

Supply side of the influence diagram has been built to model the doctor flows to fulfill the patient demand by the help of interviews with Düzce health officers. The system has a necessity of several general practitioners which depends on population of the system. Population is distributed as evenly as possible to each general practitioner considering the ideal panel size. This ideal panel size has been determined by government and defines the desired number of general practitioners in the system. Although we can define the necessary number of general practitioners, it can be impossible to reach desired level if there are not enough doctors who want to be general practitioner. Figure 3.9 shows the balancing loop of number of general practitioners (B6) in the system. Difference between the actual number of general practitioners in the system and desired number of general practitioner defines general practitioner necessity and this necessity helps the system to reach the desired level.

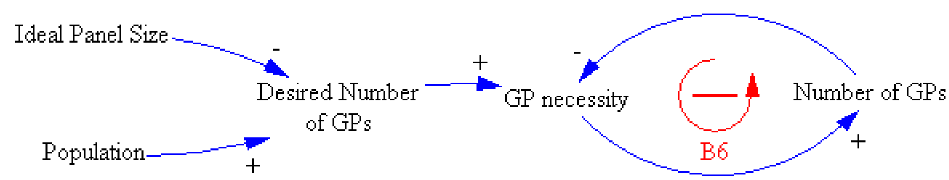


Figure 3.9: Balancing Loop for Number of General Practitioners

As mentioned above, number of general practitioners is determined due to the necessity; however, this number can be affected from attractiveness of being a general practitioner. Also by the help of interviews in the city, it is understood that salary of the general practitioner is the main factor to define this attractiveness. This salary depends on the registered number of patients (panelsize) of general practitioners since if general practitioners have more patients they earn more. Population and number of general practitioners determine the panelsize where increasing the number of general practitioner decreases the panelsize (see Figure 3.10).

Increase at salary makes the general practitioners job more attractive. As seen in Figure 3.10, this attractiveness can increase the number of potential general practitioner or decrease quitting from general practitioners job at the same time. Potential general practitioners are the doctors who prefer to work as general practitioner and wait for the available position in the city. If there are available positions, potential general practitioner become a general practitioner in the model and increase the number of general practitioners. Similarly, number of general practitioners who leave the job decreases the number of general practitioner in the model.

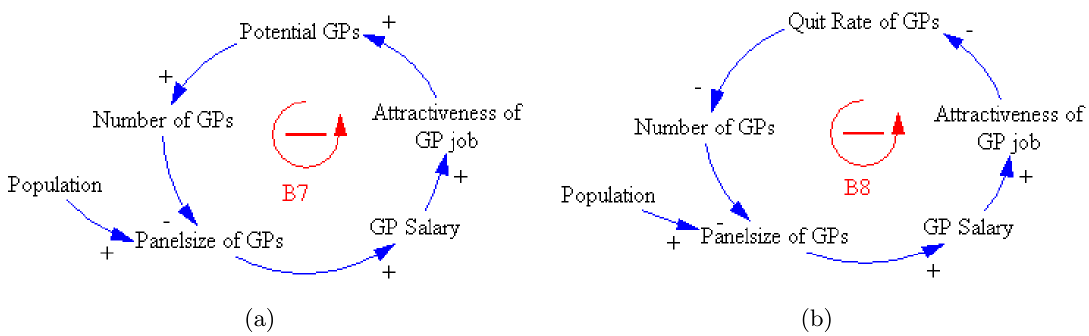


Figure 3.10: Attractiveness of GP Job

There are various variables to calculate the salary of general practitioners. These are panelsize, excessive referral fraction of general practitioner and income per patient. General practitioners earn according to number of their registered patient. If this number increases, they will earn more and also an increase in income per patient will increase the salary. Besides these increases, there are some reductions from this salary based on general practitioners' performances. These performance criteria are excessive referral fractions, baby and pregnancy observations and number of vaccinations. In this system, we will just model the excessive referral fraction since referral fraction has a significant role on patient flow behaviour. This excessive referral fraction is the difference between the monthly referral fractions of general practitioner and maximum referral fraction allowed. As seen in Figure 3.11, if referral fraction of general practitioners increases, excessive referral fraction will increase, however this increases will force the referral fraction to decrease. This relation causes a balancing loop (B9) on referrals.

Finally, when all loops and variables are combined, causal loop diagram of supply side will be as seen in Figure 3.12. It is obvious from the figure that supply side of the model just defines the number of general practitioners depending on dynamic variables.

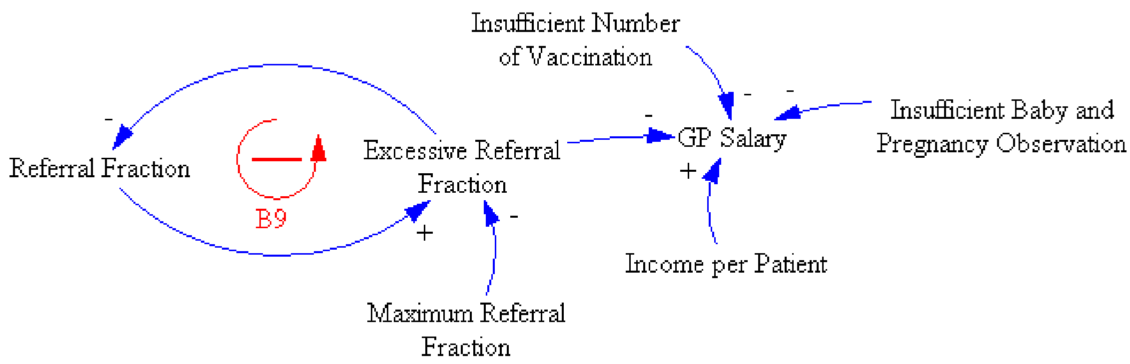


Figure 3.11: Salary of General Practitioner

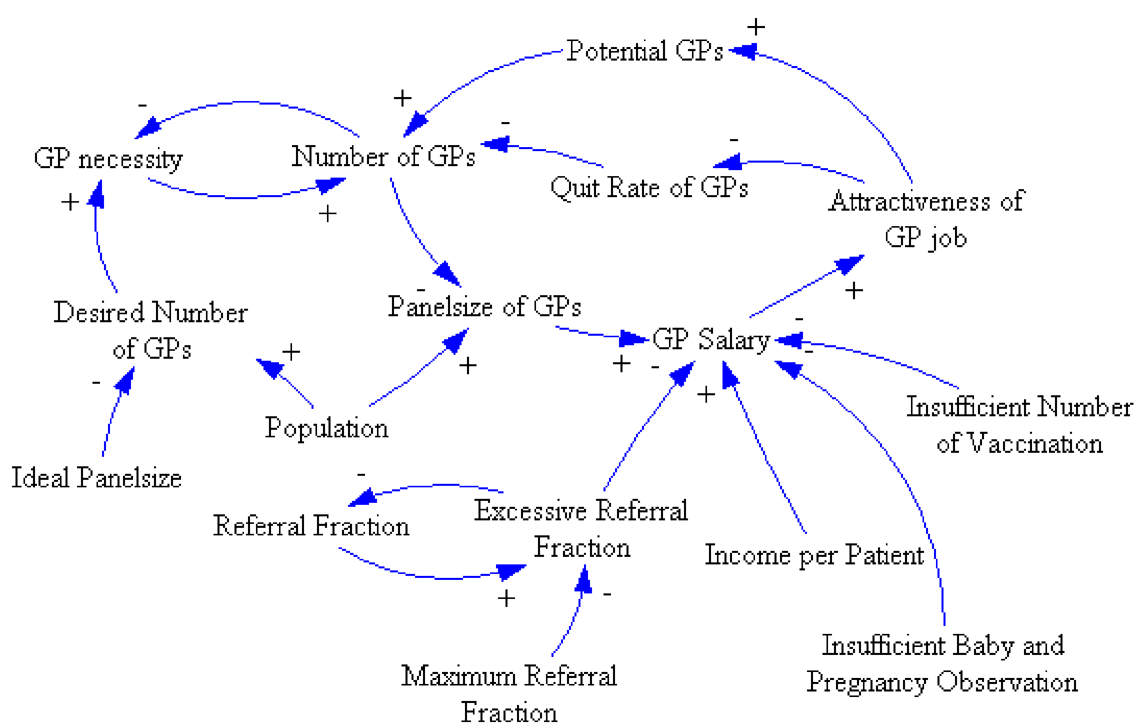


Figure 3.12: Casual Loop Diagram of Supply Side

Combination of model's demand side as in Figure 3.8 and supply side as in Figure 3.12 can be seen in Figure 3.13.

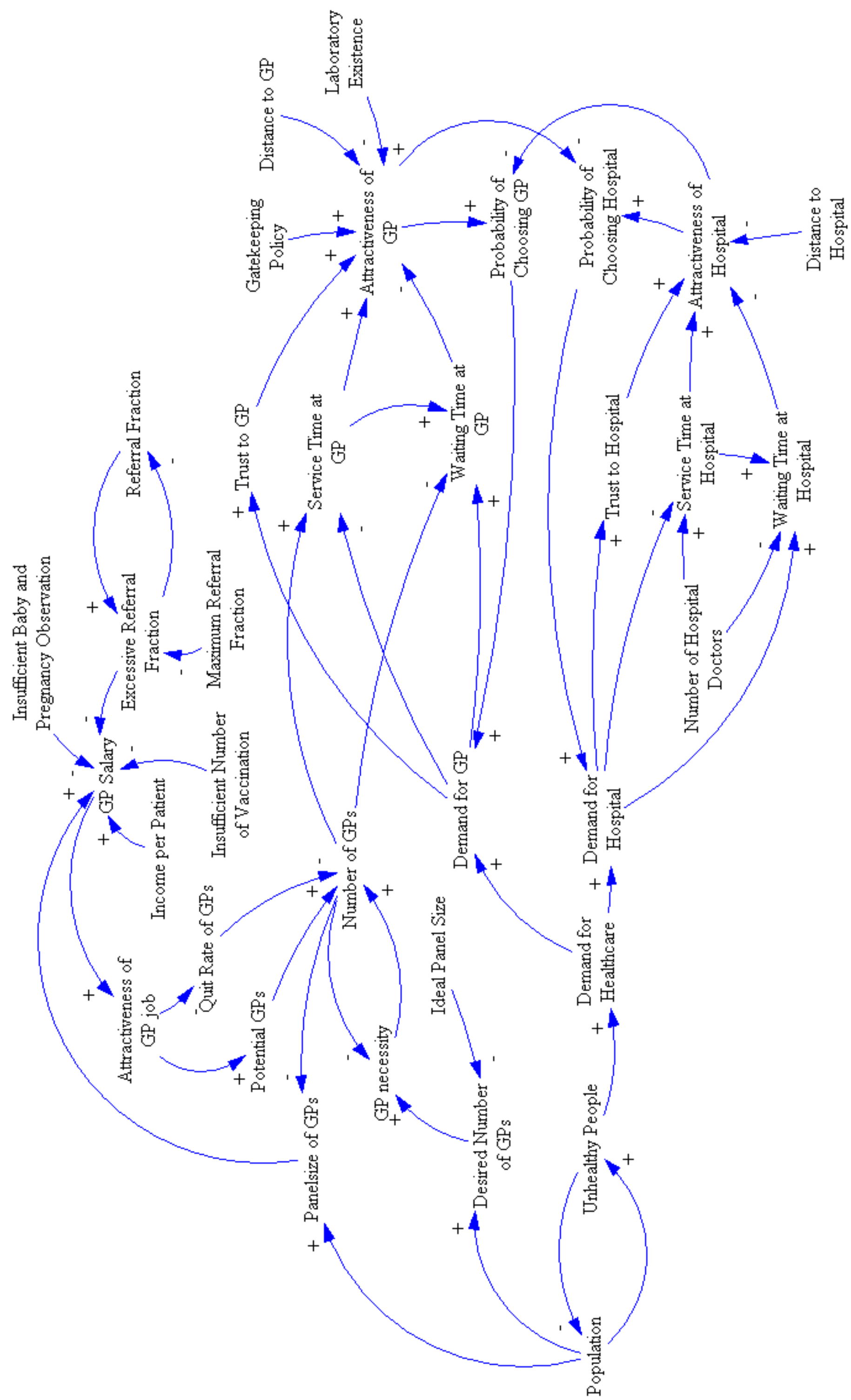


Figure 3.13: Causal Loop Diagram of Model

3.2 Stock and Flow Maps

3.2.1 Stock-Flow Map of Patient Flow

There are 7 main stocks in the patient flow side of the model. These stocks have been built from causal loop diagrams as mentioned in Section 3.1 which are *Healthy People*, *Sick People*, *Waiting at GP*, *Waiting at Hospital*, *Treatment at General Practitioner*, *Treatment at Hospital* and *Referrals*. These stocks are linked to each other by patient flows. First stock has been determined as *Healthy People* whose initial value is population of the system. *Sickness Rate* decreases the number of healthy people with sickness fraction and increases the stock *Sick People*. *Sickness Fraction* represents the fraction of people who become sick in one day. In Equation 3.1 and in Figure 3.14, representation of Sickness Loop can be seen.

$$Sickness\ Rate = Sickness\ Fraction \times Healthy\ People$$
$$Unit : Patients/Day \tag{3.1}$$

When people become sick they need to choose their treatment center. These choices are

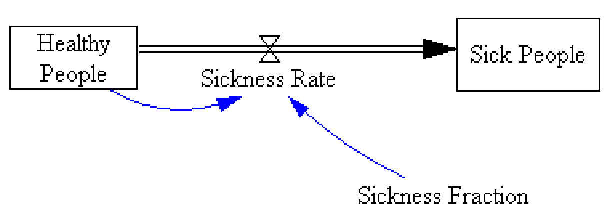


Figure 3.14: Sickness Flow

made by patient comparing the attractiveness of the treatment centers. These attractiveness determine directly the probability of choosing general practitioner or hospital by proportions of their summation as seen in Equation 3.4 and 3.5. In Section 3.2.2, detailed explanation will be mentioned for equations of attractiveness. As seen in Equation 3.2 and 3.3, probabilities show how the flow of people from *Sick People* stock, who decide to seek healthcare will be split between the general practitioner and hospital. Patients take some time before seeking health care, which are *Average Time to Go GP* and *Average Time to Go Hospital*. Finally, number of sick people decreases with these choices and increases with *Sickness Rate* as seen in Equation 3.6. In Figure 3.15, stock flow map can be seen with the addition of choosing rates.

$$GP\ Choice\ Rate = \frac{Sick\ People \times Probability\ of\ Choosing\ GP}{Average\ Time\ to\ Seek\ Healthcare}$$
$$Unit : Patients/Day \tag{3.2}$$

$$Hospital\ Choice\ Rate = \frac{Sick\ People \times Probability\ of\ Choosing\ Hospital}{Average\ Time\ to\ Seek\ Healthcare}$$
$$Unit : Patients/Day \tag{3.3}$$

$$Probability\ of\ Choosing\ GP = \frac{Attractiveness\ of\ GP}{Attractiveness\ of\ GP + Attractiveness\ of\ Hospital}$$
$$Unit : Dmnl \tag{3.4}$$

$$Probability\ of\ Choosing\ Hospital = 1 - Probability\ of\ Choosing\ GP$$
$$Unit : Dmnl \tag{3.5}$$

$$Sick\ People(t + dt) = Sick\ People(t)$$
$$+ (Sickness\ Rate - GP\ Choice\ Rate - Hospital\ Choice\ Rate)\,(dt)$$
$$Unit : Patients \tag{3.6}$$

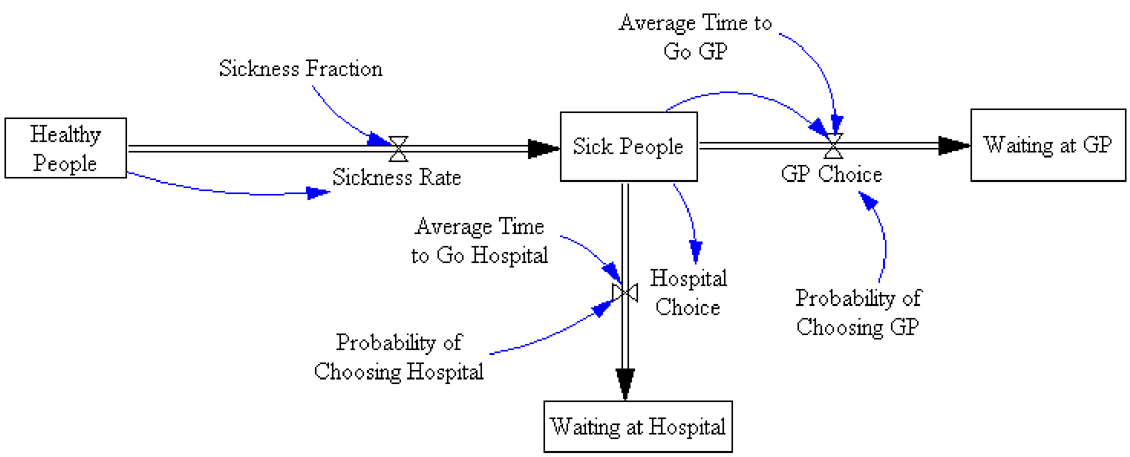


Figure 3.15: Treatment Choice Flow

After choices have been decided by patient, they cannot be accepted for their treatment immediately. Before treatment, they are taken to the waiting list of treatment centers and they can receive their treatment after they are accepted. However, if there are too many patients in waiting list of general practitioner, some patients may give up waiting for the treatment and go to hospital. As seen in Equation 3.7, stock of *Waiting at GP* increases with *GP Choice* and decreases with *Acceptance to GP* and *Giving up Rate*; also stock of *Waiting at Hospital* increases with *Hospital Choice* and *Giving up Rate* and decreases with *Acceptance to GP* as seen in Equation 3.8.

$$\begin{aligned}&Waiting\ at\ GP(t+dt) = Waiting\ at\ GP(t)\\&\qquad + (GP\ Choice - Acceptance\ to\ GP - Giving\ up\ Rate)\,(dt)\\&Unit : Patients\end{aligned} \tag{3.7}$$

$$\begin{aligned}&Waiting\ at\ Hospital(t+dt) = Waiting\ at\ Hospital(t)\\&\qquad + (Hospital\ Choice + Giving\ up\ Rate - Acceptance\ to\ Hospital)\,(dt)\\&Unit : Patients\end{aligned} \tag{3.8}$$

We analyze the flows on a daily basis, i.e. smallest average time to stay in a stock is a day, and we define the capacity as patients per day. Acceptance to the general practitioners and hospitals are determined from available capacities or patients in waiting list. If patient demand to general practitioner is more than available position at general practitioner, then acceptance rate will be depending on available position, otherwise outflow would be the available patient demand that are waiting general practitioner for treatment. Acceptance to general practitioners based on available patient demand is determined as *Maxium Acceptance Rate to GP* in the model and acceptance to general practitioners based on available capacity is determined as *Available Acceptance Rate to GP*. Same situation exists for hospitals and equations can be seen as follows:

$$\begin{aligned}&Maxium\ Acceptance\ Rate\ to\ GP = \frac{Waiting\ at\ GP}{Average\ Acceptance\ Time\ to\ GP}\\&Unit : Patients/Day\end{aligned} \tag{3.9}$$

$$Maximum\ Acceptance\ Rate\ to\ Hospital = \frac{Waiting\ at\ Hospital}{Average\ Acceptance\ Time\ to\ Hospital}$$
$$Unit: Patients/Day \tag{3.10}$$

$$Acceptance\ to\ GP = \text{MIN}\begin{pmatrix} Available\ Acceptance\ Rate\ to\ GP, \\ Maxium\ Acceptance\ Rate\ to\ GP \end{pmatrix}$$
$$Unit: Patients/Day \tag{3.11}$$

$$Acceptance\ to\ Hospital = \text{MIN}\begin{pmatrix} Available\ Acceptance\ Rate\ to\ Hospital, \\ Maxium\ Acceptance\ Rate\ to\ Hospital \end{pmatrix}$$
$$Unit: Patients/Day \tag{3.12}$$

If available acceptance capacity is less than the number waiting treatment, then there will be a waiting list of general practitioner. These patients may give up waiting in an average time (*Average Time to Give up from GP*) with *Leaving GP Fraction*. The number of patients, who will give up waiting can be found as in Equation 3.13. In these equation, (*Maximum Acceptance Rate to GP-Acceptance to GP*)× *Average Acceptance Time to GP* represents the total number of patients who are waiting for treatment. We assume that some of these waiting patients give up with the fraction of *Leaving GP Fraction*. Therefore, outflow from waiting list due to *Giving up Rate* can be seen in Equation 3.14.

$$\begin{aligned} Number\ of\ Giving\ up\ &= (Maximum\ Acceptance\ Rate\ to\ GP - Acceptance\ to\ GP) \\ &\times Average\ Acceptance\ Time\ to\ GP \\ &\times Leaving\ GP\ Fraction \end{aligned}$$
$$Unit: Patients \tag{3.13}$$

$$Giving\ up\ Rate = \frac{Number\ of\ Giving\ up}{Average\ Time\ to\ Give\ up\ from\ GP}$$
$$Unit : Patients/Day \tag{3.14}$$

After patients are accepted to general practitioners' office and hospitals, they receive treatment. Number of these patients are being represented in the stock of *Treatment at General Practitioner* and *Treatment at Hospital.* In the model, these stocks represent the cumulative number of patients in treatment center in one day. As mentioned above, there should be available positions for treatment at general practitioners' offices (*Available Capacity for GP*) and at hospitals (*Available Capacities for Hospital*) for patients to be cured. These positions are calculated from number of hospital doctors and general practitioners who have daily treatment capacities. In Equation 3.15 and 3.17, calculations for available capacities for general practitioners and hospitals can be seen.

$$Available\ Capacity\ for\ GP =$$
$$(Daily\ Treatment\ Capacity\ at\ GP \times Number\ of\ GP \times Average\ Acceptance\ Time\ to\ GP)$$
$$-Treatment\ at\ General\ Practitioner$$
$$Unit : Patients \tag{3.15}$$

$$Available\ Acceptance\ Rate\ to\ GP = \frac{Available\ Capacity\ for\ GP}{Average\ Acceptance\ Time\ to\ GP} + Treating\ Rate\ at\ GP + Referring\ Rate$$
$$Unit : Patients/Day \tag{3.16}$$

$$Available\ Capacity\ for\ Hospital = \begin{pmatrix} Daily\ Treatment\ Capacity\ per\ Doctor\ at\ Hospital \\ \times Hospital\ Doctor\ Quantity \\ \times Average\ Acceptance\ Time\ to\ Hospital \end{pmatrix} - Treatment\ at\ Hospital$$

$$Unit : Patients \tag{3.17}$$

$$Available\ Acceptance\ Rate\ to\ Hospital = \frac{Available\ Capacity\ for\ Hospital}{Average\ Acceptance\ Time\ to\ Hospital} + Treating\ Rate\ at\ Hospital$$

$$Unit : Patients/Day \tag{3.18}$$

Finally, addition of treatments at general practitioners and hospitals to the stock flow map can be seen in Figure 3.16. After treatment at general practitioners' offices, patients need to be transferred to the hospitals for detailed treatment or they can go home which means they are not unhealthy anymore and become the member of *Number of Healed People* stock. These outflows are represented as *Referring Rate* and *Treating Rate* in the model and their fractions are determined by *Referral Probability* and *Treatment Probability.* Therefore, patients can go home in average time as "*Going Home Time*" with *Treatment Probability* as seen in Equation 3.19.

$$Treating\ Rate\ at\ GP = \frac{Treatment\ at\ General\ Practitioner \times Treatment\ Probability}{Going\ Home\ Time}$$

$$Unit : Patients/Day \tag{3.19}$$

Also, patients can be transferred to hospital with *Referral Probability* in the *Referral Time.* This transfer becomes with *Referring Rate* which is seen in Equation 3.20. It should be noticed that summation of probabilites is equal to 1 since patients cannot stay at general

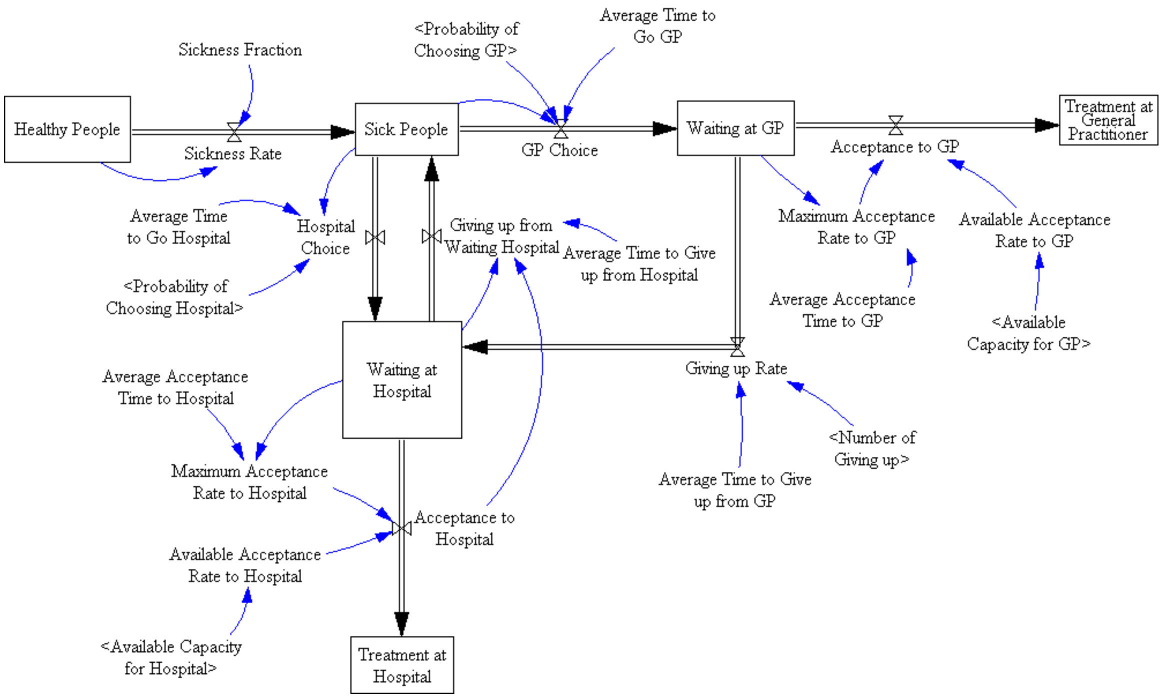


Figure 3.16: Acceptance Flow

practitioners office after treatment. Therefore, stock *Treatment at General Practitioner* increases with *Acceptance to GP* and decreases with *Referring Rate* and *Treating Rate at GP* as seen in Equation 3.22.Additionally, patients who are transferred to hospital cannot be accepted directly. They are also being accepted to the waiting list of hospitals. In the model, we define this by adding stock of *Referrals* which increases with *Referring Rate* and decreases after acceptance to hospital by rate of *Acceptance to Hospital with Referral.* This acceptance also needs a time to exist which is defined as *Average Time to be Referred.* Therefore, stock of *Waiting at Hospital* as mentioned in Equation 3.8 have another inflow. By addition of new inflow, equation for stock of *Waiting at Hospital* will be as in Equation

3.25.

$$Referring\ Rate = \frac{Treatment\ at\ General\ Practitioner \times Referral\ Probability}{Referral\ Time}$$
$$Unit : Patients/Day \tag{3.20}$$

$$Treatment\ Probability = 1 - Referral\ Probability$$
$$Unit : Dmnl \tag{3.21}$$

$$Treatment\ at\ General\ Practitioner(t + dt) = Treatment\ at\ General\ Practitioner(t)$$
$$+ (Acceptance\ to\ GP - Referring\ Rate - Treating\ Rate\ at\ GP)\,(dt)$$
$$Unit : Patients \tag{3.22}$$

$$Referrals(t + dt) = Referrals(t) + \begin{pmatrix} Referring\ Rate \\ -Acceptance\ to\ Hospital\ with\ Referral \end{pmatrix} (dt)$$
$$Unit : Patients \tag{3.23}$$

$$Acceptance\ to\ Hospital\ with\ Referral = \frac{Referrals}{Average\ Time\ to\ be\ Referred}$$
$$Unit : Patients/Day \tag{3.24}$$

$$Waiting\ at\ Hospital(t + dt) = Waiting\ at\ Hospital(t)$$
$$+ \begin{pmatrix} Acceptance\ to\ Hospital\ with\ Referral + Giving\ up\ Rate \\ +Hospital\ Choice - Acceptance\ to\ Hospital \end{pmatrix} (dt)$$
$$Unit : Patients \tag{3.25}$$

As distinct from general practitioners' treatment, we assumed that patients only go home as a healthy people after treatments at hospital since hospitals are acting as secondary healthcare center and there are not any referrals from the hospitals. Therefore, there is just one outflow from *Treatment at Hospital* stock which can be seen in Equation 3.26. This outflow is called *Treating Rate at Hospital* in the model and increases the stock *Number of Healed People*. Patients can go to *Number of Healed People* at the same time, *Going Home Time*, after they leave the general practitioners' office. *Number of Healed People* stock includes the patients who are in the healing process but not completely healthy. These patients can be healthy again in *Average Time to be Healed.* After they conclude the healing process they become the part of healthy population in the model. Therefore, demand side of the model, which includes the patient flows, becomes a closed loop system as seen in Figure 3.17.

$$\begin{aligned} &Treatment\ at\ Hospital(t+dt) = Treatment\ at\ Hospital(t) \\ &\qquad + (Acceptance\ to\ Hospital - Treating\ Rate\ at\ Hospital)\,(dt) \\ &Unit: Patients \end{aligned} \tag{3.26}$$

$$\begin{aligned} &Treating\ Rate\ at\ Hospital = \frac{Treatment\ at\ Hospital}{Going\ Home\ Time} \\ &Unit: Patients/Day \end{aligned} \tag{3.27}$$

$$\begin{aligned} &Number\ in\ Healing\ Process(t+dt) = \\ &\qquad Number\ in\ Healing\ Process(t) + \begin{pmatrix} Treating\ Rate\ at\ GP \\ +Treating\ Rate\ at\ Hospital \\ -Being\ Healed\ Rate \end{pmatrix}(dt) \\ &Unit: Patients \end{aligned} \tag{3.28}$$

$$Number\ in\ Healing\ Process = \frac{Being\ Healed\ Rate}{Average\ Time\ to\ be\ Healed}$$
$$Unit : Patients \tag{3.29}$$

$$Healthy\ People(t + dt) = Healthy\ People(t) + \begin{pmatrix} Being\ Healed\ Rate \\ -Sickness\ Rate \end{pmatrix} (dt)$$
$$Unit : Patients/Day \tag{3.30}$$

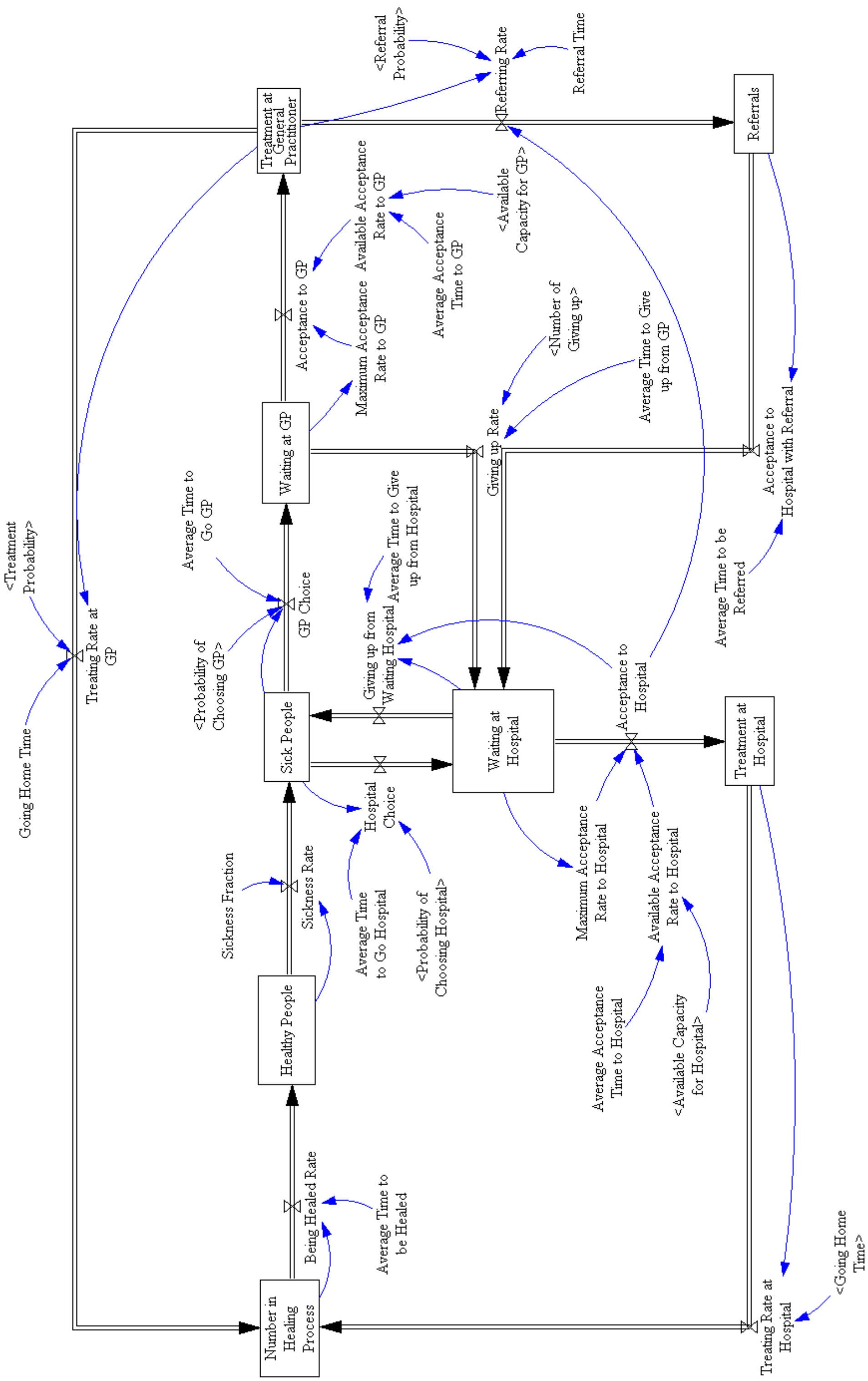


Figure 3.17: Stock-Flow Diagram of Patient Flow

3.2.2 Stock-Flow Map of Attractiveness

As mentioned above, probabilities for choosing general practitioners or hospitals are determined by the attractiveness of general practitioners or hospitals. Each attractiveness include various effects as in Equation 3.31 and 3.32 and these effects are multiplicative since when there is an extreme value of any effect it dominates the other effects [18]. These multiplicative effects are defined as gatekeeping policy, trust, service quality, waiting time, laboratory existence and distance effect.

$$Attractiveness\ of\ GP = \begin{pmatrix} Effect\ of\ Gatekeeping\ Policy\ on\ GP\ Attractiveness \times \\ Effect\ of\ Service\ Quality\ on\ GP\ Attractiveness \times \\ Effect\ of\ Trust\ on\ GP\ Attractiveness \times \\ Effect\ of\ Waiting\ Time\ on\ GP\ Attractiveness \times \\ Effect\ of\ Laboratory\ Existence\ on\ GP\ Attractiveness \times \\ Effect\ of\ Distance\ on\ GP\ Attractiveness \end{pmatrix}$$
$$Unit : Dmnl \tag{3.31}$$

$$Attractiveness\ of\ Hospital = \begin{pmatrix} Effect\ of\ Service\ Quality\ on\ Hospital\ Attractiveness \times \\ Effect\ of\ Trust\ on\ Hospital\ Attractiveness \times \\ Effect\ of\ Waiting\ Time\ on\ Hospital\ Attractiveness \end{pmatrix}$$
$$Unit : Dmnl \tag{3.32}$$

3.2.2.1 Stock Flow Map of Trust Effect

Trust effect for general practitioners and hospitals are determined by the patients' choices due to their treatment demand. Due to this, we are comparing the rate of choosing the general practitioner and choosing the hospitals in the model. As mentioned above in Section 3.2.1, general practitioners have just one inflow as *GP Choice*, however hospitals have two inflows as *Hospital Choice* and *Giving up Rate* because of number of give up patients who don't want to be in the waiting line of general practitioner. Here, we haven't added the inflow of *Acceptance to Hospital with Referrals* since these patients aren't choosing to receive treatment, they are just being transferred from general practitioners' offices. Choosing rates have been shown in Equation 3.33 and 3.34. We define a stock variable, *Trust to GP*, which accumulates patients who choose GP as their first contact over time. Similarly, *Trust to Hospital* is the cumulative number of patients who choose the hospital as first contact (see Equation 3.37 and 3.38). Also, this cumulative trust stocks can be reduced in time with the rate of *Loosing Trust from GP* and *Loosing Trust from Hospital* when patients cannot take any treatment from their health provider. Therefore, we can compare the number of patients who visit the general practitioners or hospitals and we can define the effect of trust by proportion of the patients as seen in Equation 3.39 and 3.40. In Figure 3.18, the stock flow map of trust effect can be seen.

$$\begin{aligned} &Respecting\ Rate\ to\ GP = GP\ Choice \\ &Unit : Patients/Day \end{aligned} \tag{3.33}$$

$$\begin{aligned} &Respecting\ Rate\ to\ Hospital = Hospital\ Choice + Giving\ up\ Rate \\ &Unit : Patients/Day \end{aligned} \tag{3.34}$$

$$\begin{aligned} &Loosing\ Trust\ from\ GP = Giving\ up\ Rate \\ &Unit : Patients/Day \end{aligned} \tag{3.35}$$

$$\begin{aligned}&Loosing\ Trust\ from\ Hospital = Giving\ up\ from\ Waiting\ Hospital\\&Unit: Patients/Day\end{aligned} \tag{3.36}$$

$$\begin{aligned}&Trust\ to\ GP(t+dt) = Trust\ to\ GP(t)\\&\qquad + (Respecting\ Rate\ to\ GP - Loosing\ Trust\ from\ GP)\,(dt)\\&Unit: Patients\end{aligned} \tag{3.37}$$

$$\begin{aligned}&Trust\ to\ Hospital(t+dt) = Trust\ to\ Hospital(t)\\&\qquad + (Respecting\ Rate\ to\ Hospital - Loosing\ Trust\ from\ Hospital)\,(dt)\\&Unit: Patients\end{aligned} \tag{3.38}$$

$$\begin{aligned}&Effect\ of\ Trust\ on\ GP\ Attractiveness =\\&\qquad \left(\frac{Trust\ to\ GP}{Trust\ to\ GP + Trust\ to\ Hospital}\right)\\&Unit: Dmnl\end{aligned} \tag{3.39}$$

$$\begin{aligned}&Effect\ of\ Trust\ on\ Hospital\ Attractiveness =\\&\qquad \left(\frac{Trust\ to\ Hospital}{Trust\ to\ GP + Trust\ to\ Hospital}\right)\\&Unit: Dmnl\end{aligned} \tag{3.40}$$

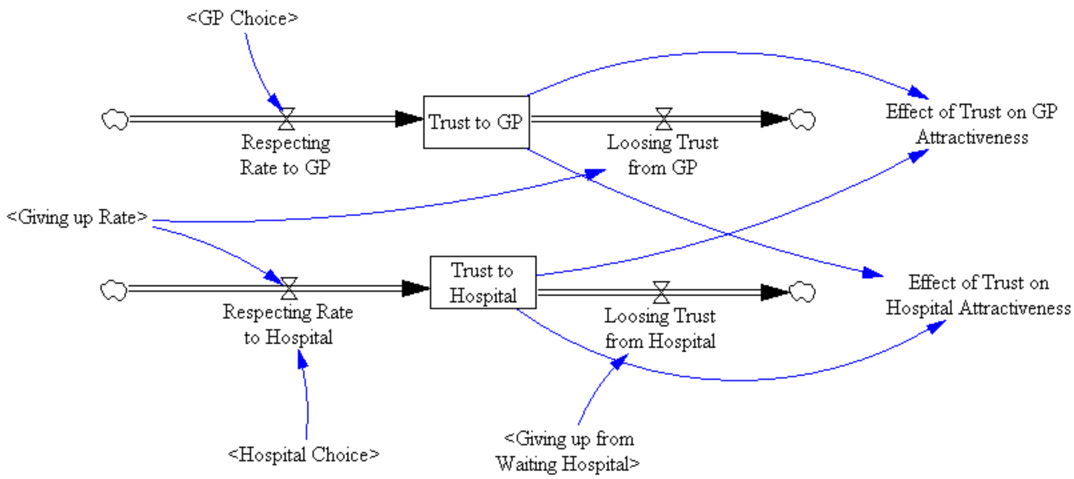


Figure 3.18: Trust Effect on Attractiveness

3.2.2.2 Stock Flow Map of Service Quality Effect

We assumed that service quality of the system is based on the service time for the patients in the treatment center. Therefore, we need to define the service time in the model to find the multiplicative effect of service quality. According to this, we need to find the number of patients per general practitioner or hospital doctor as shown in Equation 3.41 and 3.42. After finding the daily patients per doctor, we can find the actual service time by using the daily work time for doctors.

$$Daily\ Demand\ for\ GP = \frac{Treatment\ at\ General\ Practitioner}{Number\ of\ GP}$$
$$Unit : Patients/Doctors \tag{3.41}$$

$$Daily\ Demand\ for\ Hospital = \frac{Treatment\ at\ Hospital}{Hospital\ Doctor\ Quantity}$$
$$Unit : Patients/Doctors \tag{3.42}$$

$$Actual\ Service\ Time\ at\ GP = \frac{Worktime}{Daily\ Demand\ for\ GP}$$
$$Unit : Days/Patients \tag{3.43}$$

$$Actual\ Service\ Time\ at\ Hospital = \frac{Worktime}{Daily\ Demand\ for\ Hospital}$$
$$Unit : Days/Patients \tag{3.44}$$

As Sterman [18] stated, people don't change their behaviour or minds when they receive new information. There is always a time gap to adapt the new situation or to change the behaviour where people make the decisions based on experiences. Because of these differences, we assume that there are always differences between the actual service time and the time which patients feel the effect of it. We modeled this as *Perceived Service Time at GP* and *Perceived Service Time at Hospital* which needs an information delay as *Average Time to Change Perceptions*. Therefore, we are expecting an exponential smoothing to adjust the actual service time by eliminating the errors in beliefs [18]. Equations are as follows for perceptions of service time.

$$Change\ in\ Perception\ for\ Service\ Time\ at\ GP = \frac{Actual\ Service\ Time\ at\ GP - Perceived\ Service\ Time\ at\ GP}{Average\ Time\ to\ Change\ Perceptions}$$
$$Unit : Days/Patients/Days \tag{3.45}$$

$$Change\ in\ Perception\ for\ Service\ Time\ at\ Hospital = \frac{Actual\ Service\ Time\ at\ Hospital - Perceived\ Service\ Time\ at\ Hospital}{Average\ Time\ to\ Change\ Perceptions}$$
$$Unit : Days/Patients/Days \tag{3.46}$$

$$\begin{aligned}&Perceived\ Service\ Time\ at\ GP(t+dt) = Perceived\ Service\ Time\ at\ GP(t)\\&\quad + (Change\ in\ Perception\ for\ Service\ Time\ at\ GP)\,(dt)\\&Unit: Days/Patients\end{aligned} \tag{3.47}$$

$$\begin{aligned}&Perceived\ Service\ Time\ at\ Hospital(t+dt) = Perceived\ Service\ Time\ at\ Hospital(t)\\&\quad + (Change\ in\ Perception\ for\ Service\ Time\ at\ Hospital)\,(dt)\\&Unit: Days/Patients\end{aligned} \tag{3.48}$$

Multiplicative effects have always reference values (normal values) since in the nonlinear formulation when all input are at their normal values it is expected that output will be at its normal value. At this point, normalization has significant role since when the absolute values of the model is used in the multiplicative formulation, result can be out of the range of the function depending on the different parameters [8]. Therefore, we use normalization for perceived service time to keep it in the range of the function (see Equation 3.49) and then we use Table Function (Lookup) to receive the value of service time effect which is based on the service time. Table functions include the nonlinear relationships between the dependent or independent variables by using linear interpolation between the values [18]. Finally, due to these equations and relations, stock flow map of the service quality effect on attractiveness can be seen in Figure 3.19.

$$\begin{aligned}&Normalization\ of\ Service\ Time\ at\ GP = \frac{Perceived\ Service\ Time\ at\ GP}{Normal\ Service\ Time}\\&Unit: Dmnl\end{aligned} \tag{3.49}$$

$$Normalization\ of\ Service\ Time\ at\ Hospital = \frac{Perceived\ Service\ Time\ at\ Hospital}{Normal\ Service\ Time}$$
$$Unit : Dmnl \tag{3.50}$$

$$Effect\ of\ Service\ Quality\ on\ GP\ Attractiveness = Table\ for\ Service\ Quality\ Effect\,(Normalization\ of\ Service\ Time\ at\ GP)$$
$$Unit : Dmnl \tag{3.51}$$

$$Effect\ of\ Service\ Quality\ on\ Hospital\ Attractiveness = Table\ for\ Service\ Quality\ Effect \left(\begin{array}{c} Normalization\ of\ Service\ Time \\ at\ Hospital \end{array} \right)$$
$$Unit : Dmnl \tag{3.52}$$

3.2.2.3 Stock Flow Map of Waiting Time Effect

The differences between the inflow and outflow accumulate the value of the stock of material in transit and inflow will be equal to the outflow in the equilibrium. Also, it is possible to find the average length of delay at stock in transit by using Little's Law in equilibrium in which average length of the time is the ratio of the stock in transit to outflow [18]. Therefore, it is possible to find the waiting times at treatment centers in our model using Little's Law. As seen in Equation 3.53 and 3.54, we calculate waiting times to find their

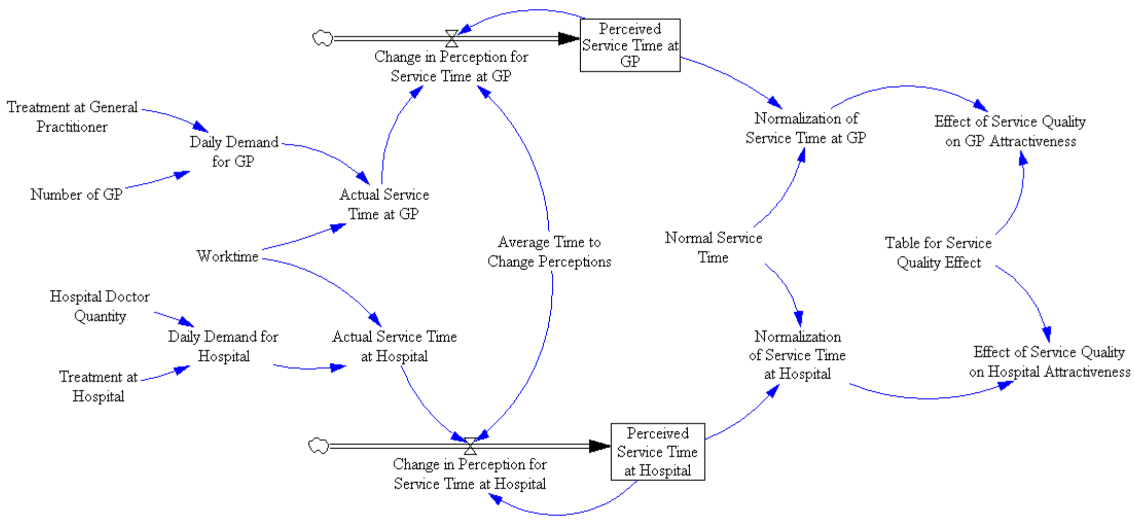


Figure 3.19: Service Quality Effect on Attractiveness

effects on attractiveness.

$$Waiting\ Time\ at\ GP = \frac{Waiting\ at\ GP}{Acceptance\ to\ GP}$$
$$Unit : Day \tag{3.53}$$

$$Waiting\ Time\ at\ Hospital = \frac{Waiting\ at\ Hospital}{Acceptance\ to\ Hospital}$$
$$Unit : Day \tag{3.54}$$

As mentioned in Section 3.2.2.2, it is essential to use perceived waiting times in the model and again normalization is done for using the table function of waiting time effects in the model as seen in the following equations. In Figure 3.20, stock flow map of the model can be seen.

$$\begin{aligned} &Change\ in\ Perception\ for\ Waiting\ Time\ at\ GP = \\ &\qquad \frac{Waiting\ Time\ at\ GP - Perceived\ Waiting\ Time\ at\ GP}{Average\ Time\ to\ Change\ Perceptions} \\ &Unit : Day/Day \end{aligned} \tag{3.55}$$

$$\begin{aligned} &Change\ in\ Perception\ for\ Waiting\ Time\ at\ Hospital = \\ &\qquad \frac{Waiting\ Time\ at\ Hospital - Perceived\ Waiting\ Time\ at\ Hospital}{Average\ Time\ to\ Change\ Perceptions} \\ &Unit : Day/Day \end{aligned} \tag{3.56}$$

$$\begin{aligned} &Perceived\ Waiting\ Time\ at\ GP(t + dt) = \\ &\qquad Perceived\ Waiting\ Time\ at\ GP(t) \\ &\qquad + (Change\ in\ Perception\ for\ Waiting\ Time\ at\ GP)\,(dt) \\ &Unit : Day \end{aligned} \tag{3.57}$$

$$\begin{aligned} &Perceived\ Waiting\ Time\ at\ Hospital(t + dt) = \\ &\qquad Perceived\ Waiting\ Time\ at\ Hospital(t) \\ &\qquad + (Change\ in\ Perception\ for\ Waiting\ Time\ at\ Hospital)\,(dt) \\ &Unit : Day \end{aligned} \tag{3.58}$$

$$\begin{aligned} &Waiting\ Time\ Normalization\ for\ GP = \frac{Perceived\ Waiting\ Time\ at\ GP}{Normal\ Waiting\ Time\ at\ GP} \\ &Unit : Dmnl \end{aligned} \tag{3.59}$$

$$Waiting\ Time\ Normalization\ for\ Hospital = \frac{Perceived\ Waiting\ Time\ at\ Hospital}{Normal\ Waiting\ Time\ at\ Hospital}$$

$$Unit : Dmnl \tag{3.60}$$

$$Effect\ of\ Waiting\ Time\ on\ GP\ Attractiveness = Table\ for\ Waiting\ Time\ Effect\,(Waiting\ Time\ Normalization\ for\ GP)$$

$$Unit : Dmnl \tag{3.61}$$

$$Effect\ of\ Waiting\ Time\ on\ Hospital\ Attractiveness = Table\ for\ Waiting\ Time\ Effect \left(\begin{array}{c} Waiting\ Time\ Normalization \\ for\ Hospital \end{array} \right)$$

$$Unit : Dmnl \tag{3.62}$$

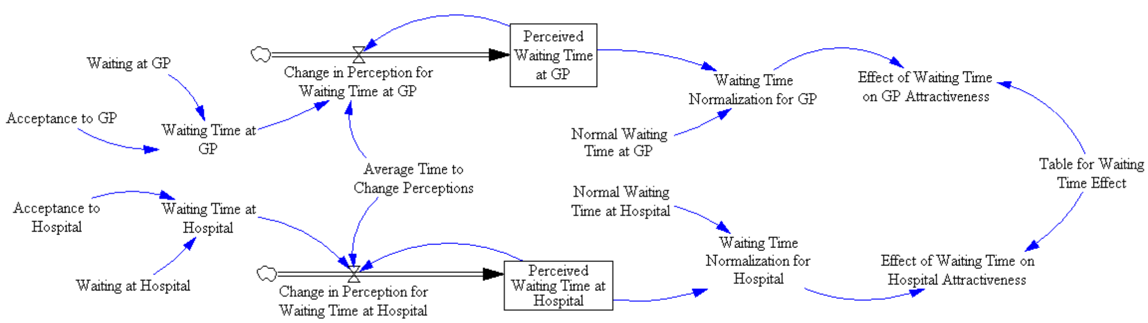


Figure 3.20: Waiting Time Effect on Attractiveness

3.2.2.4 Equations for Gatekeeping, Laboratory and Distance Effect

In the model, distance affects the attractiveness of general practitioner since each patient prefers to go to the nearest health provider. Also, general practitioners don't have their own offices in the city and there are health centers which include several general practitioners. Therefore, we calculate the panelsize of each health center using the *Average Number of General Practitioner in Health Centers* as seen in Equation 3.63. If we look at the ratio of this *Regional Panelsize* to *Population per Area*, then we will find the area in the city where people registered for a general practitioner live. Here, our assumption is the area is circular and we can find the *Distance to Travel* by calculating its radius. Therefore, *Average Distance to Travel* will be half of the *Distance to Travel* as seen in Equation 3.65. Finally, effect of the distance in the model can be found by using normalization and table function as seen in Equation 3.66 and 3.67.

$$Regional\ Panelsize = Average\ Number\ of\ GP\ in\ HC \times Ideal\ Panelsize$$
$$Unit : Patients \tag{3.63}$$

$$Density = \frac{Population}{City\ Area}$$
$$Unit : Patients/km^2 \tag{3.64}$$

$$Average\ Distance\ to\ Travel = \frac{\sqrt{\frac{Regional\ Panelsize}{(Density \times \pi)}}}{2}$$
$$Unit : km \tag{3.65}$$

$$Distance\ Normalization = \frac{Average\ Distance\ to\ Travel}{Reference\ Distance\ to\ Travel}$$
$$Unit : Dmnl \tag{3.66}$$

$$Effect\ of\ Distance\ on\ GP\ Attractiveness = Table\ for\ Distance\ Effect\,(Distance\ Normalization)$$

$$Unit : Dmnl \tag{3.67}$$

Effect of Gatekeeping Policy on GP Attractiveness and *Effect of Laboratory Existence on GP Attractiveness* do not have any equations in the model. They are just constant values which are increasing the values of attractiveness of general practitioners.

