Investigating Thailand's Public Nursing Workforce Age Structure Dynamics: A System Dynamics Approach

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Abstract

The age structure of Thailand's public nursing workforce has been evolving in an unfavorable way in the past decades. If the age structure continues to remain in this fashion, the overall healthcare system performance might deteriorate as productivity of a workforce can be influenced by its age distribution. This study investigated the problem through a systematic lens with an ultimate aim of proposing an effective policy to reshape the currently unfavorable age structure of Thailand's public nursing workforce. A quantitative SD model was built based on literature to represent Thailand's nursing workforce system. The model has gone through a number of validity tests and was populated with actual data obtained from statistics and existing studies to build confidence that it could serve the purpose of the study. The results of the structure-oriented analysis suggested that organizations deploying temporary employment schemes are prone to encountering the problem of age structure instability if effective employee retention measures are not in place. The simulation-based policy analysis pointed out that, in addition to the commonly suggested policy to increase the number of civil-servant positions, a complementary policy to stabilize nurse production at an optimal level is required to achieve the ideal uniform age structure suggested by Grund & Westergård-Nielsen (2008).

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List of Acronyms

CLD : Causal Loop Diagram
FTE : Full-Time Equivalent
MOD : Ministry of Defense
MOE : Ministry of Education
MOPH: Ministry of Public Health
PSO : Permanent Secretary Office
RNs : Registered Nurses
SD : System Dynamics
SFD : Stock and Flow Diagram
TNMC: Thailand Nursing and Midwifery Council

Chapter 1: Introduction

1.1 Background Information

The global nursing shortage has been having an adverse impact on health systems around the world. Though nursing is not the only healthcare profession facing supply shortage, the nursing shortage is the most critical for health systems, because nurses deliver the highest percentage of patient care (Oulton, 2006). Although the shortage may sound like an age-old problem and the current shortage, in many ways, looks the same, there have been newly emerging dimensions to the problem, such that pre-existing solutions alone might no longer work (Oulton, 2006).

The problem of nursing shortage in Thailand has been observed over the past 50 years (Sawaengdee, 2017). This problem has been posing a big challenge to the Thai government as the country is expected to become an aged society in 2021 (Office of the national economic and social development council, 2017). That will imply a larger demand for healthcare services. In addition, as a part of the Thailand 4.0 initiative, the Thai government aspires to make Thailand a leading producer of pharmaceuticals and medical devices and a world-class provider of medical care. Apparently, this ambition has become another factor influencing the shortage discussed here. As Thailand has developed several health coverage schemes for its citizens, certainly, more pressure has been put on the public hospitals. A study (Sawaengdee, 2017) estimated that the healthcare facilities under the Permanent Secretary Office (PSO) of Ministry of Public Health (MOPH) of Thailand, the public healthcare units, would require 136,520 Full-Time Equivalent (FTE) of nurses by 2021. This is in contrast to the current situation where the coverage is only 71.87% of the estimated requirement by the end of 2017 (Sawaengdee, 2017).

The measure used by the authority to tackle the problem, thus far, has been focusing only on the production of nurses. This effort resulted in the existence of 86 nursing schools in 2017, in both the public and private sources, that were able to produce 11,000 to 12,000 nurse graduates per year. However, the measure has been proved not to be so effective in PSO facilities as the increase in nursing workload was much greater than the increase in the nursing workforce during the past 10 years (Sawaengdee, 2017). This was potentially a result of the economic and social development of the country which entailed drastic changes in the healthcare market. A new problem of high nurse turnover emerged due to the advent of alternative careers, a development that may also be observed in OECD countries (Sawaengdee, 2017). A report revealed that the average duration of employment of registered nurses has decreased to only 22.45 years (Sawaengdee, 2009).

The failure to retain qualified and experienced nursing personnel has been more severe in the public sector. It has been found that, on average, almost 50% of new entry nurses intended to resign from their PSO facilities during their first year (Sawaengdee, et al., 2016). This raises the issue of aged nurses becoming the majority of the public workforce which can affect productivity in an unfavorable way (Sawaengdee, 2017).

Like the populations they serve, the nursing workforce is also aging. In the USA, there were approximately one million registered nurses older than 50 years in 2016, meaning one-third of the workforce could be at the retirement age in the course of the next 10 to 15 years (Grant, 2016). Multiple factors are thought to be affecting this structural problem in Thailand

(Khunthar, 2014). The aim of this study is to address problem of the unfavorable dynamics of the public nursing workforce age structure by synthesizing and analyzing the influential factors using an integrated approach.

1.2 Problem Formulation

1.2.1 Age Structure of the Nursing Workforce

The ubiquitous shortage of nurses across the globe has been reinforced by the aging workforce. Nowadays, healthcare agencies in most developed countries are confronting the rapidly aging nursing workforce while healthcare demands are increasing (Sherman, Chiang-Hanisko , & Koszalinski, 2013). The common indicators used to monitor the severity of a particular aging workforce are the proportion of working individuals older than a certain age, 50 years in this study, and the average age of the particular workforce. The average age of the working nurses in Australia, Canada and the United Kingdom has been reported to be mid-to-late-40s, with 30–40% being over the age of 50 (Fitzgerald, 2007). In the United States, the average age of registered nurses was 51 years, with around 50% being 50 years or older (Smiley, et al., 2018). Sawaengdee (2016) estimated the average age of Thai nursing workforce under PSO to be around 37 years. In addition, one may use the workforce age structure to conduct detailed analyses. The age structure of a population is an important aspect of population dynamics. It represents the proportions of individuals at different age stages. Figure 1-4 present nursing workforce age distribution of Thailand, Japan, the USA and Australia, respectively.

The figures clearly show that while the average ages of the nursing workforces across countries are more or less the same, the age distributions can look very different. The problem of an aging workforce can be seen most clearly in the USA as most of the working nurses are concentrated in over 50-year-old age classes. This means that the USA will be losing about half of its nursing workforce in the coming 10 years if the country cannot find a way to substitute this number of nurses. The problem could be deemed less severe in Australia and Japan as their age distributions are more even. Australia has a very low number of the youngest nurses, compared to the total workforce, which may indicate the new nurse recruitment problem in the country, Japan has a more uniform distribution. The story is somewhat different for the workforce in Thailand as a constant instability in the age structure may be observed up until 2017. While the age distributions of other countries may instantly give some clues about the root causes of their problems, Thailand's nursing age distribution seems to involve more complex mechanisms that constitute its unevenness.

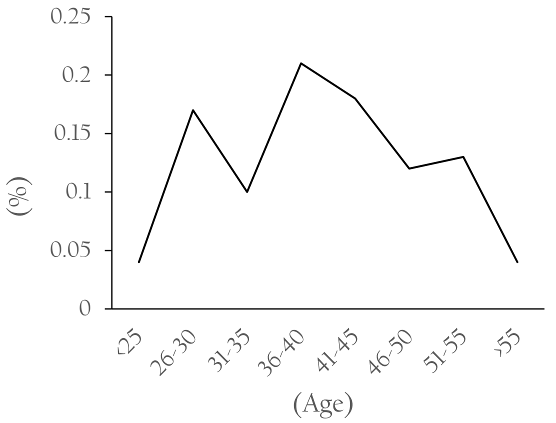


Figure 1 Age Structure of Registered Nurses in the Healthcare Facilities under the PSO of MOPH of Thailand in 2017. Adapted from Sawaengdee (2017)

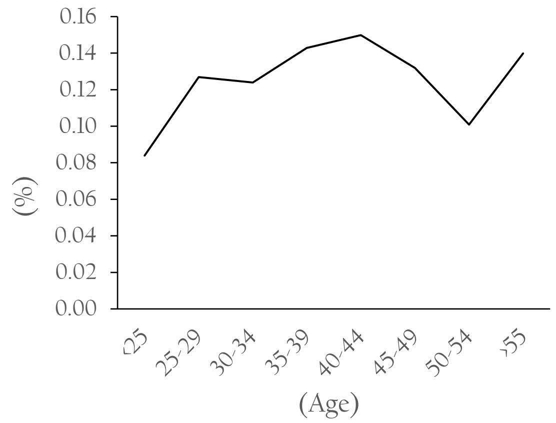


Figure 2 Age Structure of Registered Nurses of Japan in 2016 Adapted from the Japanese Nursing Association (2015)