3.2.3 Stock-Flow Map of Doctor Flow

There are five main stocks in doctor flow side of the model and they are determined from the interviews in Düzce city. These stocks have relations with each other by flows which are creating closed-loop model as seen in Figure 3.21. Therefore, these stocks are *Potential Doctor*, *Other Jobs*, *Potential GP Pool*, *Number of GP* and *Working at Hospital*. The aim of this stock flow model is to find the number of general practitioners working actively in the equilibrium.

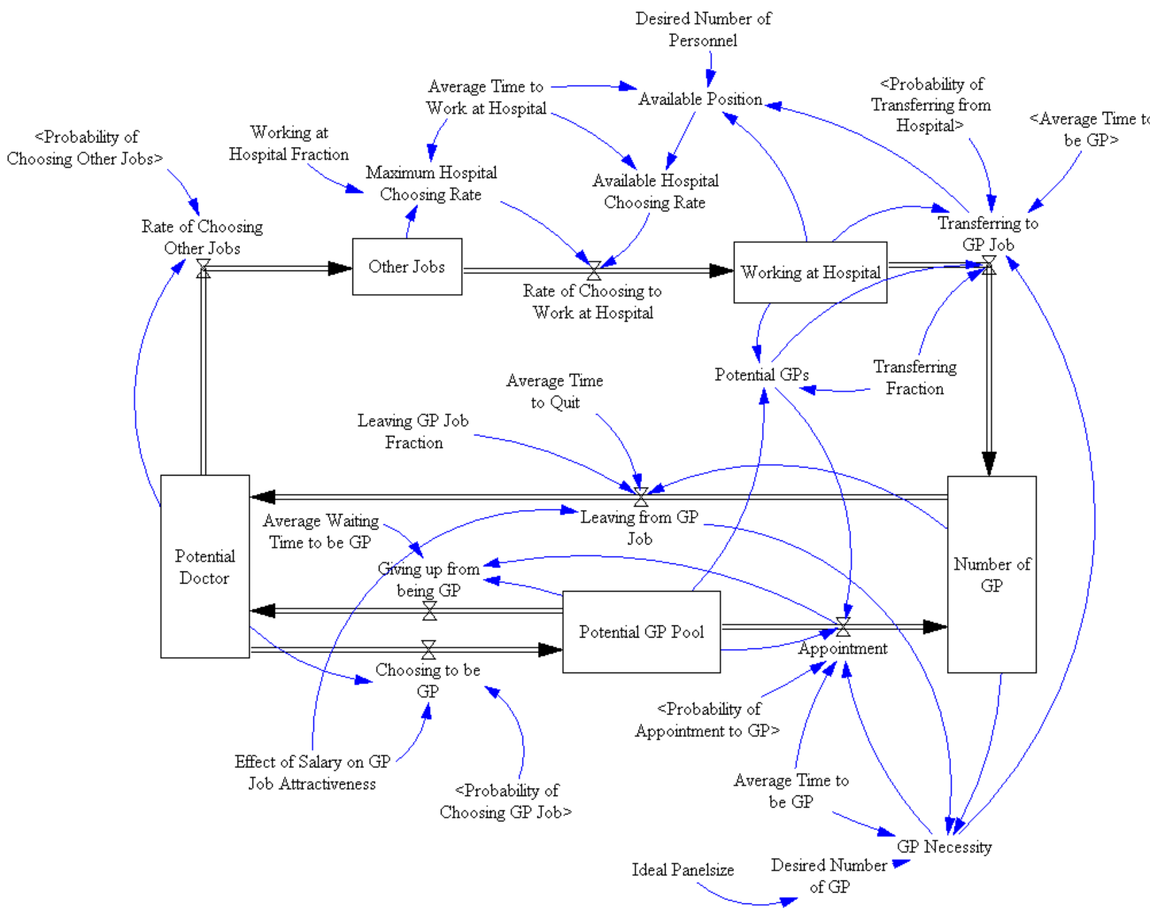


Figure 3.21: Stock-Flow Map of Doctor Flow

First of all, we have limited number of potential doctor as seen in Figure 3.21. This is analogous to the total population size in the demand model. These doctors have possibility to choose being general practitioner (i.e. work as a family doctor) or to choose being practitioner or specialist in hospital or to choose working as a health officer. These *Potential Doctor* make this decision by the probabilities of *Probability of Choosing GP Job per Day* and *Probabilities of Choosing Other Jobs per Day*. Outflows from the stock, which are shown based on the probabilities can be seen in Equation 3.68 and 3.69. Salary of general practitioner has an effect on choosing the general practitioner job, as will be explained in detail later in Section 3.2.4.

$$\begin{aligned}
&Rate\ of\ Choosing\ to\ be\ GP = \\
&Potential\ Doctor \times Probability\ of\ Choosing\ GP\ Job\ per\ Day \\
&\times Effect\ of\ Salary\ on\ GP\ Job\ Attractiveness \\
&Unit : Doctors/Day
\end{aligned} \tag{3.68}$$

$$\begin{aligned}
&Rate\ of\ Choosing\ Other\ Jobs = \\
&\qquad Potential\ Doctor \times Probability\ of\ Choosing\ Other\ Jobs\ per\ Day \\
&Unit : Doctors/Day
\end{aligned} \tag{3.69}$$

$$\begin{aligned}
&Probability\ of\ Choosing\ Other\ Jobs\ per\ Day = \\
&\qquad 1 - \begin{pmatrix} Probability\ of\ Choosing\ GP\ Job\ per\ Day \times \\ Effect\ of\ Salary\ on\ GP\ Job\ Attractiveness \end{pmatrix} \\
&Unit : Doctors/Day
\end{aligned} \tag{3.70}$$

When *Potential Doctor* prefer to be general practitioner, they have been first accepted to *Potential GP Pool* since they need an appointment to be general practitioner. However, there is always possibility for these general practitioners candidates to give up from the job if they don't receive any appointment. As seen in Equation 3.71, if the number of *Potential GP Pool* is larger than the rate of *Appointment* that means these doctors are at the waiting list for being general practitioner. Therefore doctors at *Potential GP Pool* stock will start to give up being candidates in average time of *Average Waiting Time to be GP*. Also, general practitioners can leave their job,*Leaving from GP Job*. Until this point, all outflows and inflows are explained for *Potential Doctor* and *Potential GP Pool* stocks whose equations are as seen in Equation 3.72 and 3.73. Initial value of *Potential Doctor*, 401, will be explained in the following chapters.

$$\begin{aligned} &Giving\ up\ from\ waiting\ to\ be\ GP = \\ &\qquad \text{MAX}\left(\left(\frac{Potential\ GP\ Pool}{Average\ Waiting\ Time\ to\ be\ GP} - Appointment\right), 0\right) \\ &Unit : Doctors/Day \end{aligned} \tag{3.71}$$

$$\begin{aligned} &Potential\ Doctor(t+dt) = Potential\ Doctor(t) \\ &+ \left(\begin{array}{l} Leaving\ from\ GP\ Job + Giving\ up\ from\ being\ GP \\ -Rate\ of\ Choosing\ to\ be\ GP - Rate\ of\ Choosing\ Other\ Jobs, \end{array}\right)(dt) \\ &Unit : Doctors \end{aligned} \tag{3.72}$$

$$\begin{aligned} &Potential\ GP\ Pool(t+dt) = Potential\ GP\ Pool(t) \\ &\qquad + (Rate\ of\ Choosing\ to\ be\ GP - Appointment - Giving\ up\ from\ being\ GP)(dt) \\ &Unit : Doctors \end{aligned} \tag{3.73}$$

If *Potential Doctor* prefer to be health officer or hospital doctors, they have been in the stock of *Other Jobs*. From this stock, just the number of (*Working at Hospital Fraction* × *Other Jobs*) can choose to work at hospital. This rate is defined as *Maximum Hospital Choosing*

Rate in the model. If there are limited available doctor positions in hospitals, at this point member of *Other Jobs* can work at hospital with the rate of *Available Hospital Choosing Rate*. Therefore, outflow rate *Choosing to Work at Hospital* will be as seen in Equation 3.74 and doctors can start to work at hospital in *Average Time to Work at Hospital*.

$$\begin{aligned}&Rate\ of\ Choosing\ to\ Work\ at\ Hospital =\\&\text{MIN}\left(Available\ Hospital\ Choosing\ Rate, Maximum\ Hospital\ Choosing\ Rate\right)\\&Unit: Doctors/Day\end{aligned} \tag{3.74}$$

$$\begin{aligned}&Other\ Jobs(t+dt) = Other\ Jobs(t)\\&+\left(Rate\ of\ Choosing\ Other\ Jobs - Rate\ of\ Choosing\ to\ Work\ at\ Hospital\right)(dt)\\&Unit: Doctors\end{aligned} \tag{3.75}$$

$$\begin{aligned}&Maximum\ Hospital\ Choosing\ Rate =\\&\qquad\frac{Other\ Jobs \times Working\ at\ Hospital\ Fraction}{Average\ Time\ to\ Work\ at\ Hospital}\\&Unit: Doctors/Day\end{aligned} \tag{3.76}$$

$$\begin{aligned}&Available\ Hospital\ Choosing\ Rate = \frac{Available\ Position}{Average\ Time\ to\ Work\ at\ Hospital}\\&Unit: Doctors/Day\end{aligned} \tag{3.77}$$

Available Position in the hospitals are defined from the *Desired Number of Personnel* which is the behaviour of goal-seeking. Therefore number of hospital doctors can be at maximum the value of *Desired Number of Personnel*. In Equation 3.78, it is possible to see the calculation of available position and last term of *Transferring to GP Job*× *Average Time* *to Work at Hospital* has been added to close the steady-state error in equilibrium since *Transferring to GP Job* decreases the value of stock *Working at Hospital* and this rate explains the doctors who will work as a general practitioner after leaving to work at hospital.

$$\begin{aligned} Available\ Position = {} & Desired\ Number\ of\ Personnel - Working\ at\ Hospital \\ & + (Transferring\ to\ GP\ Job \times Average\ Time\ to\ Work\ at\ Hospital) \\ Unit: Doctors & \end{aligned} \tag{3.78}$$

$$\begin{aligned} & Working\ at\ Hospital(t+dt) = Working\ at\ Hospital(t) \\ & + (Rate\ of\ Choosing\ to\ Work\ at\ Hospital - Transferring\ to\ GP\ Job)\,(dt) \\ & Unit: Doctors \end{aligned} \tag{3.79}$$

As mentioned above, our aim is to find the *Number of GP* in the model and it is the last stock in the map. As explained above and seen in Figure 3.21, *Appointment* and *Transferring to GP Job* increases the value of the stock, however *Leaving from GP Job* decreases. The values of inflows are defined from the *GP Necessity* which is the gap to reach the *Desired Number of GP* in an adjust time as *Average Time to be GP*. Behaviour of the stock is goal-seeking and this goal is calculated from the *Ideal Panelsize* which is determined by government as seen in Equation 3.81.

$$\begin{aligned} & Number\ of\ GP(t+dt) = Number\ of\ GP(t) \\ & \quad + (Appointment + Transferring\ to\ GP\ Job - Leaving\ from\ GP\ Job)\,(dt) \\ & Unit: Doctors \end{aligned} \tag{3.80}$$

$$\begin{aligned} & Desired\ Number\ of\ GP = \frac{Population}{Ideal\ Panelsize} \\ & Unit: Doctors \end{aligned} \tag{3.81}$$

$$GP\ Necessity = \left(\begin{array}{l} Desired\ Number\ of\ GP - Number\ of\ GP \\ +Leaving\ from\ GP\ Job \times Average\ Time\ to\ be\ GP \end{array} \right)$$
$$Unit : Doctors \quad (3.82)$$

When there is a *GP Necessity* in the model, this gap is closed from *Potential GP Pool* stock or *Working at Hospital* stock. However, it should not be forgotten that all doctors in the *Working at Hospital* stock are not candidate since most of them works as a specialist doctor in the hospital. Therefore, only the rate as *Transferring Fraction* of all doctors can be general practitioner in the model. We model the potential candidate from the stocks as a variable called *Potential GPs* as seen in Equation 3.83.

$$\begin{aligned} Potential\ GPs =& Working\ at\ Hospital \times Transferring\ Fraction \\ & + Potential\ GP\ Pool \end{aligned}$$
$$Unit : Doctors \quad (3.83)$$

In this pool, doctors can be the general practitioner with the *Probability of Appointment to GP* probability if they are from *Potential GP Pool* stock and the *Probability of Transferring from Hospital* probability if they are from *Working at Hospital* stock. Probabilities are found from the proportions of *Potential GP Pool* and *Working at Hospital* × *Transferring Fraction* values (see Equation 3.84 and 3.85). Therefore number of available doctors in these stocks have significant role on defining the probability since as much as high number of doctor increases the value of probability.

$$Probability\ of\ Appointment\ to\ GP = \frac{Potential\ GP\ Pool}{Potential\ GPs}$$
$$Unit : Dmnl \quad (3.84)$$

$$\begin{aligned}
&Probability\ of\ Transferring\ from\ Hospital = \\
&\qquad \frac{Working\ at\ Hospital \times Transferring\ Fraction}{Potential\ GPs} \\
&Unit : Dmnl
\end{aligned} \tag{3.85}$$

Therefore, if the number of necessity is larger than the potential general practitioners, all of them have been accepted for the job. However if there are more candidates than the necessity, then general practitioners have been chosen by the probabilities as explained above. At this point, equations for inflow rates will be:

$$\begin{aligned}
&Appointment = \\
&\frac{\mathrm{MIN}(GP\ Necessity \times Probability\ of\ Appointment\ to\ GP, Potential\ GP\ Pool)}{Average\ Time\ to\ be\ GP} \\
&Unit : Doctors/Day
\end{aligned} \tag{3.86}$$

$$\begin{aligned}
&Transferring\ to\ GP\ Job = \\
&\frac{\mathrm{MIN}\begin{pmatrix} GP\ Necessity \times Probability\ of\ Transferring\ from\ Hospital, \\ Working\ at\ Hospital \times Transferring\ Fraction \end{pmatrix}}{Average\ Time\ to\ be\ GP} \\
&Unit : Doctors/Day
\end{aligned} \tag{3.87}$$

Finally, general practitioners can leave the job with the fraction of *Leaving GP Job Fraction* and delay of *Average Time to Quit*. Salary has negative effect on leaving the job as mentioned in Section 3.1.2 and equation for the outflow is as follows.

$$\begin{aligned}
&Leaving\ from\ GP\ Job = \\
&\frac{Leaving\ GP\ Job\ Fraction \times Number\ of\ GP}{Average\ Time\ to\ Quit \times Effect\ of\ Salary\ on\ GP\ Job\ Attractiveness} \\
&Unit : Doctors/Day
\end{aligned} \tag{3.88}$$

3.2.4 Stock-Flow Map of Attractiveness of General Practitioner Job

Salary of general practitioners is calculated based on the number of registered patients per doctor. That means panelsize of the doctor and income per patient define the value of salary. Here, panelsize is a variable in the model as seen in Equation 3.89 since the number of general practitioners is the stock value which is mentioned in Section 3.2.3. Although salary is based on number of patients; general practitioners can earn *Fixed Salary*for each patient above 1000 registered patients and cannot earn more after they have 4000 registered patients [19]. This salary calculation can be seen in Equation 3.90.

$$
\begin{aligned}
&Panelsize = \frac{Population}{Number\ of\ GP} \\
&Unit : Patients/Doctors
\end{aligned}
\tag{3.89}
$$

$$
\begin{aligned}
Salary \quad &= \text{MAX}\left(\text{MIN}\left(Panelsize - 1000, 4000\right), 0\right) \times Income\ per\ Patient \\
&\quad + Fixed\ Salary \\
Unit : TL &
\end{aligned}
\tag{3.90}
$$

However, there is reduction from salaries based on referral probabilities of the general practitioner which is called performance reductions in Düzce. General practitioners earn their salaries monthly and this reduction exists for just one month depending on previous month's referral probability. Because of that time period, we use *Average Salary Calculation* variable in the model and assume the actual salary as a stock which increases with incomes and decreases with reductions by using this time period as an adjustment time and material delay. Therefore, we are modelling *Salary of General Practitioner* as a stock with inflow *Salary Increase* and outflow *Salary Reduction* as seen in Equation 3.91. Initial value of

Salary of General Practitioner is assumed as *Salary* in the model.

$$Salary\ of\ General\ Practitioner(t+dt) = Salary\ of\ General\ Practitioner(t) + (Salary\ Increase - Salary\ Reduction)(dt)$$
$$Unit: TL \tag{3.91}$$

Salary Increase is modeled as to close the gap in adjustment time as in Equation 3.92 since there is a gap between the *Salary of General Practitioner* and *Salary* as also seen in Equation 3.93. This gap is the result of existence of *Salary Reduction* in the model.

$$Salary\ Increase = \frac{\mathrm{MAX}(Salary\ Gap, 0)}{Average\ Salary\ Calculation}$$
$$Unit: TL/Day \tag{3.92}$$

$$Salary\ Gap = Salary - Salary\ of\ General\ Practitioner$$
$$Unit: TL \tag{3.93}$$

Each month, based on the referral probability of general practitioners, there exists a *Salary Reduction Rate*. This rate defines the value of decreasing due to the *Salary* of general practitioner as seen in Equation 3.95.

$$Salary\ Reduction\ Rate = Reduction\ Rate\ due\ to\ Referral\ Rate\,(Referral\ Probability)$$
$$Unit: Dmnl \tag{3.94}$$

$$Salary\ Reduction = \frac{Salary \times Salary\ Reduction\ Rate}{Average\ Salary\ Calculation}$$
$$Unit: TL/Day \tag{3.95}$$

Table of Salary Effect is a table function in the model to define the *Effect of Salary on GP Job Attractiveness*. This effect can be found based on the salary of general practitioner however to ensure staying in the bound of table function, normalization is necessary in the model. This normalization should be done by using *Salary of Practitioner* as in Equation 3.96 to understand the effect of general practitioner job. Since, if general practitioners do not choose this job, they have to work as normal practitioner doctor. Stock flow map of *Effect of Salary on GP Job Attractiveness* can be seen in Figure 3.22.

$$Normalizations\ of\ Salaries = \frac{Salary\ of\ General\ Practitioner}{Salary\ of\ Practitioner}$$
$$Unit: Dmnl \tag{3.96}$$

$$Effect\ of\ Salary\ on\ GP\ Job\ Attractiveness =$$
$$Table\ of\ Salary\ Effect\,(Normalizations\ of\ Salaries)$$
$$Unit: Dmnl \tag{3.97}$$

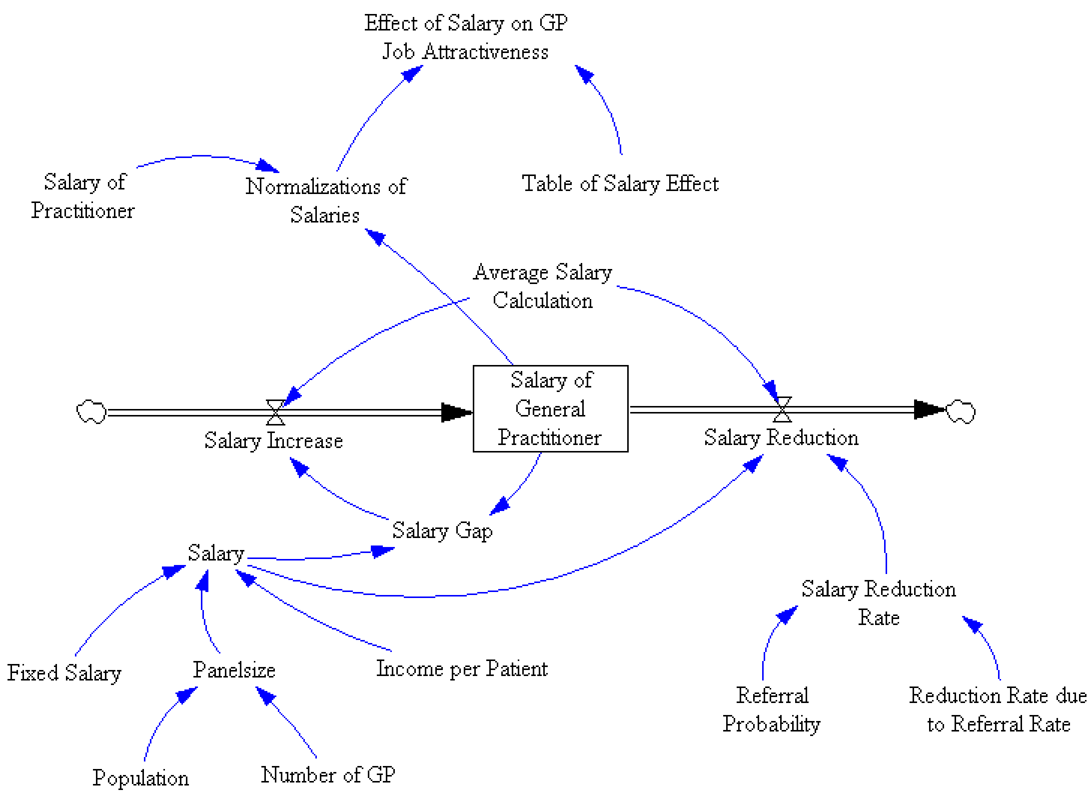


Figure 3.22: Effect of Salary on GP Job Attractiveness

Chapter 4

VALIDATION AND MODEL TESTING

Testing the model is another important step in system dynamic model-building. The purpose of the model testing can be summarized as understanding the model behaviour and working the system in detail [10]. This detailed study help us to make important decisions in our model. It should not be forgotten that the models with which we make decisions are always mental or formal models. Thus, the important point is to choose the best model which is available for our purpose despite its limitations. Model testing help us to find these limitations and uncovering the flaws to improve the model [18].

4.1 Boundary Adequacy Test

Our model is built under two structure as mentioned in Chapter 3. These structures are patient flow side and doctor flow side of the model. At first, model is built without any effects that have impacts on flows of these structures. However, it has been seen that model is inappropriate without effects since it cannot reflect the real life situation. Therefore, we model the effects as a new structure and it is included to the model to represent the real life system.

The model focuses on patients' choices between general practitioner and hospital. Therefore the model boundary does not include service providers such as emergency services and private practices. We also focus on outpatient services, and exclude inpatient services from our model.

4.2 Structure Assessment Tests

Model should be consistent with the real life system and this consistency can be checked by structure assessment test. That means all inconsistencies or inappropriate assumptions in the model should be detected by an assessment of the physical realities or realism of the decision rules. For example, due to the physical law, stocks cannot be negative if they are real quantities such as inventories, populations or cash balances. Thus, each stock should be controlled by checking all equations in the model and model should not contradict with the real system [18], [20].

In our model, we analyze the causal diagrams, stock flow maps, policy structures and each equation for structure assessment test. As a result, we believe our model structure is validated with the real life system and all variables can be determined in the real life.

4.3 Dimensional Consistency

Sterman states [18] that a dimensional inconsistency may indicate a significant problem to understand the structure of model during decision process. Therefore, every equation in the model should be dimensionally consistent with meaningful units. By using simulation software packages, Vensim, we have checked the model for dimensional errors and it is seen that unit check of the model is consistent. As shown in equations at Section 3.2, all equations and variables have also real world meaning as $Patients/Day$, $Day/Patient$, $Doctor/Day$, $Patients$, $Doctors$, $Days$, Day/Day,km^2, $Patients/Doctor$, $TL/Doctor$, $Patients/km^2$, $TL/Day/Doctor$, $Day/Doctor$ which make our model as dimensionally consistent.

4.4 Parameter Assessment

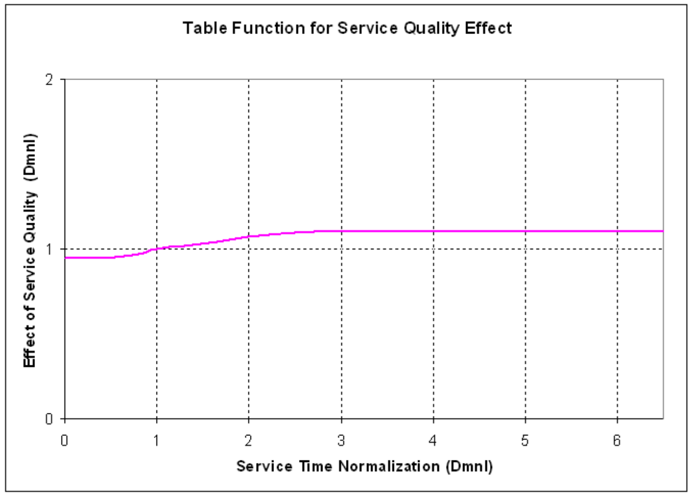
All parameters in the model should have real life meaning and they should be estimated from numerical data or judgmental estimation. There can be limitations because of availability of numerical data. At this point, parameters should be estimated by interviews, workshops, archival materials or direct experiences which is called judgmental estimation. In a large model, critical parameters usually cannot be estimated simultaneously since they can lead to a problem because of underidentified large models. Instead, statistical and judgmental methods are used together [18].

In our model, all parameters have real life meaning and they are estimated from literature review, interviews with health officers in city Düzce and numerical data from Düzce. From numerical data, we estimate the sickness fraction and referral probability (see also A.3 also Table A.4 in Appendix A). These parameters have two values depending on the existance of gatekeeping policy. *Average Time to Quit* and *Leaving GP Job Fraction* values are estimated from a survey done with general practitioner in Düzce. All parameter values are shown in Table 4.1.

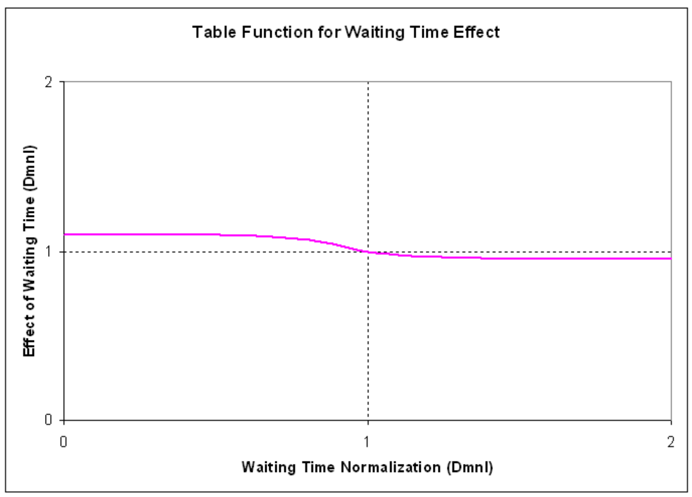
Finally, we use the graphs of table function for waiting time effect from the article of Taylor and Dangerfield [14]. Because of the inverse relation between service time and waiting time in our model, we also use the symmetric values for service quality effect. We estimate the table function for salary effect by judgmental method. Graphs for table functions can be seen in Figure 4.1.

Table 4.1: Parameter Estimation Table

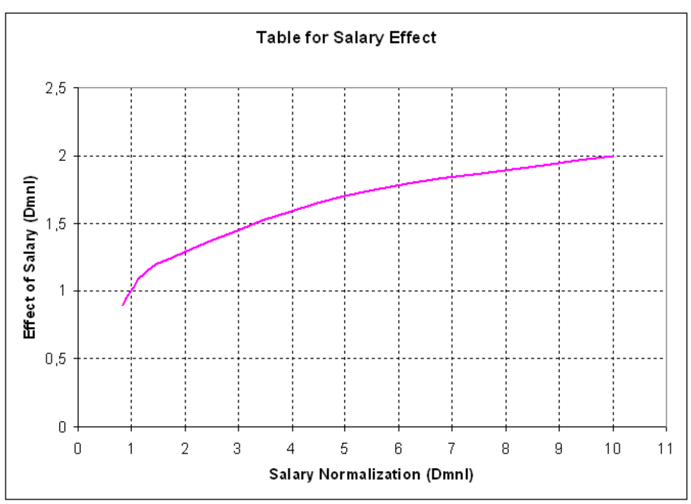
Parameter	**Value**	**Unit**	**Source**
Sickness Fraction	0.0236 or 0.237	1/ Day	Numerical Data
Referral Probability	0.25 or 0.76	Dmnl	Numerical Data
Population	335193 or 328905	Patient	Numerical Data
Average Time to Go GP	1	Day	Judgmental Estimation
Average Time to Go Hospital	1	Day	Judgmental Estimation
Average Acceptance Time to GP	1	Day	Judgmental Estimation
Average Acceptance Time to Hospital	1	Day	Judgmental Estimation
Average Time to Give up from GP	1	Day	Judgmental Estimation
Average Time to Give up from Hospital	1	Day	Judgmental Estimation
Referral Time	1	Day	Judgmental Estimation
Going Home Time	1	Day	Judgmental Estimation
Average Time to be Referred	2	Day	Judgmental Estimation
Average Time to be Healed	7	Day	Judgmental Estimation
Average Time to Change Perceptions	7	Day	Judgmental Estimation
Normal Waiting Time at GP	1	Day	Judgmental Estimation
Normal Waiting Time at Hospital	1	Day	Judgmental Estimation
Average Time to be GP	30	Day	Judgmental Estimation
Average Time to Work at Hospital	30	Day	Judgmental Estimation
Average Waiting Time to be GP	30	Day	Judgmental Estimation
Leaving GP Fraction	0.75	Dmnl	Judgmental Estimation
Leaving GP Job Fraction	0.246	Dmnl	From Survey in Düzce
Average Time to Quit	1825	Day	From Survey in Düzce
Daily Treatment Capacity at GP	60	Patient	Düzce [21]
Daily Treatment Capacity at Hospital	60	Patient	Düzce Data [21]
Average Number of GP in HC	3.47	Doctors	Literature Review [21]
Average Salary Calculation	30	Day	Policies & Procedures Documents [19]
Fixed Salary	1500	TL	Policies & Procedures Documents [19]
Income per Patient	1	TL	Policies & Procedures Documents [19]
Probability of Choosing GP Job	0.24	$1/Day$	Official Reports [22]
Transferring Fraction	0.129	Dmnl	Official Reports [22]
Working at Hospital Fraction	0.51	Dmnl	Official Reports [22]
Desired Number of Personnel	155	Doctors	Interviews in Düzce
Normal Service Time at GP	$\frac{10}{24\times60}$	Day	Interviews in Düzce
Normal Service Time at Hospital	$\frac{15}{24\times60}$	Day	Interviews in Düzce
Ideal Panelsize	3500	Patients	Interviews in Düzce
Work time	$\frac{1}{4}$	Day	Interviews in Düzce



(a) Service Quality Effect



(b) Waiting Time Effect



(c) Salary Effect

Figure 4.1: Table Functions

4.5 Extreme Condition Tests

Extreme condition test is applied to the system dynamic models to examine the robustness of the model under the extreme cases. Therefore, flaws in the model which cause unplausible behaviour can be revealed and necessary improvements can be done for the equations in the model. When extreme inputs or policies are implemented to the model, model should behave in realistic way. This check can be done by either simulation or by checking the equations in the model directly.

Hereby, we define extreme cases, for which we can estimate the model behaviour before running simulation. These extreme cases have been applied by changing population, sickness fraction, number of general practitioners, number of hospital doctors.

$Population = 0$

In this extreme case, we change the value of population by decreasing it to zero. As seen in Figure 4.2, all stock values become 0 which is meaningful since without any population there won't be any treatment.

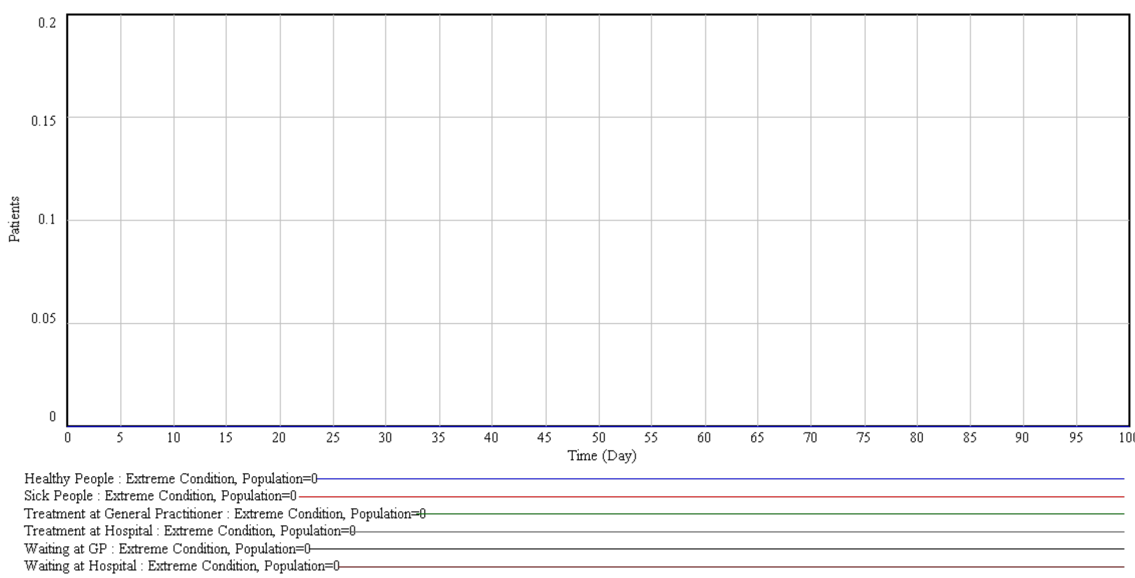


Figure 4.2: Population=0

Sickness Fraction=1

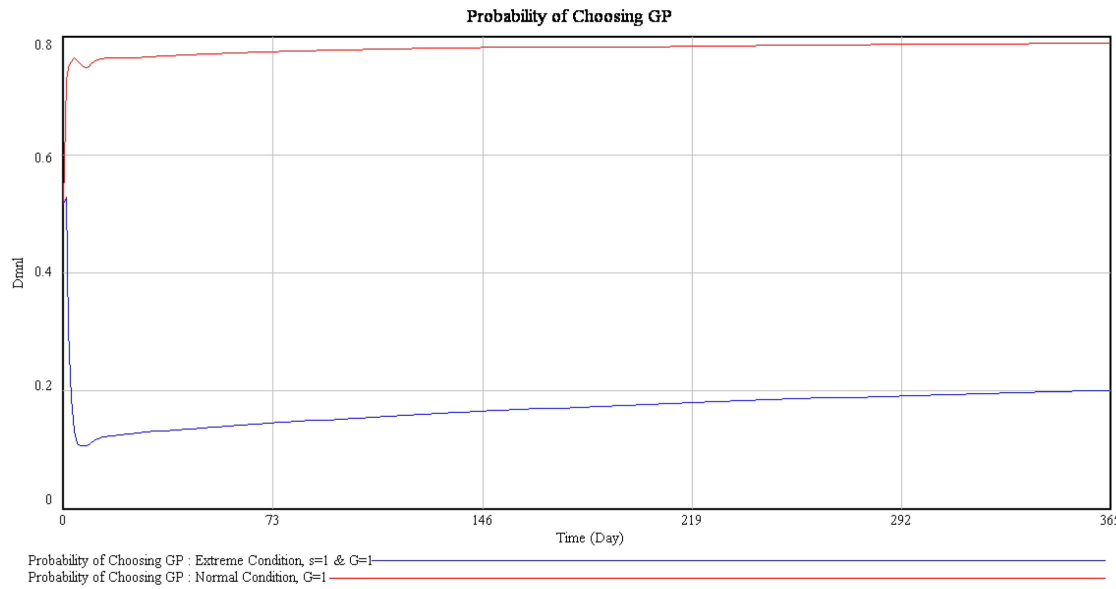
In this extreme case, we are increasing the sickness fraction to its maximum value. We are expecting that healthy people in the model should decrease rapidly and there must be long waiting times in general practitioner or hospital. When we run the model, we see that these situation exists. Although both general practitioners and hospitals have not enough doctors and there is a gatekeeping policy to force to patients to go to general practitioners, patients prefer to go hospitals since trust effect to hospital dominates the trust to general practitioner. This dominance is the result of giving up rate from waiting to general practitioner's treatment. As seen in Figure 4.3 , probability of choosing general practitioner is 0.79 under normal condition, however it becomes 0.20 when sickness fraction becomes maximum. Also healthy people in the model decreases from 267341 to 6265.34 where 271531 sick people prefers to go hospital. This value is obtained by addition of patients who are referred and give up from general practitioner. These results have real life meaning and shows the system is consistent when sickness fraction takes an extreme value.

Sickness Fraction=0

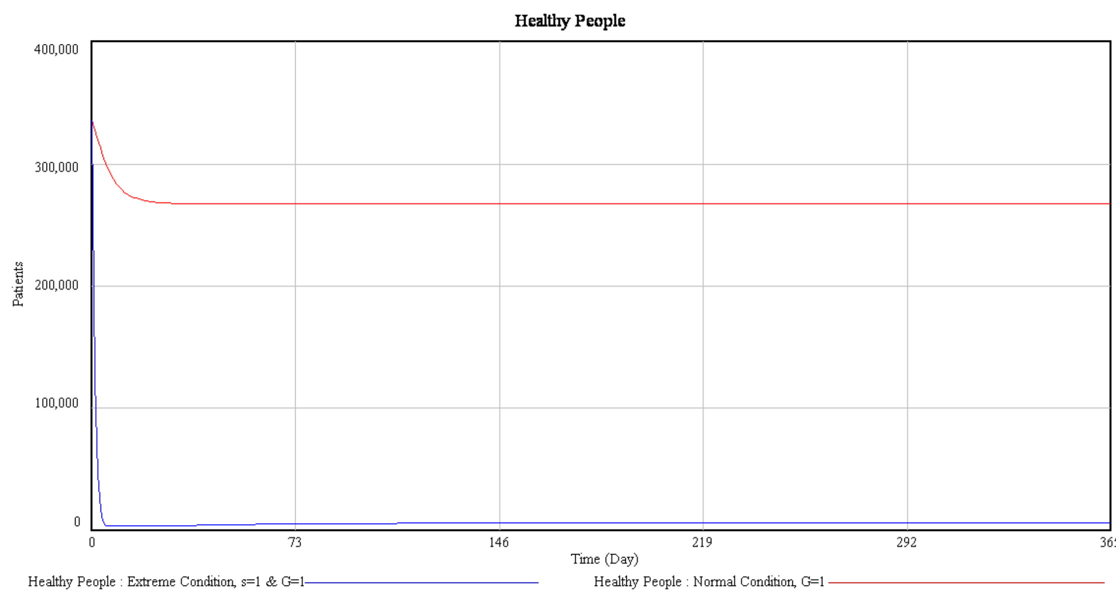
When we set the sickness fraction to 0, we expect that nobody will be sick and there will not be need for any treatment for the population. As seen in Figure 4.4, stock of *Healthy People* will be stable which is the expected behaviour under this extreme condition.

Number of General Practitioners=0

In this case, we are expecting that there will be changes in the number of healthy people and sick people because of limited treatment capacity at the hospital. Although, patients are being forced by gatekeeping policy to go to general practitioner they will give up from waiting GP because of long waiting times. This situation will also decrease the trust to general practitioners which decreases attractiveness general practitioner. When we run the model, we have seen that this expectation is fulfilled and model results are meaningful. $Probability\ of\ Choosing\ GP$ decreases until it becomes zero as seen in Figure 4.5. Also because of limited treatment availability in the hospital, number of sick people in the system

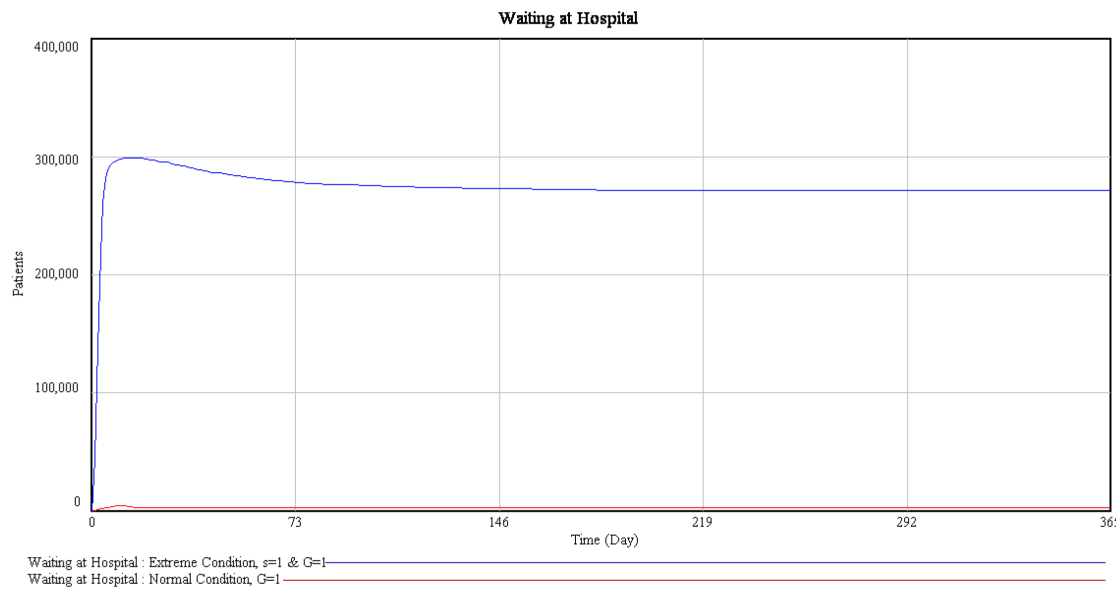


(a)

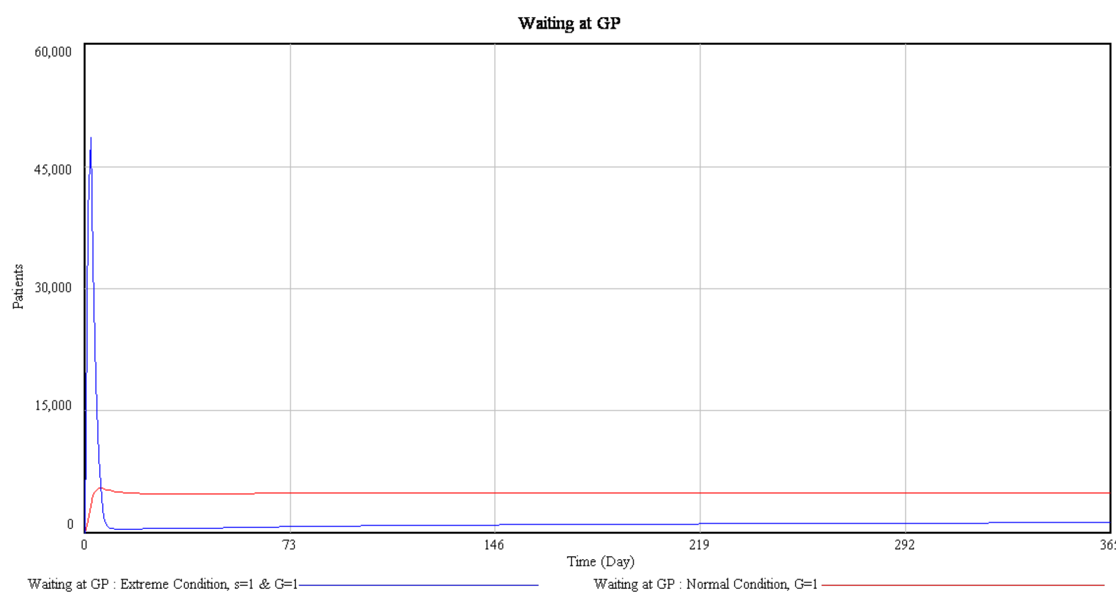


(b)

Figure 4.3: Sickness Fraction=1



(c)



(d)

Figure 4.3: Sickness Fraction=1 (cont.)