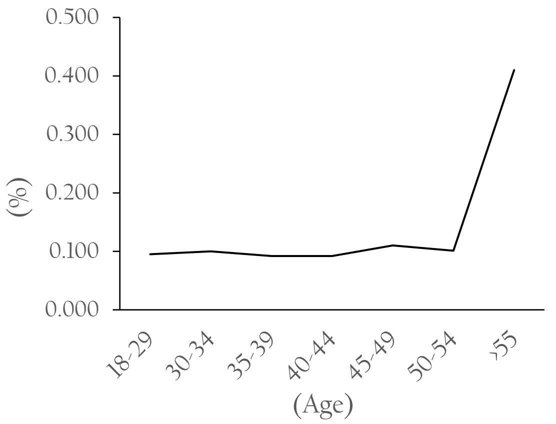


Figure 3 Age structure of Registered Nurses of the USA in 2017 Adapted from Smiley, et al. (2018)

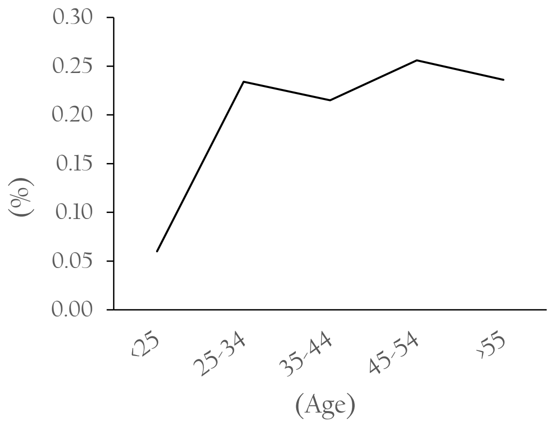


Figure 4 Age Structure of Registered Nurses of Australia in 2015 Adapted from Australian Institute of Health and Welfare (2016)

1.2.2 Dynamics of the Public Nursing Workforce Age Structure of Thailand

In Thailand, the public nursing workforce age structure did not look like Figure 1 in the first place. In 2005, the age structure looked more like a right-skewed normal distribution (Figure 5). Comparatively, it is apparent that the nursing workforce has become older as there were fewer young nurses and more senior nurses in 2017. In addition, one may observe an unevenness in the age distribution.

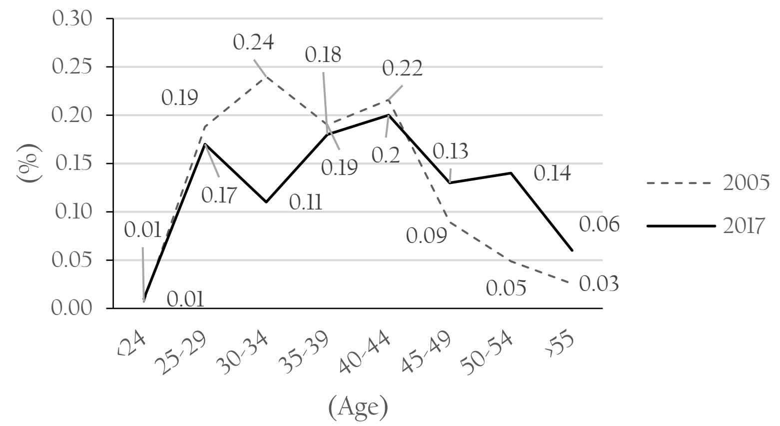


Figure 5 Dynamics of Public Nursing Workforce Age Structure of Thailand in 2005 and 2017
Adapted from Sawaengdee (2009) and Sawaengdee (2017)

1.2.3 Implication of the Age Structure Dynamics

Grund and Westergård-Nielsen (2008) found that both mean age and standard deviation of age in firms are inversely u-shaped related to firm performance. This means that an optimal or near-optimal workforce age distribution that maximizes firm performance can be defined. Together with the theoretical approach of Cremer (1986), they suggested a uniform distribution with a mean age of 37 years and standard deviation 9.5 years as one of the most optimal workforce structures (Grund & Westergård-Nielsen, 2008). This is clearly in contrast to the current situation of Thai nursing workforce under PSO (Figure 1). First, the mean age of the workforce has significantly increased, from 37.5 in 2005 (Sawaengdee, 2009) to above 38 in the past few years (Sawaengdee, 2017). In addition, the fraction of nurses older than 45 years has increased since then. This trend indicates that the nursing workforce has become older and might affect the overall productivity of the workforce. McIntosh et al. (2010) suggested that the shift toward an aging nursing workforce has significant implications, including the need for building more age-diverse cultures, offering more training in intergenerational relationships, rethinking the way work is structured, paying increasing attention to ergonomics and to job reengineering, and further developing employee assistance programs.