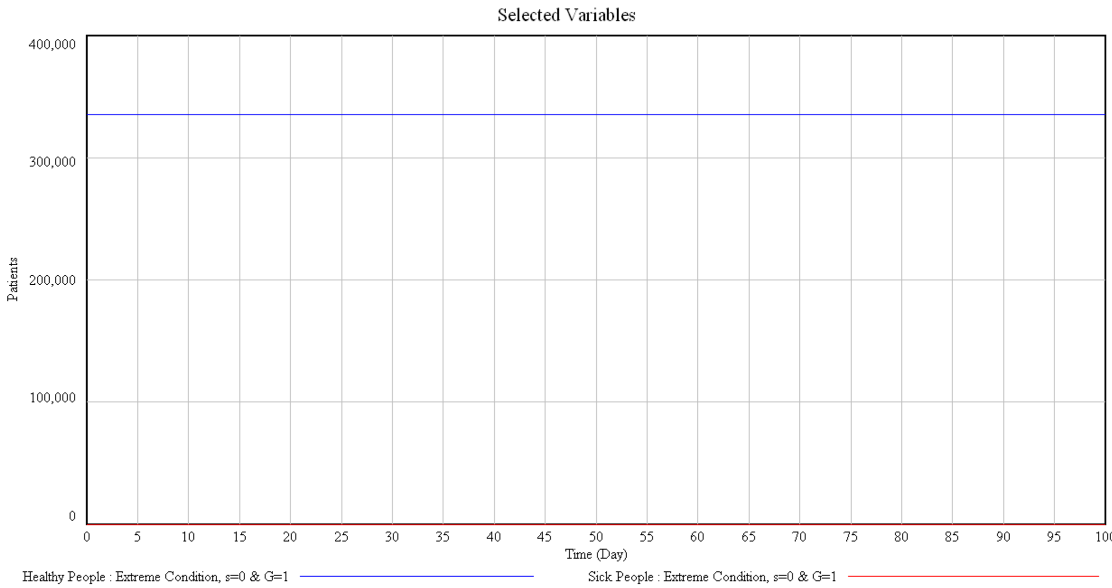
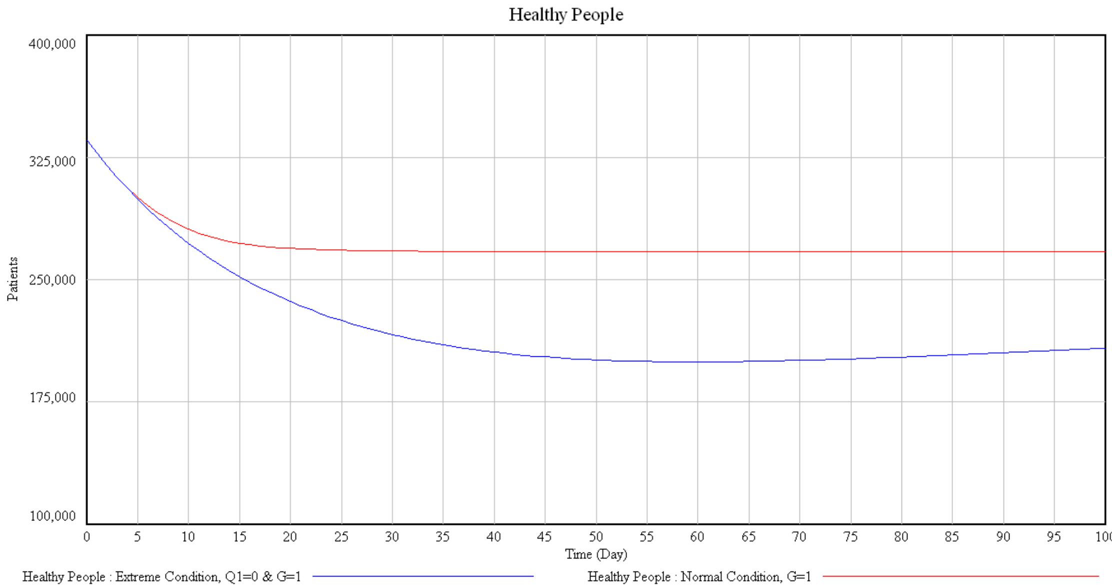
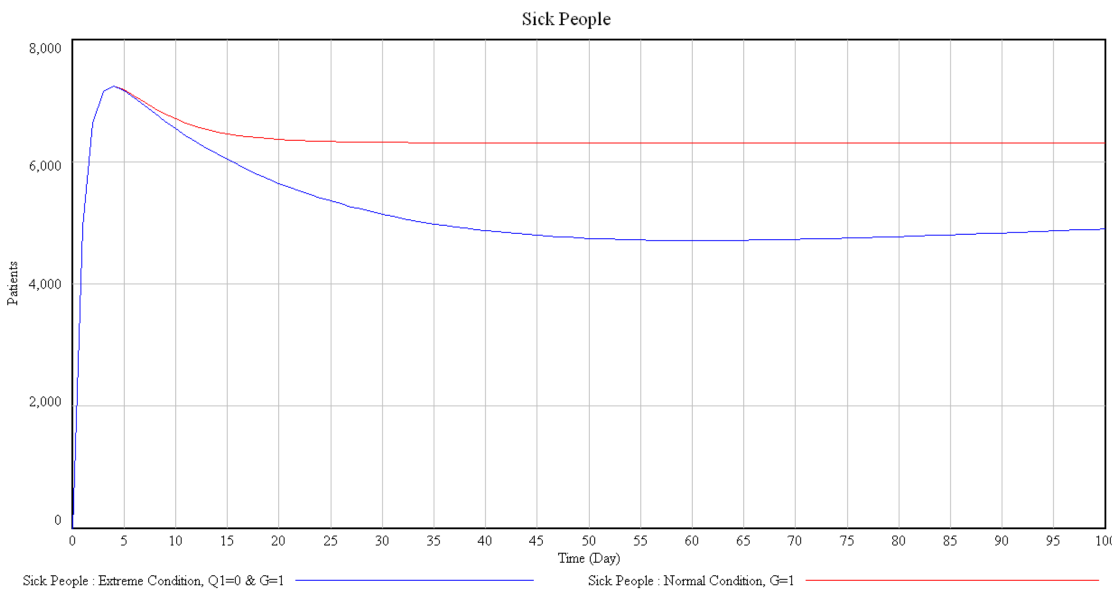


Figure 4.4: Sickness Fraction=0

will increase which can be understood from the decay in *Healthy People* stock and increase in *Waiting at Hospital* stock. Model shows that it works appropriately under this extreme condition.

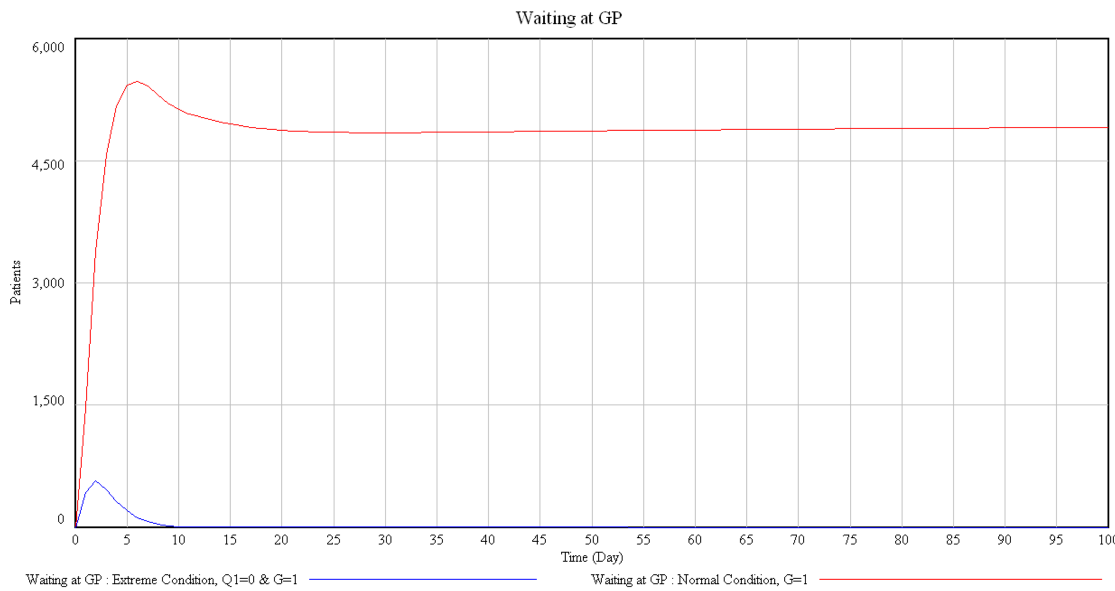


(a)

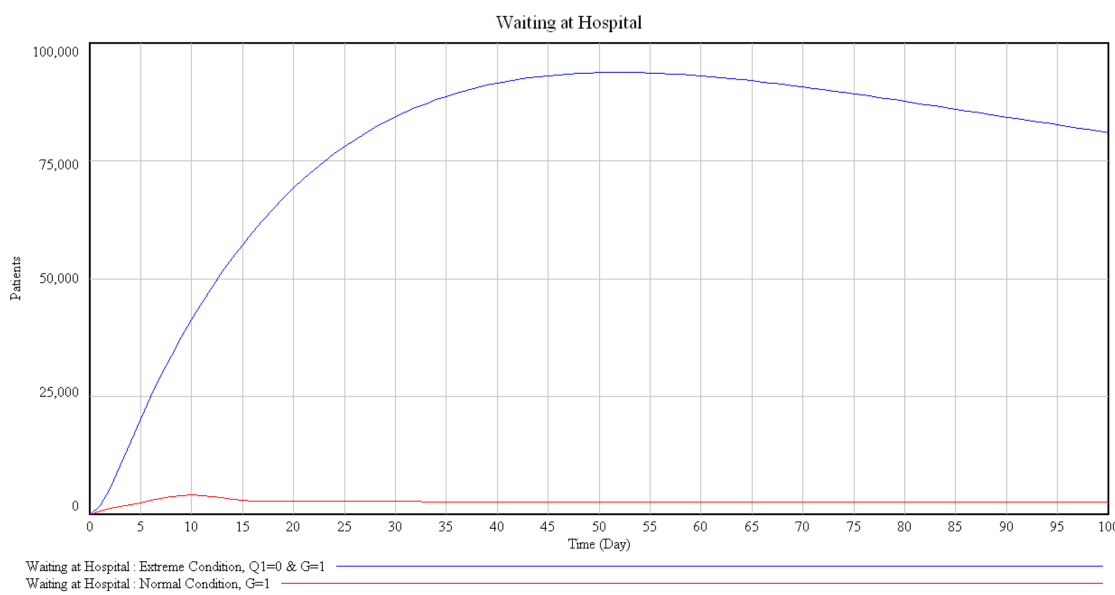


(b)

Figure 4.5: Number of General Practitioner=0

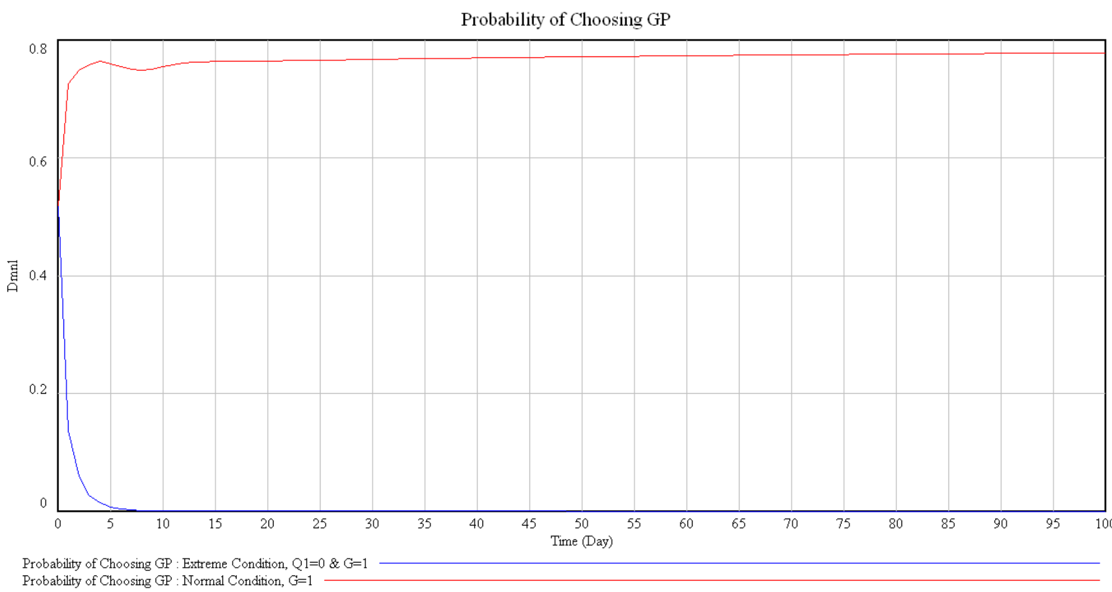


(c)



(d)

Figure 4.5: Number of General Practitioner=0 (cont.)



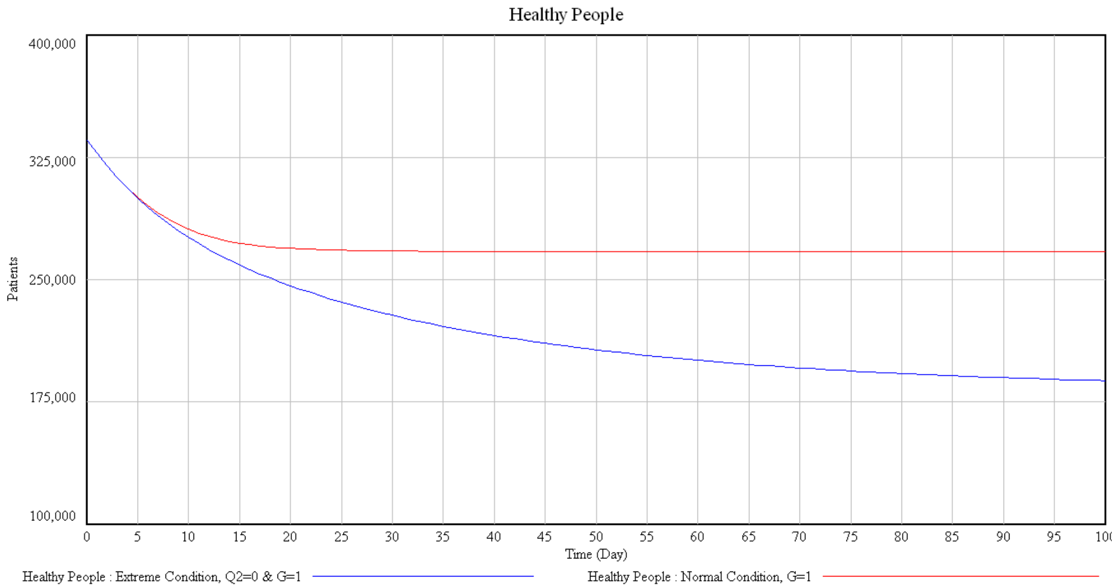
(e)

Figure 4.5: Number of General Practitioner=0 (cont.)

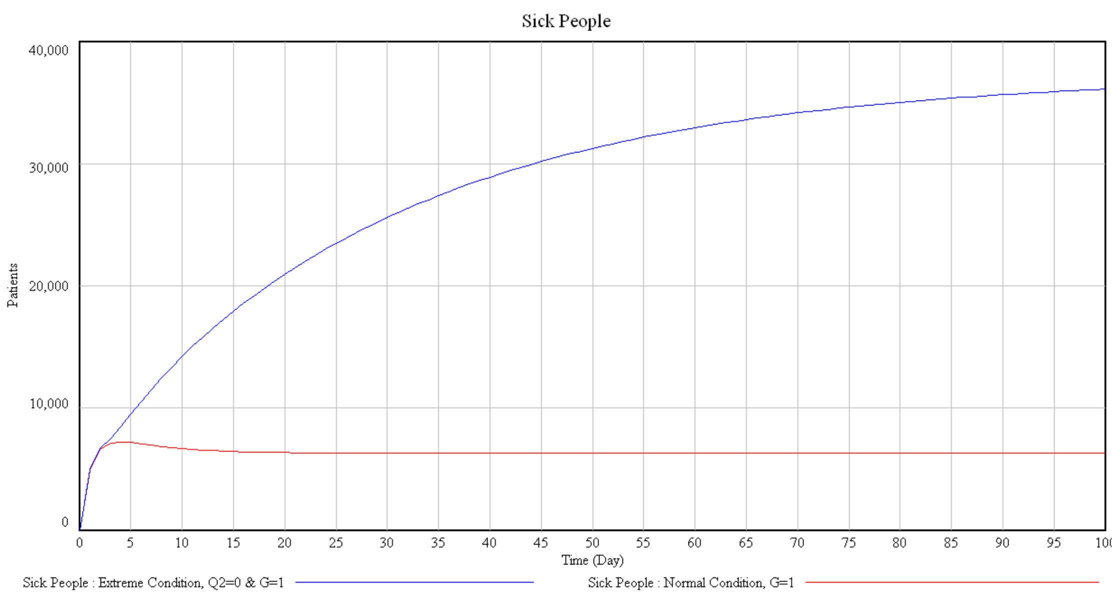
Number of Hospital Doctor=0

In this extreme condition, we are expecting to obtain an increase in *Probability of Choosing GP* than normal condition. As similar to the extreme condition in which number of general practitioner is zero, we are expecting to have less healthy people because of limited treatment capacity at general practitioner. When we run the model, it has been seen that our expectations are matching with the simulation output. Different from the zero general practitioner case, *Probability of Choosing GP* does not reach the value of 1 because of the trust to hospital although there are not any doctors at hospital. Patients prefer to go general practitioner more at the beginning and long waiting time causes reneging behaviour, i.e. patients leave the office, which causes a decay in the value of *Probability of Choosing GP* as seen in Figure 4.6(e). These patients prefer the hospital because of their past experiences at hospital. This further decreases the effect of trust to general practitioner, which increases the trust effect to hospital at the same time. Therefore, reneging affect the trust to hospital which results in *Probability of Choosing Hospital* equaling the value of 0.061 in steady state situation. As also seen in Figure 4.6, because of limited treatment availability at general practitioners, number of healthy people is decreased and these patients are waiting at general practitioners' office or at hospital as being sick. Finally, our model is also working properly under this extreme condition.

To conclude, our model is working properly under extreme conditions which have been explained above. This test increases the confidence of our model.

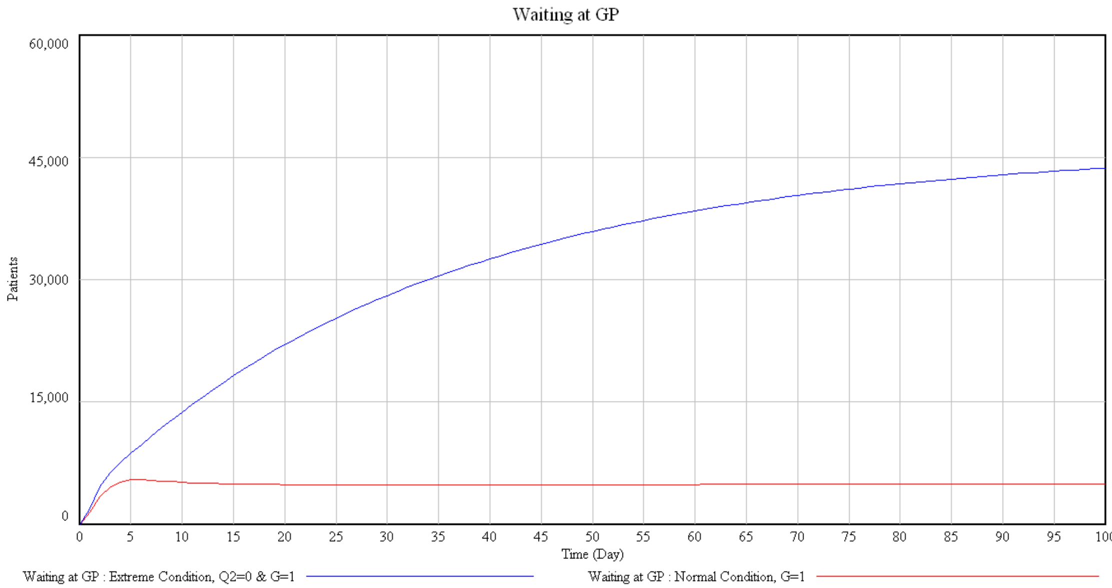


(a)

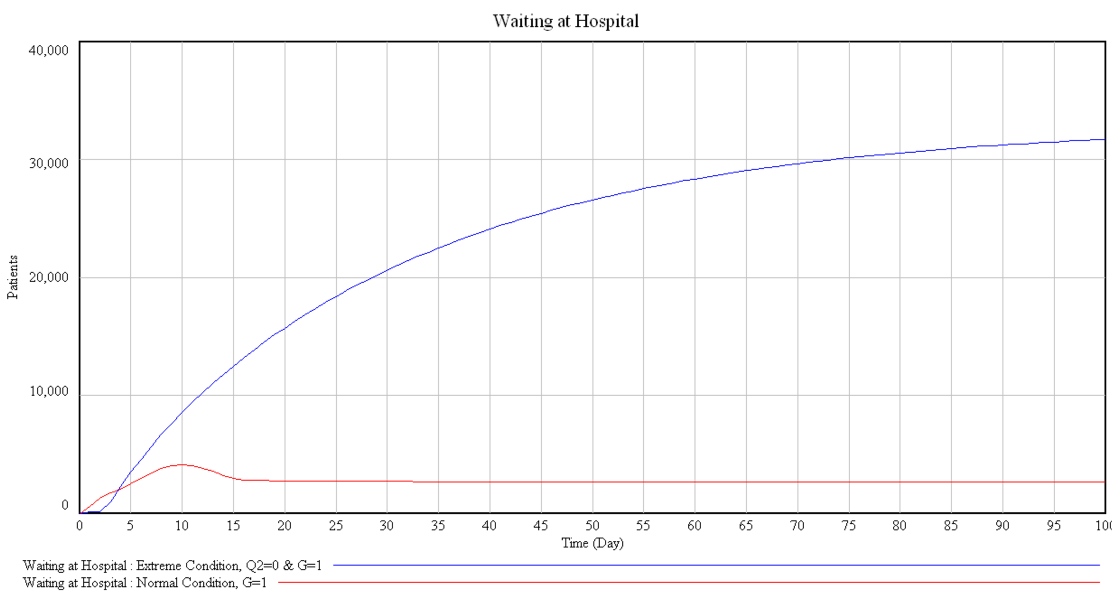


(b)

Figure 4.6: Number of Hospital Doctor=0

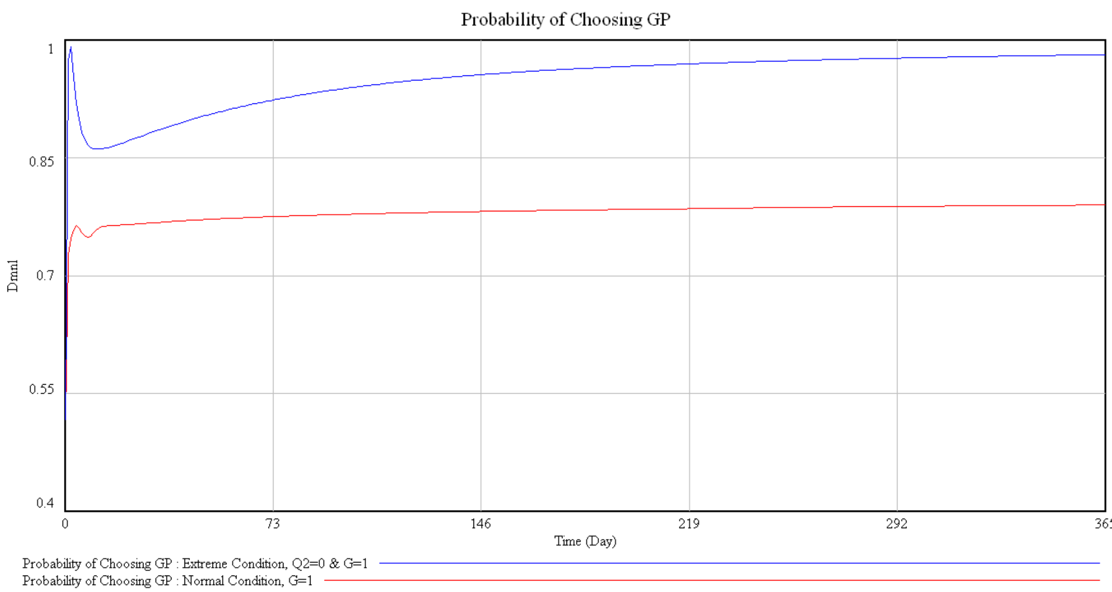


(c)



(d)

Figure 4.6: Number of Hospital Doctor=0



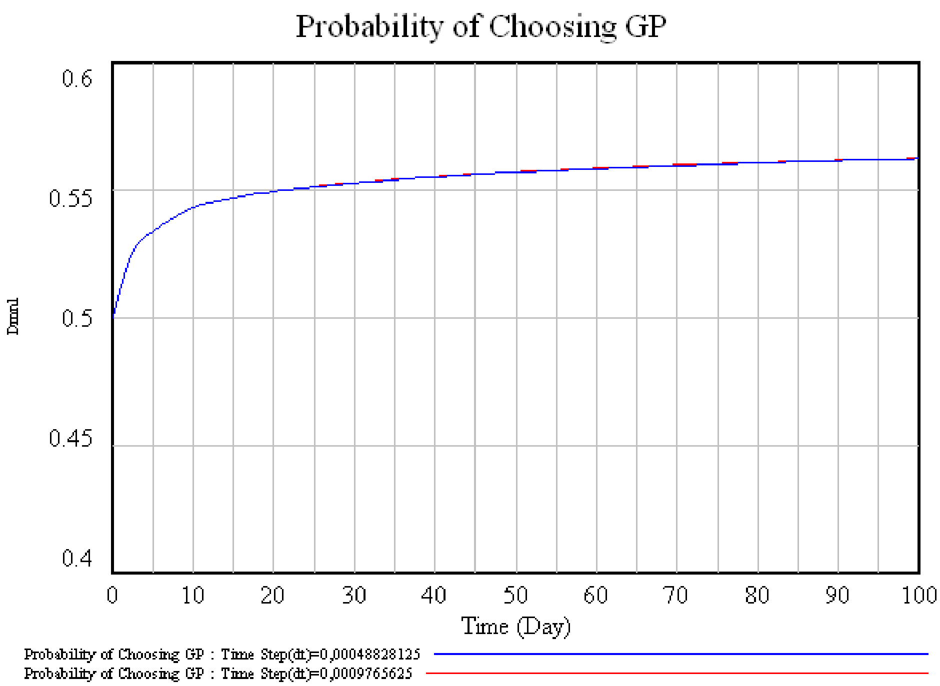
(e)

Figure 4.6: Number of Hospital Doctor=0 (cont.)

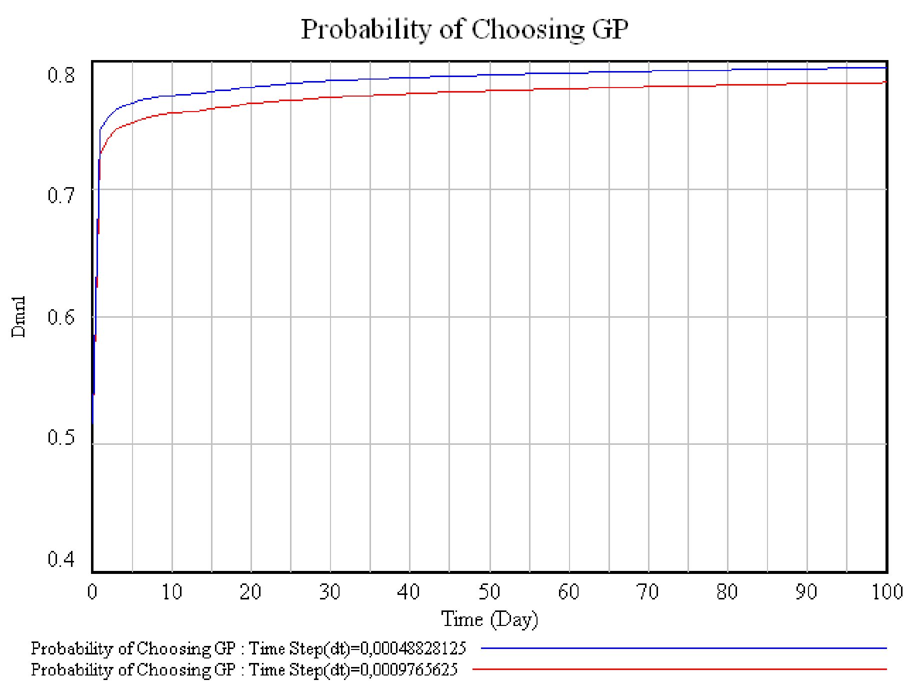
4.6 Integration Error Tests

Integration error test is the analysis of errors in the model which are based on the time step (dt). These errors can be also called as “DT error” and they are the result of wrong choice of time step or numerical integration method in the model. Because of formulating in continuous time, time steps have significant role in the system dynamic models. These errors can be controlled by cutting the time step in half until there are no changes at outputs in the model. Smaller time step means more accurate results since between the time steps, changes of rates will be same. This stability causes to obtain closer result to the continuous time solution. However, it should not be forgotten that smaller time steps causes more round-off and truncation errors in the model. To summarize, time step should be chosen between the one-fourth and one-tenth to the smallest time constant in the model to avoid these errors.Also, integration method has significant role on model’s behavior. Euler integration or higher-order Runge-Kutta integration are common methods at solving system dynamic models. Although, higher order Runge-Kutta integration has better results than Euler integration, Runge-Kutta needs continuity to estimate the average rate over subintervals. However, in system dynamic methods there are test functions as step and pulse, random noises or queuing-type elements which cause discontinuity in the model [18].

Thus, we are using Eular integration method in our model since we have test functions in our analysis. Also, smallest time constant has been chosen as $10/(24 \times 60) \cong 0.007$ day for normal service time and we have chosen time step as 0.0009765625 because of the range of the one-fourth and one-tenth to the smallest time constant. When we compare the result as seen in Figure 4.7, it seems that there are not any differences between the behaviour with half time step 0.00048828125. Simulation is run without and with gatekeeping policy and probability of choosing general practitioner is used for comparison. As a result, it is suitable to choose time step 0.0009765625 in the model and our model can pass the integration error test.



(a) Without Gatekeeping Policy



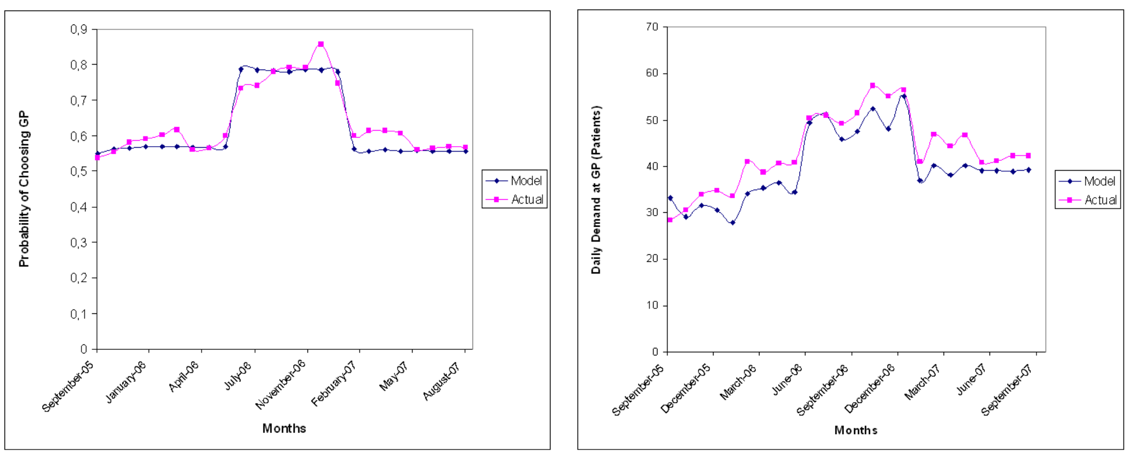
(b) With Gatekeeping Policy

Figure 4.7: Integration Error Test

4.7 Behaviour Reproduction Tests

The purpose of the Behaviour Reproduction Test is to expose the differences between the actual and simulated data in the model. It is more important to show these differences instead of showing point-by-point fitted data in the model since these differences show the incorrect or improper assumptions. Each differences or discrepancies should be discussed and solved until the remain discrepancies will not affect the model during the policy analysis [18].

For this test, we run our model with the sickness rate, population, referral probability and number of general practitioner from historical data month by month. It has been showed that simulated data and actual data do have not significant differences between each other, and this can be called a reasonable fit. Summary of the not significantly results and the comparison are shown in Table 4.2 and in Figure 4.8. We also conducted t-Test to check the confidence of the model. As seen from the values, differences are not significant which increases the confidence in our model's ability to replicate behaviour.



(a) Probability of Choosing GP (b) Daily Demand at GP

Figure 4.8: Behaviour Reproduction Test

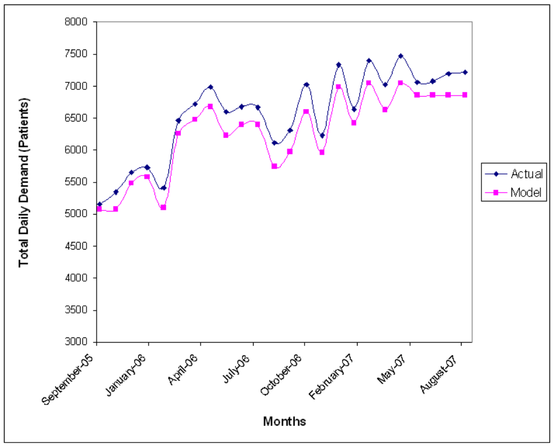
Table 4.2: Comparison of Model Generated and Actual Values

Months	Probability of Choosing GP		Daily Demand per GP		Daily Demand per Doctor at Hospital		Total Daily Demand	
	Model	Actual	Model	Actual	Model	Actual	Model	Actual
October-05	0,549	0,537	33,21	28,49	27,28	28,30	5077,76	5150,003
November-05	0,562	0,554	29,11	30,57	27,2	29,20	5073,84	5352,339
December-05	0,565	0,582	31,61	33,95	29,29	29,30	5488,49	5656,006
January-06	0,57	0,591	30,56	34,87	29,82	29,29	5578,27	5724,909
February-06	0,57	0,602	27,96	33,56	27,93	27,79	5103,34	5405,603
March-06	0,569	0,616	34,18	40,98	34,28	32,39	6251,07	6455,533
April-06	0,568	0,560	35,33	38,81	35,52	37,27	6469,32	6718,115
May-06	0,568	0,565	36,45	40,69	37,55	39,41	6678,06	6985,427
June-06	0,57	0,599	34,51	40,79	36,51	37,02	6235,43	6602,673
July-06	0,787	0,734	49,33	50,49	30,56	34,84	6393,58	6674,906
August-06	0,784	0,741	51,2	50,92	29,63	33,11	6401,45	6669,121
September-06	0,783	0,781	45,88	49,21	27,64	29,45	5742,86	6110,888
October-06	0,78	0,791	47,55	51,45	26,83	27,48	5977,05	6309,609
November-06	0,786	0,792	52,4	57,39	31,64	33,40	6603,34	7025,779
December-06	0,785	0,857	48,21	55,02	29,13	26,69	5960,3	6229,352
January-07	0,78	0,748	55,03	56,56	28,94	32,27	6989,29	7329,582
February-07	0,563	0,600	36,87	41,10	34,79	33,45	6421,04	6642,1
March-07	0,557	0,614	40,08	46,84	38,61	36,05	7049,85	7394,921
April-07	0,56	0,613	38,28	44,39	36,15	34,28	6634,39	7020,379
May-07	0,557	0,607	40,08	46,78	38,61	36,85	7049,85	7472,545
June-07	0,558	0,561	39	40,85	36,21	37,25	6853,6	7066,421
July-07	0,557	0,565	39	41,22	35,43	35,90	6859,85	7073,661
August-07	0,557	0,569	38,99	42,24	35,04	35,90	6862,96	7197,297
September-07	0,556	0,569	39,34	42,33	35,09	35,90	6862,97	7220,524
Mean	0,627	0,640	39,76	43,31	32,49	33,03	6275,748	6561,987
Std. Dev.	0,10297	0,09532	7,61441	7,90937	4,00473	3,74866	639,085	686,253
t_{23}**(0.05)=2.069**	**-0.4487**		**-1.5866**		**-0.4888**		**-1.4954**	

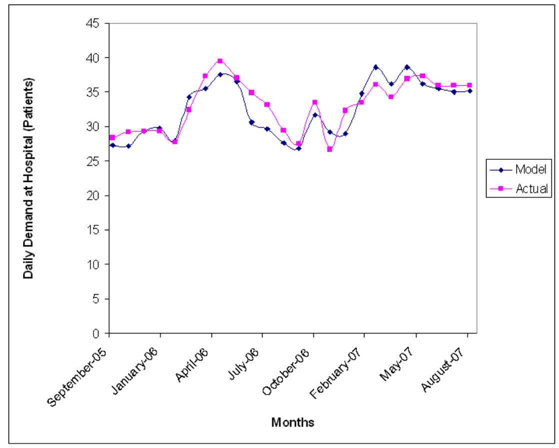
4.8 Behaviour Anomaly Test

Loop knockout analysis is the method for revealing the anomalous behavior of the model with deletion of the important relationships or formulations in the model. Therefore, the significance and strength of the loops can be determined and plausible ranges for the parameters and relationships can be established to overcome the data limitations. Generally, extreme conditions are used in loop knockout analysis during the simulation under historical data since inactive loops under normal operating conditions can become significant under extreme conditions. This significance show that these loops should be included in the model.

In our model, we eliminated the trust, service quality and waiting time effect loops which defines the probability of choosing general practitioner or hospital. As seen in Figure 4.9,



(c) Total Daily Demand



(d) Daily Demand at Hospital

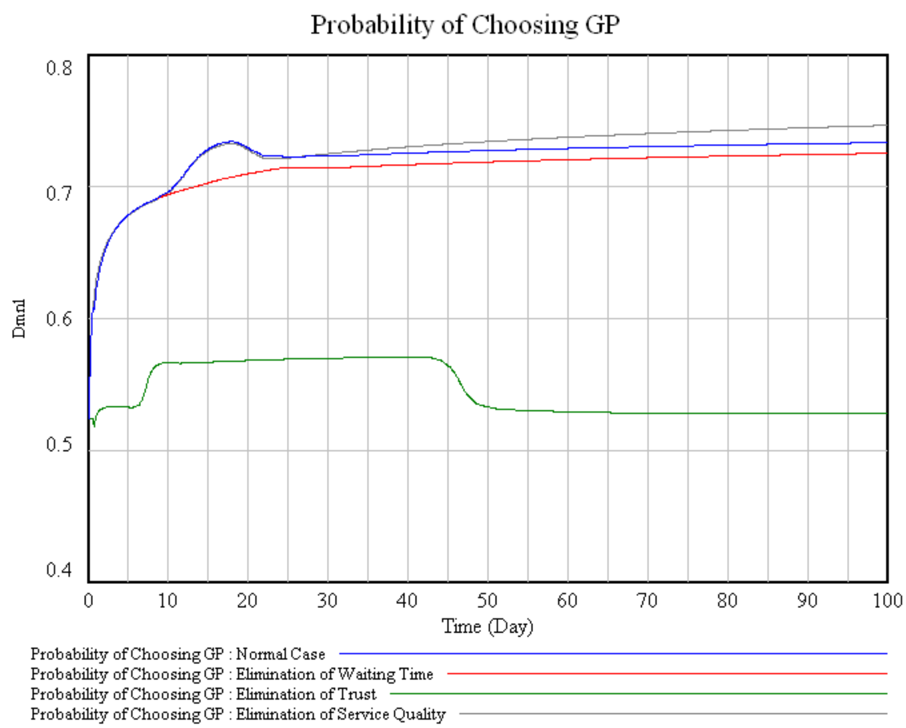
Figure 4.8: Behaviour Reproduction Test (cont.)

trust effect loop is the strongest loop in the model when the behavior is compared with normal conditions. Waiting time loops also have impact on the behavior, however service quality is not as strong as the others. As seen in Figure 4.9, elimination of the service quality does not change the behaviour however it affects the output data of the model. As a result, all effects in our model should be included in the model because of their strength in the model.

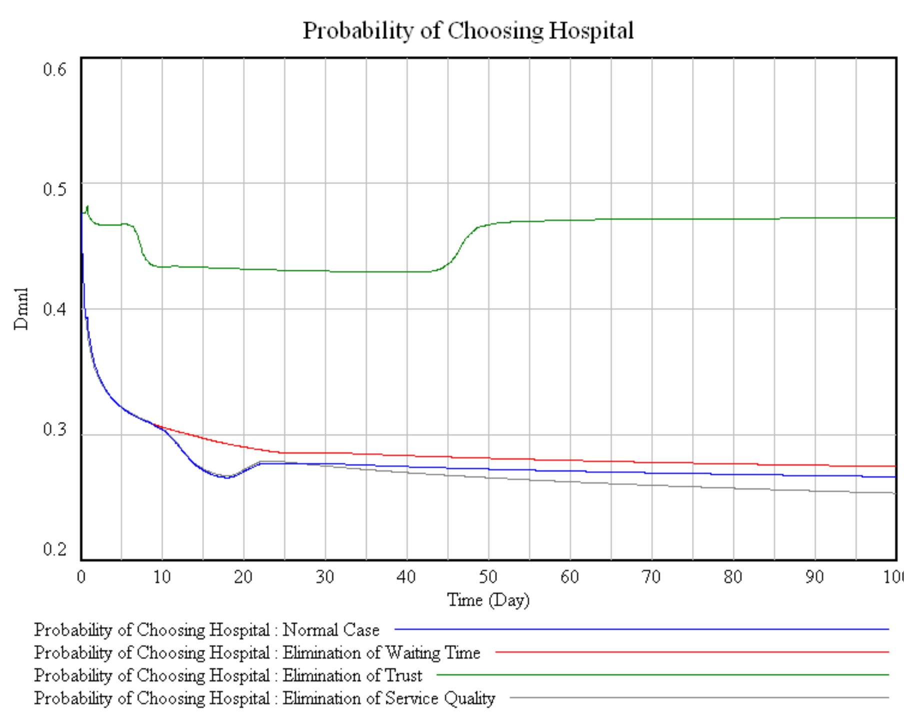
4.9 Family Member Tests

Family member test is the method to show that model can behave in different mode when the parameters or policies have been changed [18]. Model which can reveal single mode of behaviour under different parameters cannot reflect a behaviour of general model of class of the system since general models have particular members with different parameter values [18], [20].

Our model is developed with the parameter values from city Düzce. However it can be applied to another city with different initial values and parameter values in Turkey since



(a) Test for General Practitioners



(b) Test for Hospitals

Figure 4.9: Behaviour Anomaly Test

two-tier healthcare system is general system valid in Turkey.

4.10 Surprise Behaviour Tests

There can be differences between the behaviour of the model and expectations because of the defects at mental model or formal model. These flaws can be the result of interpreting the data inaccurately and they need revision. The surprise behaviour test helps to find the unexpected behaviour in the model, generally when it is not recognized before although it occurs in the real system. For an effective surprise behaviour test, all variables in the model should be analyzed to find the unexpected behaviour and to overcome the problems [18]. When a surprise behaviour is recognized in the model, it increases the confidence of the model [20]. We analysed our model by checking the variables and we could not find any suprise behaviour.

4.11 Sensitivity Analysis

Sensitivity analysis is the method for understanding the robustness of your model due to the assumptions in the model. Therefore, by the help of this analysis, a plausible range of uncertainty for your assumptions can be defined. This analysis can be in three types: numerical, behaviour mode and policy sensitivity. In numerical sensitivity, numerical results change due to the changed assumptions. In behaviour mode sensitivity, assumptions will change the pattern of behaviour mode and finally in policy sensitivity, changing assumptions eliminate the effect of policy. Types of the sensitivities are based on the aim of the model. Generally, behaviour mode and policy sensitivity have significant role in the analysis [18].

In our model, we analyze all our assumptions to see their effects on the results of the model. Explanations for these sensitivity analysis are as follows:

Sensitivity Analysis for "Average Time to be Healed"

We estimate this average time to be healed as 7 days in the model. However, we want to see its effect on the model when we change its interval between 1 and 30 days. As we expect (see Figure 4.10), stock of *Number of Healed People* is influenced directly from the delay which also affects numerical results of the total daily demand for treatment. Thus the number of waiting list at general practitioner is affected too. However, it does not change any behaviour pattern in the model and has nearly no effect on *Probability of Choosing GP* which means this estimation can be acceptable for the model.[1]

Sensitivity Analysis for "Average Acceptance Time to GP"

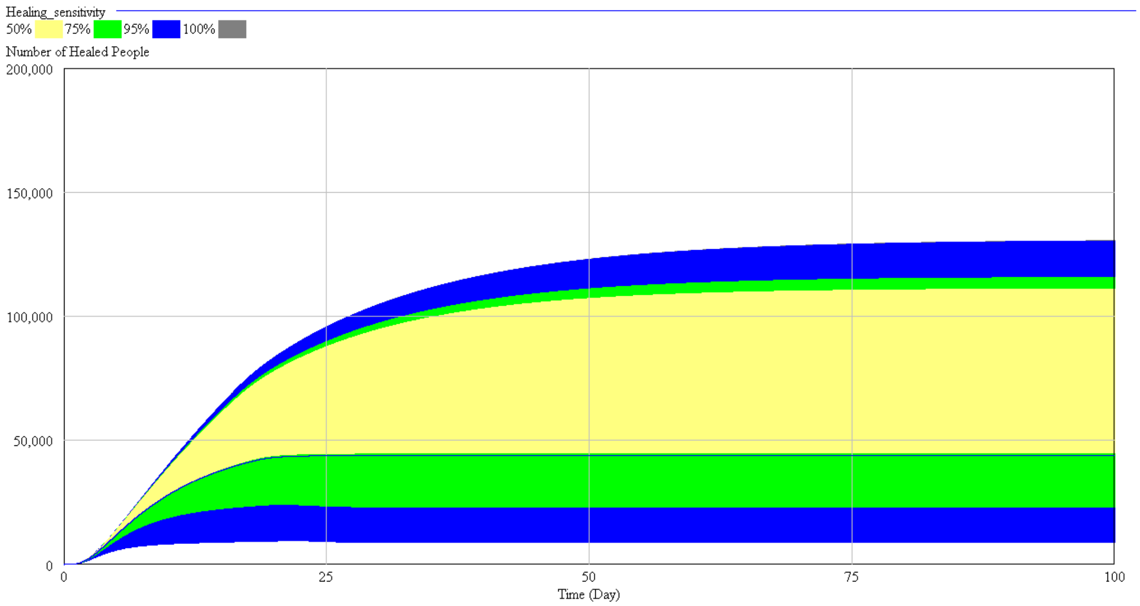
We estimate *Average Acceptance Time to GP* as 1 day in the model and change its range between 10 minutes to 2 days. It should be noted that it is one of the important parameters since it affects waiting time and service quality loops for general practitioners. Therefore, we expect the model to be really sensitive to this parameter. As seen in the Figure 4.11, numerical results are changing directly in the wide range as the value of *Average Acceptance Time to GP* changes. However, its effect on dynamic behaviour pattern remains the same. To conclude, the model is sensitive to this parameter due to the changes in assumptions and we are assuming it as 1 day in the model.

Sensitivity Analysis for "Average Acceptance Time to Hospital"

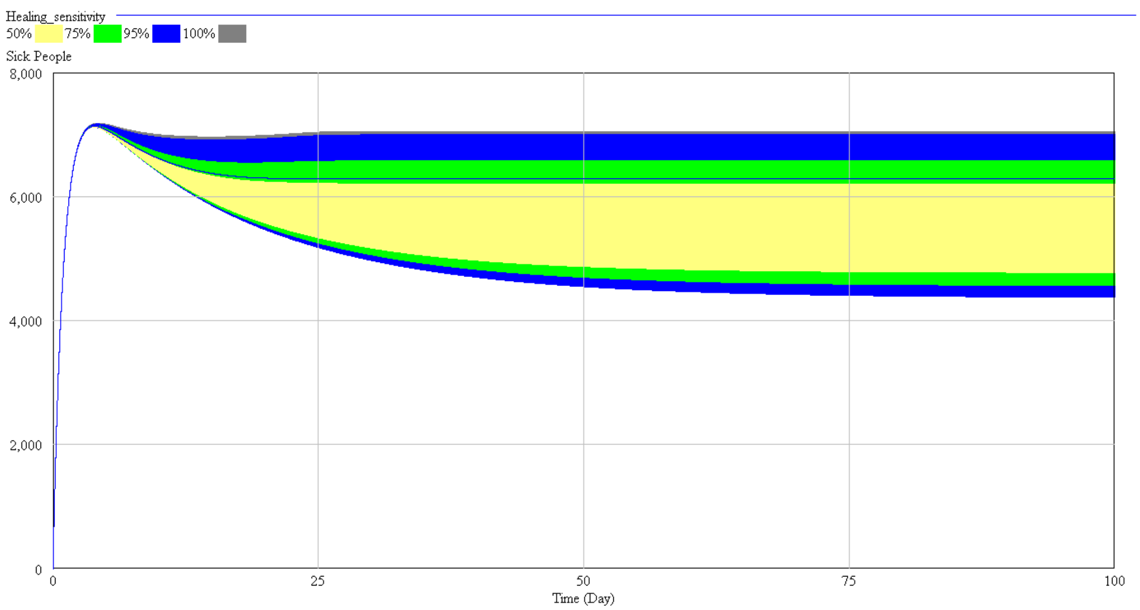
Model should be also sensitive to parameter *Average Acceptance Time to Hospital*, since it also affects waiting time and service quality loops for hospital directly. As seen in Figure 4.12, it affects the *Waiting at Hospital* stock in a wide range. At the same time, it saves its behaviour pattern. However, *Probability of Choosing GP* is being affected in small range. We also know this probability influences the number of patients at *Waiting at GP* and *Treatment at General Practitioner* stocks. These stok values are changing in small ranges in the sensitivity analysis. As a result, this parameter is really important in the model because of its effect on *Waiting at Hospital* stock.

Sensitivity Analysis for "Leaving GP Fraction"

[1]Simulation results are displayed in confidence bounds as seen in figures. Each colour represents just one confidence bounds where yellow is 50%,green is 75%, dark blue is 95% and grey is 100%. Simulations runs are sampled and ordered at each computed time. For example, 1/4 of the simulation runs at 50% confidence bound have a value bigger than top of the bound and 1/4 of the simulaiton runs have value lower than bottom of the bound [23].