Second, though the distribution has become less skewed, the unevenness of the nursing workforce age structure indicates a fiscal implication for the Thai government. Seen in Figure 1, PSO has lost a significant number of nurses aged 30 to 35 and a tendency to fail to retain the new entry nurses. Implicitly, its facilities have been treated as training places by new nurses graduates after which they quit to join the private healthcare facilities who offer more attractive compensation packages and better working conditions. The cost of turnover was estimated to be around 96.12 million baht per year (Sawaengdee, 2017). This clearly suggests that investment in increasing nurse production capacity cannot be effective without proper retention measures.

Therefore, one might conclude that the age structure of Thailand's nursing workforce has been evolving in an unfavorable way. If the structure continues to remain in this form, the overall healthcare system performance might deteriorate.

The evolving distribution indicates significant changes in the structure of the nursing workforce systems, including production, recruitment, types of employment, promotion, and retirement of public nurses in Thailand, - factors that this study helps to understand. The details regarding such mechanisms and their development are discussed more in Chapter 2 and Chapter 4.

1.3 Research Objective

It is, thus, the aim of this study to systematically investigate this system and to propose an effective policy that can address the adverse dynamics of the public nursing workforce age structure in Thailand. For this purpose, a System Dynamics model is proposed, one that represents the public nursing workforce system of the country by synthesizing the relevant public health management theories and reported facts from the relevant organizations. The model is intended to serve as a complementary tool for policymakers and scholars to enhance their understanding of the system and to identify potential solutions to the problem, namely, to change the age distribution from the current unfavorable shape to the near-optimal shape suggested by Grund and Westergård-Nielsen (2008). This can be illustrated by the reference mode of the study problem (Figure 6).

The research questions in this study are formulated in the form of a hypothesis for model structure, representing the real-world system, that produces the problematic dynamic development over time. The hypothesis is discussed in detail in Chapter 4.

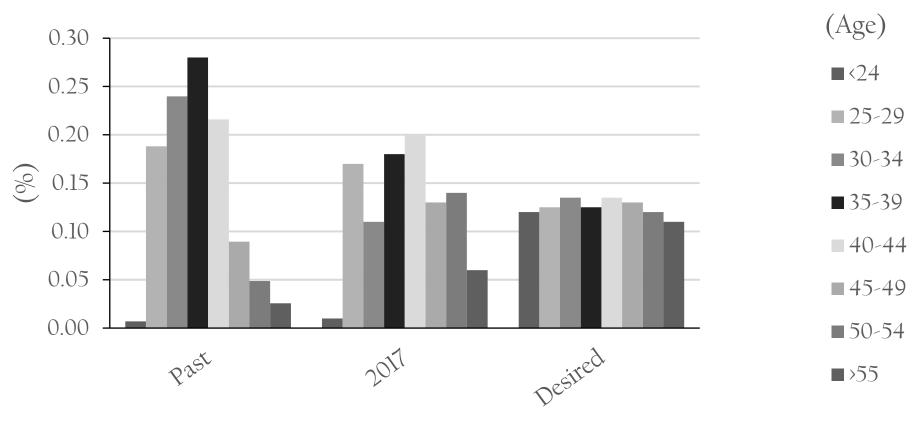


Figure 6 Reference Mode of the Study Problem

1.4 Organization of the Study

The organization, and thus the suggested reading sequence, of this study, is as follows. Chapter 1 discusses the state of the problem, its importance, and the focuses of this study. Chapter 2 reviews the existing relevant literature addressing the problem of interest. Chapter 3 explains the background, suitability, and process of the methodology, namely System Dynamics (SD), and the data collection method used in this study. Chapter 4 mainly describes the SD model structure as a synthesis of the relevant theories and empirical data from existing literature and, subsequently, proposes hypotheses on how this structure results in the observed dynamics of the nursing workforce age structure. After the model structure has been described, Chapter 5 discusses the values of the parameters that would align the model-generated (simulated) behavior with the current real-system behavior. The chapter also provides a preliminary analysis of the baseline simulation result. Chapter 6 presents the hypothesis testing in the form of a formal model validation process, including a number of model structure and behavior validity tests. Once the confidence in the model has been established, the model is utilized to explore the system behavior under different scenarios in Chapter 7. In Chapter 8, a widely suggested policy by studies and official reports was tested and analyzed whether it could help in reshaping the age structure or if any complementary measure(s) are needed. Chapter 9 discusses the contribution of this study, limitation of the model, recommendations for future research and conclusion.

Chapter 2: Literature Review

This chapter provides a summary of the relevant literature which serves as a basis for the construction of the System Dynamics model in Chapter 4. As mentioned in the previous chapter that the purpose of this study is to address the adverse dynamics of public nursing workforce age structure in Thailand, hence, the literature concerning the importance of workforce age structure on organization performance was first reviewed. Then, public nursing workforce system (under PSO) of Thailand was investigated. The result covered the knowledge about production, recruitment, types of employment, promotion, and retirement of public nurses in Thailand. Subsequently, a number of studies addressing the Thai nursing shortage and associated issues were consulted. A special effort was put into reviewing the intention to leave from public healthcare facilities of registered nurses. Finally, definitions and statistical data regarding healthcare service and nursing workforce demands were inquired to provide a realistic context for the model.

2.1 Age Structure of Workforce and Organization Performance

There have been a number of studies conducted regarding the effect of workforce age structure on organization performance in many aspects, for example, that changes in strategy can be more observed in firms with young top-management teams (Wiersema & Bantel, 1992), that labor turnover is negatively interrelated with both age and homogeneity in age (O'Reilly III, Caldwell , & Barnett, 1989), that positive and negative interrelations can be found between age heterogeneity and group performance (Pelled , Eisenhardt , & Xin , 1999; Simons, Pelled, & Smith, 1999).

A study over 7,000 different firms during 1992–1997 found inversely u-shaped interrelations between mean age and standard deviation of age with firm performance (Grund & Westergård-Nielsen, 2008). The study suggested organizations with a mean age (standard deviation of age) of 37 years (9.5 years) have the highest performance (Grund & Westergård-Nielsen, 2008). However, a study showed that increasing age diversity has a positive effect on company productivity if and only if a company engages in creative rather than routine tasks (Backes-Gellner & Veen, 2013).

The number of literature studying the interrelation between age structure and nursing workforce performance has been limited and whether the distribution shape suggested by Grund & Westergård-Nielsen (2008) should be aimed for the nursing workforce is to be confirmed. However, general observations (Sawaengdee, 2017) suggest that the balance between young and senior nurses is needed. Older nurses possess knowledge and experience but their productivity might decrease as they age due to high-physical demand of nursing tasks. On the other hand, young nurses are capable of handling such tasks but they might need some time before they become fully skilled. Therefore, the author believes that the aim of attaining the uniform or near-uniform distribution is reasonable for nursing workforce context.

2.2 Public Nursing Workforce System of Thailand

2.2.1 Nurse Production and Recruitment to Public Healthcare Facilities

In Thailand, nurses are categorized as registered nurses (RNs) and technical nurses (TNs). RNs obtain the first-class license after receiving an associate degree or completing a baccalaureate nursing program and passing a licensure examination approved by Thailand Nursing and Midwifery Council (TNMC). On the other hand, it requires only two years of study to become a technical nurse.

Similar to other countries, there are 2 main categories of nursing school in Thailand, public and private nursing schools. The public institutions are run under Ministry of Public Health (MOPH), Ministry of Education (MOE), Ministry of Defense (MOD), or other government agencies. At the end of 2018, there were 87 nursing schools in Thailand. With this number, more than 10,000 nursing graduates were produced every year (Sawaengdee, 2017). Figure 7 shows the number of nursing schools by operator in Thailand.