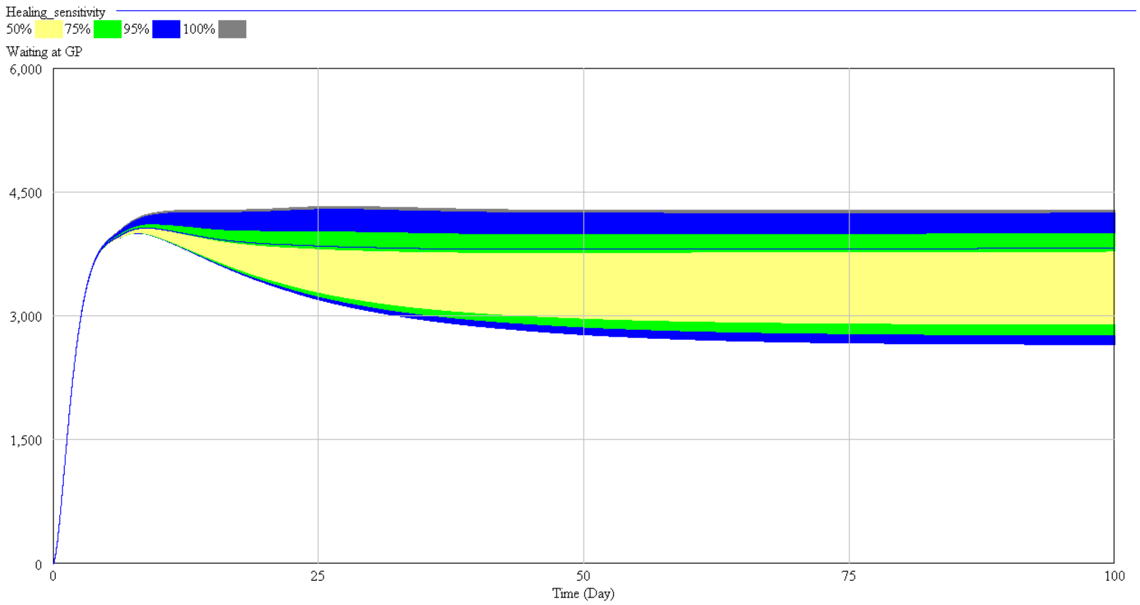


(a) Number of Healed People

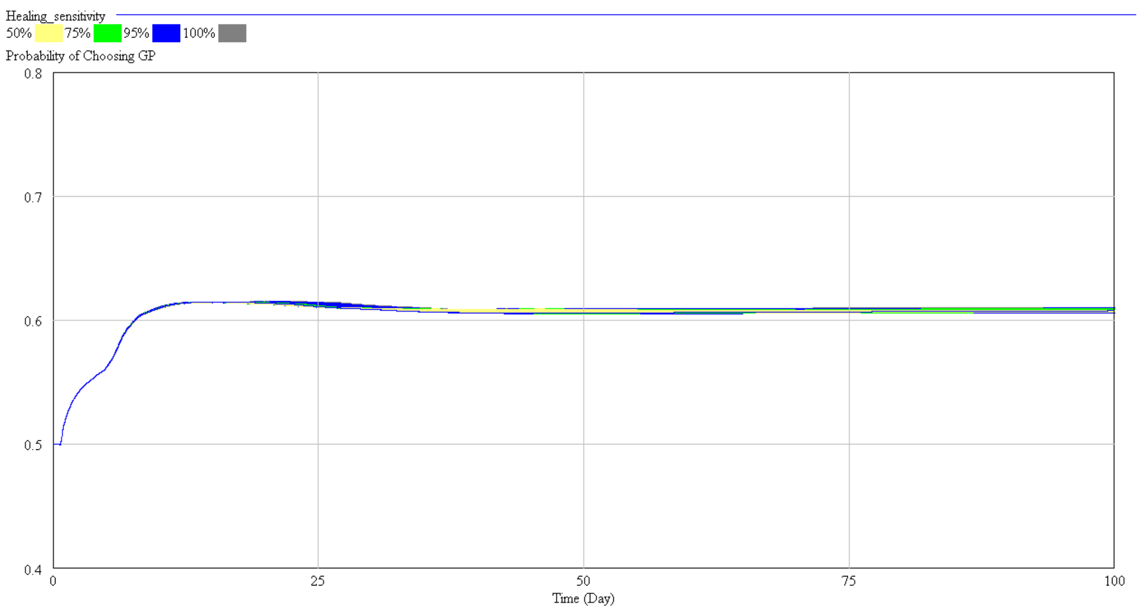


(b) Sick People

Figure 4.10: Sensitivity Analysis for "*Average Time to be Healed*"

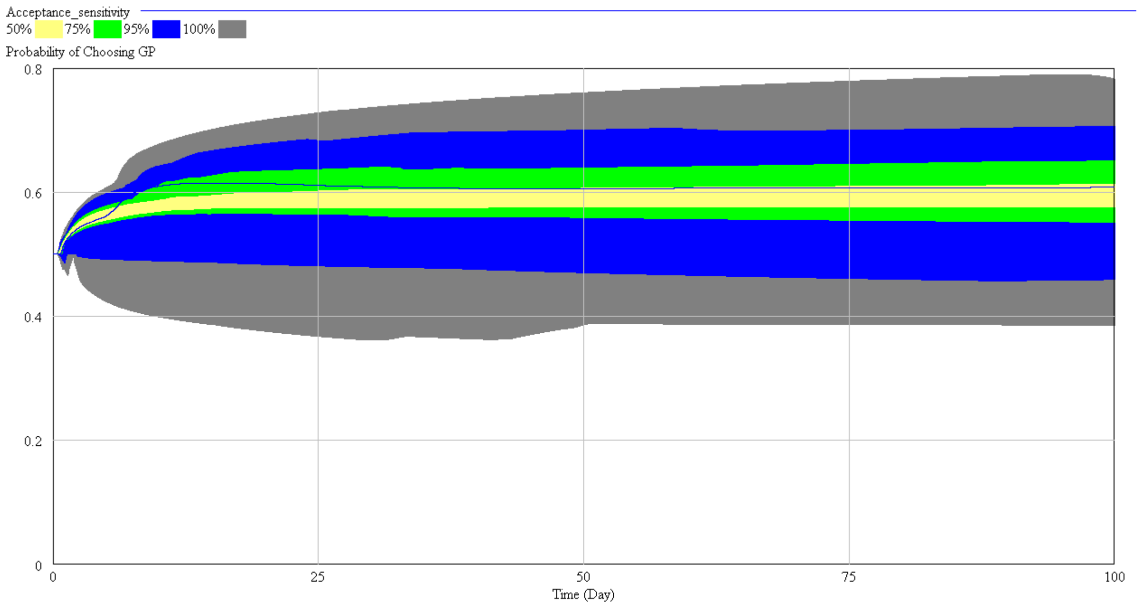


(c) Waiting at GP

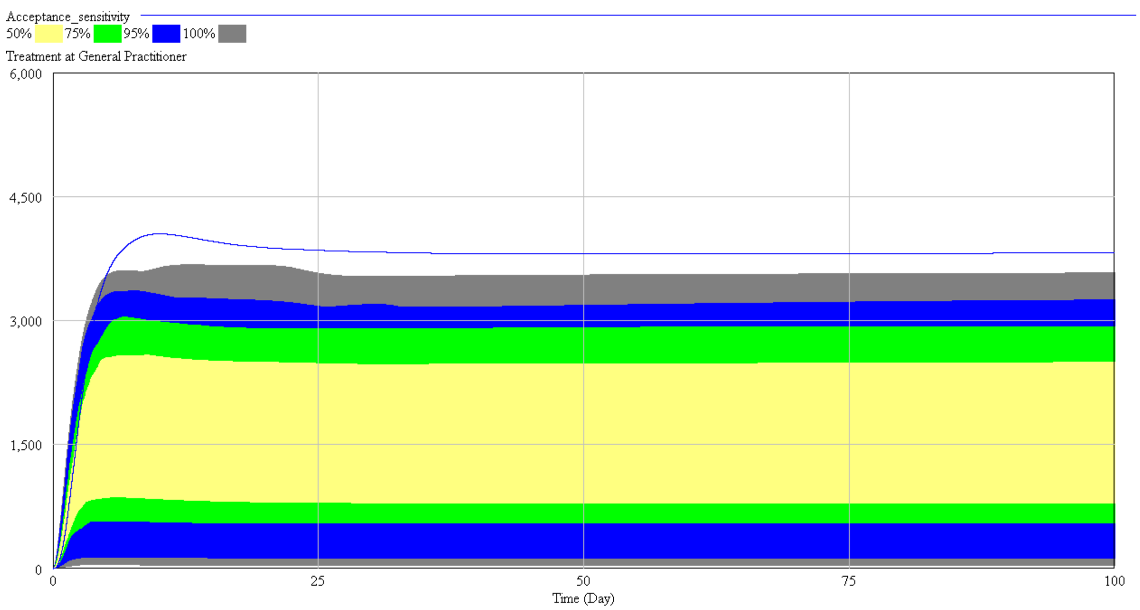


(d) Probability of Choosing GP

Figure 4.10: Sensitivity Analysis for "*Average Time to be Healed* (cont.)"

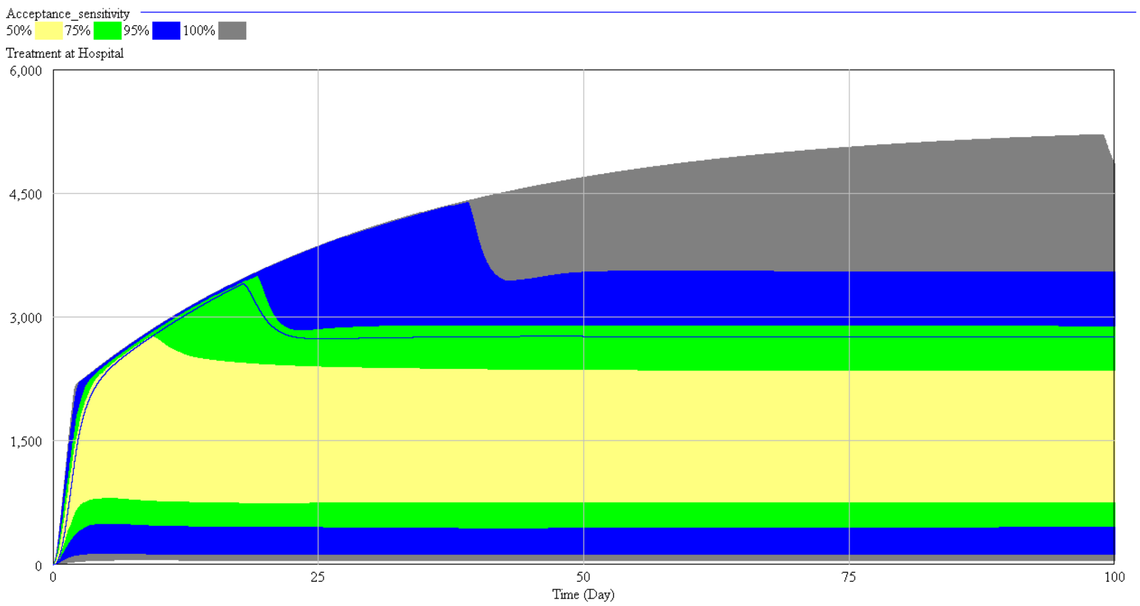


(a) Probability of Choosing GP

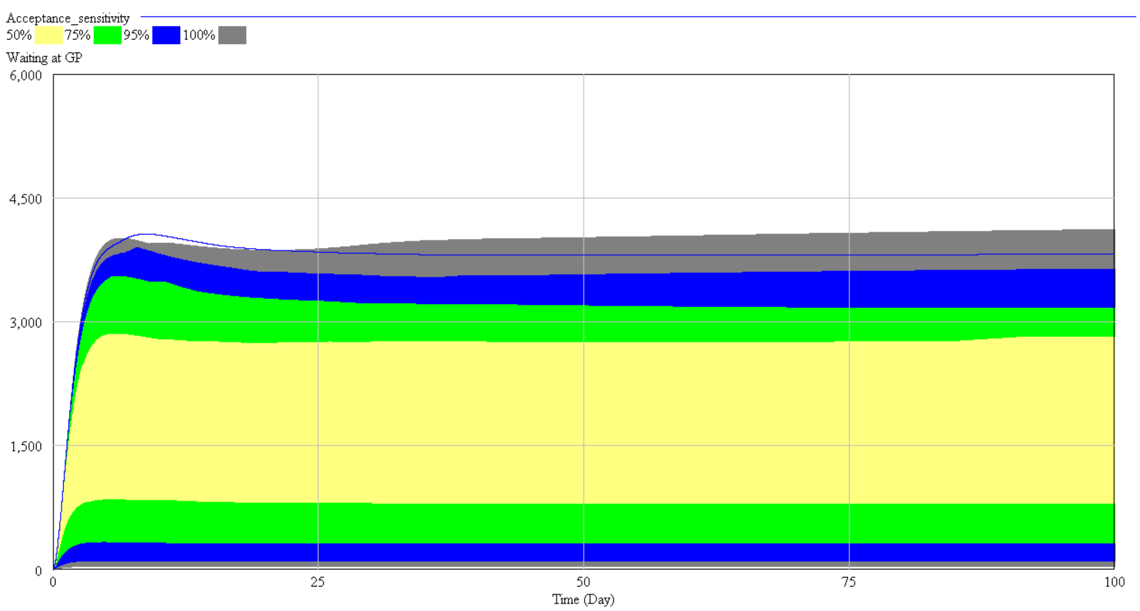


(b) Treatment at GP

Figure 4.11: Sensitivity Analysis for "*Average Acceptance Time to GP*"

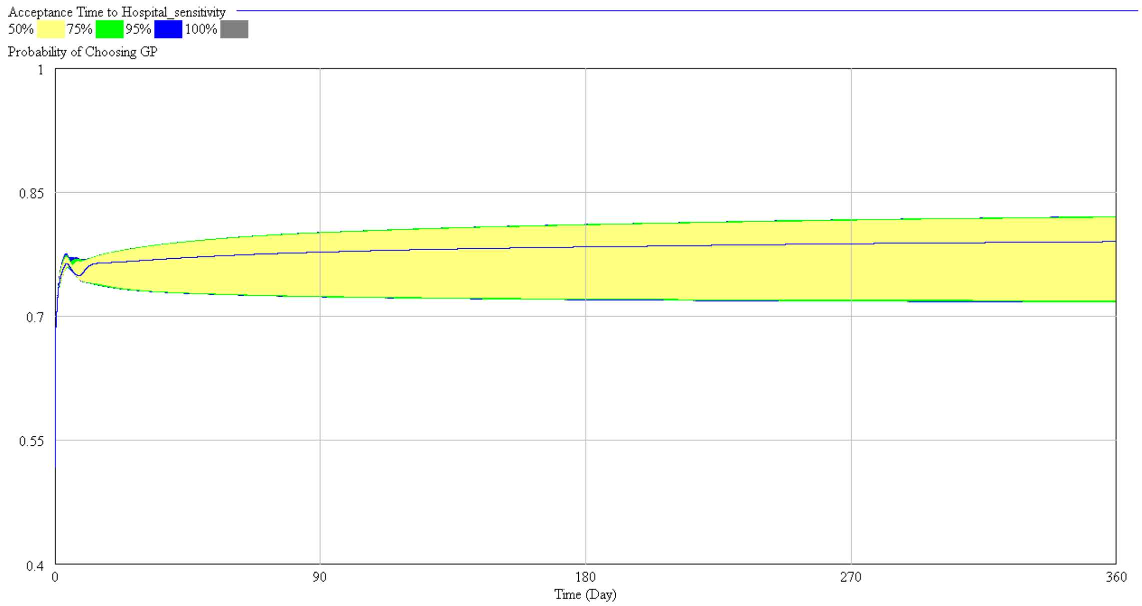


(c) Treatment at Hospital

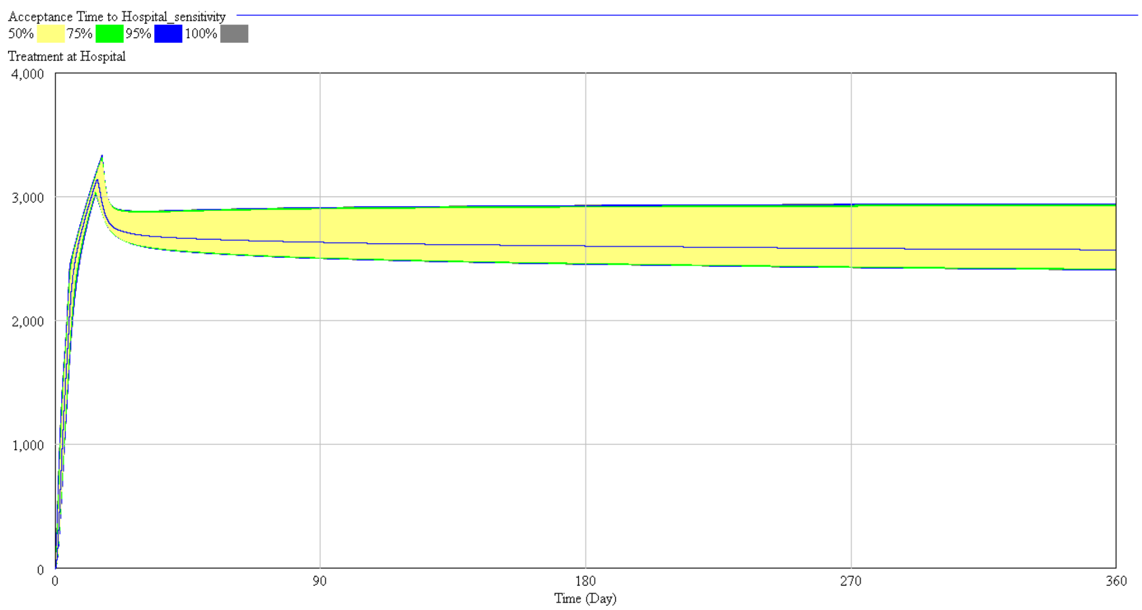


(d) Waiting at GP

Figure 4.11: Sensitivity Analysis for "*Average Acceptance Time to GP*"

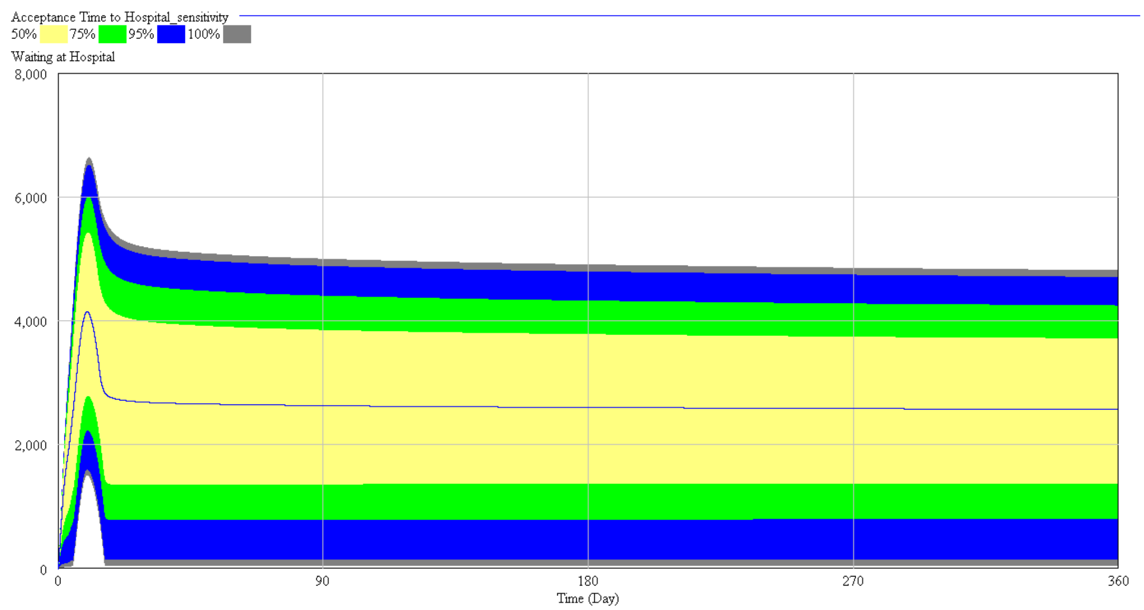


(a) Probability of Choosing GP

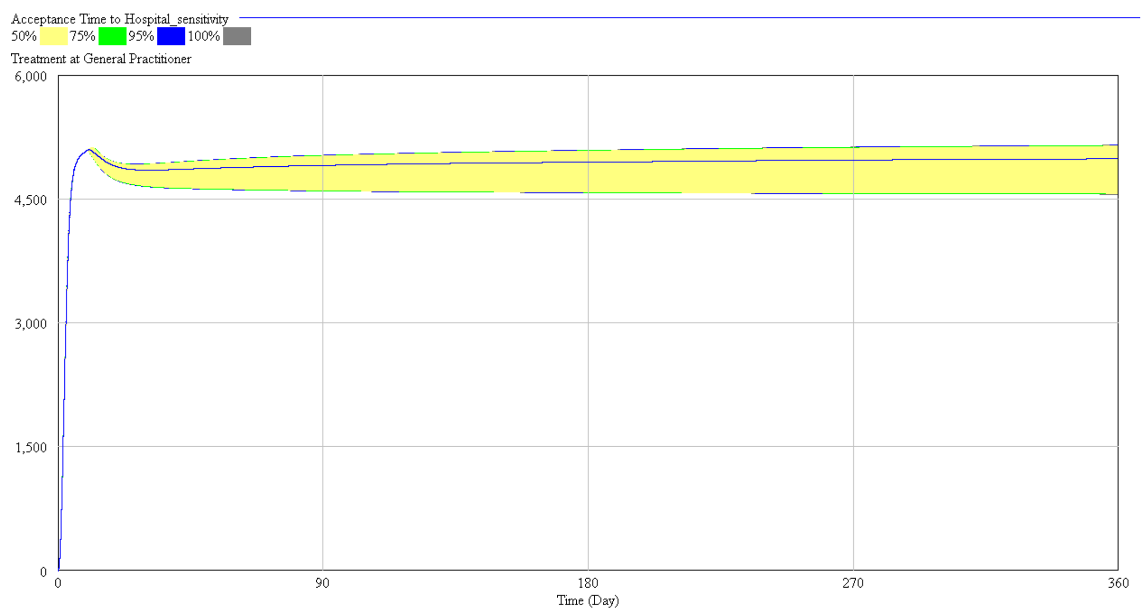


(b) Treatment at Hospital

Figure 4.12: Sensitivity Analysis for "*Average Acceptance Time to Hospital*"



(c) Waiting at Hospital



(d) Treatment at GP

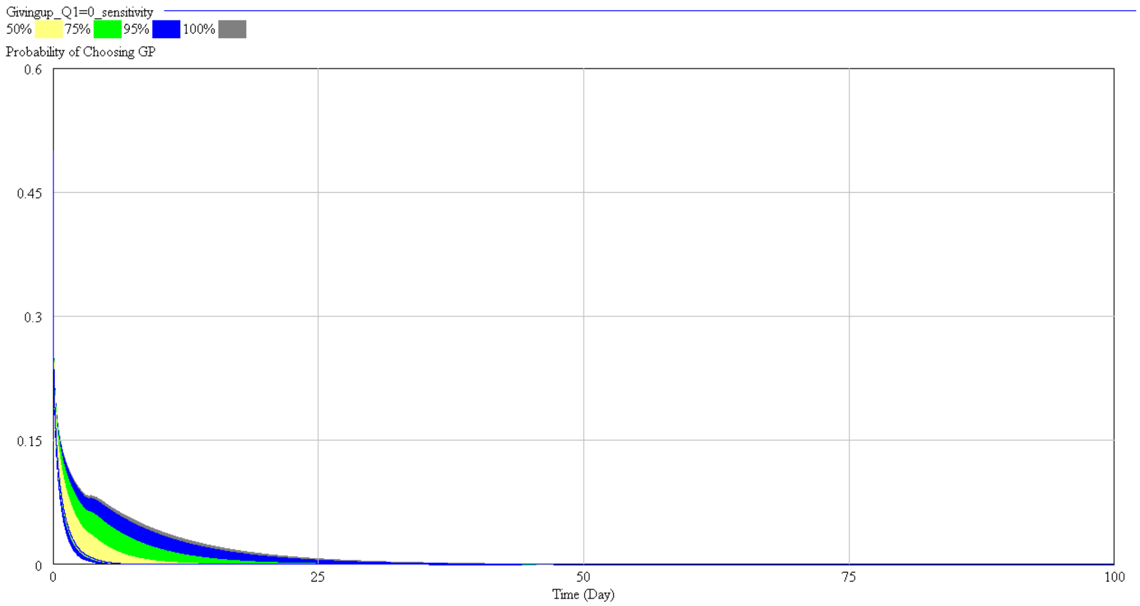
Figure 4.12: Sensitivity Analysis for "*Average Acceptance Time to Hospital*" (cont.)

Leaving GP Fraction has significant role on patients' decisions for treatment since the flow of *Giving up Rate* influences directly the value of trust effects for hospital and general practitioners. In the base case, when the system runs with the average values of Düzce, we observe the effect of this parameter only at the beginning since the system has enough doctors and treatment capacity in steady-state. In order to see the sensitivity of the model to this parameter, we decrease the number of general practitioners and hospital doctors. We define the number of general pratitioner and hospital doctors as 0 and 25 respectively as extreme conditions. As seen in the Figure 4.13, it is obvious that numerical results do not change the value for *Probability of Choosing GP* at steady state position, they just change the values at the beginning of the simulation with the same behaviour pattern. The value of the *Waiting at GP* stock is based on *Leaving GP Fraction* in the model since changes of this parameter directly affects the stock (see Appendix B). Although, probability values have small changes in the run, *Waiting at GP* stock changes in a wide range at the beginning. However it reaches same value at steady-state situation. Also stock of *Waiting at Hospital* is being affected from the value of this parameter as seen in Appendix B. When we compare the results at *Waiting at GP* and *Waiting at Hospital* stock, it is seen that in the case of zero hospital doctor, numerical results change in a wider range.

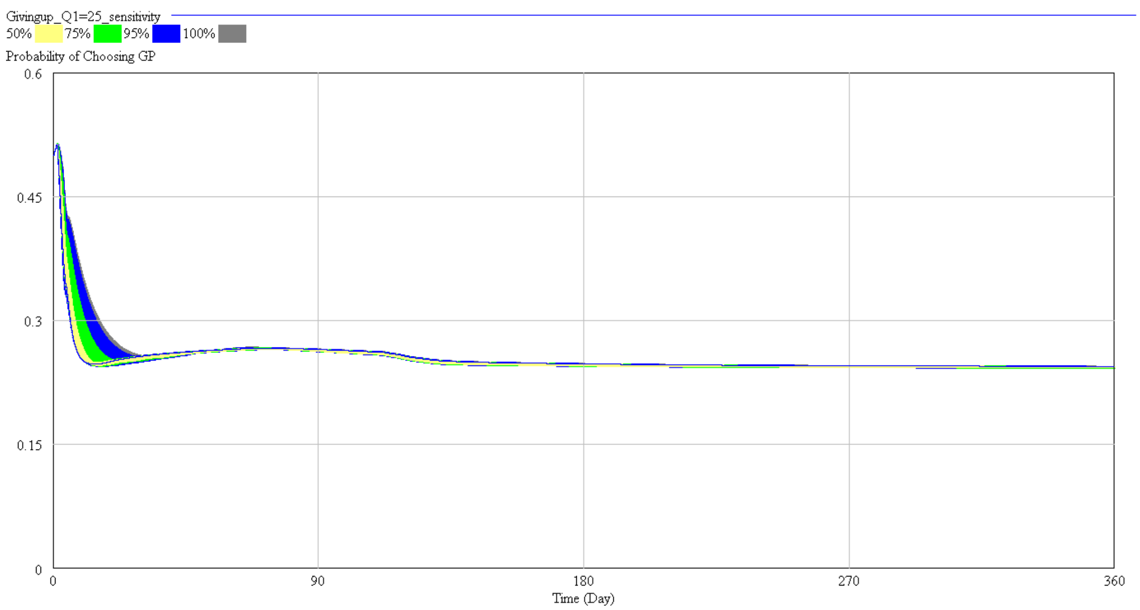
If we look at the sensitivity of this parameter only cases -without changing number of doctors- , we see that numerical values change in a small range while behaviour pattern is the same (see Figure 4.14). As a result, we can accept this parameter as 0.75 which is not sensitive in case of the changes under normal conditions.

Sensitivity Analysis for "Referral Probability"

In our model, we use fixed values of *Referral Probability* as 0.076 and 0.25 depending on the existence of gatekeeping policy. This values are estimated from data of Düzce which is mentioned above in Section 4.4. However, it is obvious that there is a huge difference between the values. We change the value of *Referral Probability* in the range (0.076, 0.25) when there is gatekeeping policy, to see the sensitivity at numerical results. As seen in Figure 4.15, behaviour of the model has not changed however numerical results are different. If we

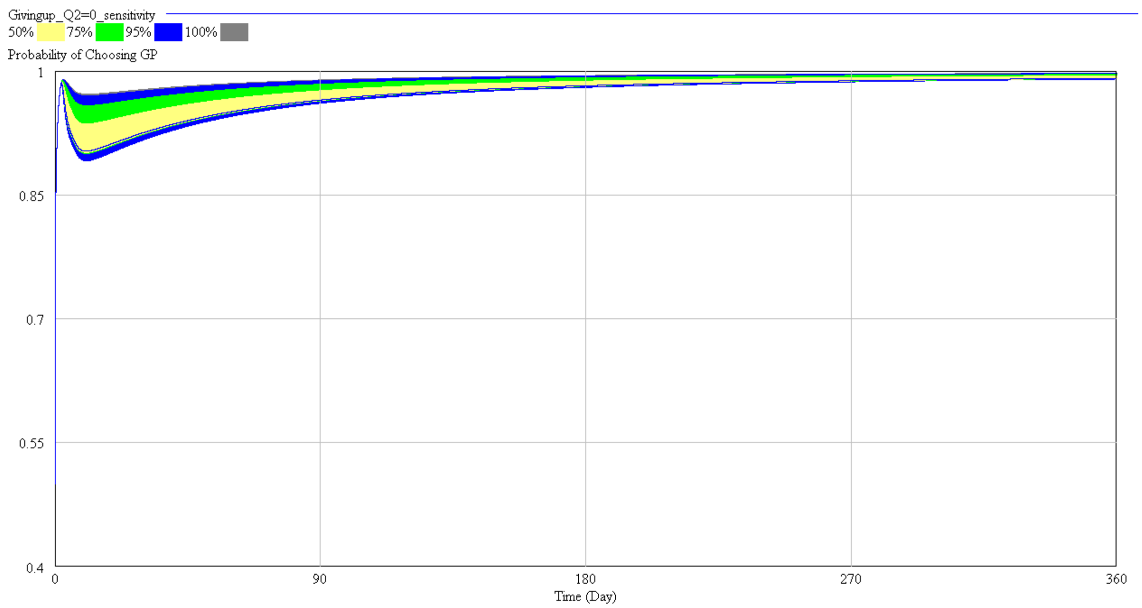


(a) Probability of Choosing GP(Q1=0)

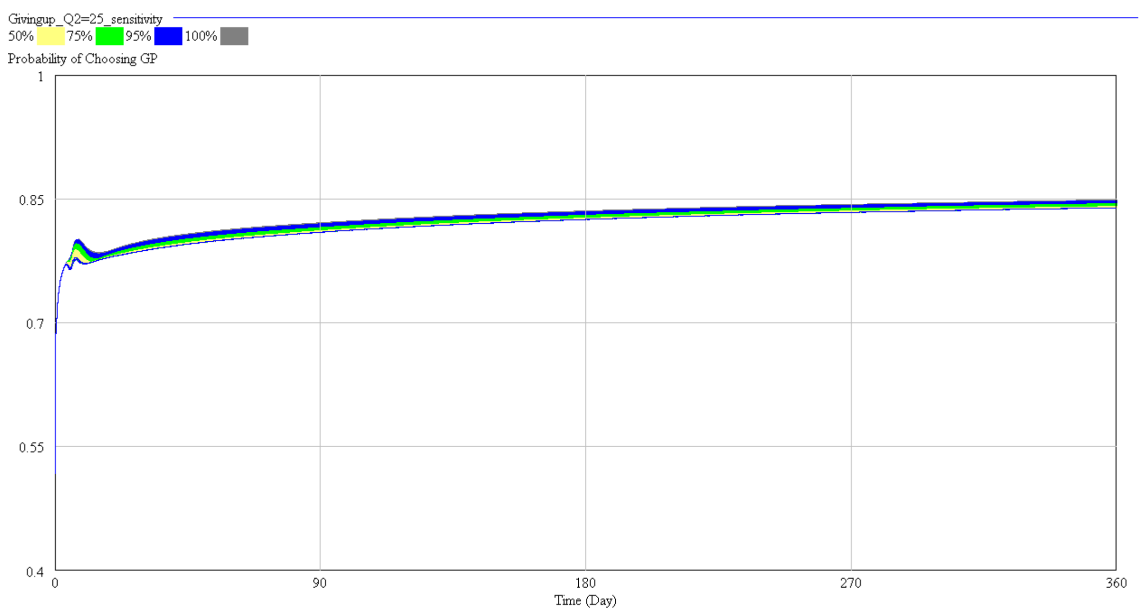


(b) Probability of Choosing GP(Q1=25)

Figure 4.13: Sensitivity Analysis for "*Leaving GP Fraction*"

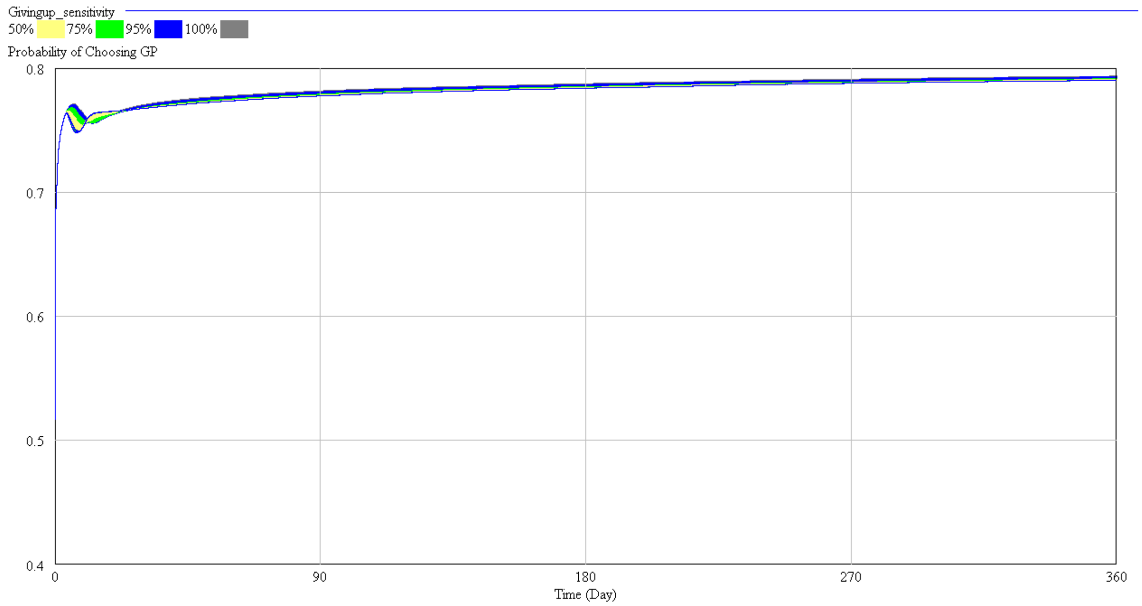


(c) Probability of Choosing GP(Q2=0)

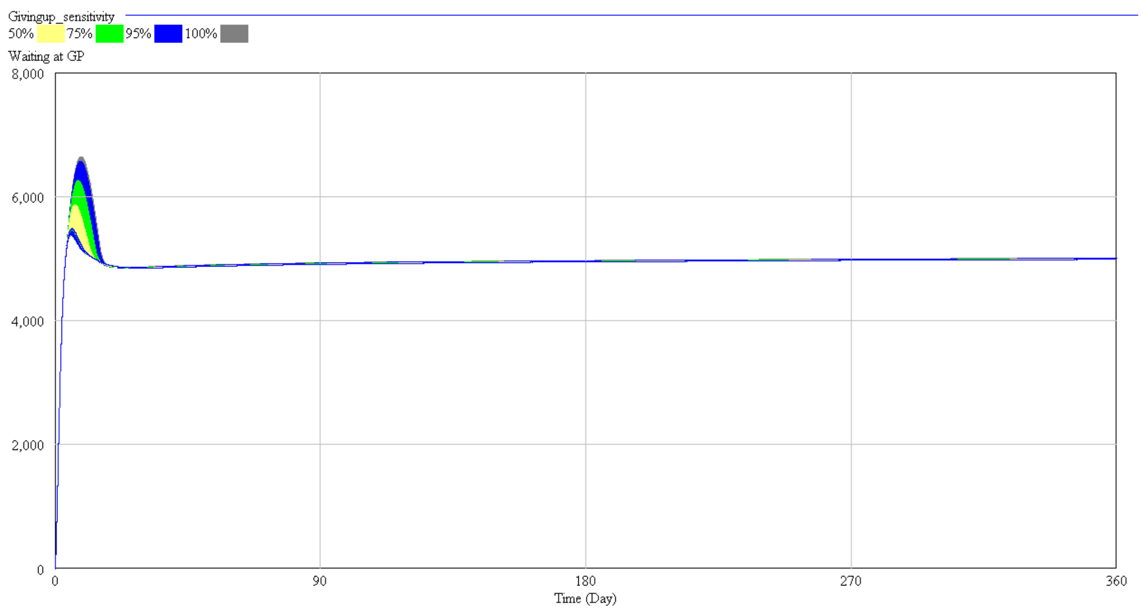


(d) Probability of Choosing GP(Q2=25)

Figure 4.13: Sensitivity Analysis for "*Leaving GP Fraction*" (cont.)

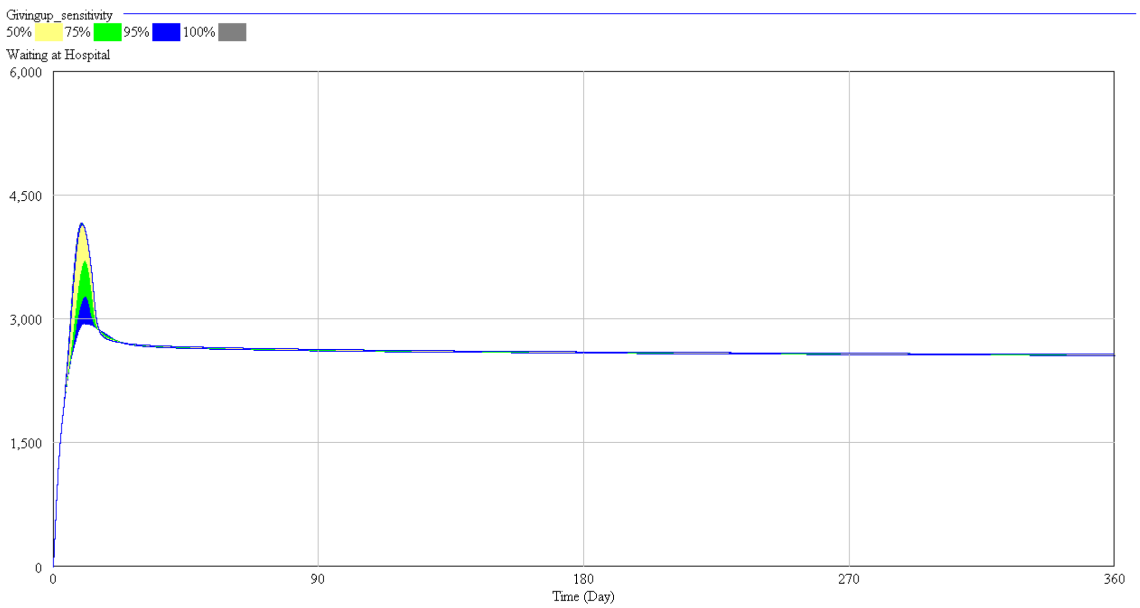


(a) Probability of Choosing GP



(b) Waiting at GP

Figure 4.14: Sensitivity Analysis for "*Leaving GP Fraction*"



(c) Waiting at Hospital

Figure 4.14: Sensitivity Analysis for "*Leaving GP Fraction*" (cont.)

look at the confidence bounds at *Probability of Choosing GP*, we can see that most of the results are closer to the upper limit. Also from figure, it is seen that value at *Treatment at General Practitioner* and *Waiting at Hospital* stocks changes in small range despite the value of *Referrals* stock. It is acceptable for changes in this stock since the value of this stock depends directly on this parameter.

Sensitivity Analysis for "Average Time to be GP"

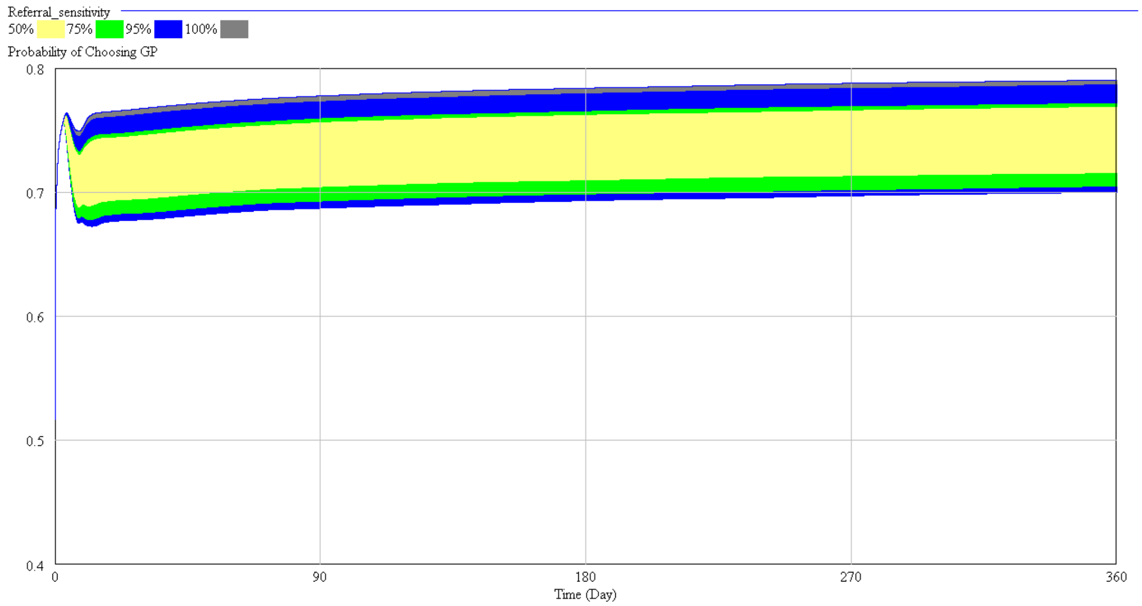
This parameter is defined as 30 days in the model and we change its value between 1 and 60 days to see its effect on model's output. As seen in Figure 4.16, this value affects the numerical values of *Number of GP* stock in the model and it can be seen that our choice is standing at the 50% confidence bounds. That means our choice is an average value and we should look at its effect on other system outputs as *Probability of Choosing GP*. From the analysis, we realize that it affects the probability only at numerical results in small ranges and behaviour pattern is not affected. Changes at stocks *Potential GP Pool* and *Working at Hospital* can be neglected. As a result, estimation for this parameter is acceptable due to its little effect on the model.

Sensitivity Analysis for "Average Time to Work at Hospital"

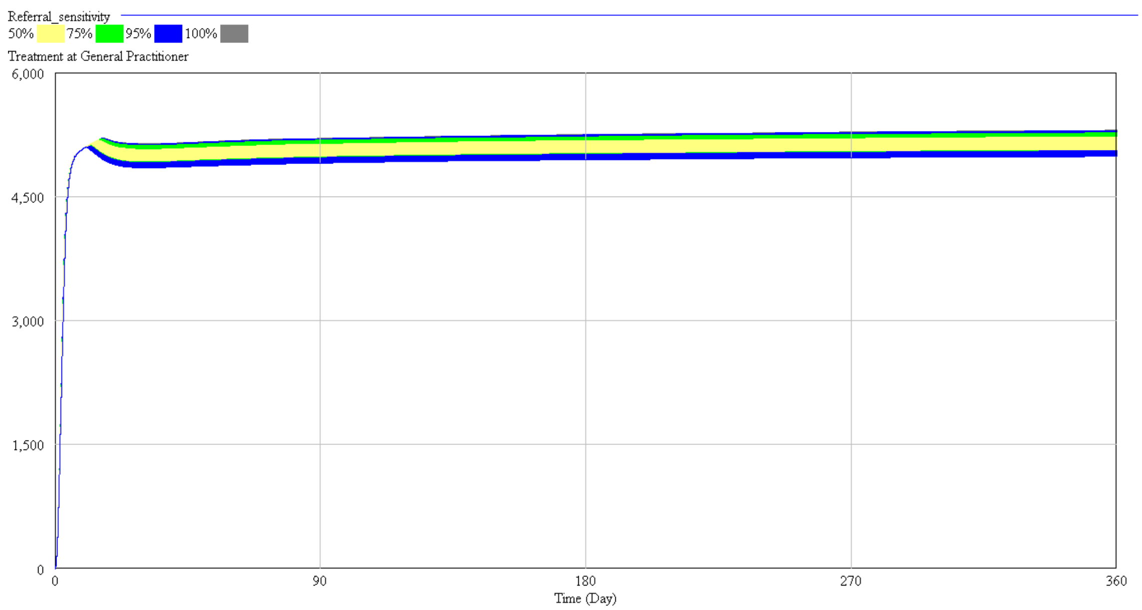
This parameter is also defined as 30 days in the model and we change its value again between 1 and 60 days. As we expect from the model, changes in this assumption only affects the value of *Working at Hospital* and *Probability of Choosing GP*. The probability is changing again in small range with the same behaviour and number of general practitioners and potential general practitioner candidates are not affected (see Figure 4.17). Therefore, estimation for this paramater can be accepted in the model.

Sensitivity Analysis for "Average Waiting Time to be GP"

We assume this parameter's value as 30 days in the model. Changing its value between 1 and 60 days has no effect on *Number of GP*, *Probability of Choosing GP*, or *Working at Hospital*. It just changes the number of general practitioner candidates at *Potential GP Pool* stock as seen in Figure 4.18. But the *Probability of Choosing GP* and *Number of GP* are not affected and the value of this parameter can be acceptable in the model.

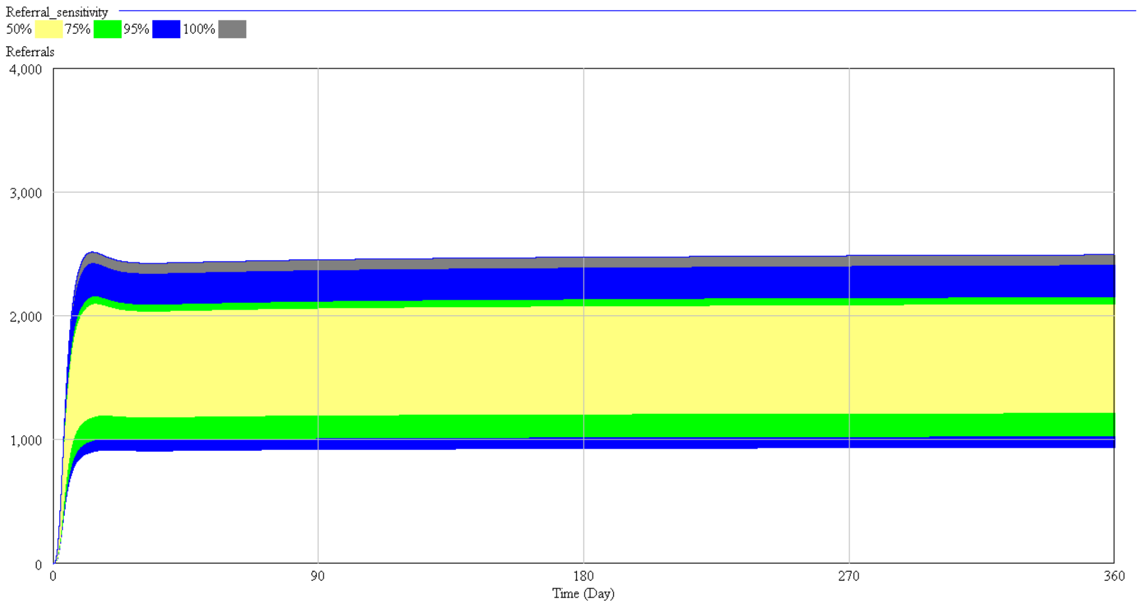


(a) Probability of Choosing GP

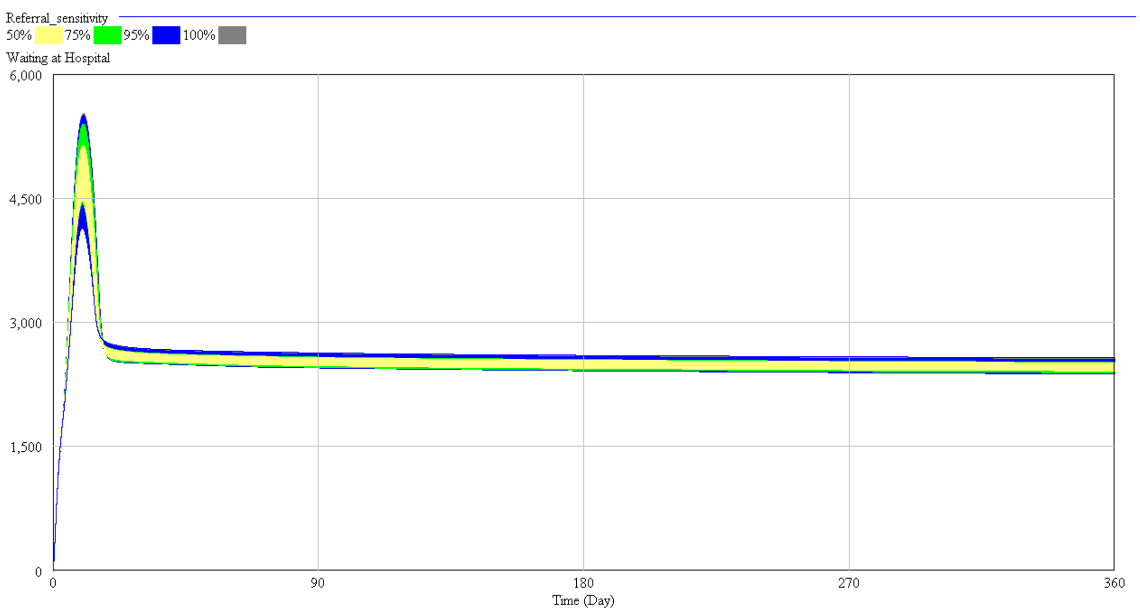


(b) Treatment at GP

Figure 4.15: Sensitivity Analysis for "*Referral Probability*"

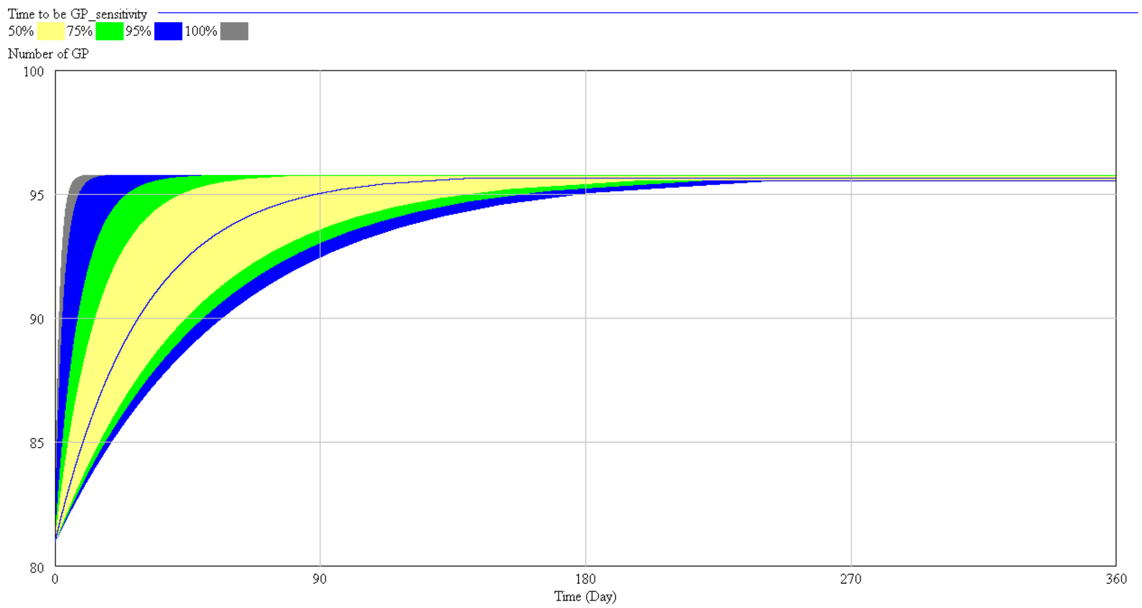


(c) Referrals

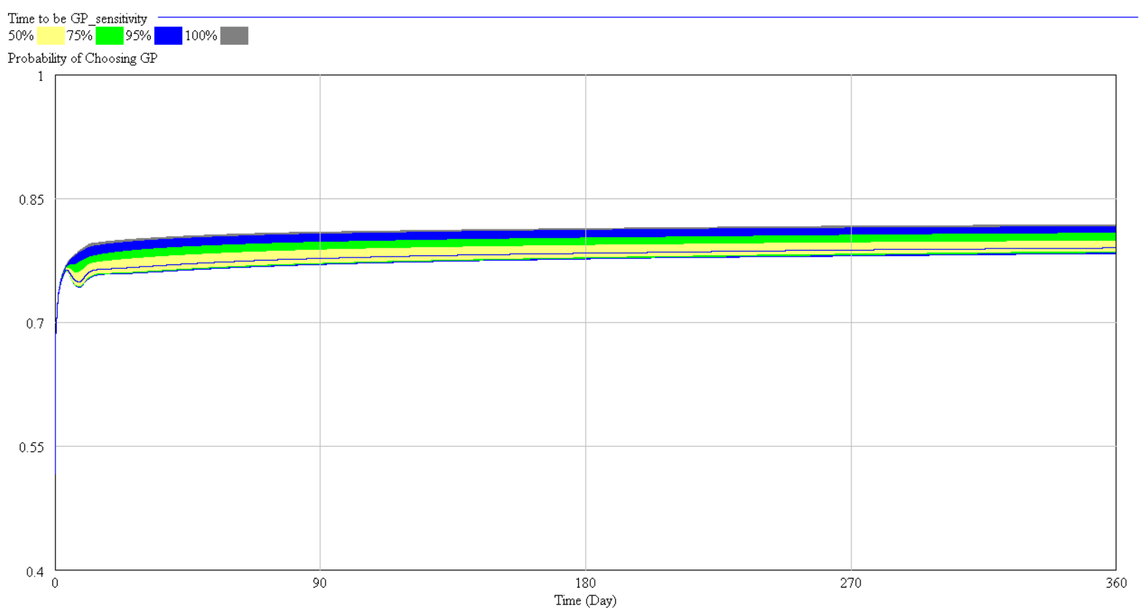


(d) Waiting at Hospitals

Figure 4.15: Sensitivity Analysis for "*Referral Probability*" (cont.))

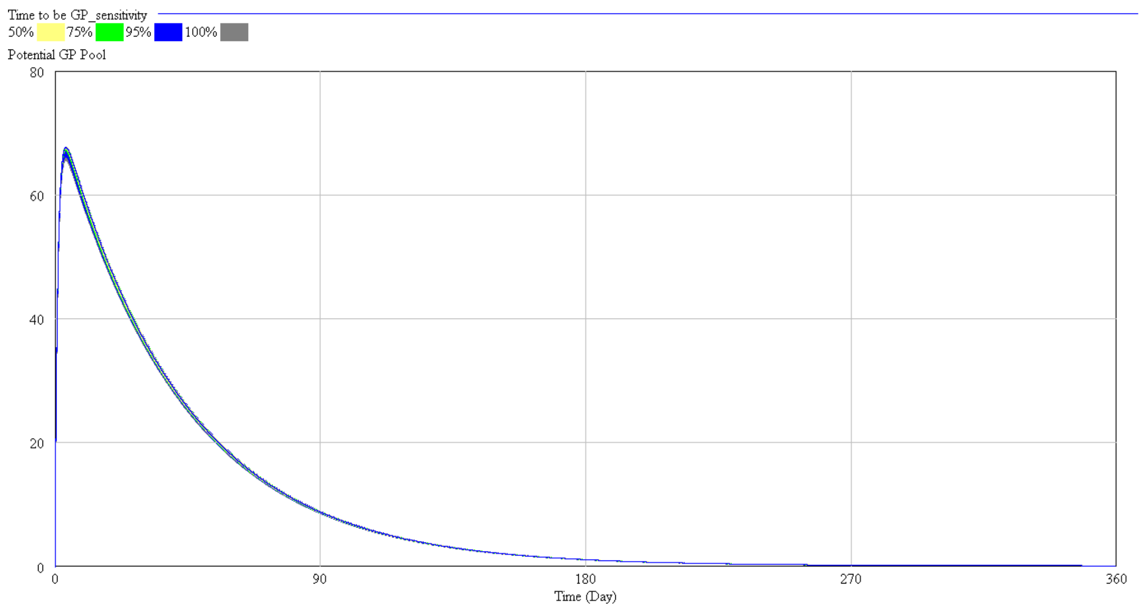


(a) Number of GP

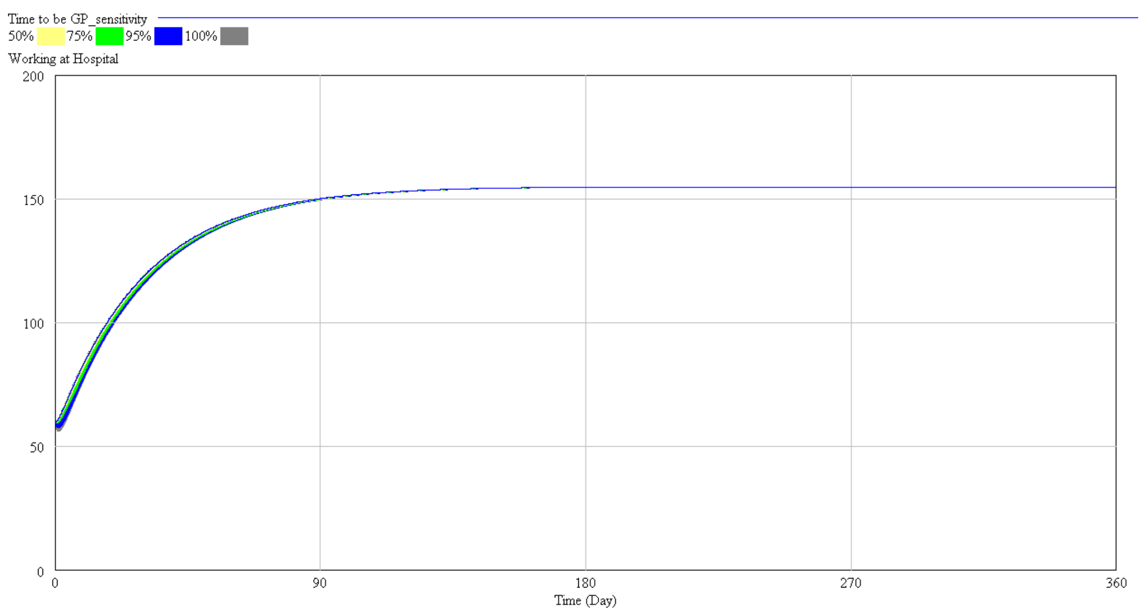


(b) Probability of Choosing GP

Figure 4.16: Sensitivity Analysis for "*Average Time to be GP*"

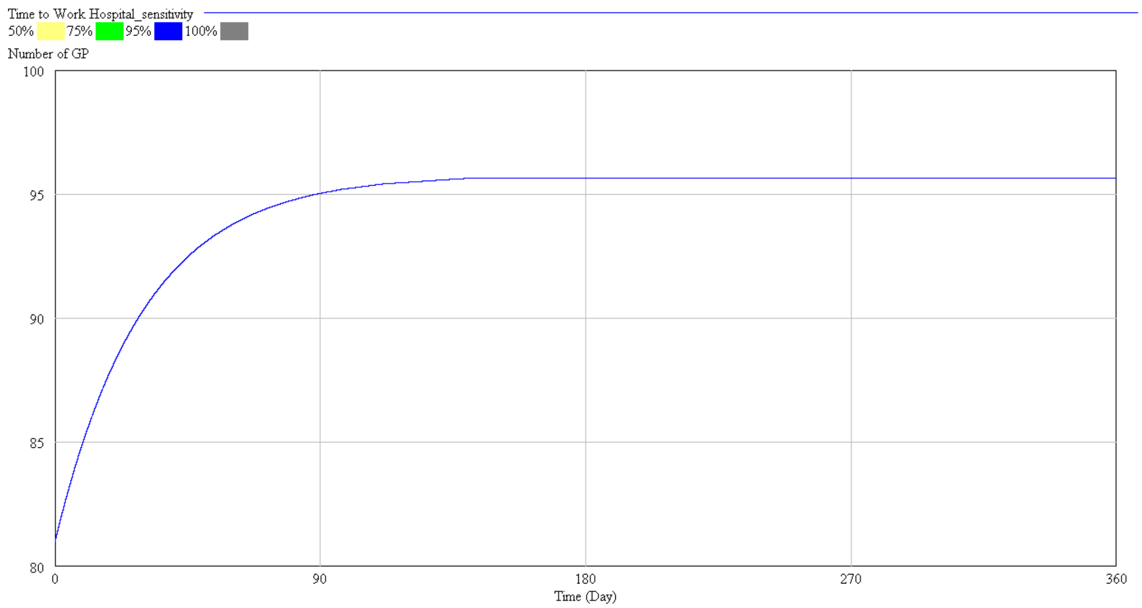


(c) Potential GP Pool

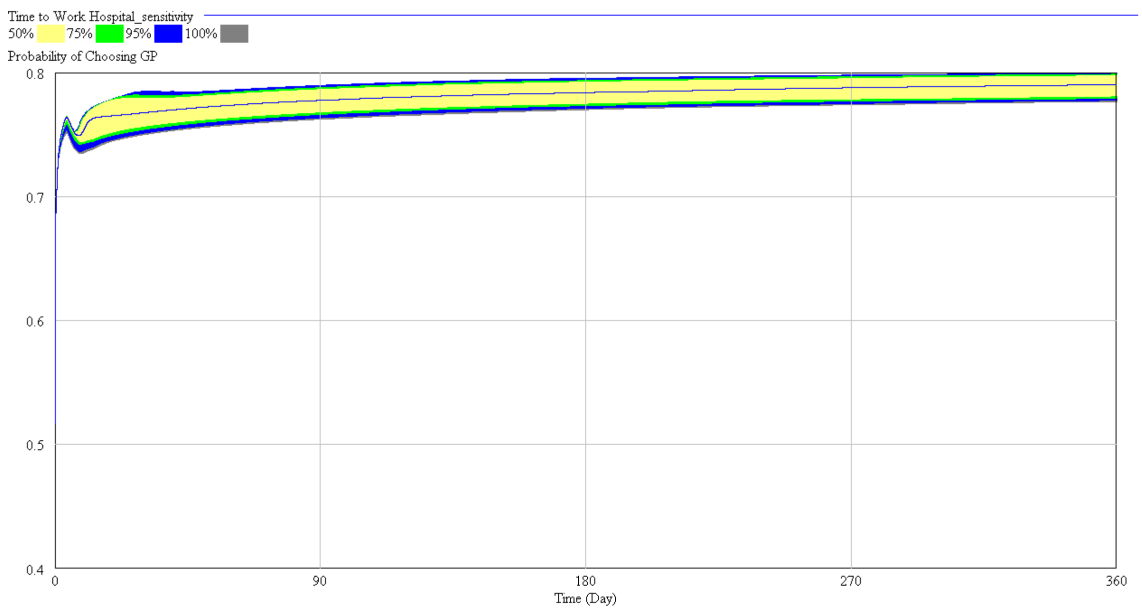


(d) Working at Hospital

Figure 4.16: Sensitivity Analysis for "*Average Time to be GP*" (cont.)

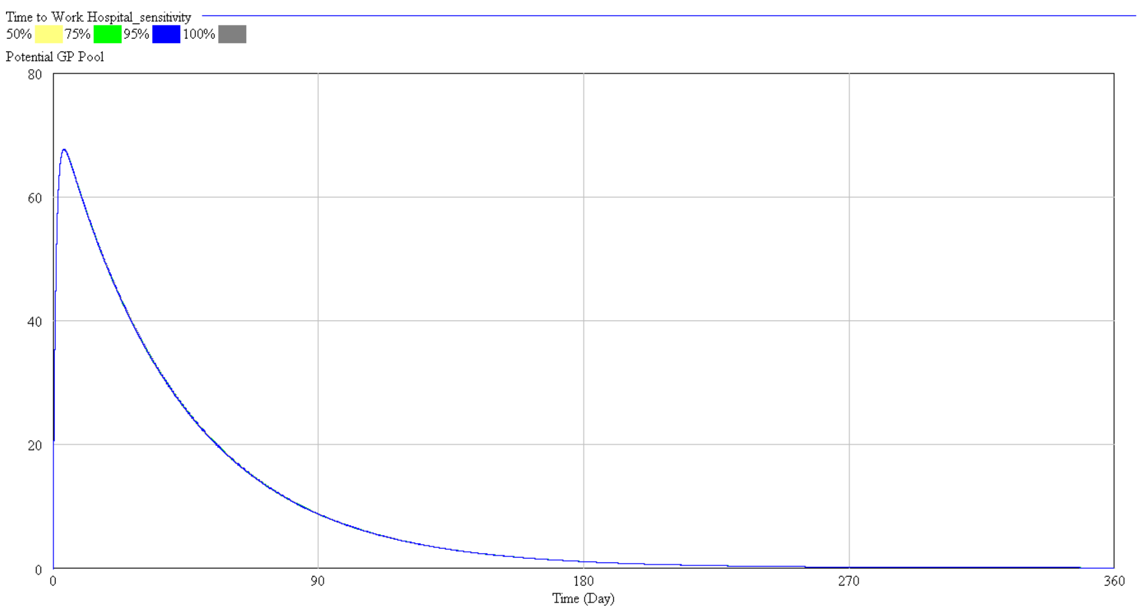


(a) Number of GP

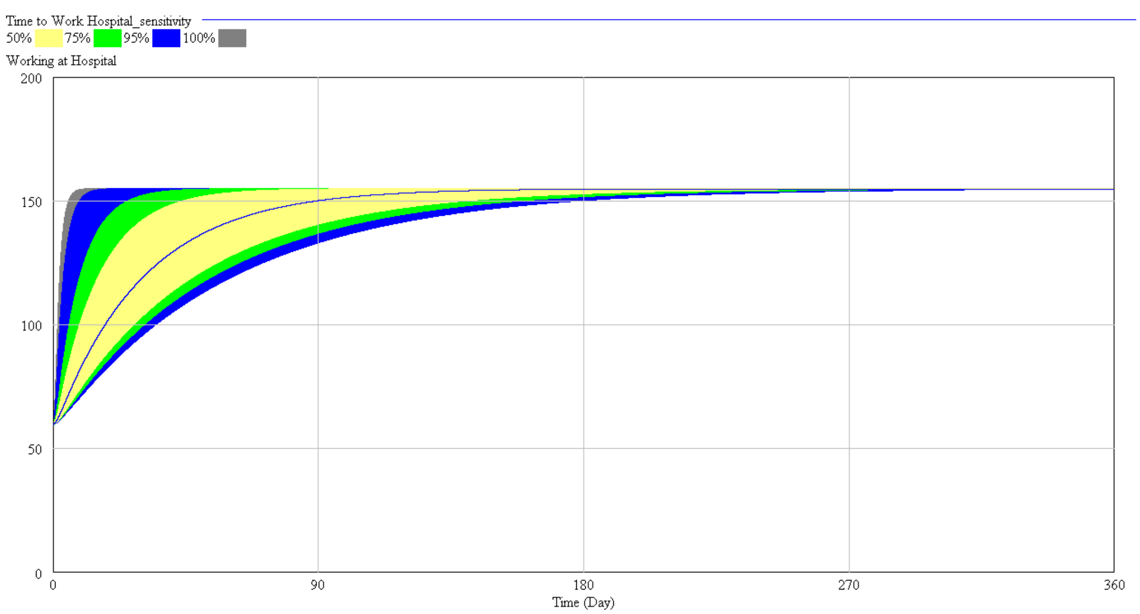


(b) Probability of Choosing GP

Figure 4.17: Sensitivity Analysis for “*Average Time to Work at Hospital*”

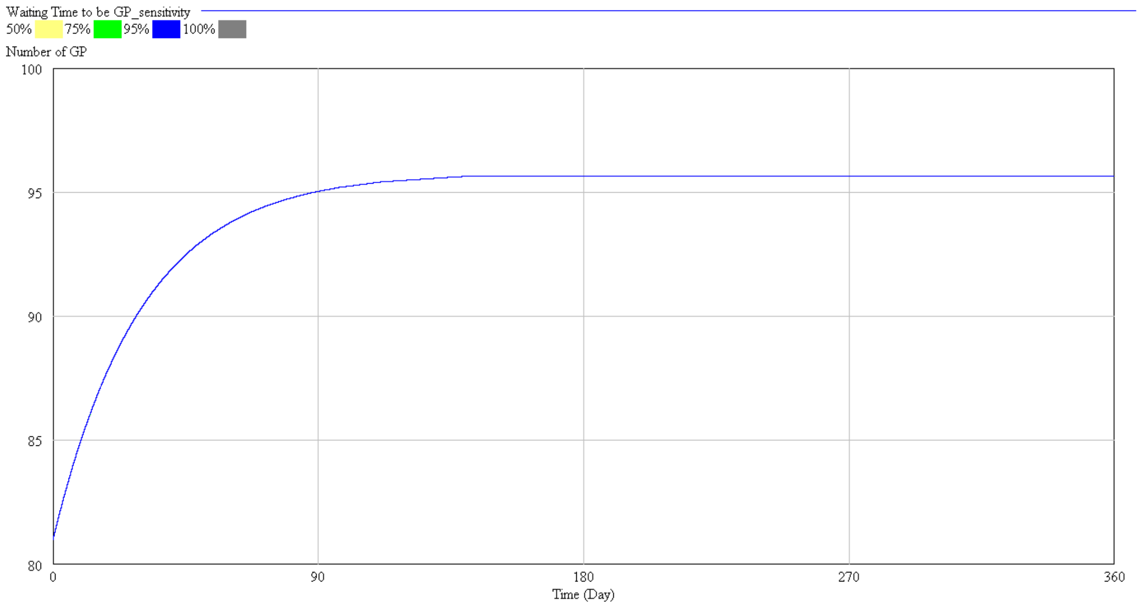


(c) Potential GP Pool

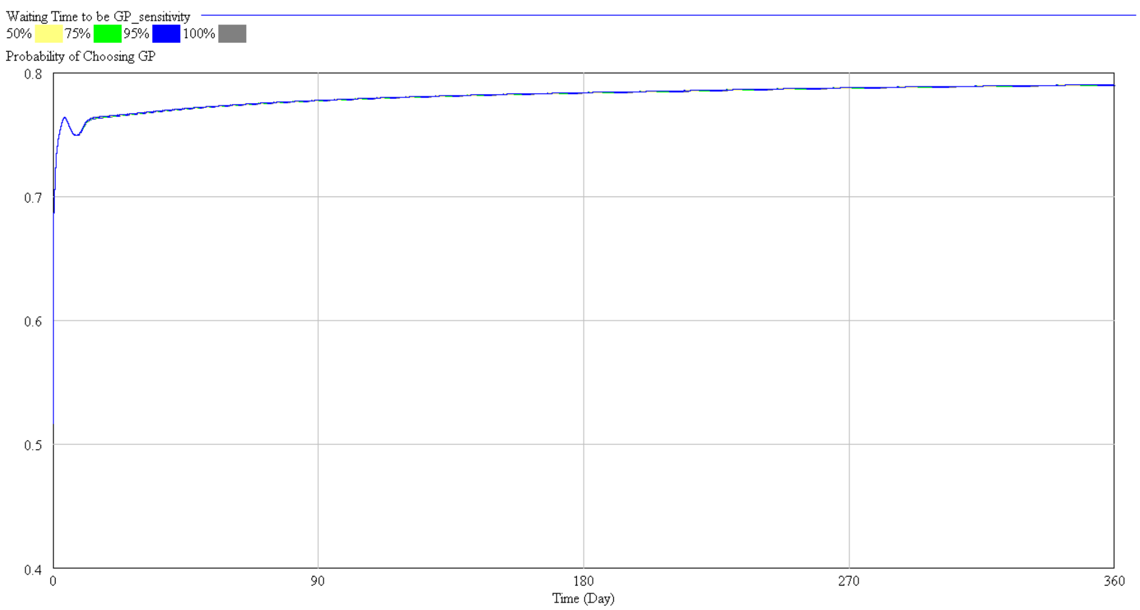


(d) Working at Hospital

Figure 4.17: Sensitivity Analysis for "*Average Time to Work at Hospital*" (cont.)

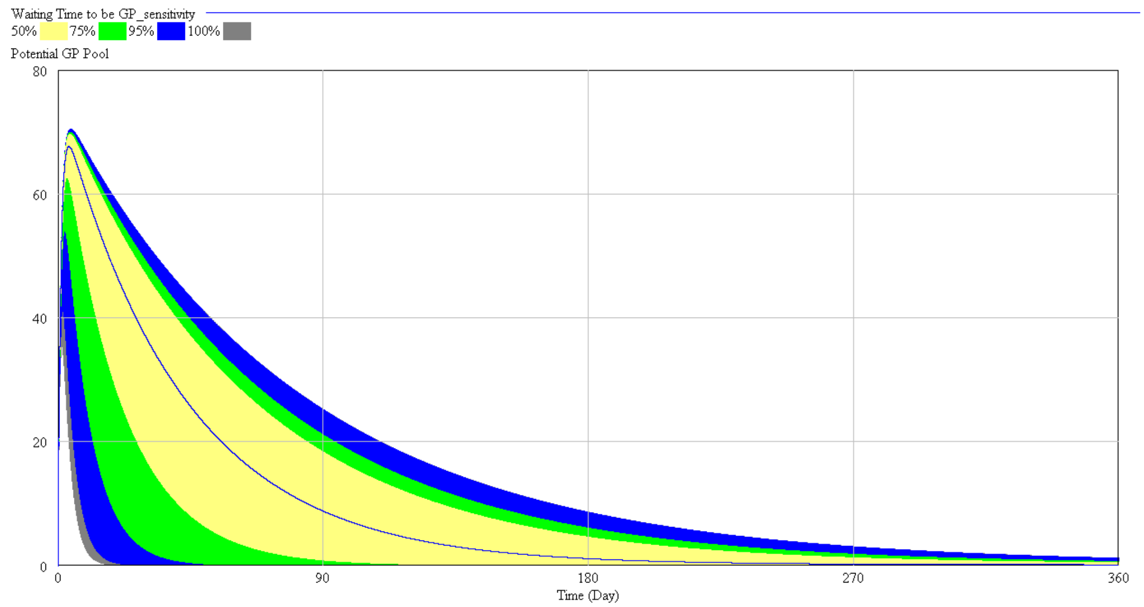


(a) Number of GP

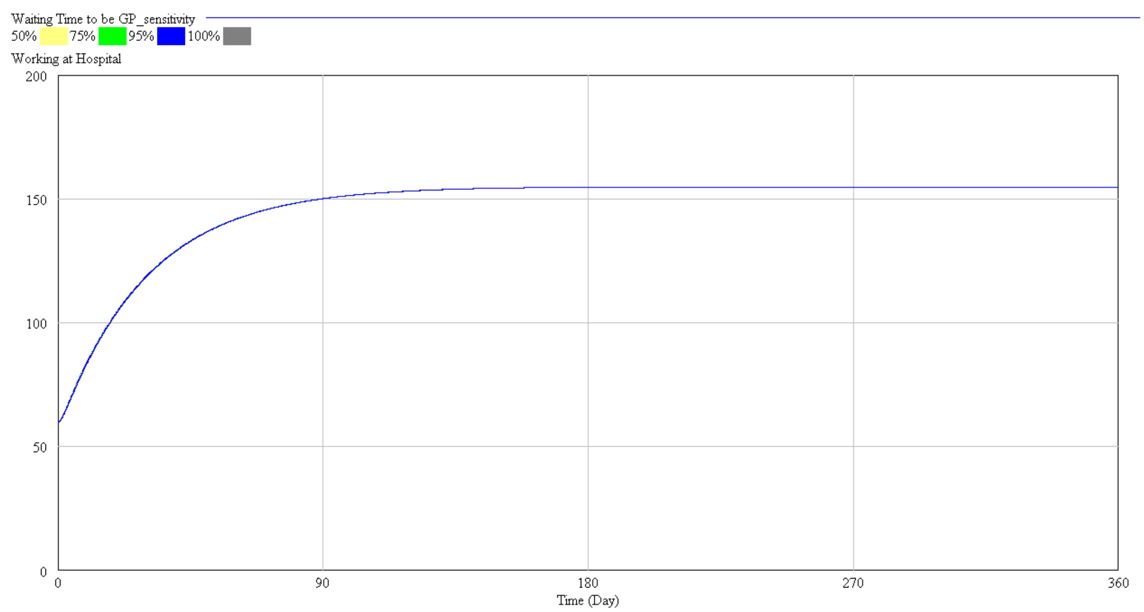


(b) Probability of Choosing GP

Figure 4.18: Sensitivity Analysis for "*Average Waiting Time to be GP*"



(c) Potential GP Pool



(d) Working at Hospital

Figure 4.18: Sensitivity Analysis for "*Average Waiting Time to be GP*" (cont.)

Sensitivity Analysis for "Normal Service Time"

We set *Normal Service Time at GP* and *Normal Service Time at Hospital* to 10 minutes and 15 minutes respectively. For sensitivity analysis, we change the values in the range 5-30 minutes and we try to analyse its effect on probability in the model. First, we fix the value of *Normal Service Time at Hospital* and change the *Normal Service Time at GP* (see Figure 4.19) and then we did the reverse (see Figure 4.20). Finally, we change the values of assumptions together (see Figure 4.21).

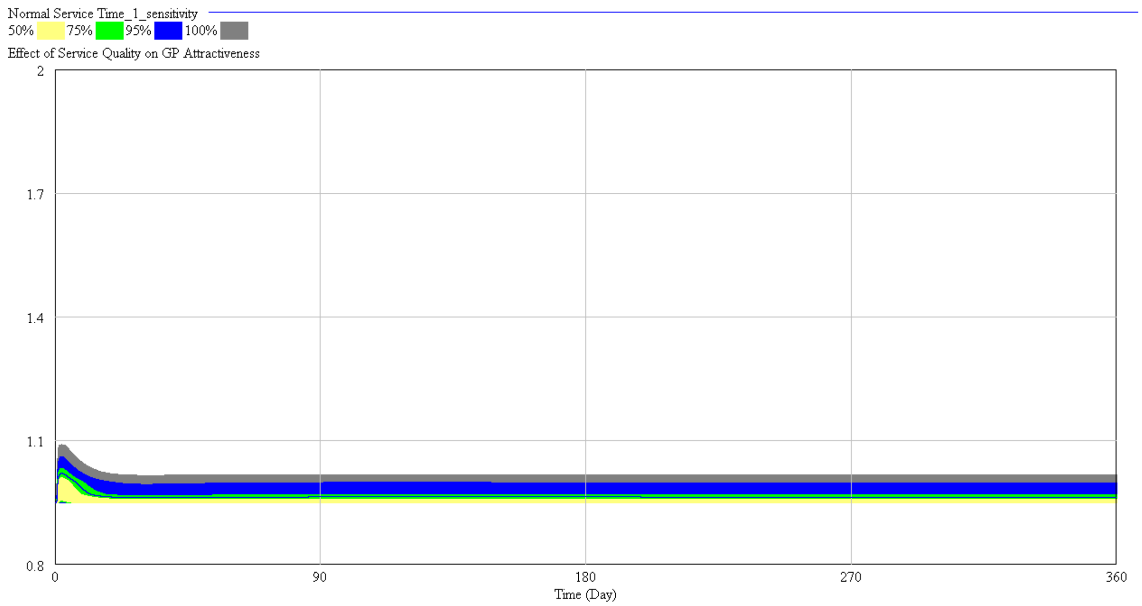
As seen in Figure 4.19, when we change the *Normal Service Time at GP* the numerical result will change with the same behaviour in small range. Because of this range, also the value of *Probability of Choosing GP* is staying in small range with same behaviour.

We are doing the same analysis for *Normal Service Time at Hospital* by fixing the value of *Normal Service Time at GP*. As seen in Figure 4.20, again *Effect of Service Quality on Hospital Attractiveness* is changing numerically in small range with same behaviour which is affecting the *Probability of Choosing GP* inversely. This inverse relation is expected also since decreasing the value of time gives higher credit on *Effect of Service Quality on Hospital Attractiveness* which is decreacing the *Probability of Choosing GP* normally.

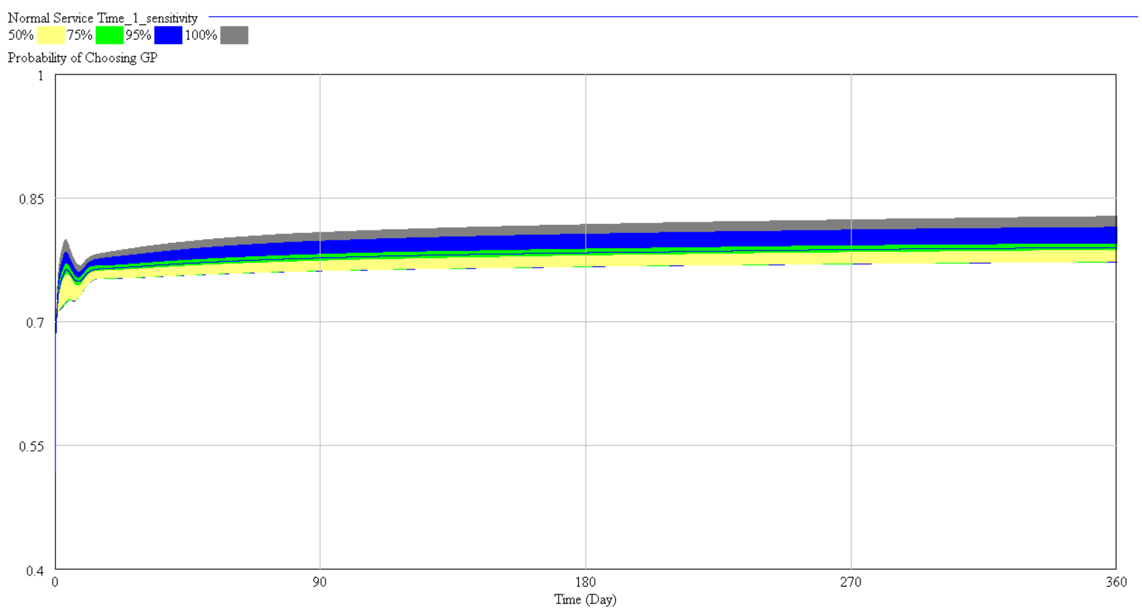
However, essential sensitivity analysis is done with changing the normal service times at the same time. That means we analyze all combinations of normal service times between the range of 5 minutes and 30minutes. When we look at the results, we have seen that model is really sensitive to the normal service time parameter since it can change the results of *Probability of Choosing GP* in a wide range. We can understand from the confidence bounds that the results in this range seem to be uniformly distributed. As it is seen from Figure 4.21, the confidence bounds at 95% and 75% level are more wide at *Effect of Service Quality on Hospital Attractiveness* than *Effect of Service Quality on GP Attractiveness*. We can see this situation on the results of *Probability of Choosing GP* where it accumulates at lower value with 95% confidence bound.

Sensitivity Analysis for "Table Function for Service Quality Effect"

Table functions for service quality is based on the literature and its contribution to

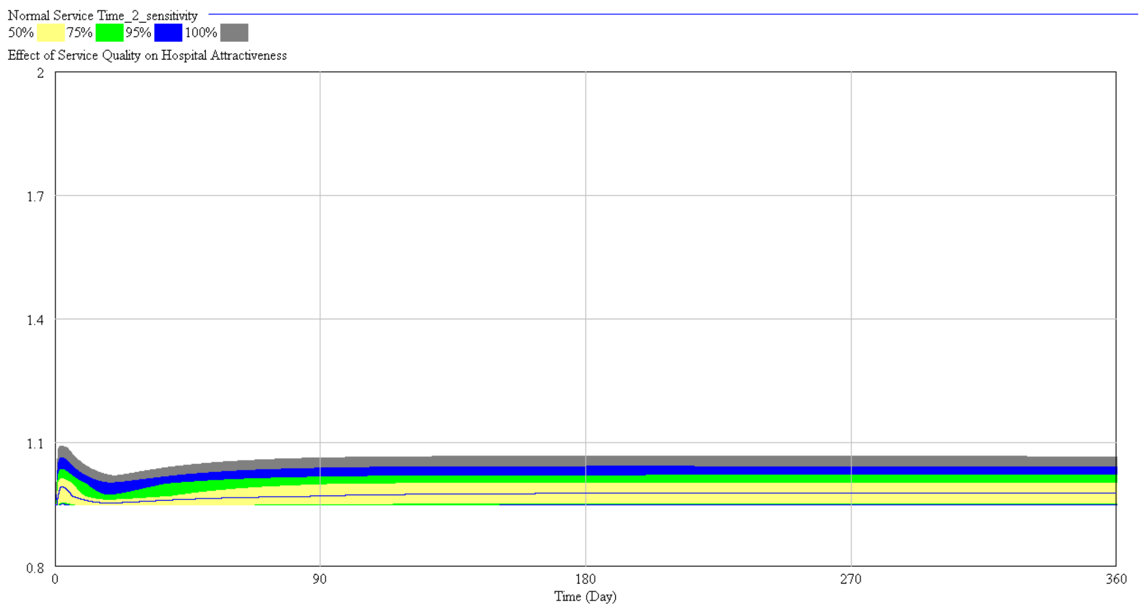


(a) Effect of Service Quality on GP Attractiveness

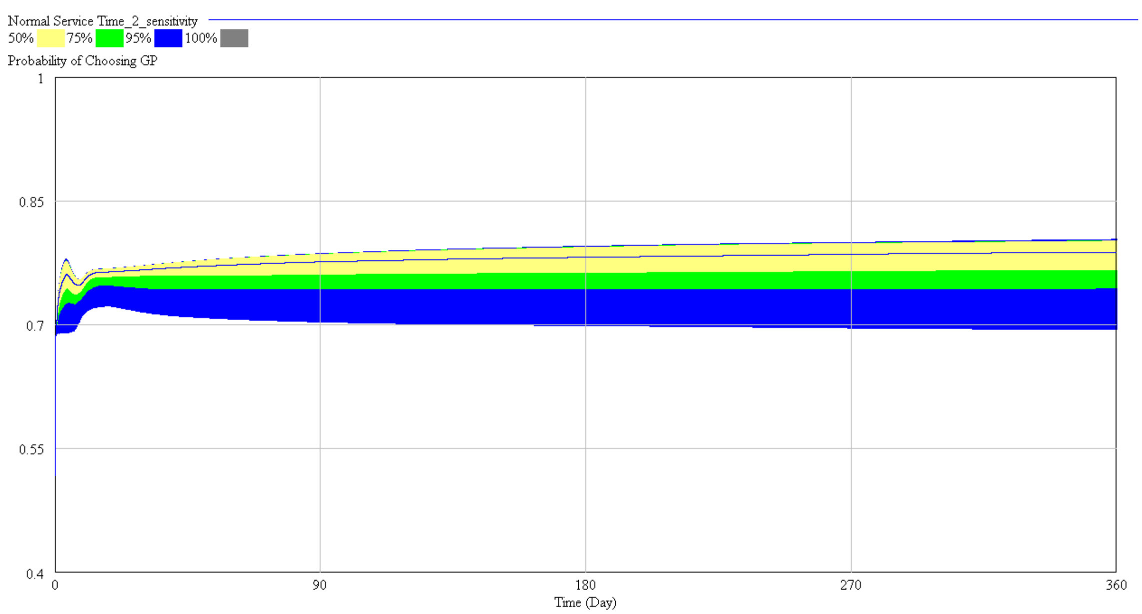


(b) Probability of Choosing GP

Figure 4.19: Sensitivity Analysis for "*Normal Service Time at GP*"

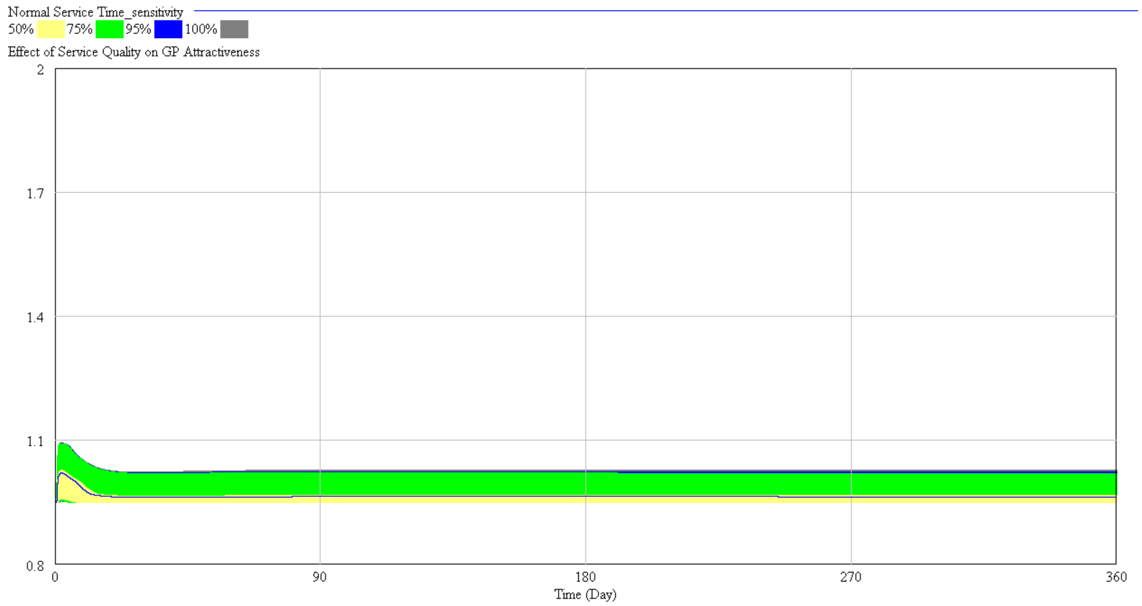


(a) Effect of Service Quality on Hospital Attractiveness

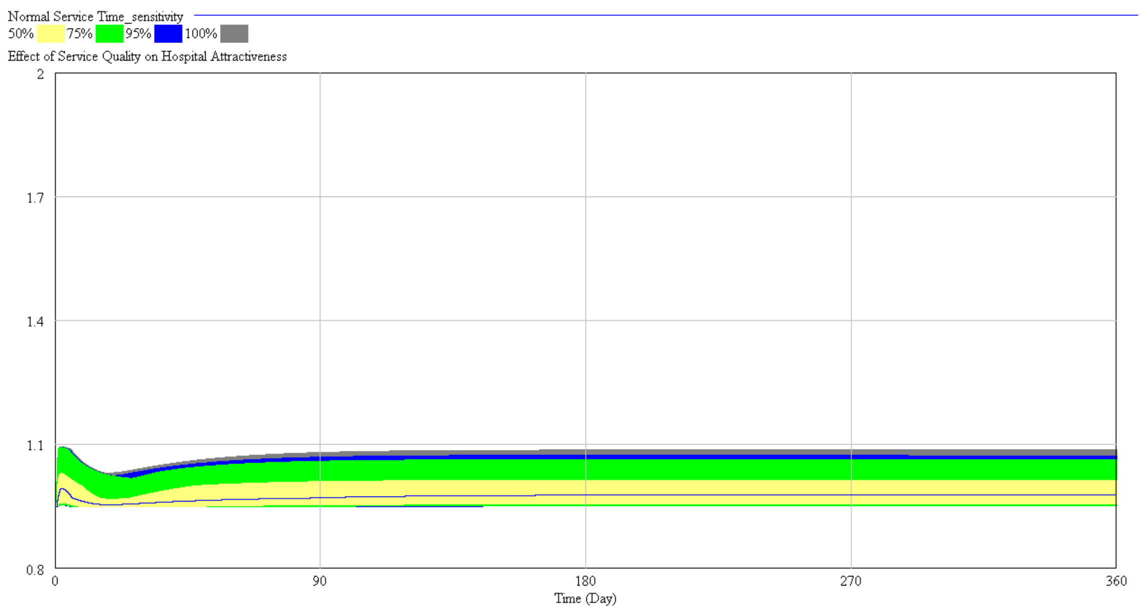


(b) Probability of Choosing GP

Figure 4.20: Sensitivity Analysis for "*Normal Service Time at Hospital*"

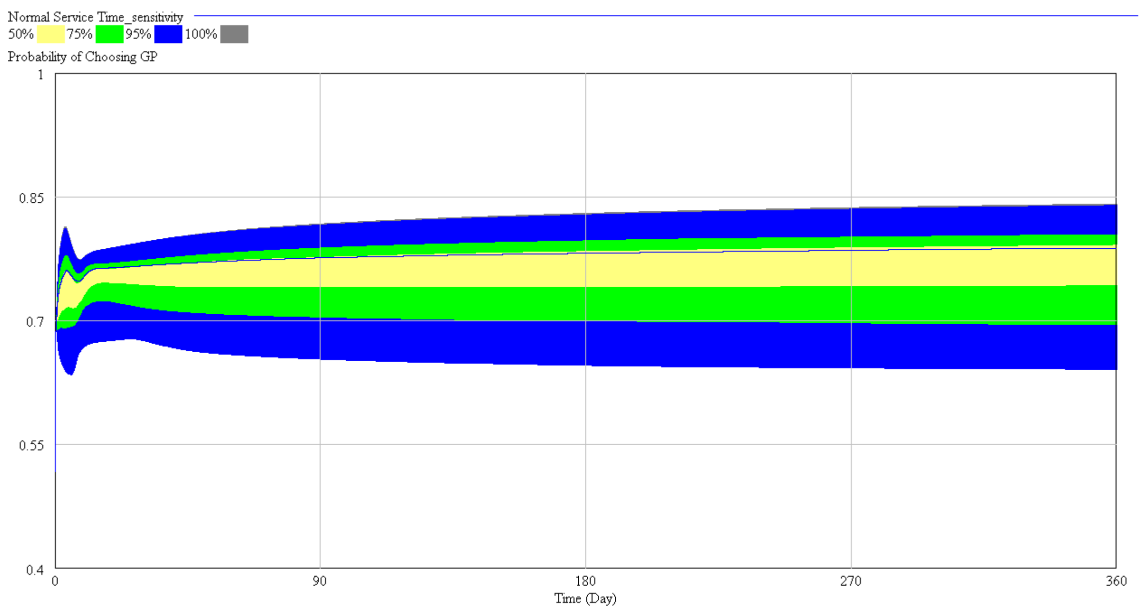


(a) Effect of Service Quality on GP Attractiveness



(b) Effect of Service Quality on Hospital Attractiveness

Figure 4.21: Sensitivity Analysis for "*Normal Service Time*"



(c) Probability of Choosing GP

Figure 4.21: Sensitivity Analysis for "*Normal Service Time*" (cont.)

model is explained in Section 4.8. We know from this section that service time loops for general practitioners and hospitals have significant role on models numerical result. To see this effect, we change the boundaries of table function in the sensitivity analysis and we keep its behaviour same as seen in Figure 4.22(a). As it is seen in Figure 4.22, when we increase the value of the boundaries, effects of service quality is also changing due to the expansion of boundaries. However, when we look at its effect on *Probability of Choosing GP*, it is obvious that in the long term it influences the probability in small ranges.

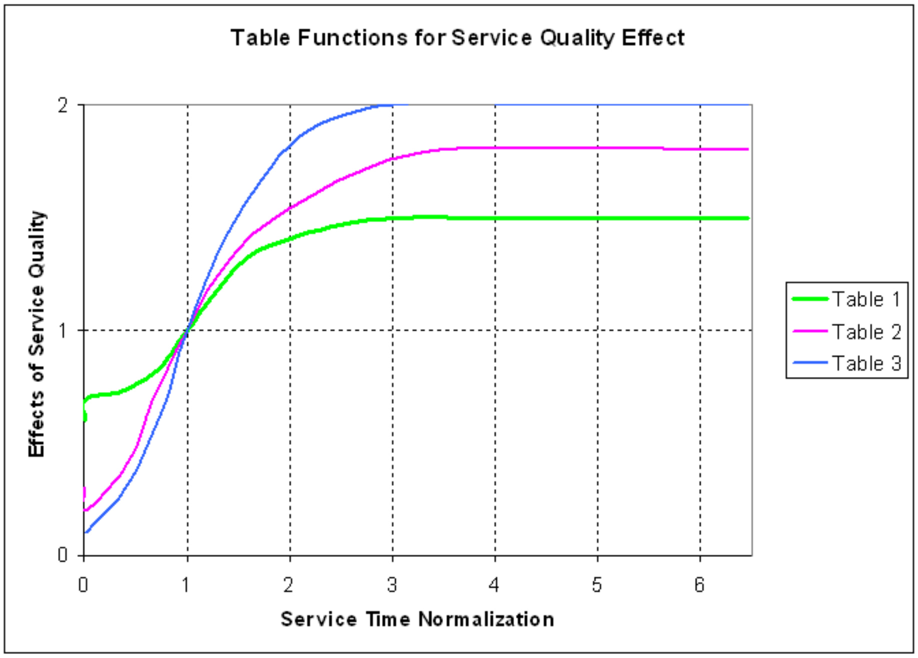
Sensitivity Analysis for "Table Function for Waiting Time Effect"

Table functions for waiting time is based on the literature and we mentioned its significance in the model in Section 4.8. As sensitivity analysis for *Table Functions for Service Quality*, we changed the boundaries of the table function by expanding the values again (see Figure4.23(a)). As seen in figures, because of this expansion, the effects on attractiveness are changing in a wide range but they reach the same value at steady state position. Thus, *Probability of Choosing GP* is influenced in small range and it saves its behaviour despite changes in numerical results.

Sensitivity Analysis for "Table Function for Salary Effect"

This table function is developed using judgment. Therefore, it is important to apply sensitivity analysis to this function. We change the values of the function as seen in Figure 4.24(a) by expanding again and we see that it has no effect on *Number of GP*. Because this stock is determined by goal-seeking loop due to the *Desired Number of GP*. However, this function affects the candidates in *Potential GP Pool* and so *Hospital Doctor Quantity*. Because, when candidates cannot be general practitioner, they prefer to work at hospital or in health department as a health officer. Therefore, changes in *Hospital Doctor Quantity* affects the *Probability of Choosing GP*. As seen in Figure 4.25, these changes are in a small range and they are negligible. Therefore, we can assume that our model is not sensitive to this table function.