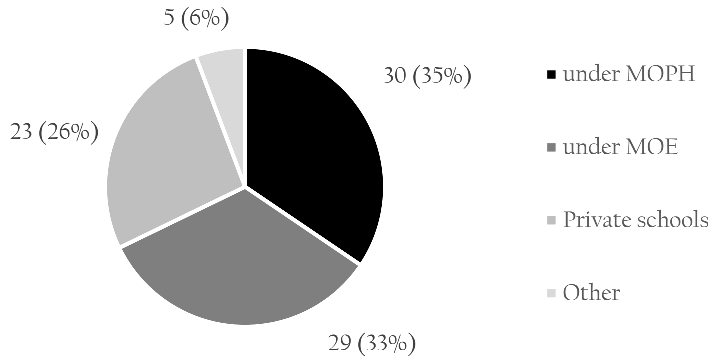


Figure 7 Number of Nursing Schools by Operator in 2018
From Thailand Nursing and Midwifery Council (2018)

Considering the career destination of these nurses, the percentage of public hospitals to total hospitals in Thailand has been standing over 70% all the time (Figure 8). A study found that nurses trained in public schools are more likely to choose to work in the public sector, both immediately after graduation and up to 5 years after graduation (RESYST, 2016).

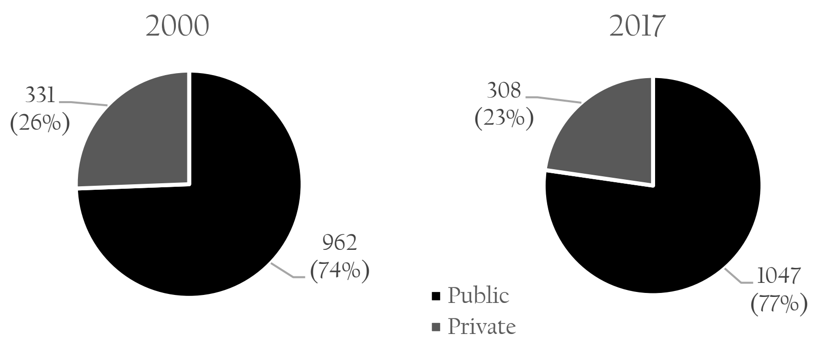


Figure 8 Number of Hospitals and Medical Establishments with beds by operator type in 2000 and 2017
From Strategy and Planning Division, Ministry of Public Health (2017)

There are 2 cases for nursing graduates to work in public hospitals.

First, the registered nurses who graduate from MOPH nursing schools are usually obliged to work in state hospitals under PSO in rural areas, at least for a certain period, as most of them are normally granted a full scholarship from the government for their studies (Sawaengdee, 2009).

Second, the registered nurses who graduate from non-MOPH nursing schools may choose to work either in public university hospitals or state hospitals under PSO.

Figure 9 shows the number of registered nurses working in different types of hospital from over 12 years (2004-2016). Note that, in this study, the focus is on the nursing workforce under PSO hospitals.

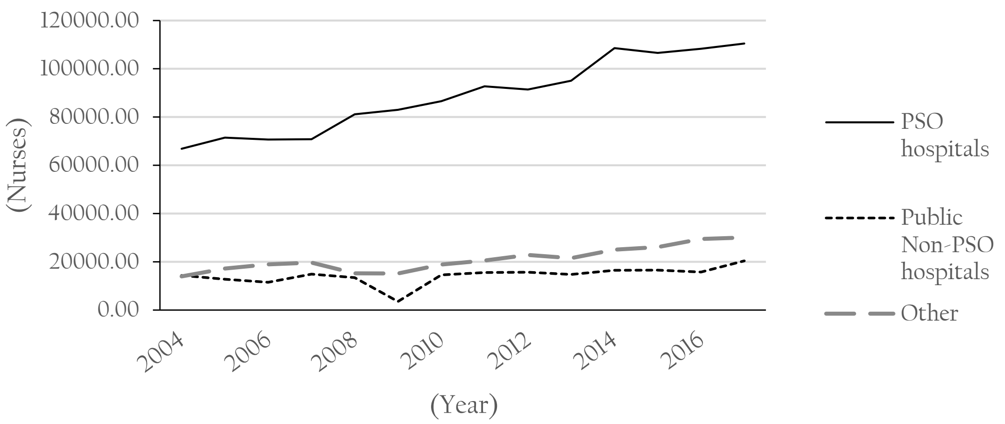


Figure 9 Number of Registered Nurses by Working Site 2004-2016
From Strategy and Planning Division, Ministry of Public Health (2017)