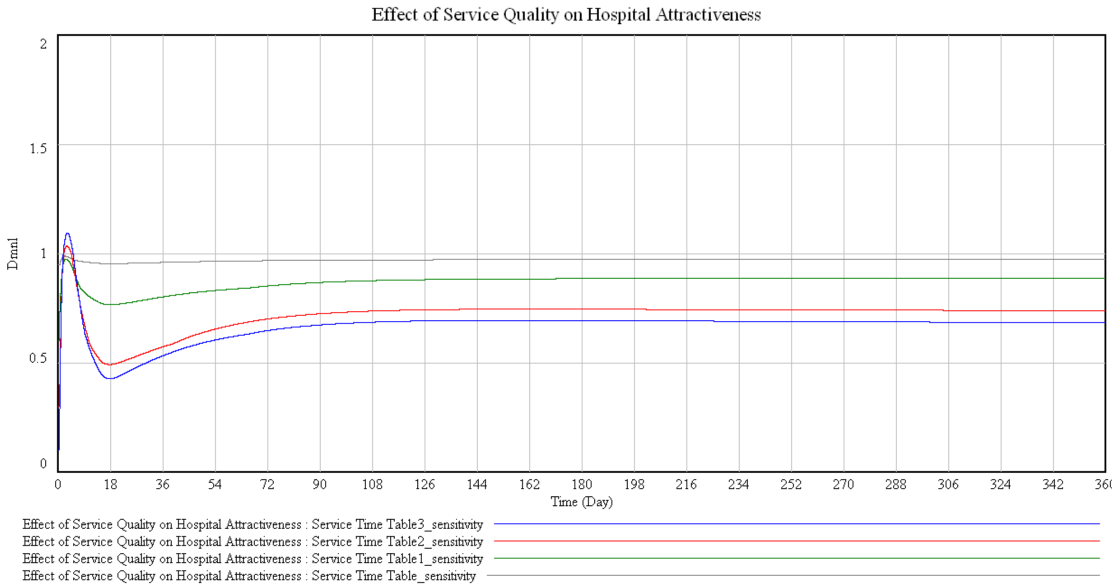
To conclude, our model is sensitive to the parameter which are influencing the effects directly such as *Average Acceptance Time to GP*, *Average Acceptance Time to Hospital*,



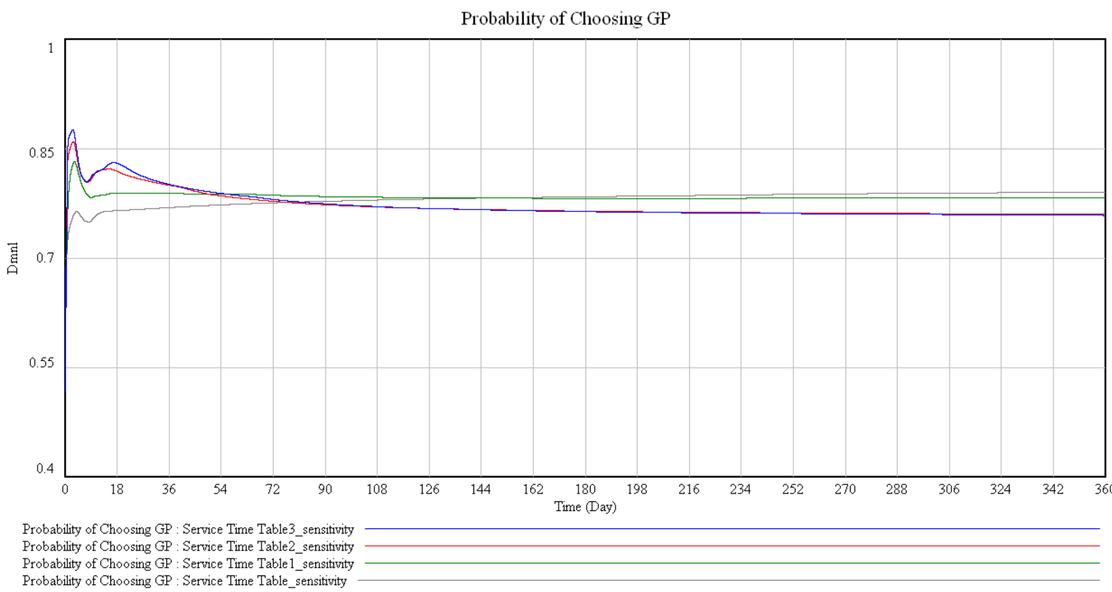
(a) Table Functions for Service Quality

(b) Effect of Service Quality on GP Attractiveness

Figure 4.22: Sensitivity Analysis for "*Table for Service Quality Effect*"

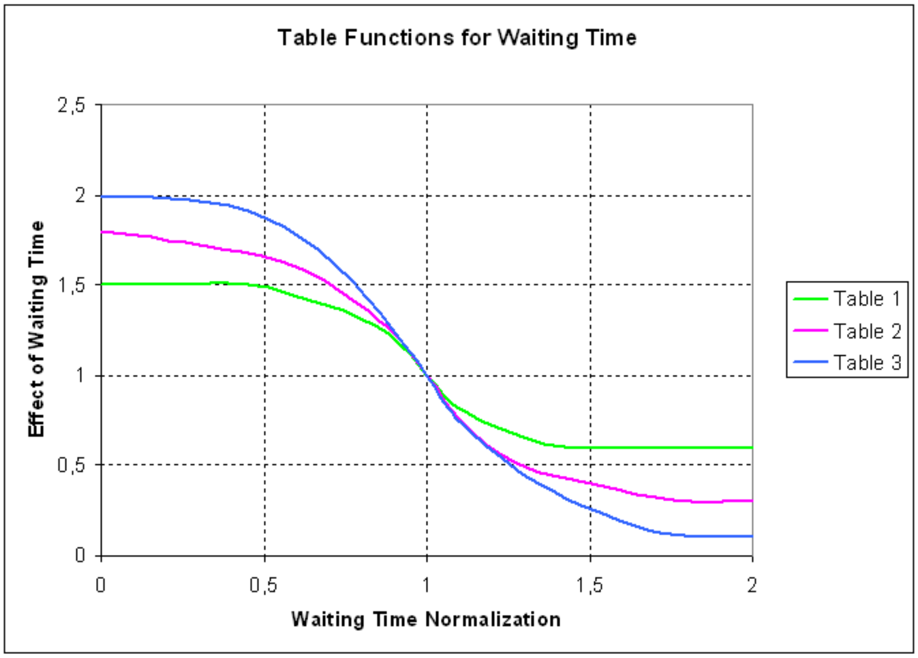


(c) Effect of Service Quality on Hospital Attractiveness

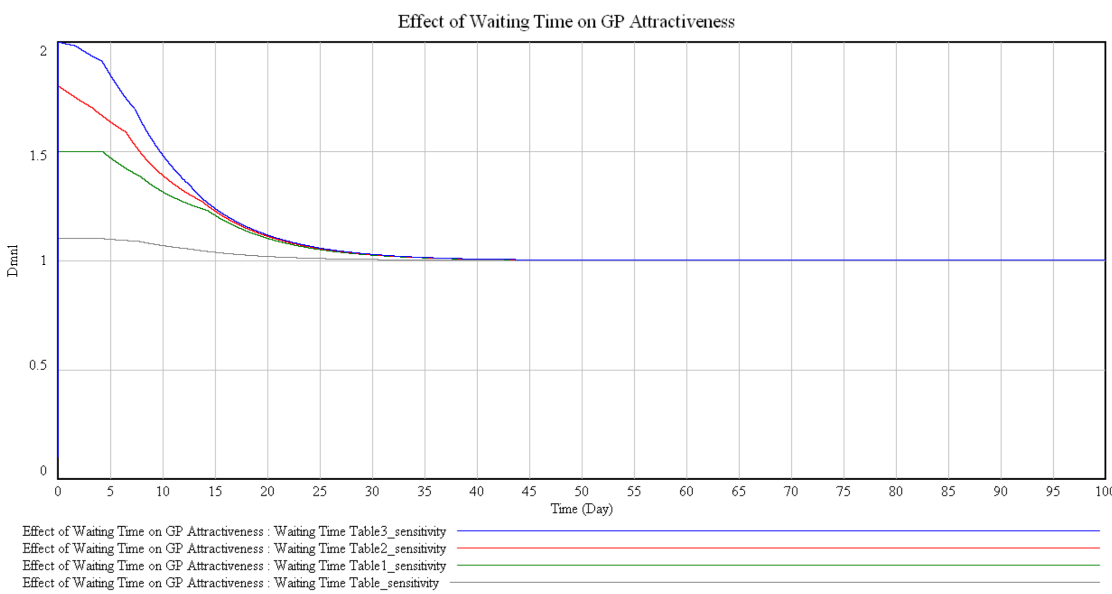


(d) Probability of Choosing GP

Figure 4.22: Sensitivity Analysis for "*Table for Service Quality Effect*" (cont.)

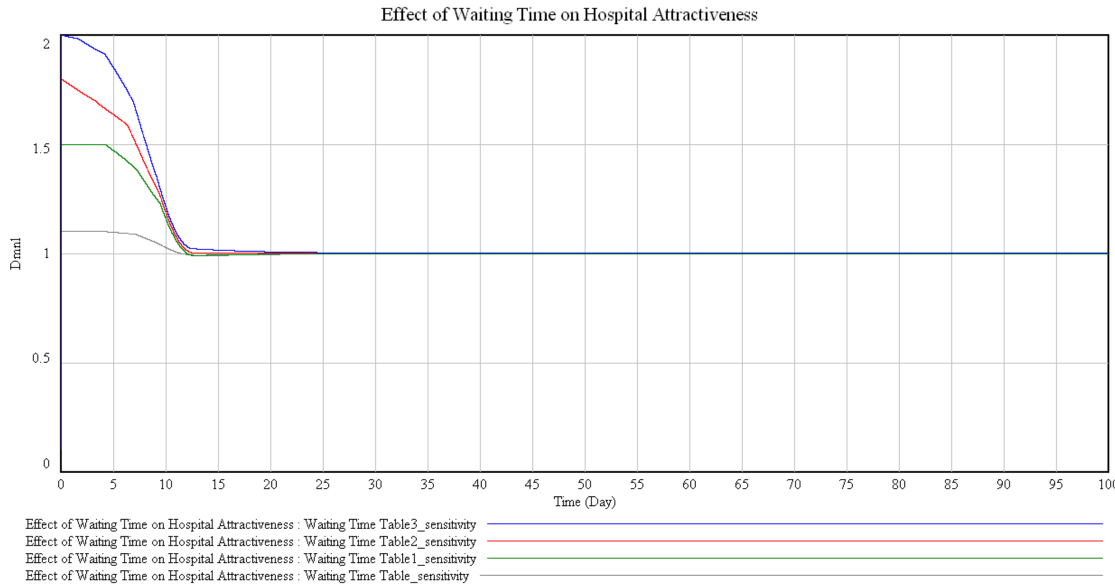


(a) Table Functions for Waiting Time

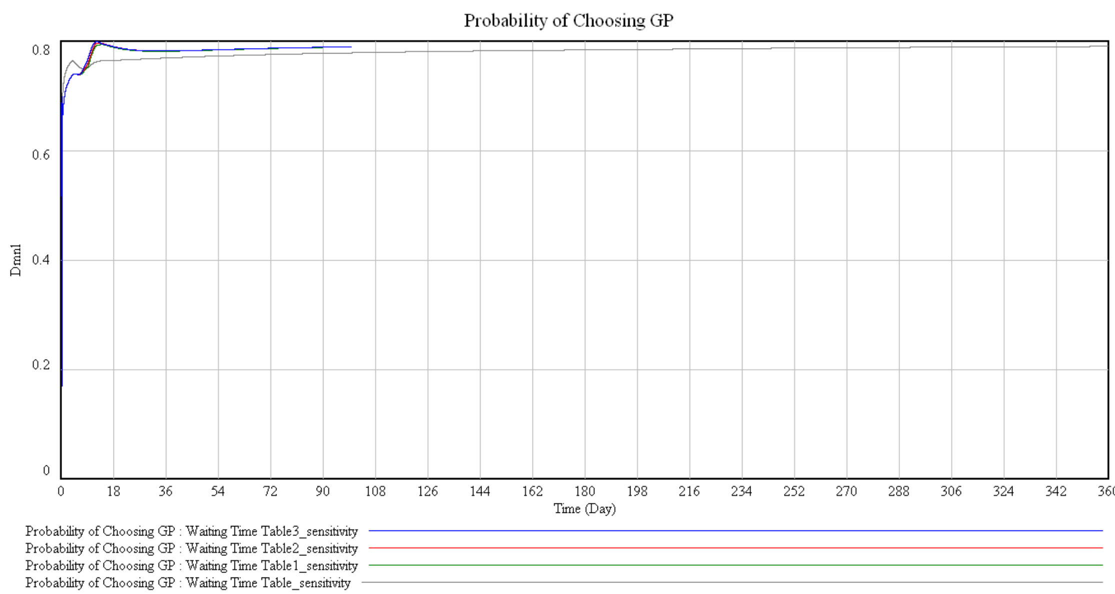


(b) Effect of Waiting Time on GP Attractiveness

Figure 4.23: Sensitivity Analysis for "*Table for Waiting Time Effect*"

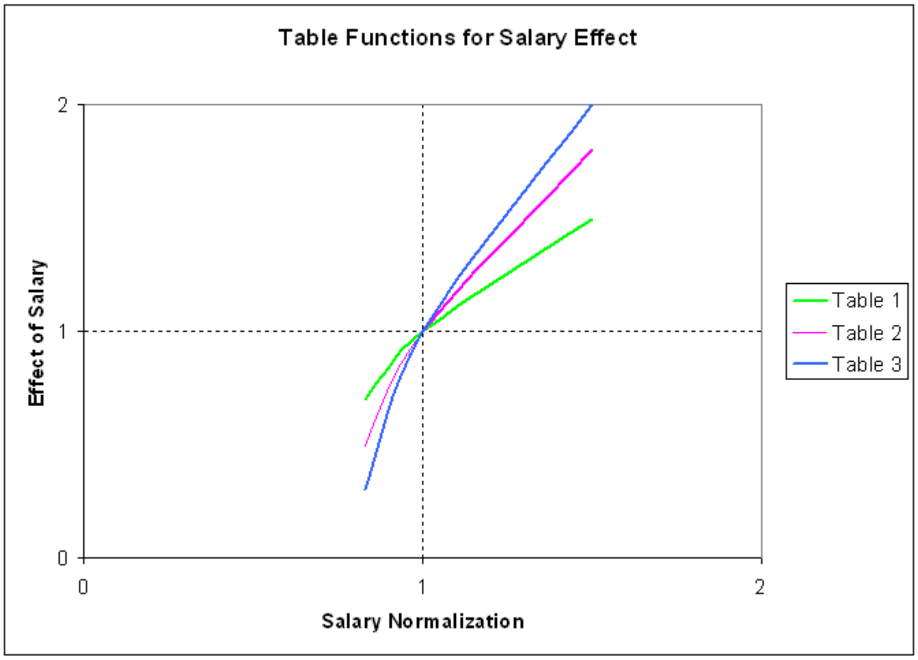


(c) Effect of Waiting Time on Hospital Attractiveness

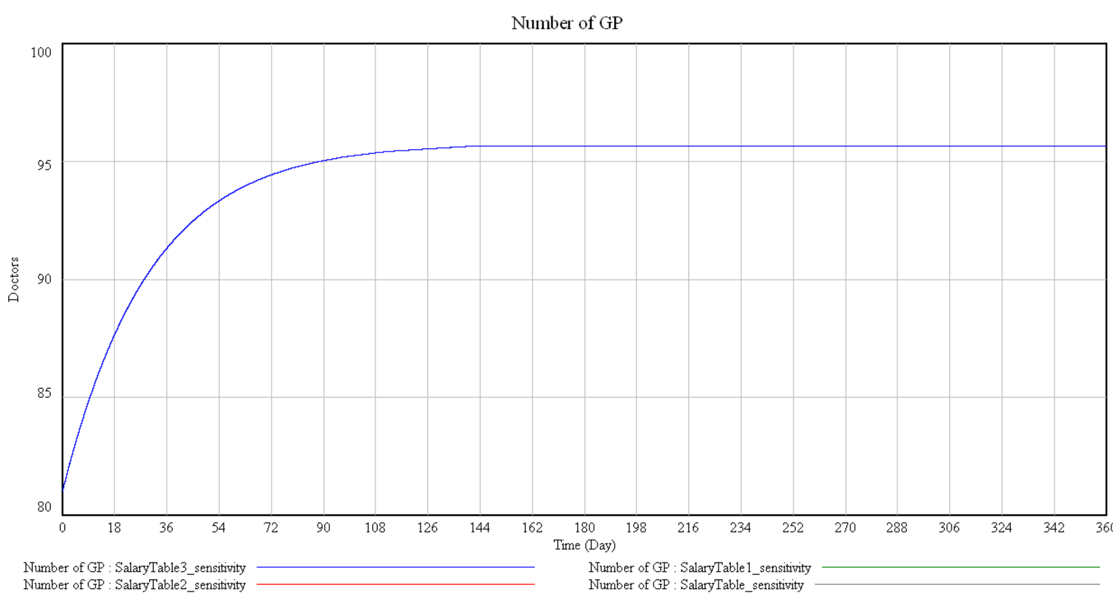


(d) Probability of Choosing GP

Figure 4.23: Sensitivity Analysis for "*Table for Waiting Time Effect*" (cont.)

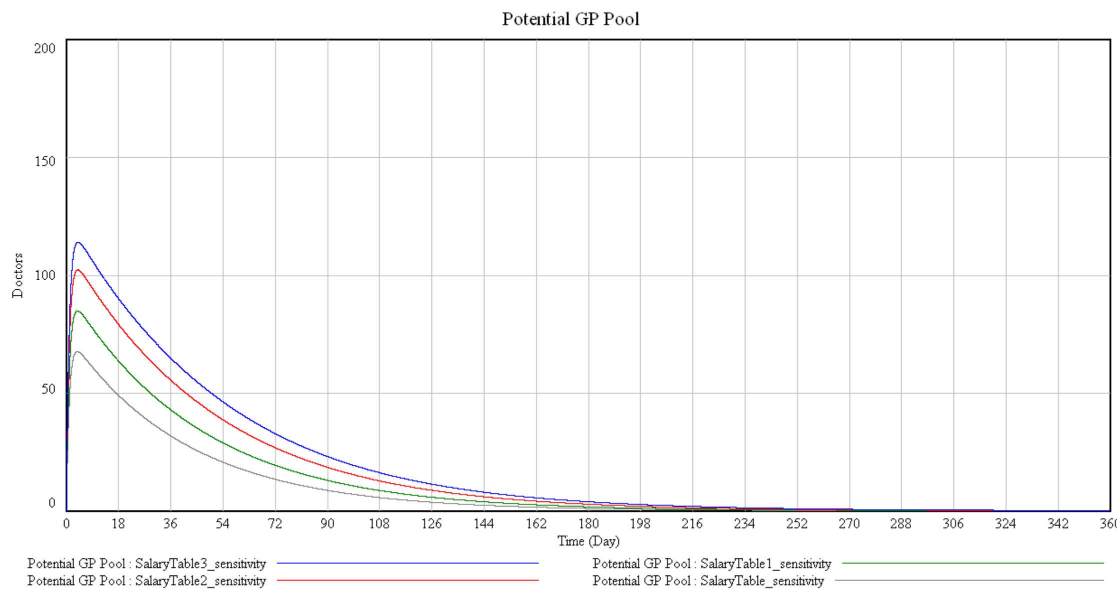


(a) Table Functions for Salary

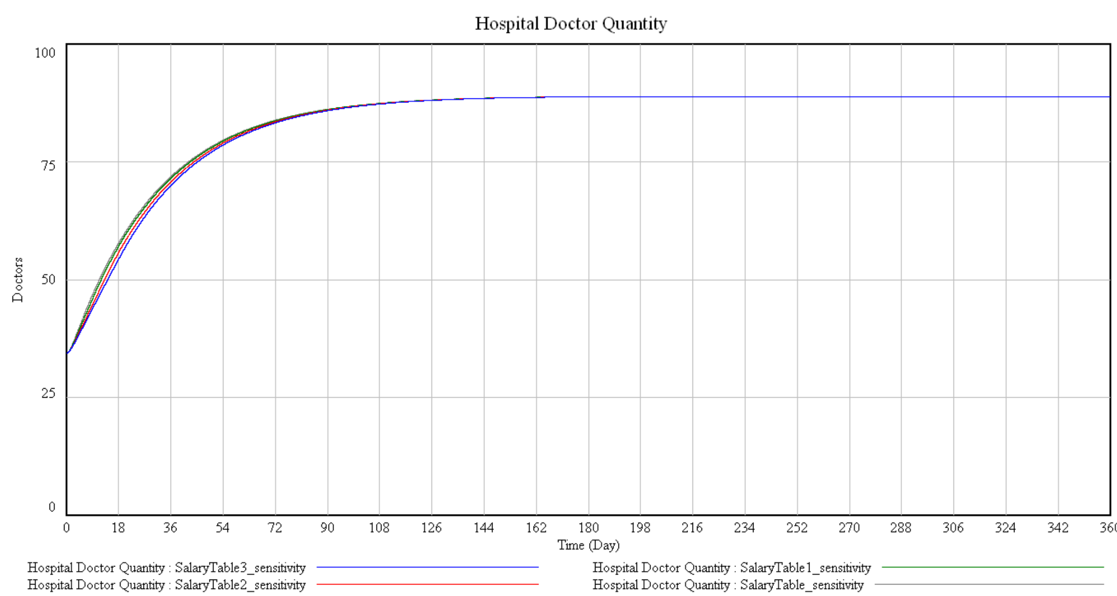


(b) Number of GP

Figure 4.24: Sensitivity Analysis for "*Table for Salary Effect*"

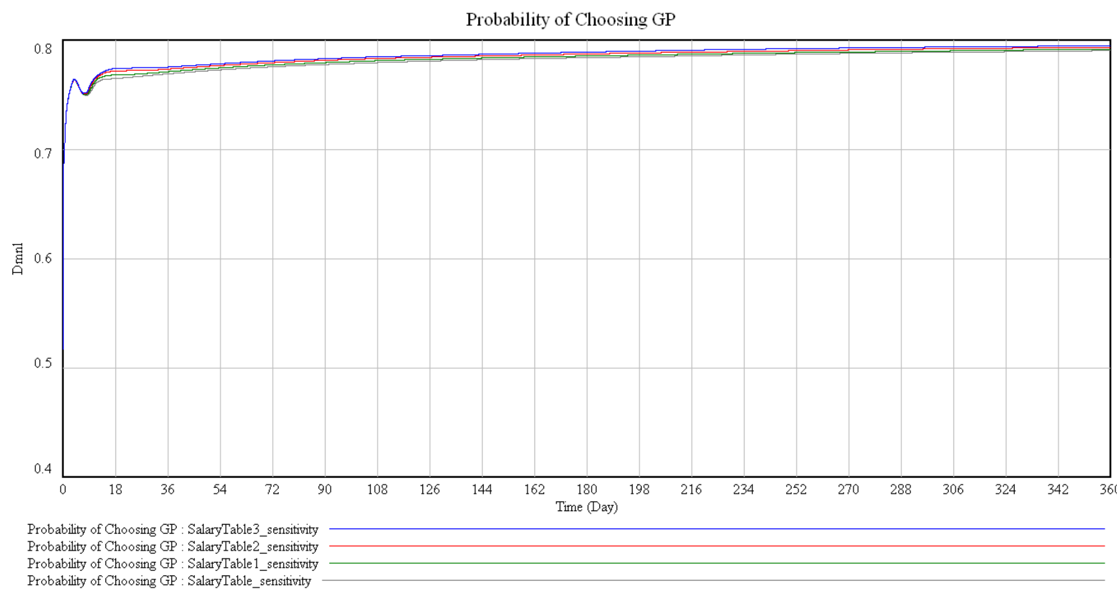


(c) Potential GP Pool



(d) Hospital Doctor Quantity

Figure 4.24: Sensitivity Analysis for "*Table for Salary Effect*" (cont.)



(a) Probability of Choosing GP

Figure 4.25: Sensitivity Analysis for "*Table for Salary Effect*" (cont.)

Leaving GP Fraction and *Normal Service Time*. This is the expected behaviour of the model and we see that changing the assumptions affect the numerical results in a wide range. However behaviour pattern of the model is the still same when we change these parameters and this result is more important than numerical changes since behaviour mode sensitivity is more important in human system models than numerical sensitivity [18].

Chapter 5

SCENARIOS AND POLICY ANALYSES

In this chapter, we run our system dynamic model to understand the behaviour and influences of dynamic effects. With this purpose, we first study our system's actual behaviour and then we conduct scenarios for model to explore the variables that can be regulated by policy analyses.

5.1 Base Case: Current Situation in Düzce

This system dynamic model is built with two assumptions about the existance of gatekeeping policy. We put this regulation because of the actual model; since between the months July 2006 and January 2007, the government introduced a law about referral obligation from primary healthcare to secondary healthcare in Düzce. Then, government abolished this policy. To understand the deficiency and the reason of omission of policy, we should analyse and explain the current situation briefly. When we run the base case (without gatekeeping policy), we see that the system can reach steady-state and capacity is enough at both hospital and general practitioners. However, there is a problem with the choice of patients since 0.425 of the patients prefer to go to the hospital as a first contact. This rate is very high in health services where general practitioners have the role in primary care. Also, when we compare the number of patients per hospital doctor and general practitioner, we have seen that values are so close each other. As seen in Figure 5.1, each general practitioner is responsible for 38.5 patient in a day and each hospital doctor is responsible for nearly 33 patients in a day. In the beginning of the model run, it can be seen there is a small decline in number of patients in general practitioners office but a wide decline in hospitals. The reason of this situation is explained by the service quality effect. Although there is no capacity problem in the model, service quality decreases because of the inadequate number of doctors and general practitioners at the beginning of the model. This decline is larger for the general practitioner than the hospital due to the service quality effect. In Figure 5.2, service quality effects can be seen for hospitals and general practitioners.

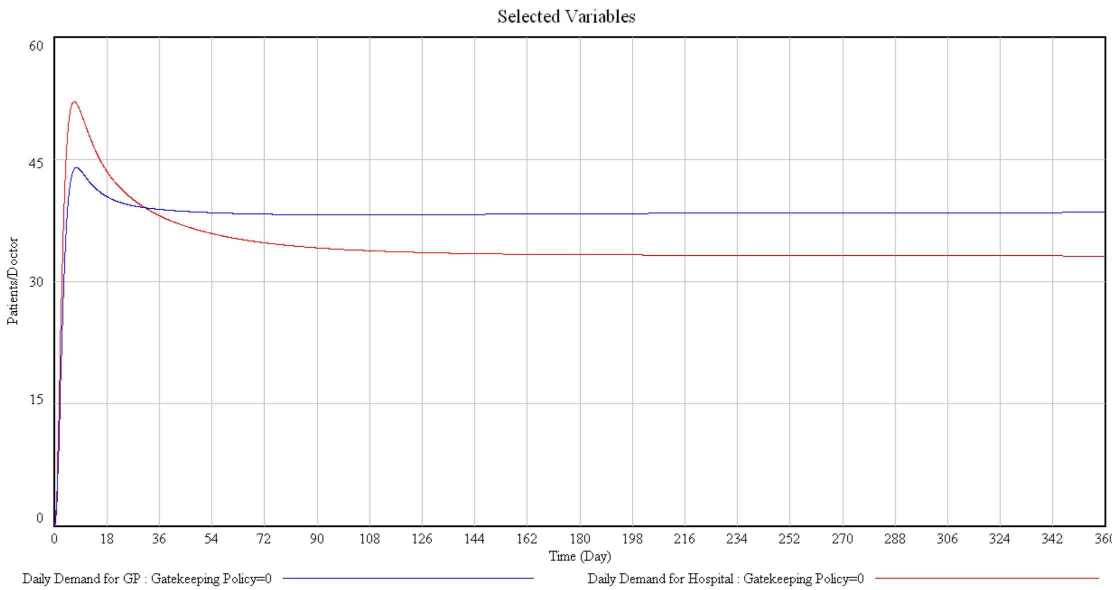


Figure 5.1: Daily Demand, Base Case

5.1.1 Introducing Gatekeeping Policy

When we introduce the gatekeeping policy to the model, we have seen that there is a significant increase at the value of probability of choosing general practitioners (see Figure 5.3) As seen from figure, the probability is increasing from 0.575 to 0.791 and it forces patients to go to general practitioners. Our expectation is that hospital work load decrease and there is a significant increase for daily demand of each general practitioner. However, when we check the results we see that daily patient per general practitioner increases from 38.5 to 52; however hospital cannot reduce its work load; the value decreases from 33 to 29

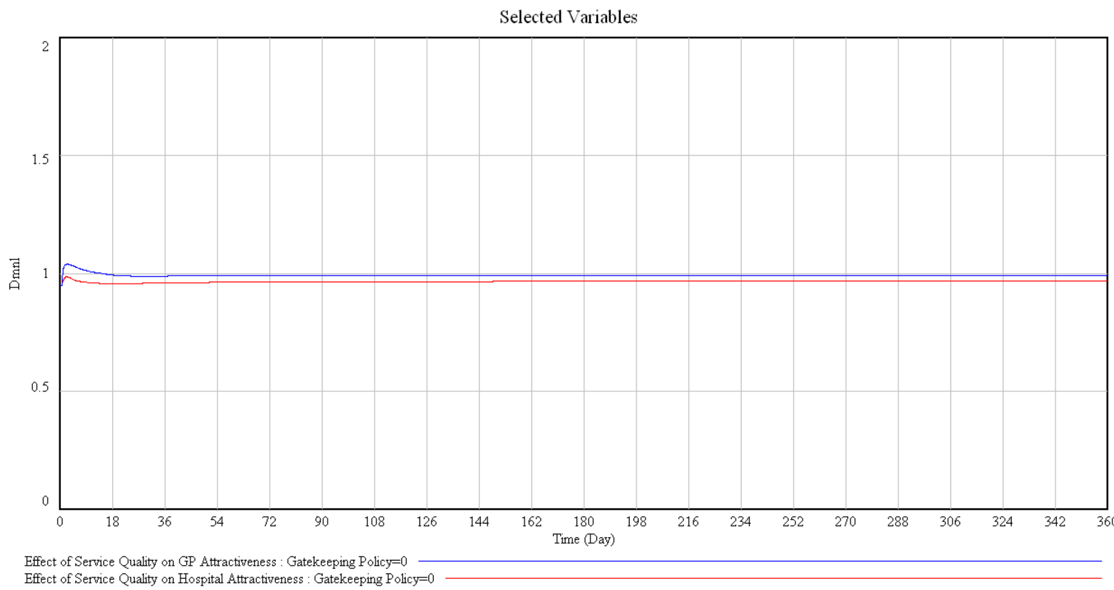


Figure 5.2: Service Quality Effect, Base Case

patients only (see Figure 5.4). This situation can only be explained by referral rates, since the number of patients referred from general practitioner to hospital increases from 549 to 2496. In the model, we do not consider the excessive referrals' negative effect on trust effect. Thus, truct effect has significant role and it increases the probability (see Figure 5.5). To conclude, gatekeeping policy can increase the rate of choosing general practitioner, however because of the excessive referral rates it does not benefit the system by decreasing hospital work loads. Therefore, we try to develop some policies to increase the probability while reducing the hospitals' work load.

5.1.2 Improving Current Situation

When we look at the figure, it is obvious that there is a small difference on the behavior pattern at the beginning of the simulation although we put the value of gatekeeping policy as a constant value 1.07. Because we were expecting the same behaviour with just different values. However, this results shows that effects on hospitals' and general practitioners'

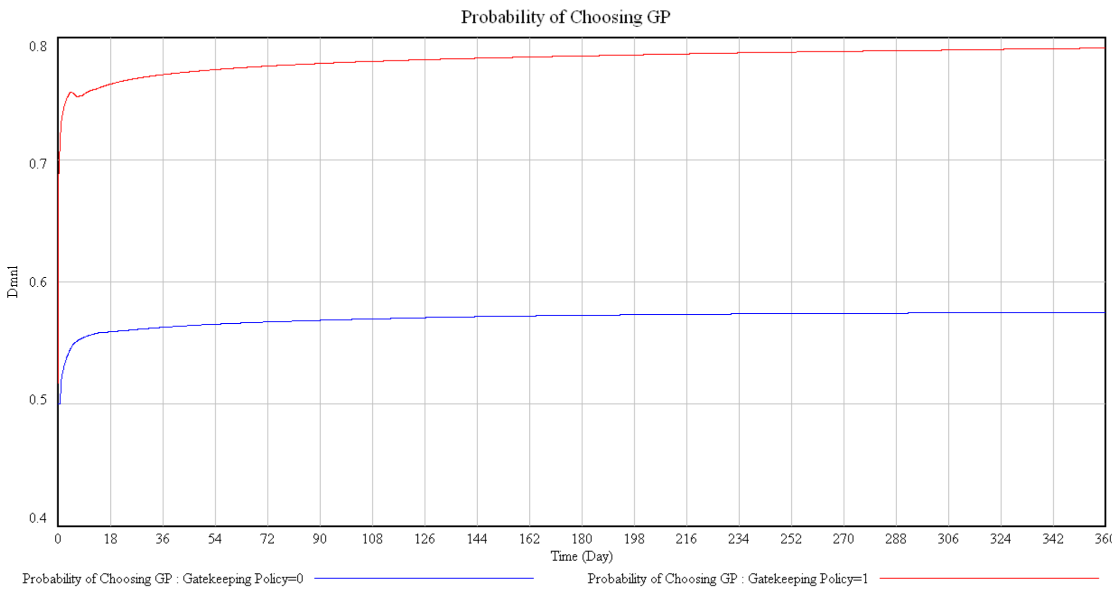


Figure 5.3: Introducing Gatekeeping Policy

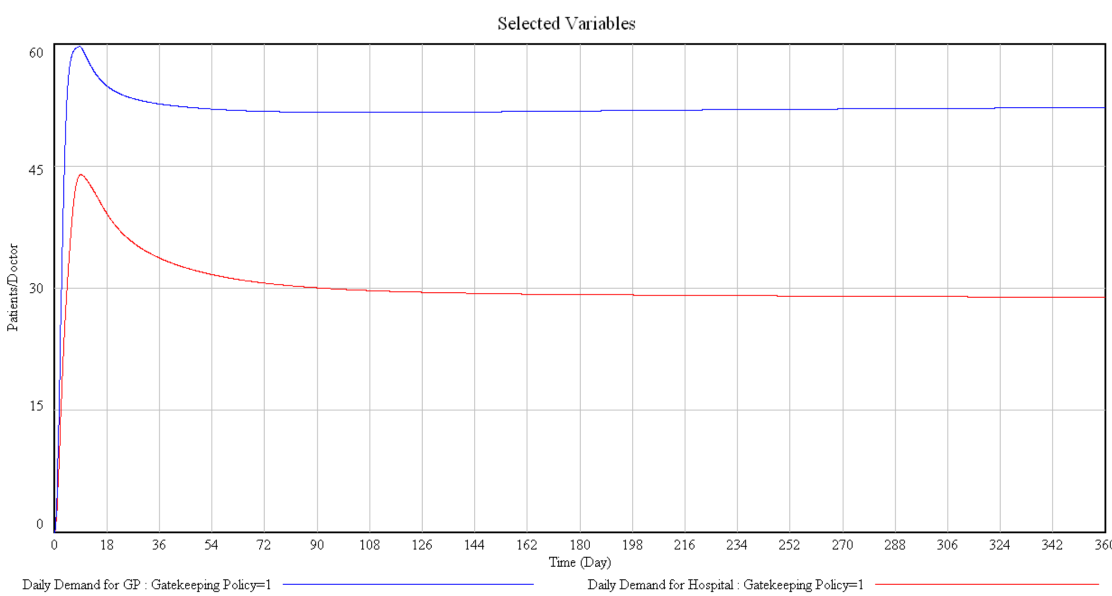


Figure 5.4: Daily Demands, G=1

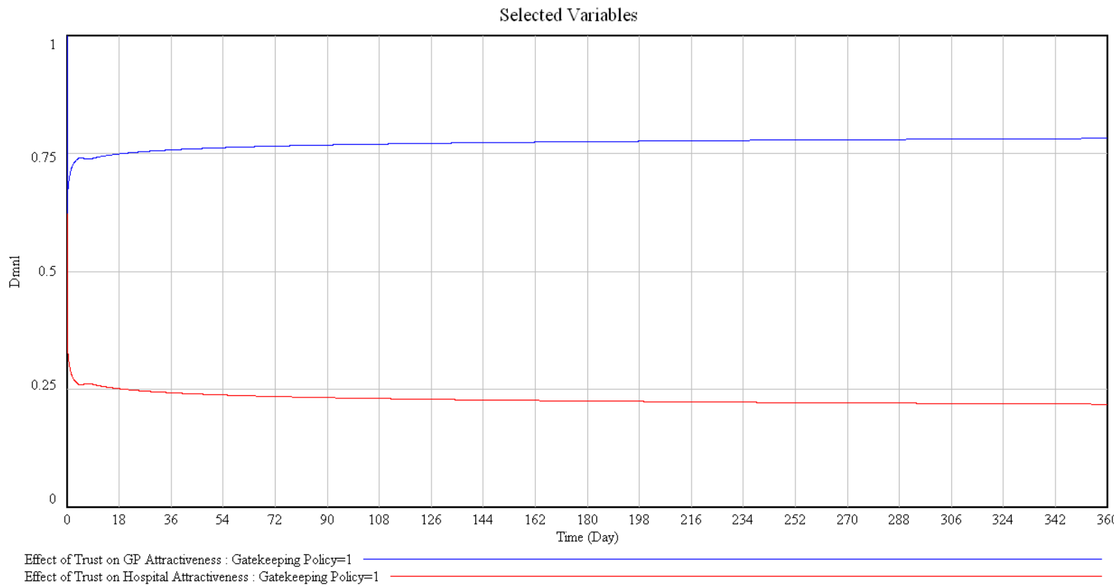


Figure 5.5: Trust Effect, G=1

attractiveness have a significant role on the behaviour. Because of that effects, if we want to increase the value of *Probability of Choosing GP* without *Gatekeeping Policy*, we should always be sensitive to the effects of trust, waiting time and service quality in the model.

Modifying Hospital Capacity

There can be several ways to increase this probability in the model without gatekeeping policy. First one is to change the daily treatment capacities of general practitioners and hospitals in the model. If we want patients to choose general practitioner as in the existance of gatekeeping policy, we should increase the capacity of general practitioners or decrease the capacity of hospital doctors. However if we look at the results at the existence of gatekeeping, it can be seen that there is not any capacity problem at the general practitioner since there isn't any waiting queue. Thus, it is meaningless to increase the performance of general practitioners. At the same time, we can decrease the performance values for hospital doctors but it should not be forgotten that this modification can create waiting queues at the hospital and it can decrease the service quality. As seen in Figure 5.6, when we decrease each doctor's daily capacity from 60 to 30 patients, we can increase the probability however patients start to wait at hospital for treatment. However, this is not a plausible policy.

Modifying General Practitioners' Capacity

We increase the number of general practitioners by changing the panelsize in the model and we decrease our panelsize from 3500 to 2000 as seen in Figure 5.7. Increasing the number of general practitioners increases the service time in the model which means service quality will be better at general practitioners' office. However as seen in the Figure 5.7, just increasing the number of general practitioner is not enough in the model to attract the patients to general practitioners. We are not changing the number of hospital doctors in the model since decreasing the service quality is meaningless.

Modifying Work Time for General Practitioners

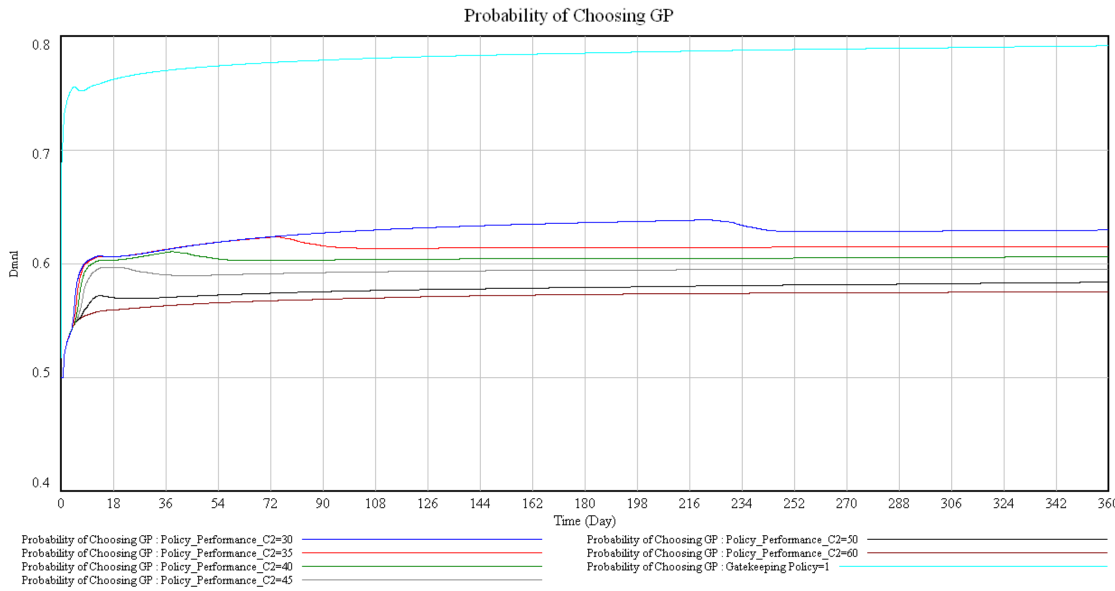
An alternative way is to increase the work time for general practitioners to increase their service quality. As seen in Figure 5.8, we increase it from 6 hours to 7 and 8 hours respectively and as seen in the results, we can increase the value of *Probability of Choosing GP* by increasing the service quality effect at general practitioner. However, we cannot reach the level when there is a gatekeeping policy in the city.

Public Campaigns

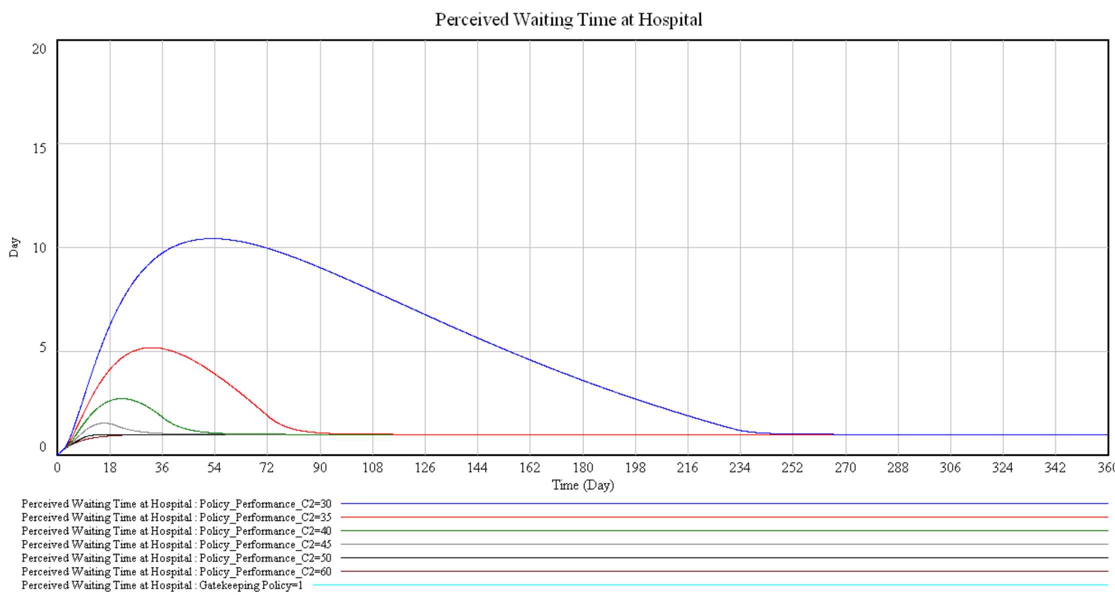
Finally, if we want to increase the probability, we should increase the confidence of patients for general practitioners. Let us assume that we are performing an impressive campaign and we gain 1 patient from 60, 45, 30 and 25 patients at hospitals respectively. As seen in Figure 5.9, we can increase the value of *Probability of Choosing GP* prominently and reach the value at existence of gatekeeping policy when we gain 1 patient from each 25 patients at hospitals.

Policy Analysis

To conclude, the best way to increase the *Probability of Choosing GP* without *Gatekeeping Policy* in the model is increasing the *Effect of Trust on GP Attractiveness* and *Effect of Service Quality on GP Attractiveness*. While increasing them, we should be careful about waiting queues at hospitals or general practitioners' offices. Therefore, we should not change

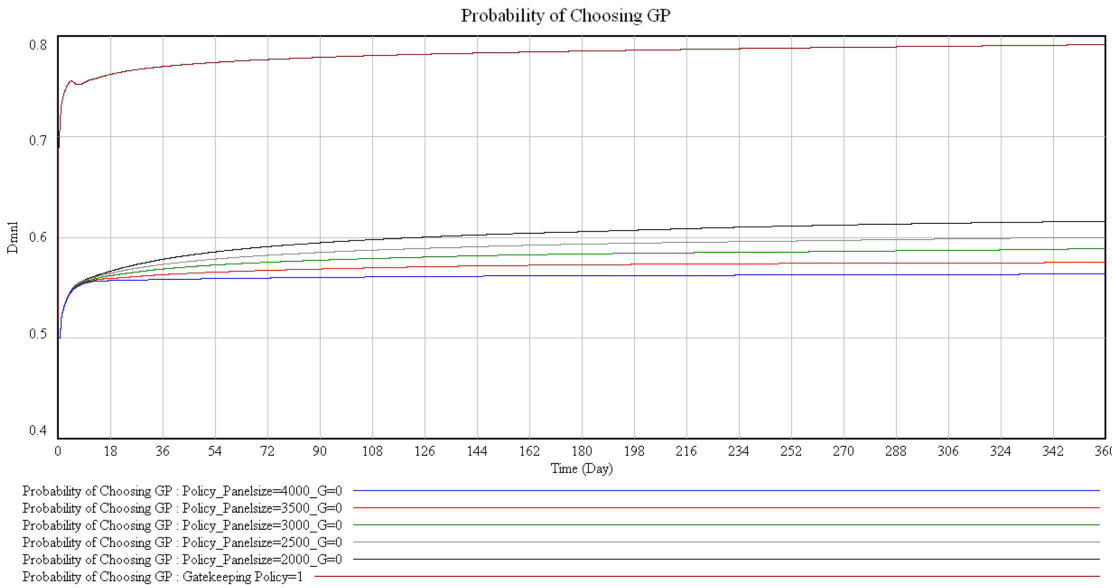


(a) Probability of Choosing GP

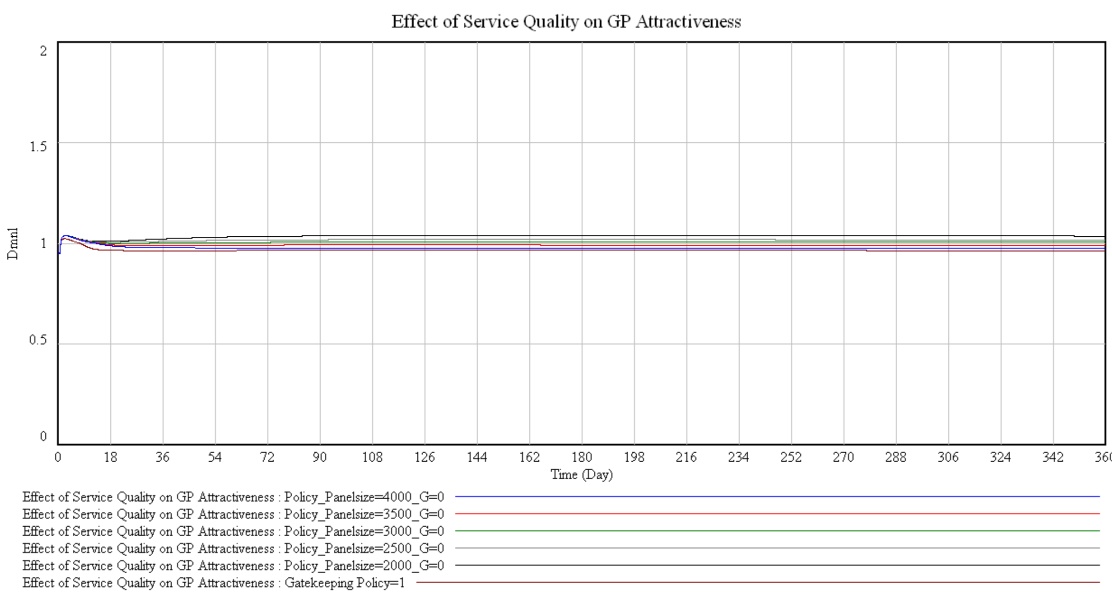


(b) Perceived Waiting Time at Hospital

Figure 5.6: Decreasing the performance at Hospital



(a) Probability of Choosing GP



(b) Effect of Service Quality on GP Attractiveness

Figure 5.7: Changing Panelsize

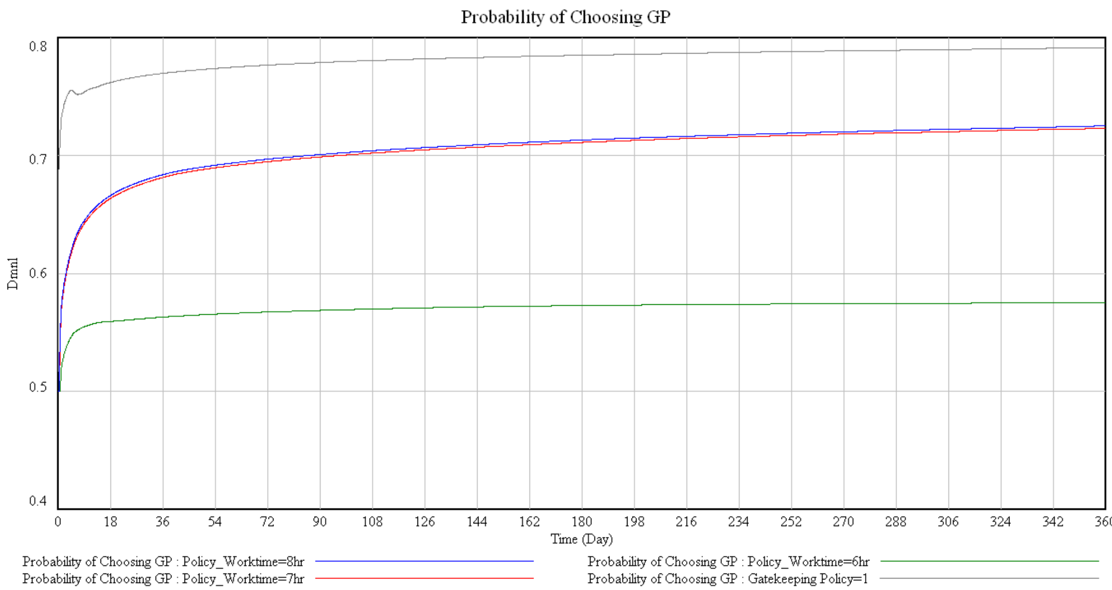


Figure 5.8: Increasing Work Time

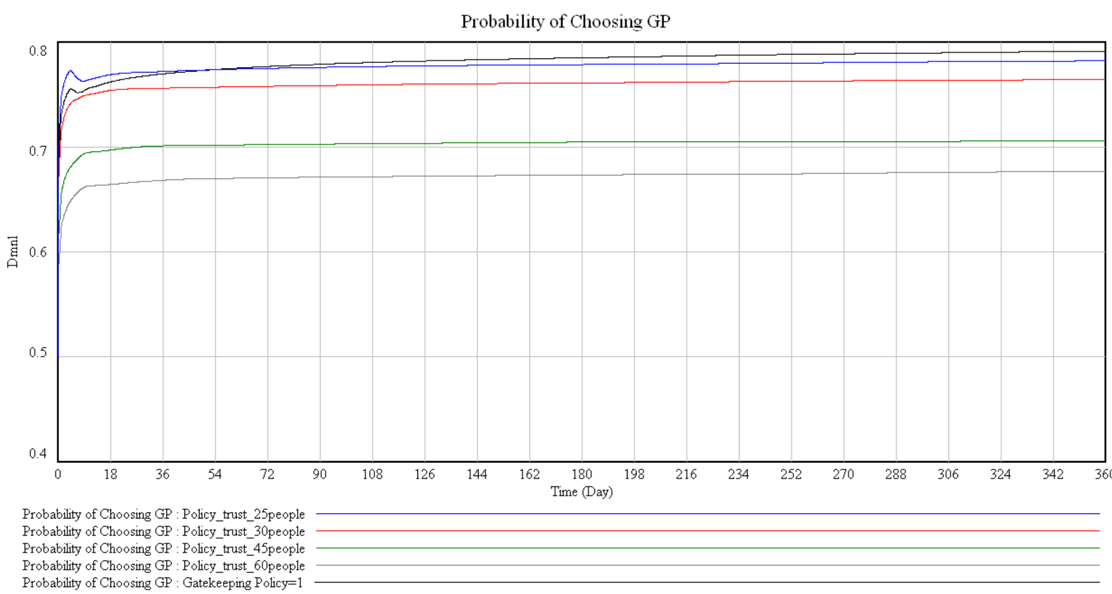
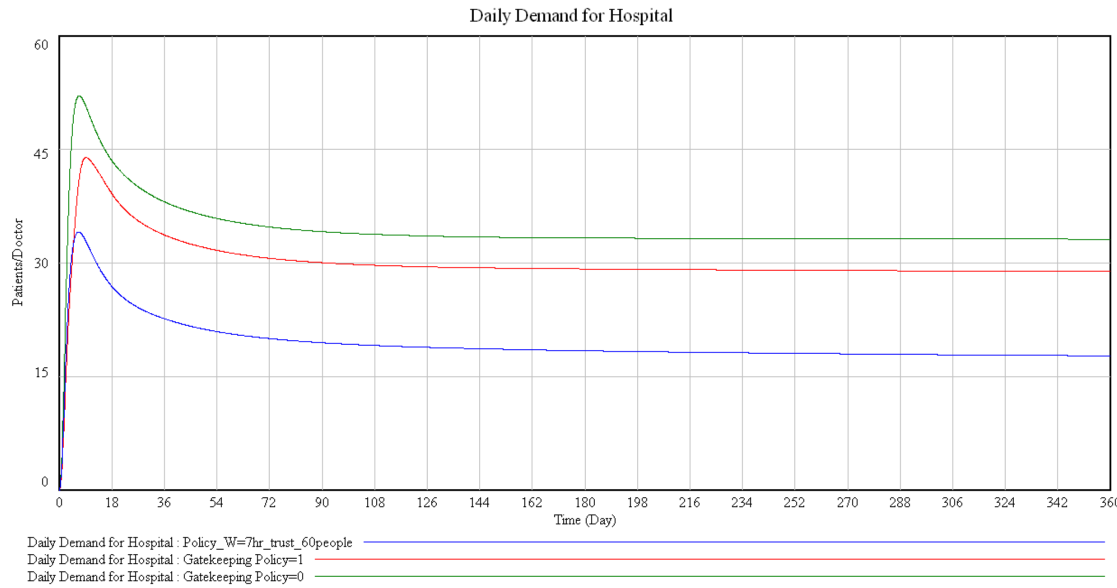
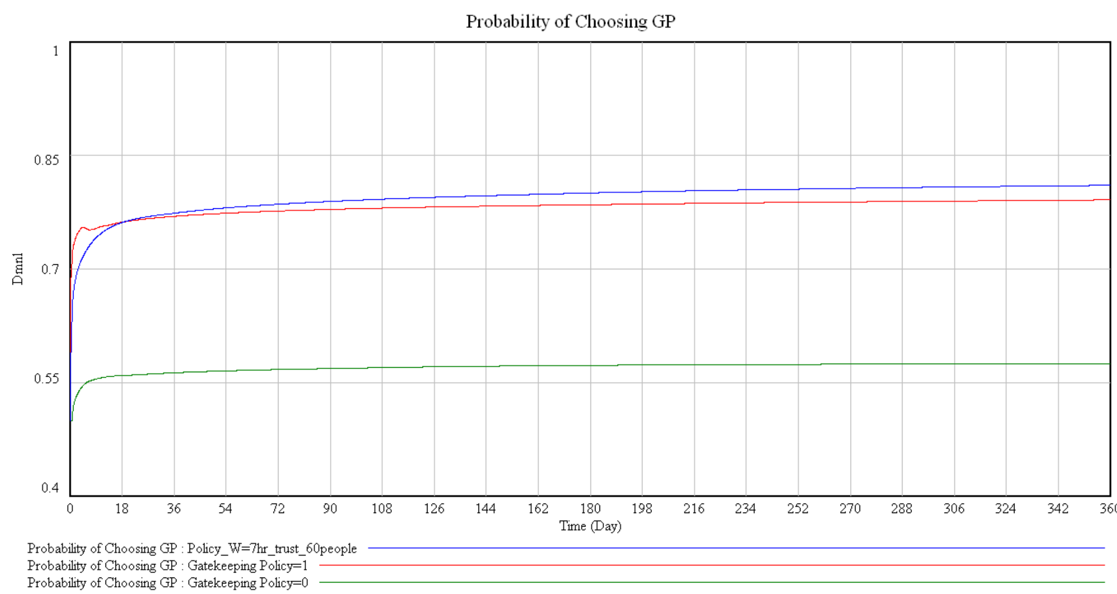


Figure 5.9: Increasing Effect of Trust on GP Attractiveness

the performances of doctors. Instead, we can increase work time or decrease panelsize. Increasing the work time is better than increasing the number of general practitioners by reducing the panelsize. Because reducing panelsize means allocating more budget to general practitioners' salaries. Also, in addition to increasing work time, we can implement promotion campaign to gain trust of patients for general practitioners' treatment. From the Figure 5.10, the result of the policy can be seen. Thus, daily demand per hospital doctors decreases to 18 patients. To conclude, the most important effect in the system is the trust effect.



(a) Daily Demand at Hospital



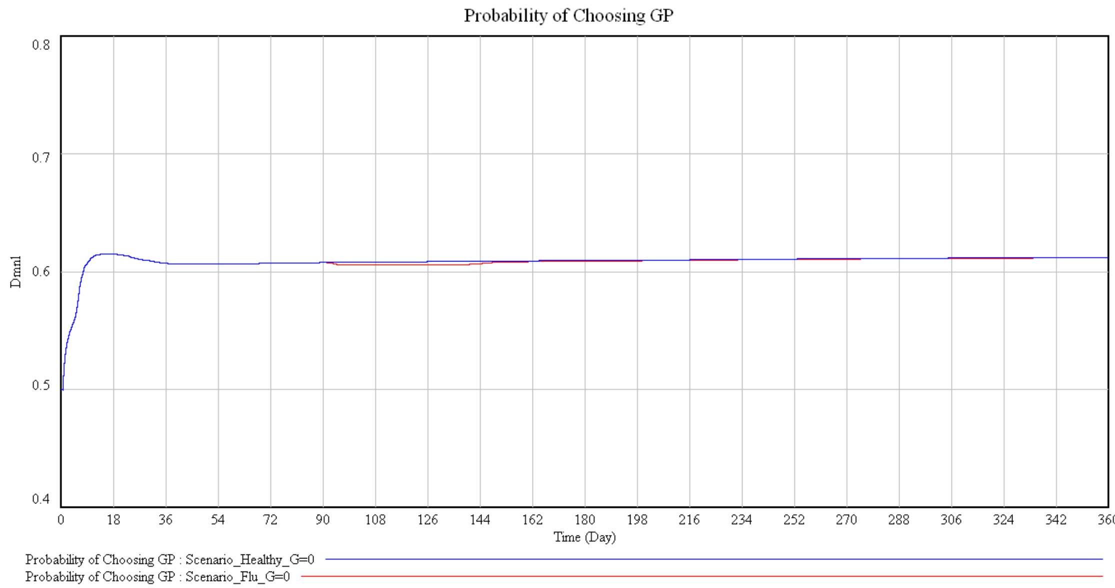
(b) Probability of Choosing GP

Figure 5.10: Policy for Reaching the Existence of Gatekeeping

5.2 Scenario 2: Flu Epidemic

In this scenario, we assume that there is a flu epidemic in the city in spring months. For this reason, we increase the number of sick people in the city to see the effects on workloads and patients' decision. In the simulation, we increase the value of "*Sickness Fraction*" by 0.01 at the 90$^{\text{th}}$ day for 45 days. When there is not any gatekeeping policy, people can go to hospital as their first contact instead of general practitioner. However, when we look at the simulation results in this case, we have seen that patients are not changing their behaviour to general practitioner or hospital. That means trust effect is not changing in this case. In addition to this, both general practitioners and hospital doctors have available capacity for these excessive patients which prevents the treatment center from negative effects of waiting time. However, this excessive patients increase the daily demand for both general practitioner and hospital. At this time, doctors should decrease their service time to overcome the extra workload which causes decay in the service quality. When we compare these decays both for hospital and general practitioners, we see that general practitioners' quality decreases in absolute value more than the hospitals'. Value of "*Effect of Service Quality on GP Attractiveness*" decreases from 0.98 to 0.96 but "*Effect of Service Quality on Hospital Attractiveness*" decreases from 0.97 to 0.96. So that, "*Probability of Choosing GP*" decreases in this flu epidemic term when there is not gatekeeping policy. However, in Figure 5.11, it can be seen that this decrease at probability value is so small that it can be ignred.

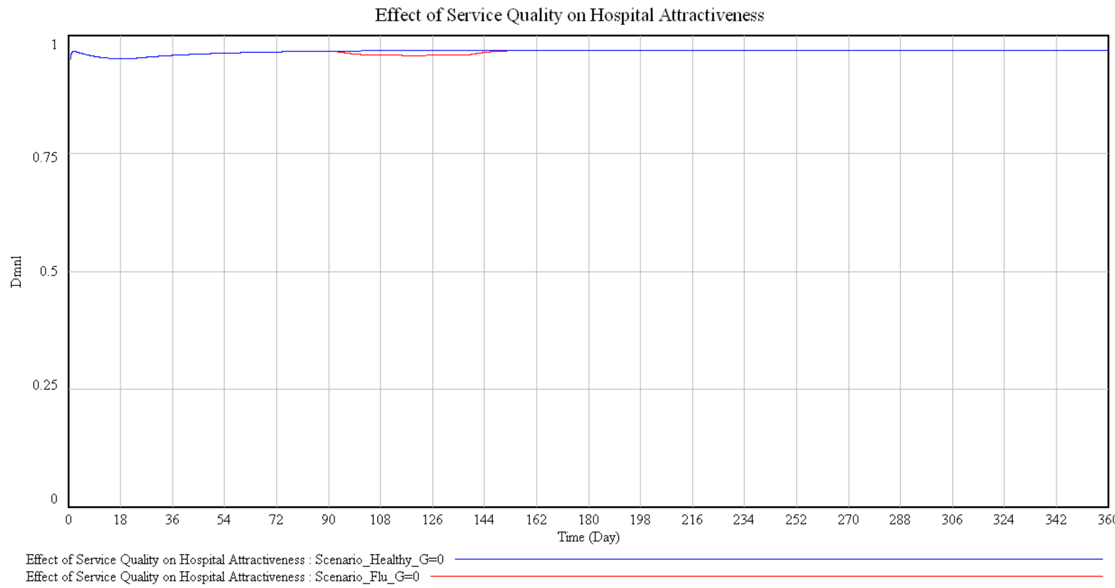
When we look at the case that there is a gatekeeping policy in the system, we see that there is a significant decay at the value of "*Probability of Choosing GP*" as seen in Figure 5.12. This decrease is the result of waiting time, trust and service quality effect in the model. Therefore, when extra patients choose to go to general practitioners they start to wait in the queue because of the limited daily patient capacity of general practitioner. This situation has two effects. It decreases attractiveness by waiting time effect and trust effect, since people who leave general practitioner office because of long waiting time decreases trust.



(a) Probability of Choosing GP

(b) Effect of Service Quality on GP Attractiveness

Figure 5.11: Flu Epidemic, G=0

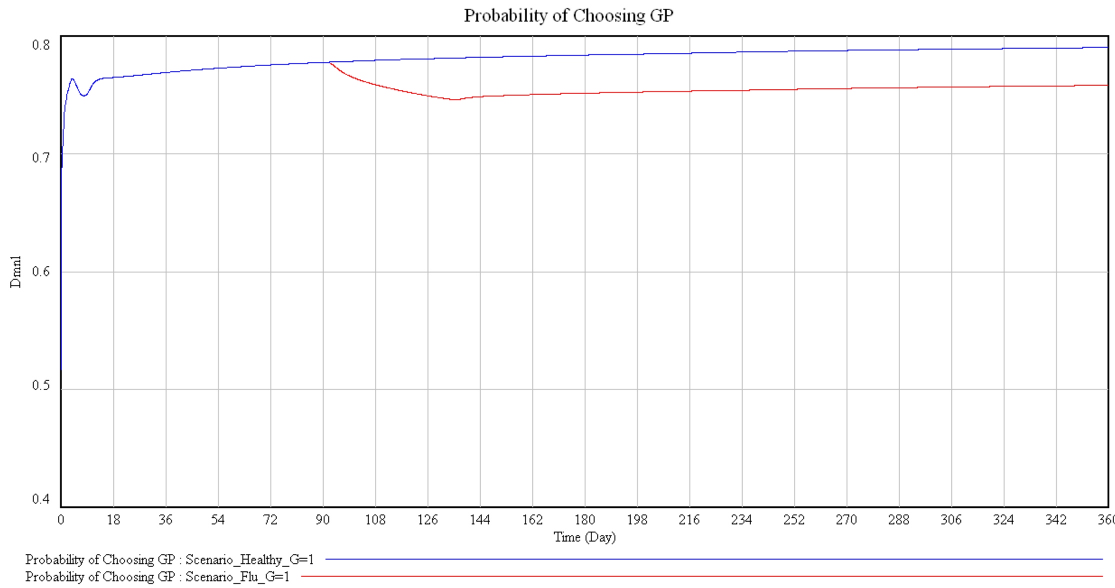


(c) Effect of Service Quality on Hospital Attractiveness

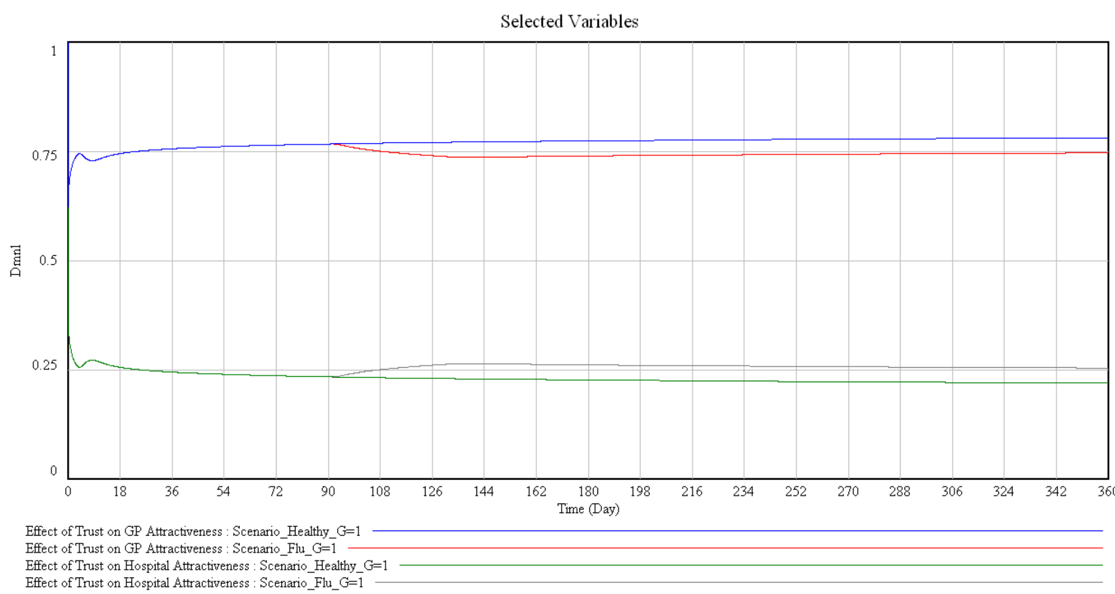
Figure 5.11: Flu Epidemic, G=0 (cont.)

Also service quality is decreasing at general practitioner but it is really in small range and it can be negligible. Therefore both trust effect and waiting time effect decrease the value of probability for choosing general practitioner. If we look at the hospital side, we will see that extra patient because of flue cause a decrease in service quality however doctors' capacities are available and patients are not waiting for their treatment. This increases the trust effect at hospital and therefore increase the value of "*Probability of Choosing Hospital*".

At this point, we should develop a policy to overcome this overload at general practitioners' office to prevent the waiting time. Thus, when we look at the daily demand at general practitioner, we see that nearly 73 people are visiting general practitioners in a day. So we can increase the daily patient capacity from 60 to 75 in the model. However, this can decrease the general practitioners' work satisfaction. From current practice, we know that general practitioners may have to serve so many people. However, although not modeled here, we can expect this to cause a decrease in work satisfaction. The other way can be the

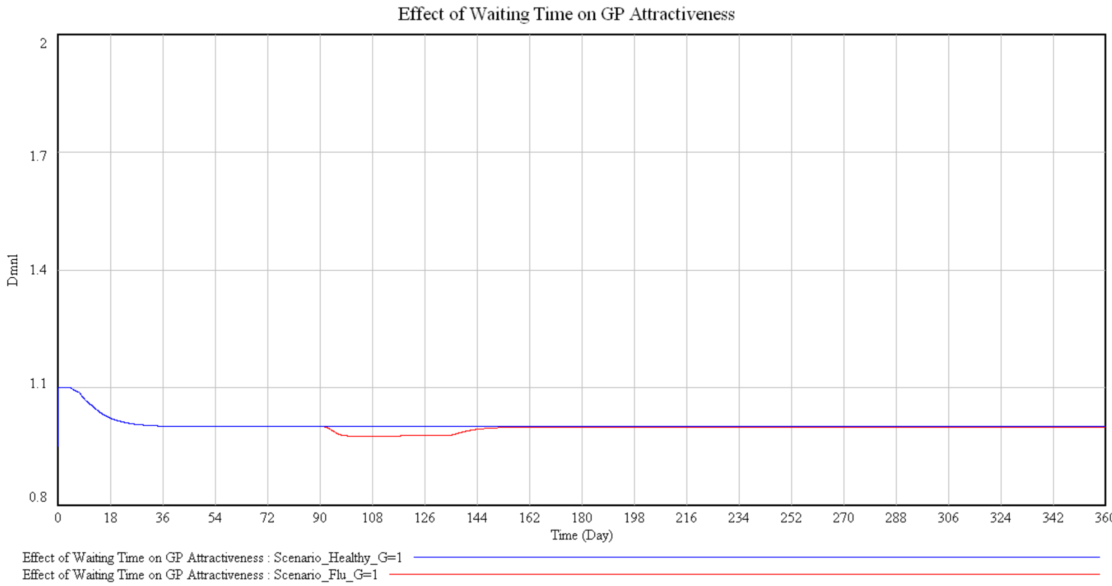


(a) Probability of Choosing GP

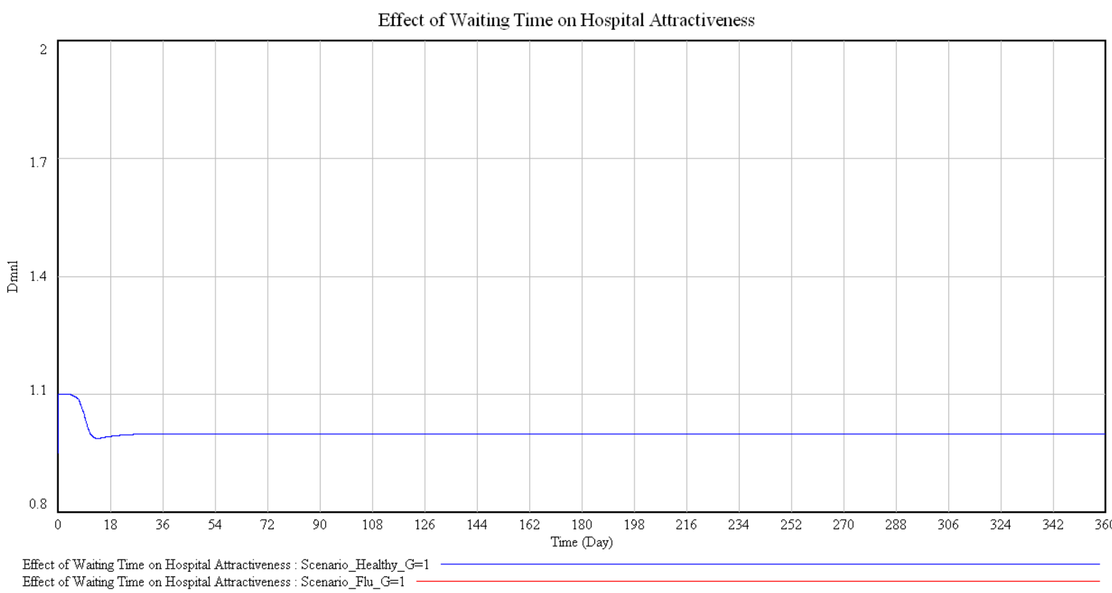


(b) Effect of Trust

Figure 5.12: Flu Epidemic, G=1



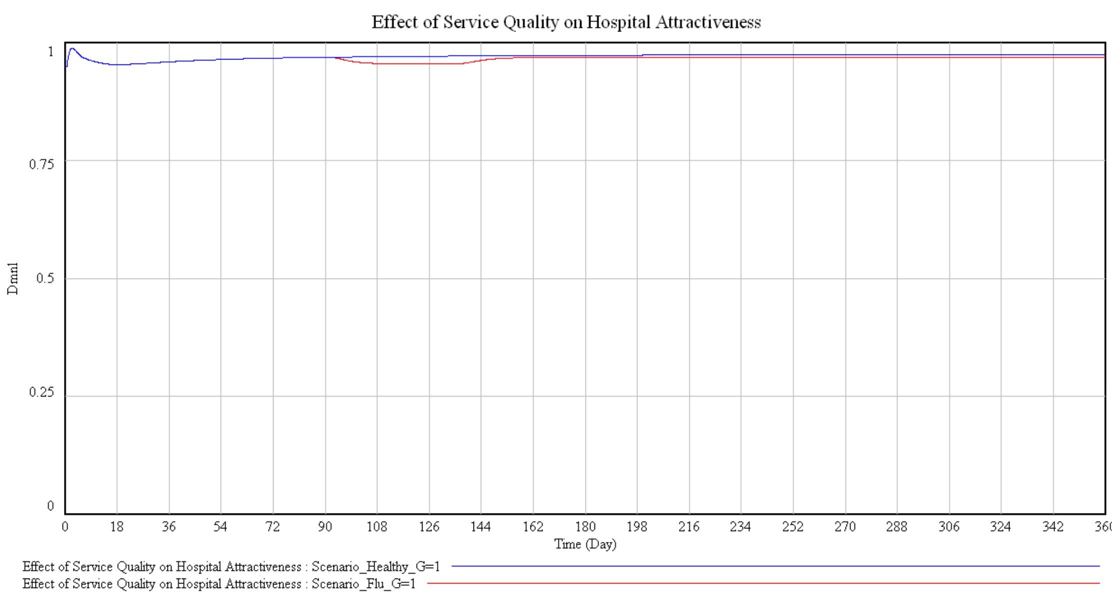
(c) Effect of Waiting Time on GP Attractiveness



(d) Effect of Waiting Time on Hospital Attractiveness

Figure 5.12: Flu Epidemic, G=1 (cont.)

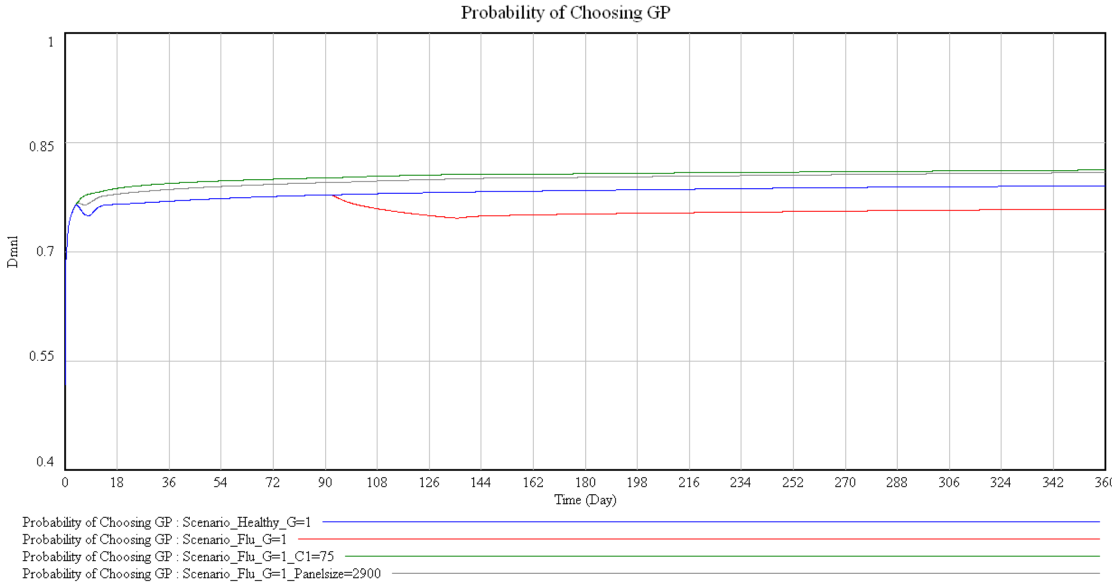
(e) Effect of Service Quality on GP Attractiveness



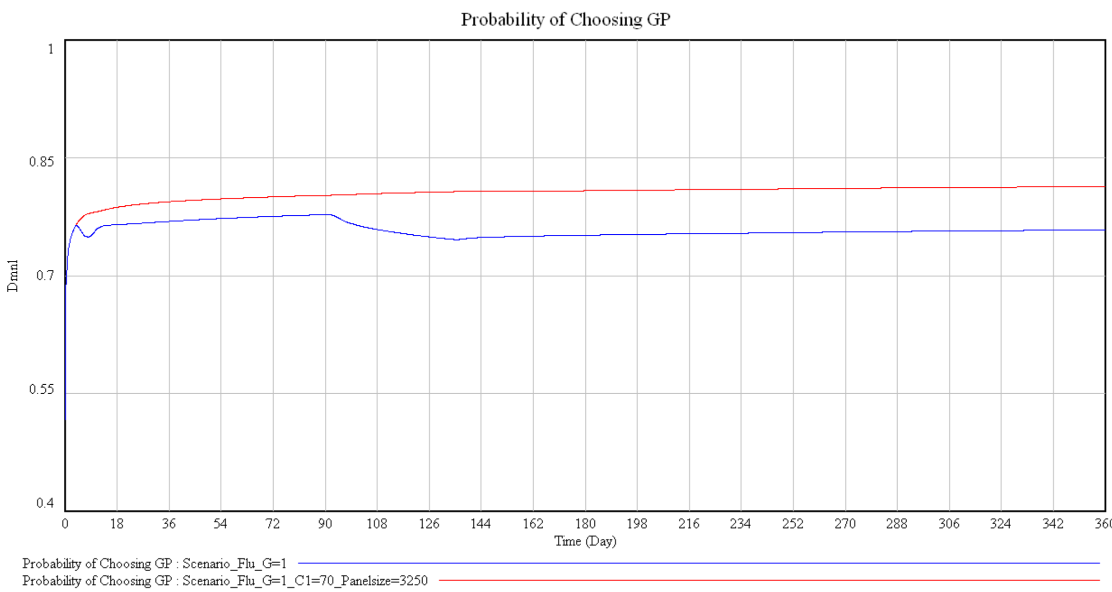
(f) Effect of Service Quality on Hospital Attractiveness

Figure 5.12: Flu Epidemic, G=1 (cont.)

increasing the number of general practitioners in the model. For this, we decrease the panelsize from 3500 to 2900 and so we obtain 116 general practitioners instead of 96. However, it is more costly to have 116 general practitioners instead of increasing the daily capacity. Also when we compare the results for *Probability of Choosing GP* (see Figure 5.13), increasing the capacity gives the maximum value. To conclude, in the model when there exists a problem with workload, it is plausible to change the daily capacity for hospital or general practitioners to prevent waiting time. It can be obtained by increasing the number of doctors or their daily performance. In this scenario, we decide to change both values by increasing the general practitioners daily performance up to 70 patients and we see that daily patient demand becomes 67 for general practitioners. In addition, we decrease the panelsize to 3250 to have 103 general practitioners in the model. So, we can optimize the cost and work satisfaction at the same time.



(a)



(b)

Figure 5.13: Flu Epidemic Policies

5.3 Scenario 3: Summer Holidays

In this scenario, we assume that general practitioners are going to holiday in summer season but hospital managers do not change their number of doctor for outpatients. Also, we assume general practitioners and hospital doctors reduce their performances due to hot weather. For this scenario, we decrease the number of general practitioners by 15 at the 150$^{\text{th}}$ day of the simulation for 90 days and also we reduce the performances for general practitioners and hospital doctors from 60 to 45 patients per doctor per day. Also, we should analyze the scenario again under the two cases: with or without gatekeeping policy. As seen in Figure 5.14, green line represents the *Probability of Choosing GP* with normal policy, red line represents it at the summer season with reduced performance (*Scenario Summer*) and finally blue line represents it with the scenario of general practitioners' holidays (*Scenario Holiday*) when there isn't any gatekeeping policy in the system. In the figure, values of normal policy and summer scenario are coinciding.

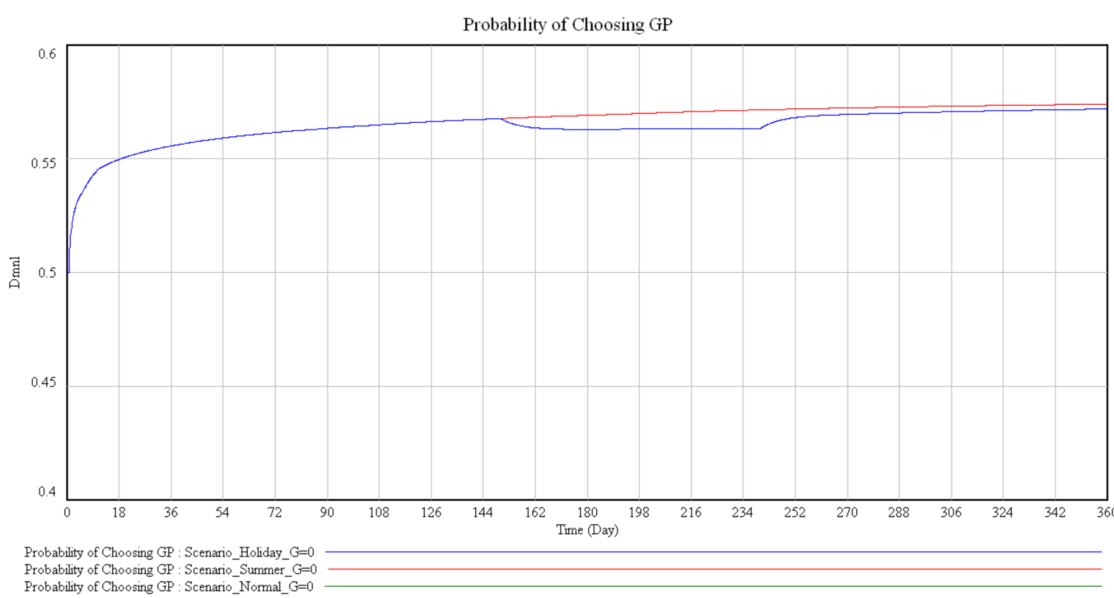


Figure 5.14: Probability of Choosing GP

As seen from the figure, in this scenario patients prefer to go to hospital instead of choosing another general practitioner. As stated in Official Journal [19], temporary general practitioners are responsible for patient list of the general practitioner who is on vacation; however results show that patients prefer to go hospital. We will explain this situation step by step to understand the decreases at the *Probability of Choosing GP*. First of all, when we decrease the performance of the doctors, system does not change its behaviour since there isn't any capacity problem at general practitioners' office or at hospital. That means there isn't any waiting line at general practitioners' office; however, number of daily patients per general practitioner increases from 36 to 42 patients and service time per patient decreases. At the same time, there is an increase at the number of daily patients per hospital doctor but it is so small that it can be negligible and its value is 33 patients per doctor in a day. As a result, service quality decreases at general practitioners' offices because of service time and patients start to prefer going to hospital in the summer season (see Figure 5.15).

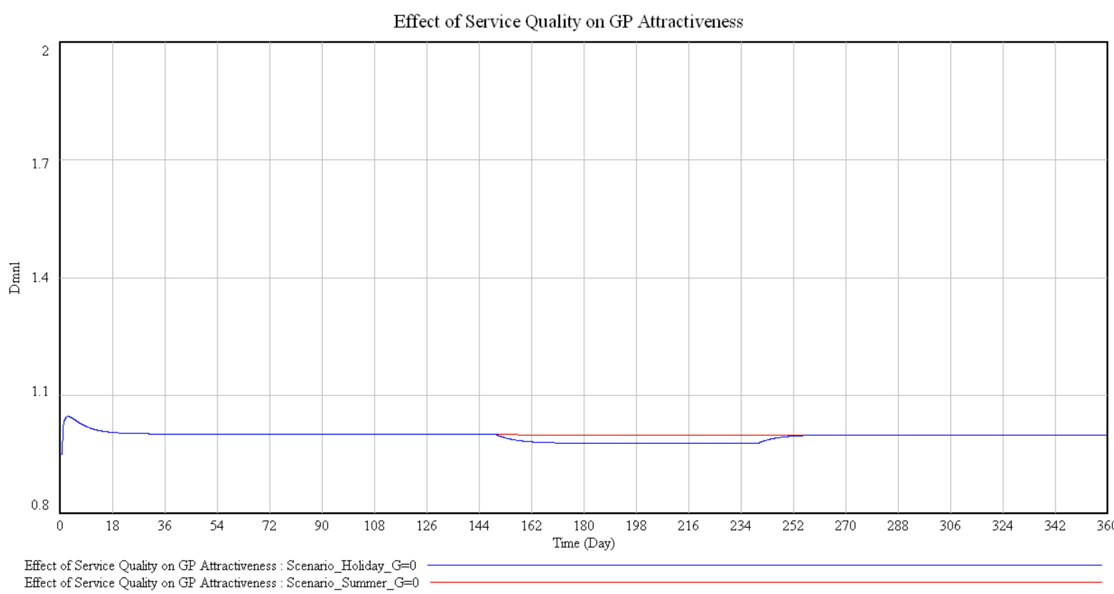
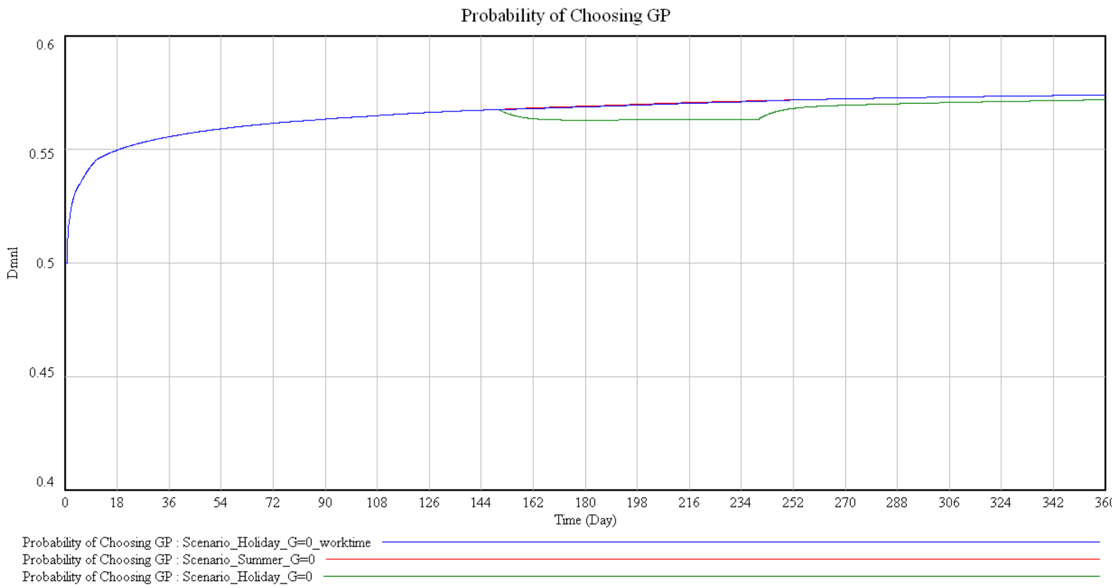


Figure 5.15: Effect of Service Quality on GP Attractiveness

At this point we should develop a policy to prevent the patients to prefer to go to hospital in holiday terms. However, there is no capacity problem in this scenario so it is unnecessary to change the panelsize or general practitioners' daily treatment performance. Therefore, we need to change the behaviour of service quality effect. As mentioned in Section 3.2.2.2, service quality effect is based on the *Perceived Service Time at GP* and *Normal Service Time at GP*. It is meaningless to change the normal service time since this value is defined from patients' expectation. Thus, we need to control *Perceived Service Time at GP* in the model. To overcome this problem, we decide to increase the work time of general practitioners by 1 hour in summer season. As seen in Figure 5.16, increasing the work time for general practitioner is saving the value of *Probability of Choosing GP*.

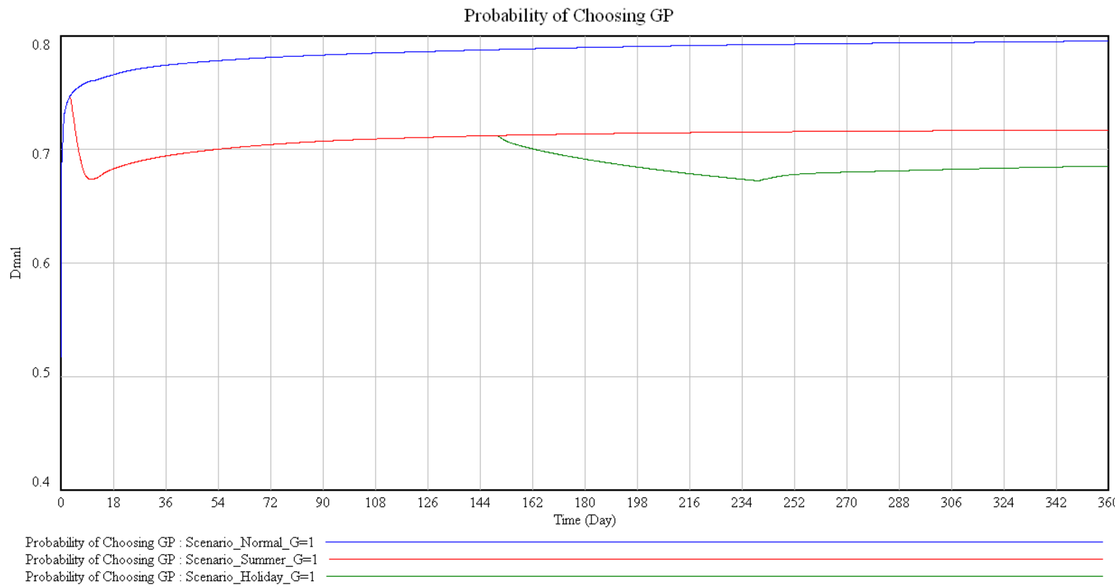
We also need to analyze the scenario when there exists gatekeeping policy in the city. In normal case, each general practitioner has daily nearly 51 patients and each hospital doctor has daily 29 patients. When we limit the capacities of general practitioners and hospital doctors to 45 patients per doctor, this causes an excessive patient at general practitioners office. So waiting time has negative effect on *Probability of Choosing GP* and patients starts to go hospital. Also if we look at the service quality, we will see that there isn't any significant changes for hospital and general practitioners but *Effect of Service Quality on GP Attractiveness* increases and *Effect of Service Quality on Hospital Attractiveness* decreases in the model. Because, daily demand for general practitioners become 45 instead of 51 and daily demand for hospital doctors become 33 instead of 29. Also trust effect will decrease for general practitioner because of queues at the general practitioners' offices. In addition to this, when we decrease the number of general practitioners in summer season because of doctors holiday, queues at general practitioners' office will increase again. Therefore, waiting time should affect the system negatively again and also trust to general practitioner will decrease more. We expect that service quality will not change because each general practitioner can cure again 45 patients in a day and hospital doctors' daily demand become 34 instead of 33. In Figure 5.17, *Probability of Choosing GP*, waiting time and trust effects can be seen.



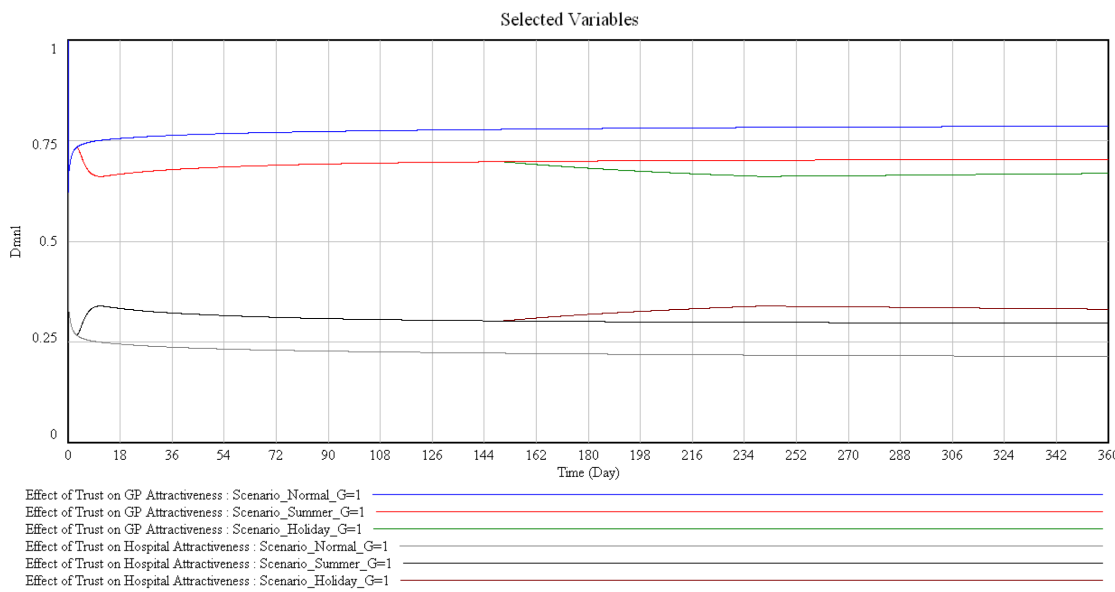
(a) Probability of Choosing GP

(b) Effect of Service Quality on GP Attractiveness

Figure 5.16: Holiday Policies, G=0

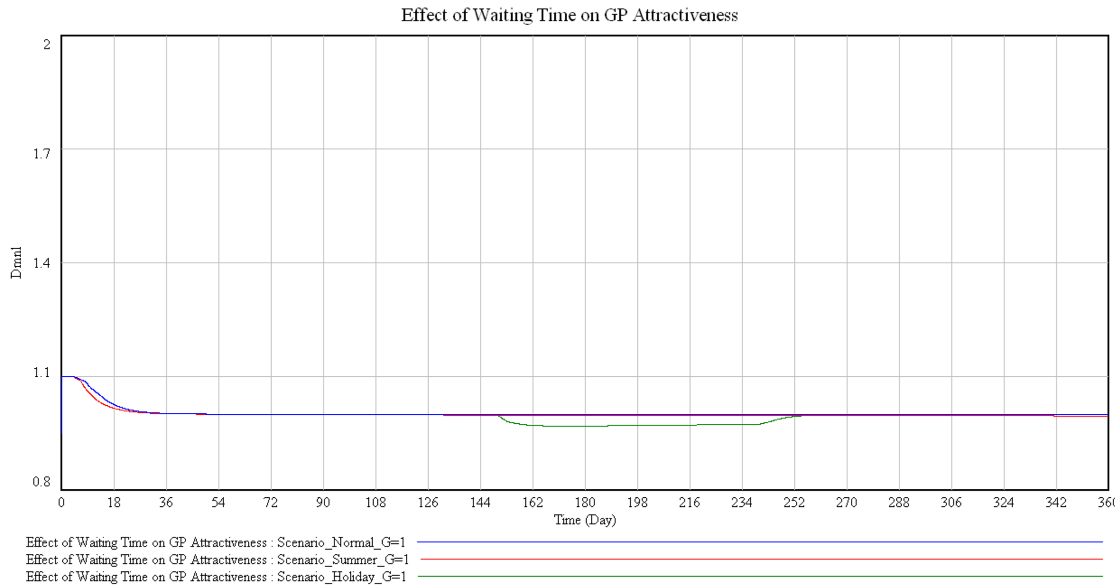


(a) Probability of Choosing GP



(b) Effect of Trust

Figure 5.17: Summer Holidays



(c) Effect of Waiting Time on GP Attractiveness

Figure 5.17: Summer Holidays (cont.)

In this case, it is obvious that there is a capacity problem in the model. Therefore, we should increase the general practitioners' performance or their quantities in the model. When we check the model, we see that if we just increase general practitioners' daily treatment capacity up to 60 patients, we can overcome this problem (see Figure 5.18).

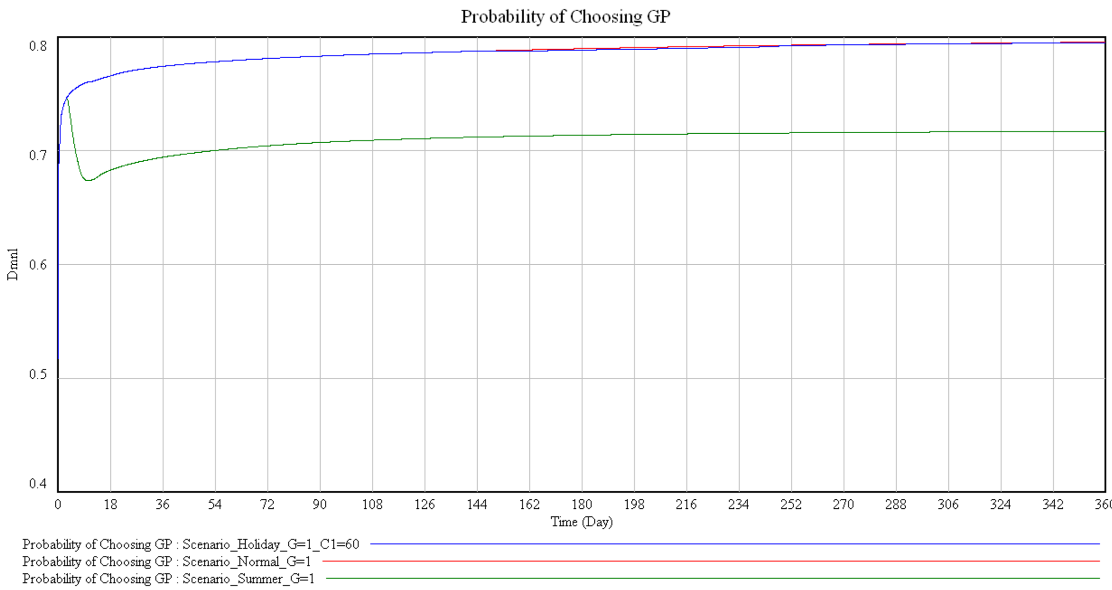


Figure 5.18: Probability of Choosing GP

5.4 Scenario 4: Unsatisfied General Practitioners

In this scenario, we assume that general practitioners leave their job because of dissatisfaction from their work. For this scenario, we change the rate *Leaving GP Job* as they quit from the job after 30 days they've started. When we implement this scenario without gatekeeping policy in the model, we see that there is not any waiting at general practitioners' offices and changes in *Probability of Choosing GP*. As seen in Figure 5.19, number of general practitioners decrease to nearly 70 in this scenario. To overcome this problem, we increase the salary of general practitioners by changing the value of *Income per Patient*. We increase it from 1 TL to 2.5 TL and we see that increase in salary satisfy the general practitioners and system reaches the value of *Desired Number of GP*.

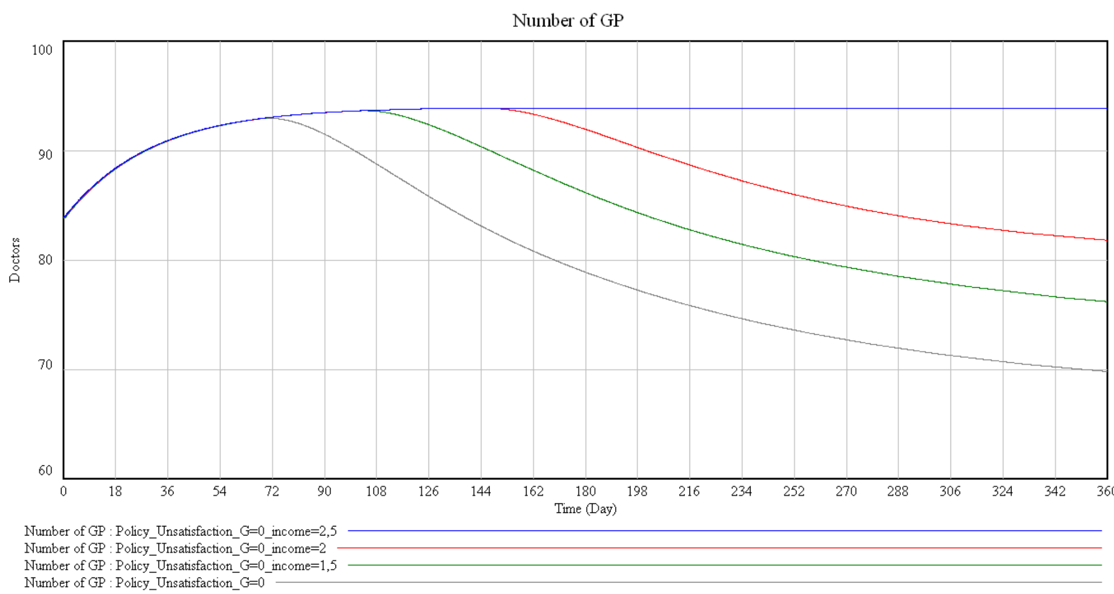
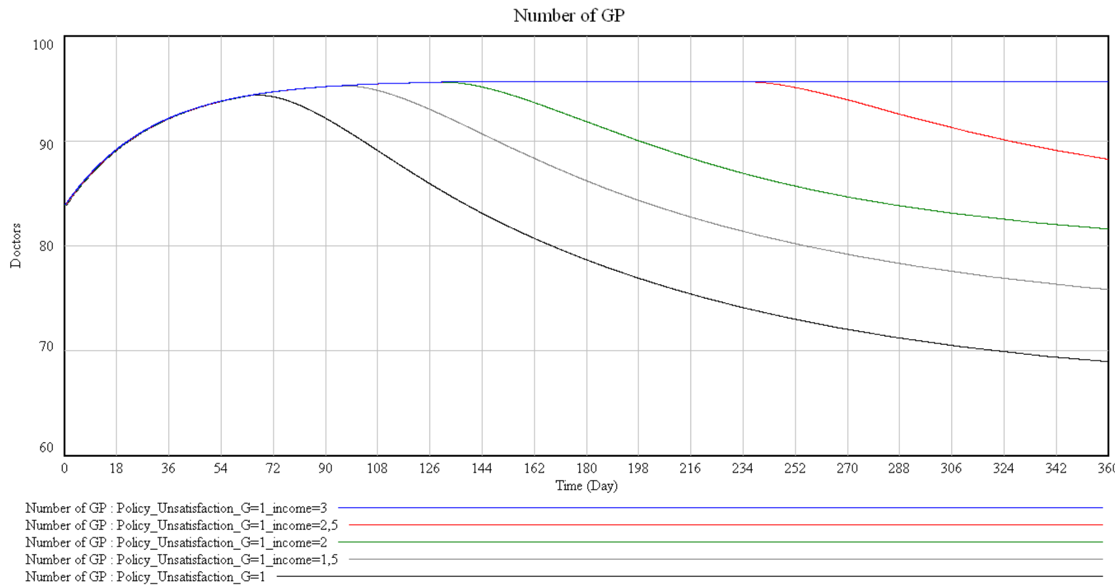


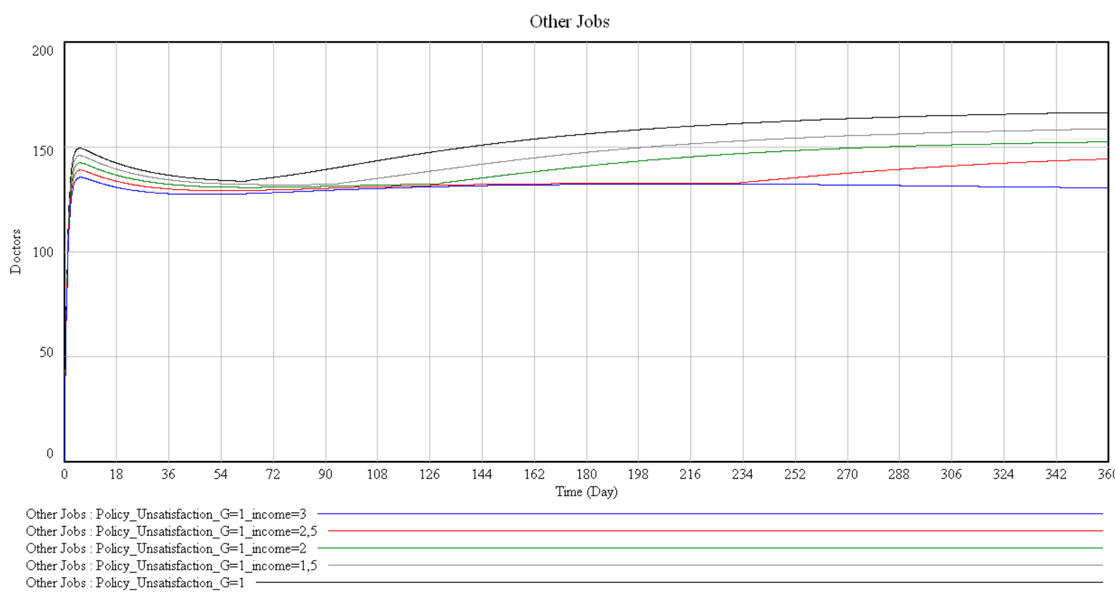
Figure 5.19: Number of GP

If we assume this scenario with existence of gatekeeping policy, we see that there is a waiting time problem at general practitioners' office. Therefore, we need to develop a policy again to overcome this problem. As seen in Figure 5.20, we can increase the *Income per*

Patient value. However this time, we should increase it until 3 TL to overcome it and to reach the desired number of general practitioners. From the figure, we also understand that at the value of 2.5 TL system works without any waiting line at general practitioners' offices (see Figure 5.20(c) for *Perceived Waiting Time*). Also, from the model we understand that, when general practitioners leave their job, they prefer to work as health officer. In Figure 5.20(b), increase in this value can be seen at *Other Jobs* stock.

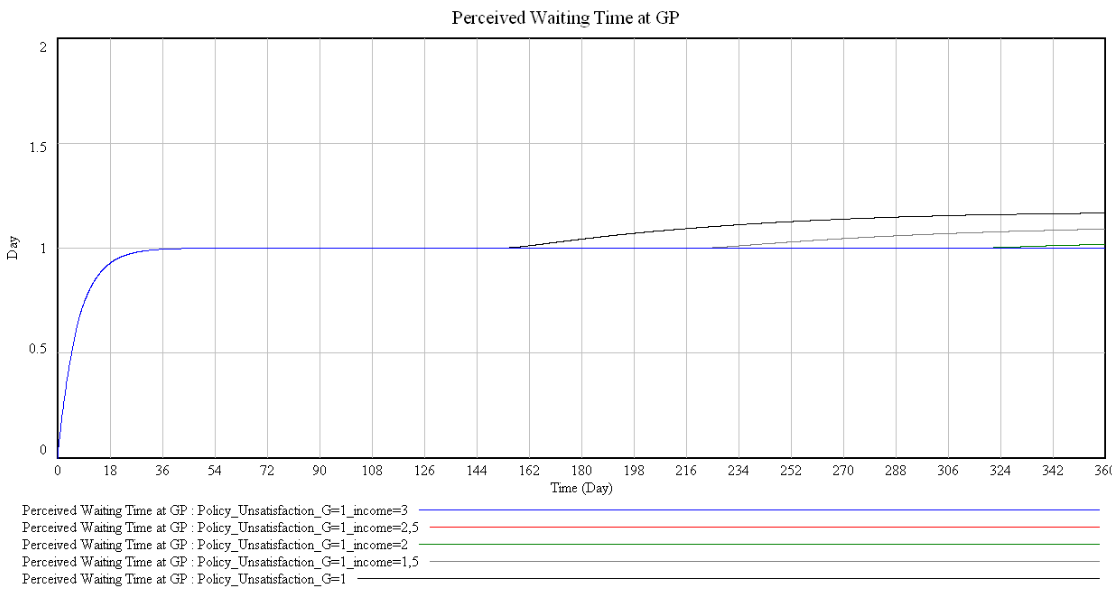


(a) Number of GP GP



(b) Other Jobs

Figure 5.20: Income Policy



(c) Perceived Waiting Time

Figure 5.20: Income Policy (cont.)

5.5 Scenario 5: Population Growth

In this scenario, we assume that population is growing with 0.013% annual growth. This annual growth rate is cited from Turkish Statistical Institute [24]. First, we implement the growth to the model when there is no gatekeeping policy and we fix the number of general practitioners and hospital doctors. We check the population at 5^{th}, 10^{th}, 15^{th}, 20^{th}, 25^{th}, 30^{th} and 35^{th} years. As seen in Figure 5.21, there are small changes at the value of *Probability of Choosing GP* which cannot cause any waiting at general practitioners' offices or at hospitals.

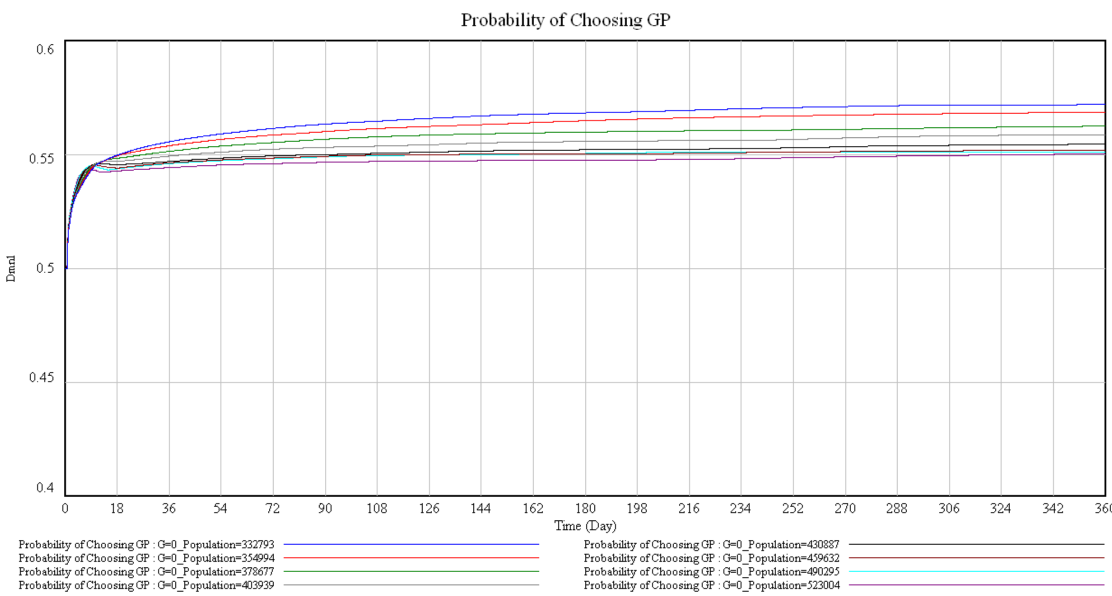
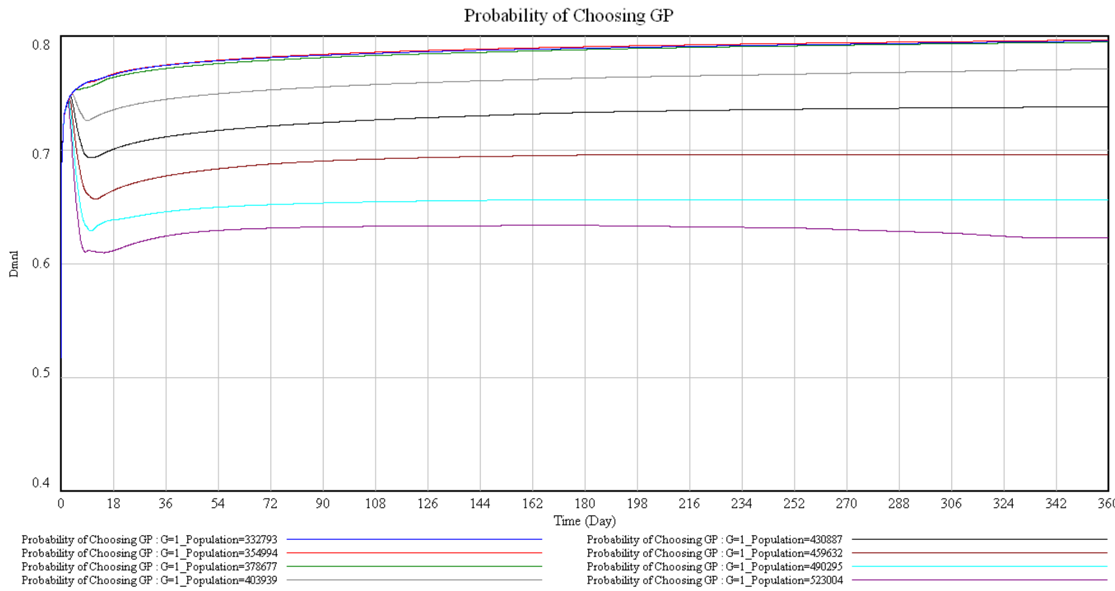


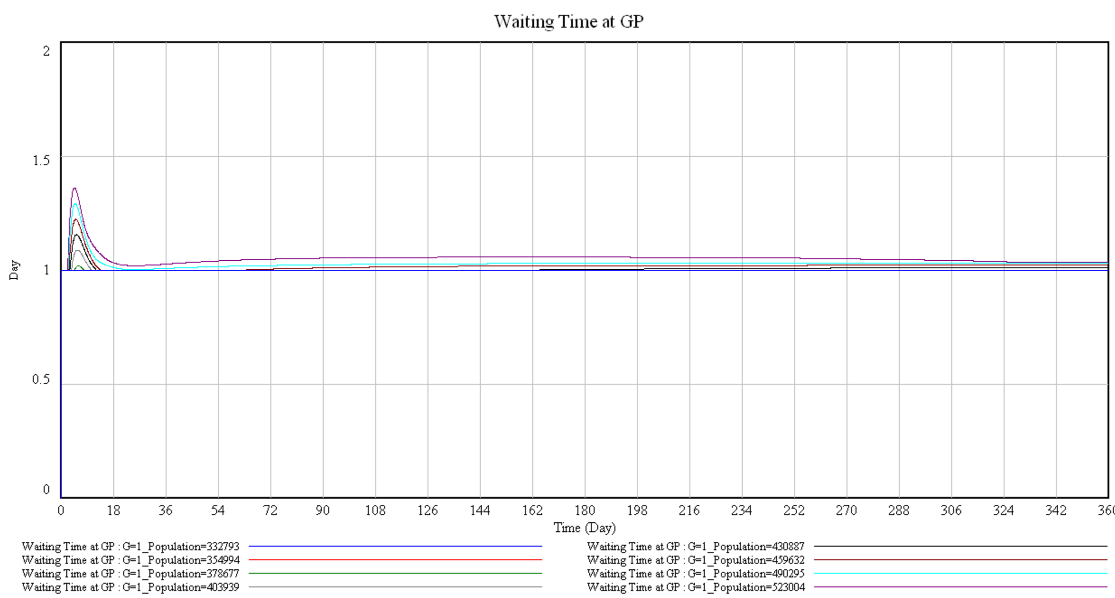
Figure 5.21: Population Growth, G=0

When there is a gatekeeping policy, population growth has more significance on the results. Since at general practitioners' offices, queues start at 10th year in the system due to the insufficient daily treatment capacity and this causes to decrease the value of *Probability of Choosing GP* in a significant level. If we look at the *Perceived Waiting Time at GP*, it is obvious that patients start to wait more than 1 day at general practitioners' offices. These results can be seen in Figure 5.22.

To overcome the problem in this scenario, it is sufficient to omit to fix the number of general practitioners and hospital doctors in the model. Thus, we can use the panelsize parameter to define the *Desired Number of GP* to have available daily treatment capacity. So we implement this policy to the model again and we see that there is not any waiting time at general practitioners' offices (see Figure 5.23).

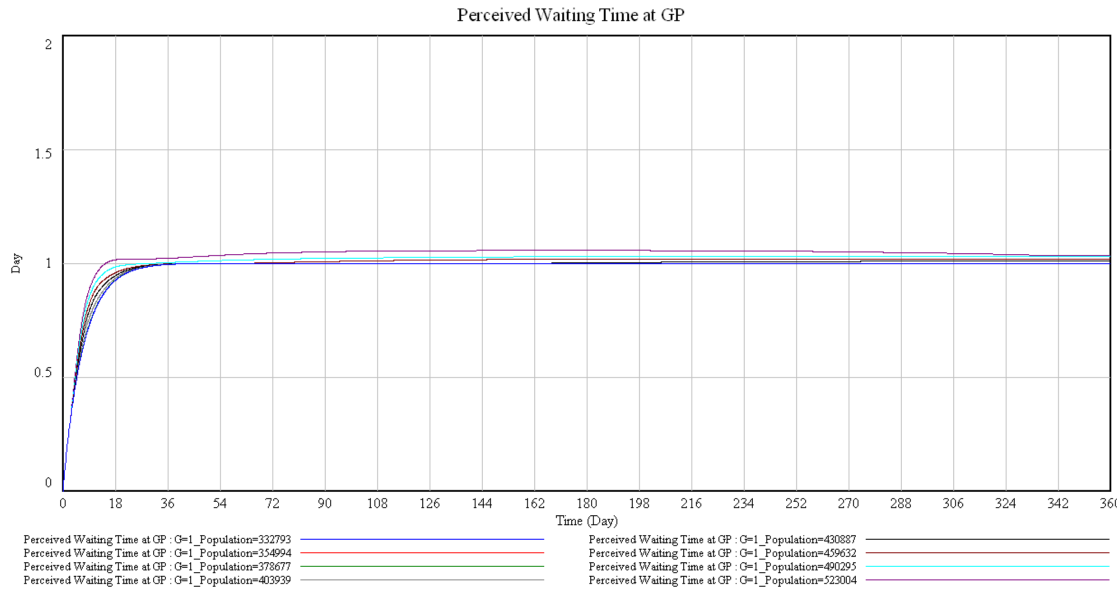


(a) Probability of Choosing GP



(b) Waiting Time at GP

Figure 5.22: Population Growth, G=1



(c) Perceived Waiting Time at GP

Figure 5.22: Population Growth, G=1 (cont.)

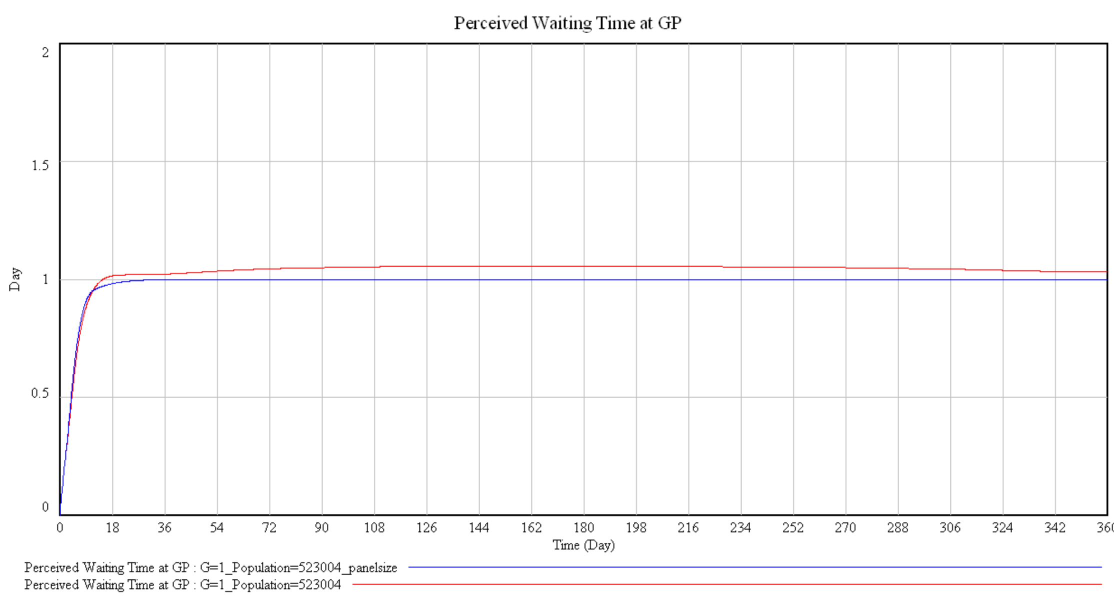


Figure 5.23: Perceived Waiting Time at GP with Panelsize Policy, G=1

Chapter 6

CONCLUSION

In this study, we use system dynamics simulation method to model the health care services, using Düzce as an example. Düzce is modeled as two-tier health service system which represents the primary and secondary health care. Both primary and secondary services are grouped as single server queues. This health service is examined from two perspectives as demand and supplier side. Demand side deals with patient flows in the health services and supplier side deals with the doctor flows to provide the demand.

In demand side, our aim is to understand the effects of dynamic factors on patients' choice when they need an outpatient treatment. These dynamic effects are building the behaviour patterns of patients. For the purpose of defining these dynamic factors, literature reviews, interviews in the city and surveys have been conducted and these factors are defined as trust, service quality, waiting time, laboratory existence at general practitioners' offices and distance effects. Laboratory existence and distance effects are modeled as exogenous variables; however, trust, service quality and waiting time effects are modeled as endogenous variables since they are modeled essentially as dynamic feedback structures in the model which determine the behaviour.

Waiting time and service quality effects are estimated as table functions and their values are based on the waiting time and service time perceptions of the patients. Waiting time has been modeled based on queuing theory and in addition to it, we consider that service quality is related with service time for patients per doctor. We contribute to the literature in this study as modeling the trust effect in health services since we are defining the trust effect by proportion of the cumulative number of patients based on their first contact choices. Exogenous factors such as laboratory existence at general practitioners' offices and distance effects are the limitations in the model since there is not any adequate data related to city Düzce. Therefore, we assume their value as 1 because of being multiplicative effects in the model.

In supply side, we determine the number of general practitioners and hospital doctors based on the health service's necessity. Our aim is to attract the doctors to be a general practitioner by offering them a salary contract. We build this contract based on the payment system of salaries in Turkey. In theory, general practitioners' salaries are calculated based on number of patients that they serve in one month and there can be some reductions from these salaries based on their performance criteria. Referral rate is a part of performance criteria; however reductions are not applied practically in the health services. Despite the fact that there are no reductions in practice, we build the model to see its effect on attractiveness of general practitioner job. Because of an inadequate historical data, we could not conduct a formulation for referral rate and so we use its value as a constant and cannot see the effects of this performance criterion in the model. Nevertheless, we related salary with the attractiveness of general practitioner job and we see that income per patient increases the rate of the doctors to be a general practitioner.

In chapter 4, we applied model testing to our model and we see that the model output fits the actual data. These tests help us to understand the behaviours and limits of the model. We implemented all tests and we see that our model is appropriate for analysis purposes.

In chapter 5, we first try to understand the current system, as our base scenario. General practitioners have the responsibilities of acting as a gatekeeper in the system between the years 2006 and 2007 for 7 months. We run the model and see that it is not a successful method to implement the gatekeeping policy since it does not change the work loads of hospitals due to the referral rate. Our contribution is applying a new policy to decrease the work loads of hospital in order to directing the patients to general practitioners. We see that new policies should increase the service quality and trust effect of general practitioners. This rises can be real by changing the panelsize or work time for service quality and using public campaign for trust effect. There is no capacity problem in the base case, and so it is unnecessary to force the doctors to increase their daily capacity. Finally, we run some scenarios to have insights about the consequences of a capacity problem, high quitting rate from being general practitioners and population growth. We suggest solutions to overcome the problems with understanding the relation of scenarios and its related dynamic feedbacks. We see that adjusting of capacity, work time, number of hospital doctors, and number of general practitioners based on panelsize are the policy parameters in the model and system can be improved by their coordinated arrangement.

To conclude, we develop a two-tier health service system model in local level and it can be implemented to national level as further work. For numerical estimations, there should be adequate historical data and also by the help of these data, one can build a nonlinear relation between the demand and referral rate, which would make the model more comprehensive to conduct contracts for general practitioners.

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Appendix A

DATA FROM DÜZCE

A.1 Calculations at Tables

$$\begin{aligned} &Daily\ First\ Contact\ at\ Secondary\ Healthcare = \\ &\quad Daily\ Contact\ at\ Secondary\ Healthcare - Daily\ Referral\ Number \end{aligned} \tag{A.1}$$

$$\begin{aligned} Total\ Daily\ Polyclinic = &\\ &Daily\ First\ Contact\ at\ Primary\ Healthcare \\ &+Daily\ First\ Contact\ at\ Secondary\ Healthcare \\ &+Emergency\ Daily\ Polyclinic \end{aligned} \tag{A.2}$$

$$\begin{aligned} &Probability\ of\ Choosing\ GP = \\ &\quad \frac{Daily\ First\ Contact\ at\ Primary\ Healthcare}{Total\ Daily\ Polyclinic} \end{aligned} \tag{A.3}$$

$$\begin{aligned} &Probability\ of\ Choosing\ Hospital = \\ &\frac{Daily\ First\ Contact\ at\ Secondary\ Healthcare + Emergency\ Daily\ Polyclinic}{Total\ Daily\ Polyclinic} \end{aligned} \tag{A.4}$$

$$Referral\ Probability = \frac{Daily\ Referral\ Number}{Daily\ First\ Contact\ at\ Primary\ Healthcare} \tag{A.5}$$

$$Sickness\ Fraction = \frac{Total\ Daily\ Polyclinic}{Population - 7 \times Total\ Daily\ Polyclinic - Total\ Daily\ Polyclinic} \tag{A.6}$$

[1]

$$Daily\ Demand\ at\ Hospital = \frac{\left(\begin{array}{l} Daily\ First\ Contact\ at\ Secondary\ Healthcare \\ +Emergency\ Daily\ Polyclinic \\ +Daily\ Referral\ Number \end{array}\right)}{89} \tag{A.7}$$

[2]

$$Daily\ Demand\ at\ GP = \frac{Daily\ First\ Contact\ at\ Primary\ Healthcare}{97} \tag{A.8}$$

[3]

[1] $7 \times Total\ Daily\ Polyclinic$ defines the number of people who have taken the necessery treatment and have been waiting to be healthy in the sytem.

[2] 89 is the number of hospital doctors in Düzce.

[3] 97 is the number of general practitioners in Düzce.

A.2 Tables for Data in Düzce

Table A.1: Population in Düzce

Population	
2005	305159
2006	335593
2007	332793

Table A.2: Weighted Average Population

Weighted Average Population	
With Gatekeeping Policy	**Without Gatekeeping Policy**
335193	328905

Table A.3: Data from Düzce

	Daily First Contact at Primary Healthcare	Daily Contact at Secondary Healthcare	Daily Referral Number	Daily First Contact at Secondary Healthcare	Emergency Daily Polyclinic	Total Daily Polyclinic	Probability of Choosing GP	Probability of Choosing Hospital	Referral Probability	Sickness Fraction	Daily Demand at Hospital	Daily Demand at GP
October-05	2764	2110	133	1977	409	5150	0,537	0,463	0,05	0,020	28,30	28,49
November-05	2965	2209	212	1997	391	5352	0,554	0,446	0,07	0,020	29,20	30,57
December-05	3293	2200	244	1955	408	5656	0,582	0,418	0,07	0,022	29,30	33,95
January-06	3383	2160	265	1895	447	5725	0,591	0,409	0,08	0,020	29,29	34,87
February-06	3255	2161	323	1838	312	5406	0,602	0,398	0,10	0,018	27,79	33,56
March-06	3975	2527	402	2125	355	6456	0,616	0,384	0,10	0,023	32,39	40,98
April-06	3765	2885	364	2521	432	6718	0,560	0,440	0,10	0,024	37,27	38,81
May-06	3947	3091	470	2621	417	6985	0,565	0,435	0,12	0,025	39,41	40,69
June-06	3956	2835	648	2187	459	6603	0,599	0,401	0,16	0,023	37,02	40,79
July-06	4898	2439	1323	1115	662	6675	0,734	0,266	0,27	0,024	34,84	50,49
August-06	4939	2436	1217	1219	512	6669	0,741	0,259	0,25	0,024	33,12	50,92
September-06	4773	2268	1284	985	353	6111	0,781	0,219	0,27	0,021	29,45	49,21
October-06	4990	2062	1127	935	384	6310	0,791	0,209	0,23	0,022	27,48	51,45
November-06	5567	2563	1514	1049	410	7026	0,792	0,208	0,27	0,025	33,40	57,39
December-06	5337	1943	1483	460	432	6229	0,857	0,143	0,28	0,022	26,69	55,02
January-07	5486	2386	1028	1358	486	7330	0,748	0,252	0,19	0,027	32,27	56,56
February-07	3987	2569	322	2246	409	6642	0,600	0,400	0,08	0,024	33,45	41,10
March-07	4543	2750	357	2393	458	7395	0,614	0,386	0,08	0,027	36,05	46,84
April-07	4306	2582	336	2246	469	7020	0,613	0,387	0,08	0,025	34,28	44,39
May-07	4538	2899	344	2555	381	7473	0,607	0,393	0,08	0,027	36,85	46,78
June-07	3963	2635	212	2423	681	7066	0,561	0,439	0,05	0,026	37,25	40,85
July-07	3999	2605	120	2485	590	7074	0,565	0,435	0,03	0,026	35,90	41,22
August-07	4097	2605	95	2510	590	7197	0,569	0,431	0,02	0,026	35,90	42,24
September-07	4106	2605	81	2524	590	7221	0,569	0,431	0,02	0,026	35,90	42,33
Average	**4201,307**	**2480,102**	**579,358**	**1900,744**	**459,936**	**6561,987**	**0,640**	**0,360**	**0,127**	**0,0236**	**33,034**	**43,312**

Table A.4: Data from Düzce with Policy Grouping

(a) With Gatekeeping Policy

With Gatekeeping Policy												
	Daily First Contact at Primary Healthcare	Daily Contact at Secondary Healthcare	Daily Referral Number	Daily First Contact at Secondary Healthcare	Emergency Daily Polyclinic	Total Daily Polyclinic	Probability of Choosing GP	Probability of Choosing Hospital	Referral Probability	Sickness Fraction	Daily Demand at Hospital	Daily Demand at GP
July-06	4898	2439	1323	1115,181818	662	6675	0,734	0,266	0,27	0,024	34,84	50,49
August-06	4939	2436	1217	1218,590909	512	6669	0,741	0,259	0,25	0,024	33,12	50,92
September-06	4773	2268	1284	984,5	353	6111	0,781	0,219	0,27	0,021	29,45	49,21
October-06	4990	2062	1127	935,0454545	384	6310	0,791	0,209	0,23	0,022	27,48	51,45
November-06	5567	2563	1514	1048,863636	410	7026	0,792	0,208	0,27	0,025	33,40	57,39
December-06	5337	1943	1483	460,4090909	432	6229	0,857	0,143	0,28	0,022	26,69	55,02
January-07	5486	2386	1028	1357,772727	486	7330	0,748	0,252	0,19	0,027	32,27	56,56
Average	**5141,396**	**2299,474**	**1282,279**	**1017,195**	**462,729**	**6621,319**	**0,778**	**0,222**	**0,250**	**0,0236**	**31,036**	**53,004**

(b) Without Gatekeeping Policy

Without Gatekeeping Policy												
	Daily First Contact at Primary Healthcare	Daily Contact at Secondary Healthcare	Daily Referral Number	Daily First Contact at Secondary Healthcare	Emergency Daily Polyclinic	Total Daily Polyclinic	Probability of Choosing GP	Probability of Choosing Hospital	Referral Probability	Sickness Fraction	Daily Demand at Hospital	Daily Demand at GP
October-05	2764	2110	133	1977	409	5150	0,537	0,463	0,05	0,020	28,30	28,49
November-05	2965	2209	212	1997	391	5352	0,554	0,446	0,07	0,020	29,20	30,57
December-05	3293	2200	244	1955	408	5656	0,582	0,418	0,07	0,022	29,30	33,95
January-06	3383	2160	265	1895	447	5725	0,591	0,409	0,08	0,020	29,29	34,87
February-06	3255	2161	323	1838	312	5406	0,602	0,398	0,10	0,019	27,79	33,56
March-06	3975	2527	402	2125	355	6456	0,616	0,384	0,10	0,023	32,39	40,98
April-06	3765	2885	364	2521	432	6718	0,560	0,440	0,10	0,024	37,27	38,81
May-06	3947	3091	470	2621	417	6985	0,565	0,435	0,12	0,025	39,41	40,69
June-06	3956	2835	648	2187	459	6603	0,599	0,401	0,16	0,023	37,02	40,79
February-07	3987	2569	322	2246	409	6642	0,600	0,400	0,08	0,024	33,45	41,10
March-07	4543	2750	357	2393	458	7395	0,614	0,386	0,08	0,027	36,05	46,84
April-07	4306	2582	336	2246	469	7020	0,613	0,387	0,08	0,025	34,28	44,39
May-07	4538	2899	344	2555	381	7473	0,607	0,393	0,08	0,027	36,85	46,78
June-07	3963	2635	212	2423	681	7066	0,561	0,439	0,05	0,026	37,25	40,85
July-07	3999	2605	120	2485	590	7074	0,565	0,435	0,03	0,026	35,90	41,22
August-07	4097	2605	95	2510	590	7197	0,569	0,431	0,02	0,026	35,90	42,24
September-07	4106	2605	81	2524	590	7221	0,569	0,431	0,02	0,026	35,90	42,33
Average	**3814,211**	**2554,479**	**289,920**	**2264,559**	**458,786**	**6537,556**	**0,583**	**0,417**	**0,076**	**0,0237**	**33,857**	**39,322**

Appendix B

GRAPHS FOR SENSITIVITY ANALYSIS

B.1 Leaving GP Fraction

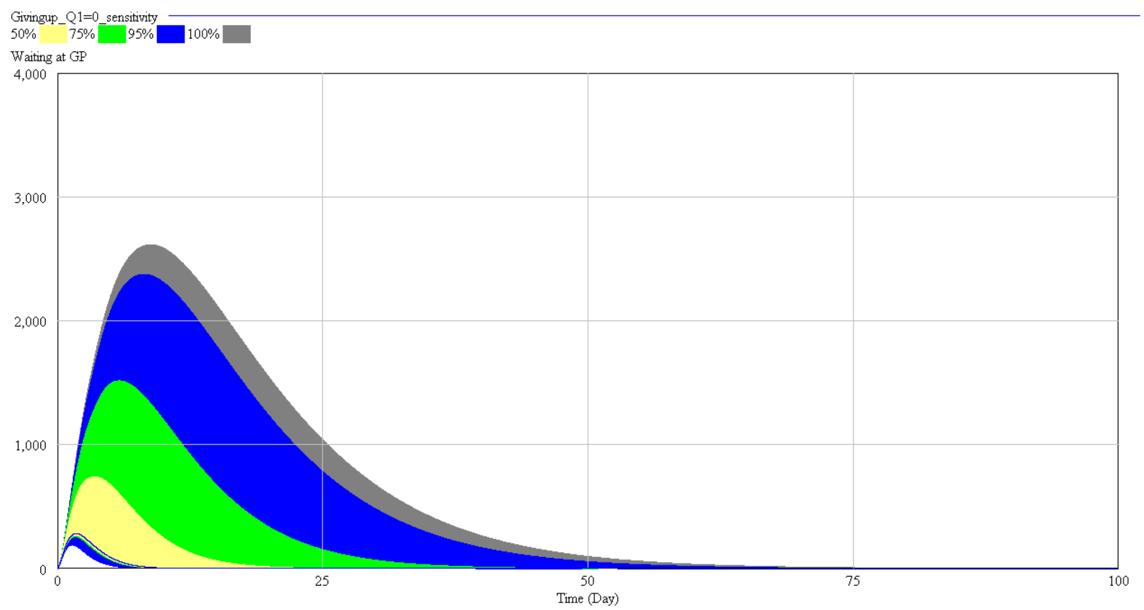

Figure B.1: Waiting at GP(Q1=0)

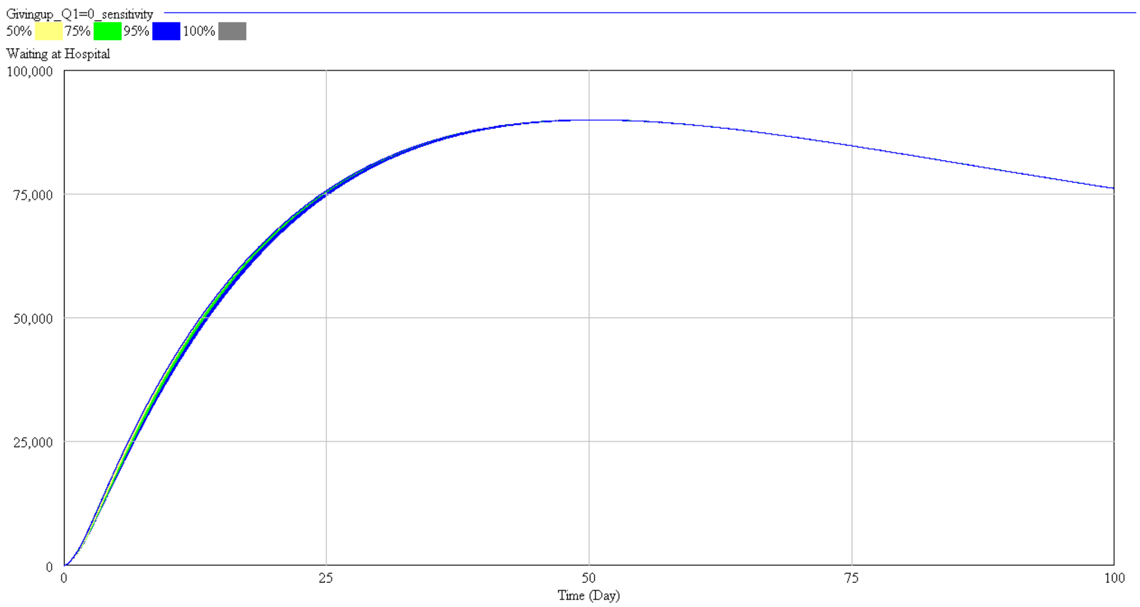

Figure B.2: Waiting at Hospital(Q1=0)

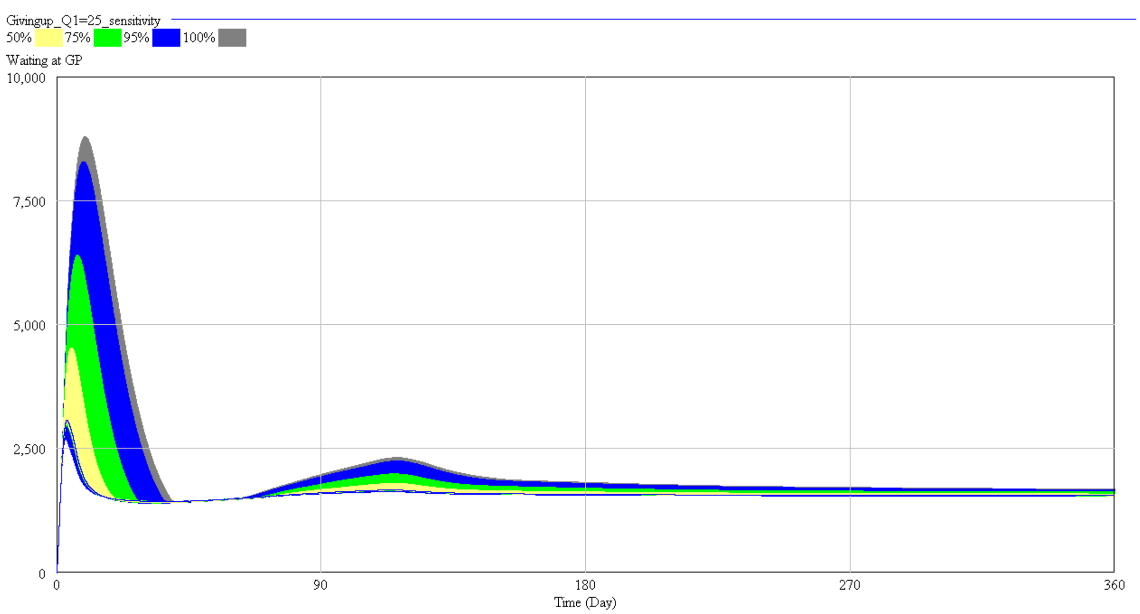

Figure B.3: Waiting at GP(Q1=25)

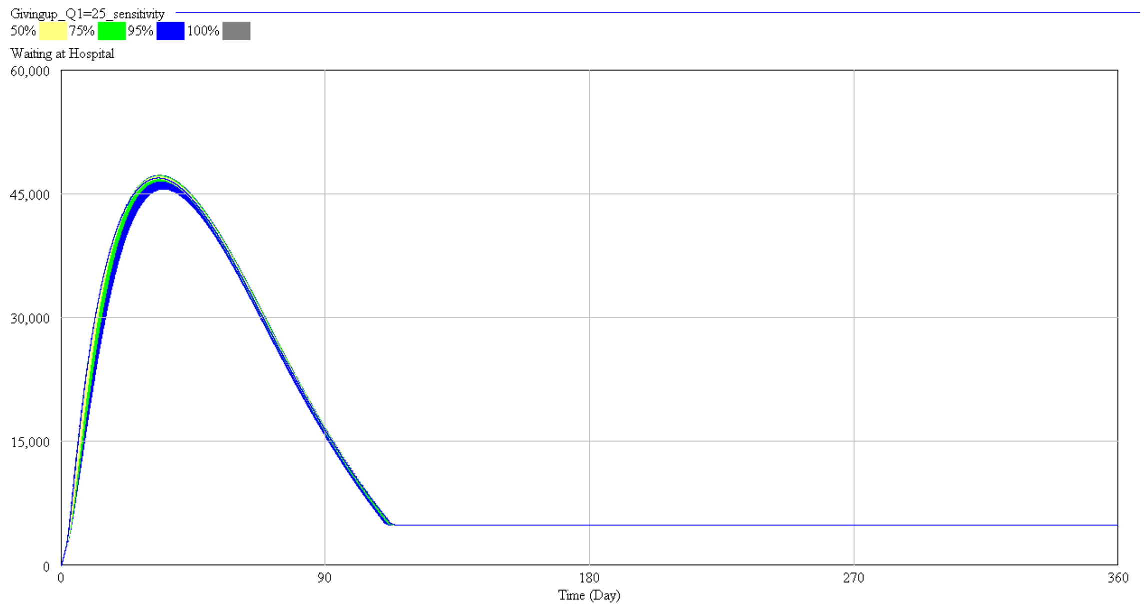

Figure B.4: Waiting at Hospital(Q1=25)

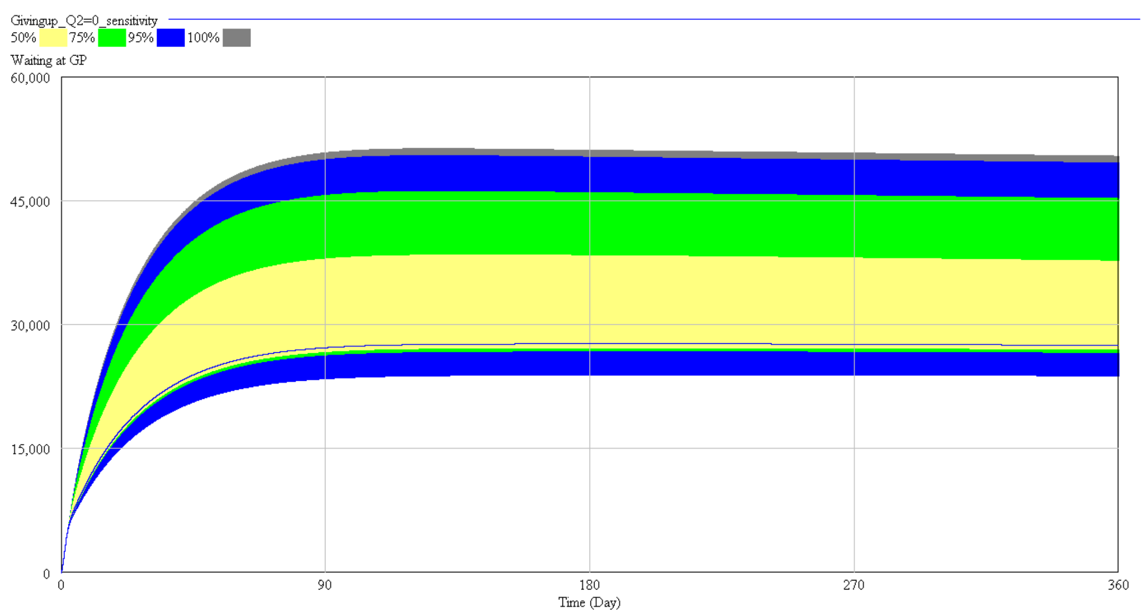

Figure B.5: Waiting at GP(Q2=0)

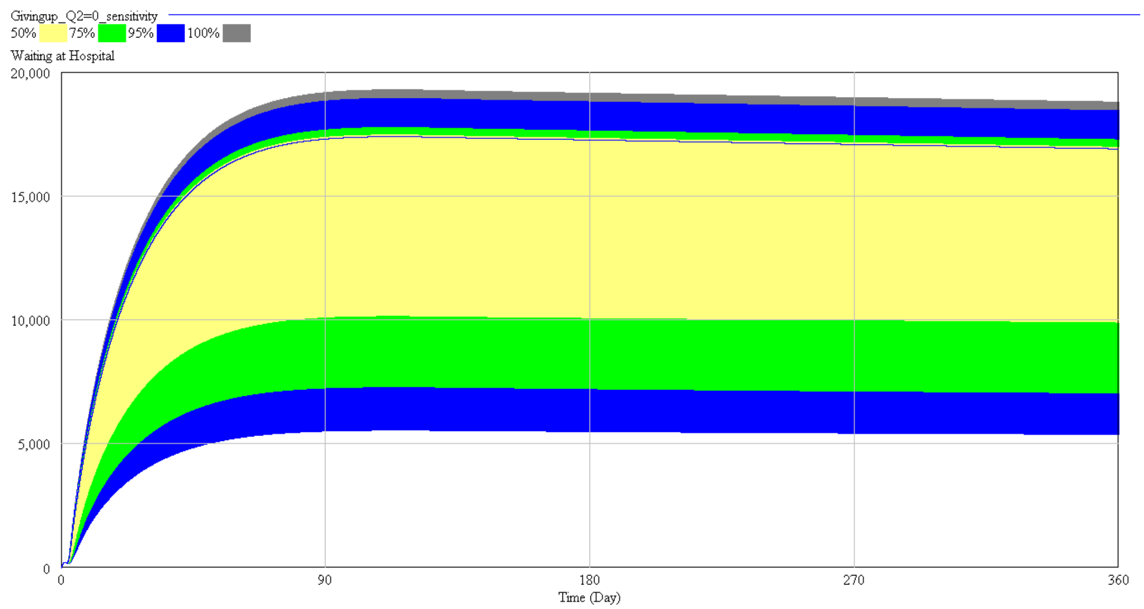

Figure B.6: Waiting at Hospital(Q2=0)

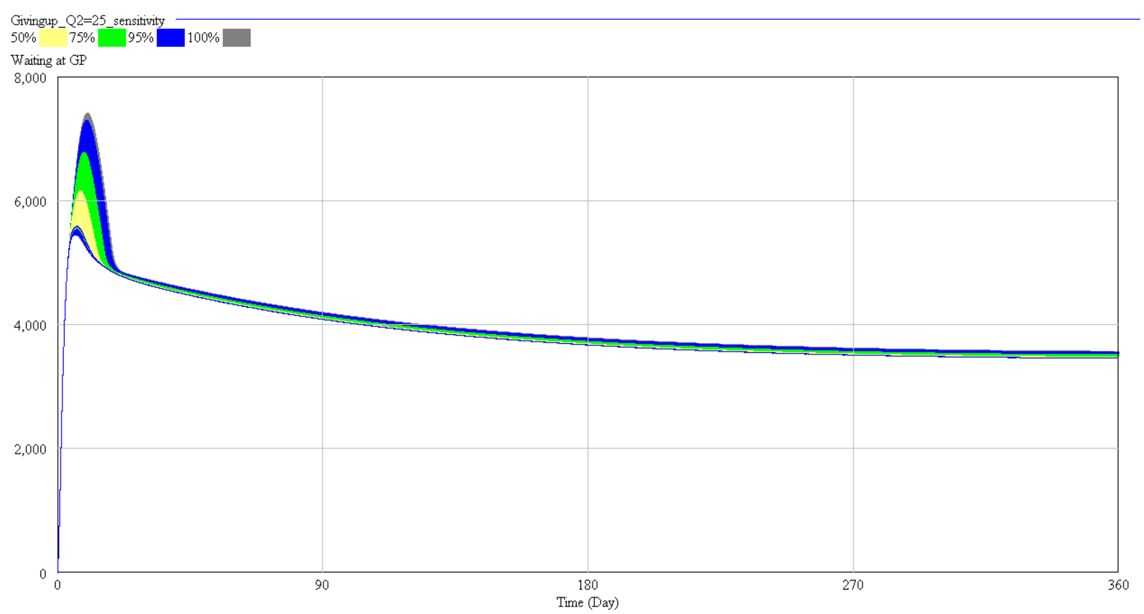

Figure B.7: Waiting at GP(Q2=25)

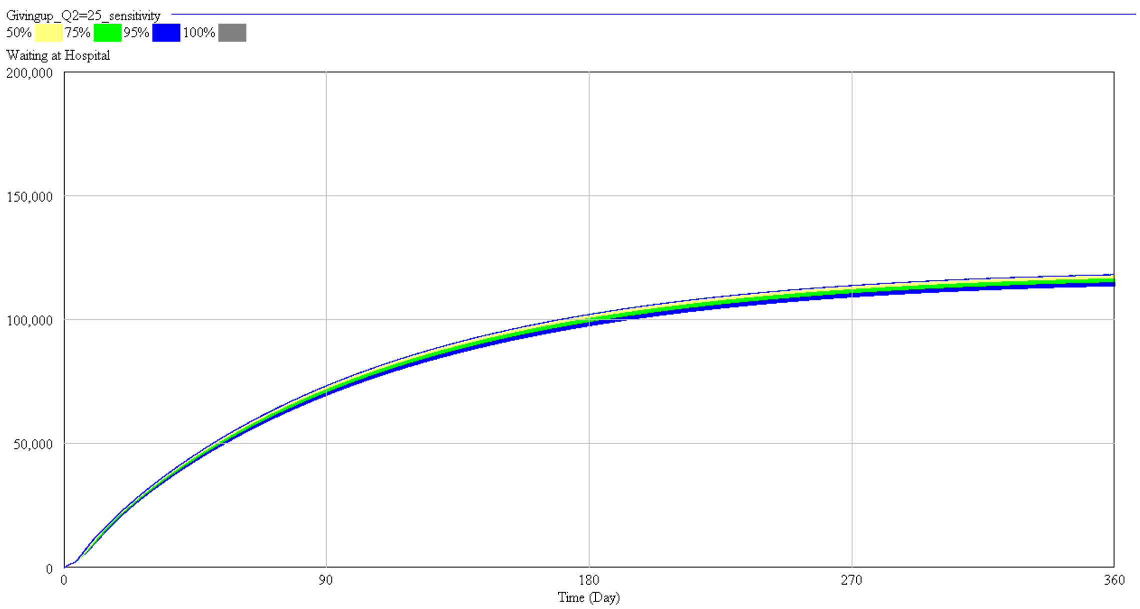

Figure B.8: Waiting at Hospital(Q2=25)

VITA

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