2.2.2 Types of Employment in Public Healthcare Facilities

Working under state healthcare facilities (under PSO), a registered nurse can have either a civil-servant or non-civil-servant status (Sawaengdee, 2017). The nurses who are not civil servants can be titled state employees or temporary employees. The biggest differences between being a civil servant and non-civil servant, which are mostly concerned by the nurses, are job security and compensation and benefits. As a civil servant, one receives a lifetime employment contract and a wider range of benefits, including his or her family members being entitled to full healthcare coverage and pension schemes. Comparatively, a non-civil servant can have only a fixed-term employment contract, lower career advancement opportunity, and inferior other benefits – e.g. only him or herself is entitled to the healthcare coverage (Office of the Civil Service Commission, 1999).

2.2.3 Placement and Promotion of Civil-Servant Nurses

Obviously, registered nurses working in state hospitals would prefer a civil servant status. However, the civil-servant positions are limited according to the predefined budget from the government. Therefore, not all nurses working in public facilities immediately obtain a civil servant position at the entrance. Most of them normally start as temporary employees, which are considered a non-civil-servant position, under the ministry.

As the graduates from MOPH nursing schools are obliged to work in state hospitals under PSO, they only have to wait for civil-servant vacancies after retiring or resigning nurses in the same hospitals. On the other hand, graduates from the institutions under MOE can choose to work in the public university hospitals from which they graduated or state hospitals under PSO. Nevertheless, only the hospitals under PSO can provide civil-servant status and the process by which they can become civil servants is more complicated. Apart from also having to wait for vacancies, they need to take a civil service entrance examination.

Regarding the ranking system for civil servants, the civil service commission decided to change from Common Level System comprising of 11 levels (C1-C11) for all professions to a new system in 2008. In this new system, the professional nurse is classified as a knowledge worker position comprising of 5 levels (K1-K5); practitioner, professional, senior professional, expert and advisory. The criteria used to promote a civil servant from practitioner level to professional level are generally work experience and education (e.g. 6 years for bachelor's degree holders and 4 years for master's degree holders), with no limited positions, However, for the higher levels, a vacant position is required, apart from an additional amount of experience (normally another 4 years for the senior professional level) and outstanding performance. Figure 10 illustrates the rank structure of registered nurses working in facilities under PSO.

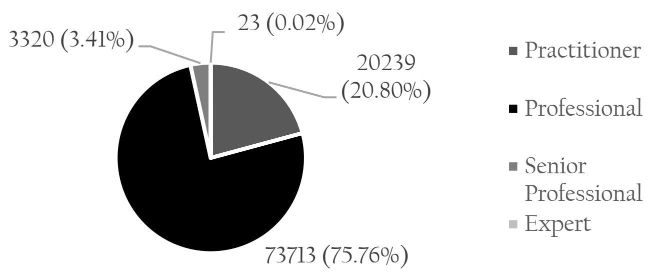


Figure 10 Number of Registered Nurses in PSO Facilities by Position Level in 2017
From Office of the Civil Service Commission (2018)

2.2.4 Retirement of Civil Servants

The official retirement age for civil servants in Thailand has been maintained at 60 years old until 2018 when the Thai government decided to extend the age to 63 under a national reform plan as Thailand has been trying address problems of turning an ageing society. However, it is expected to take 6 years to fully implement the later retirement age, meaning it will not be in full effect until 2024 (Thai Government, 2018).

2.3 Thailand's Nursing Workforce Issues

2.3.1 Mismatch Between Demand and Supply of Nursing Workforce

Sawaengdee (2017) estimated that the healthcare facilities under the Permanent Secretary Office (PSO) of Ministry of Public Health (MOPH) of Thailand, the public healthcare units, would require 136,520 Full-Time Equivalent (FTE) of nurses by 2021. This was in contrast to the current situation where there was only 71.87% of the estimated requirement at the end of 2017. Moreover, the rates at which the amount of nursing workload increased have been always higher than the increase rate of the nursing workforce in the same years (Figure 11).

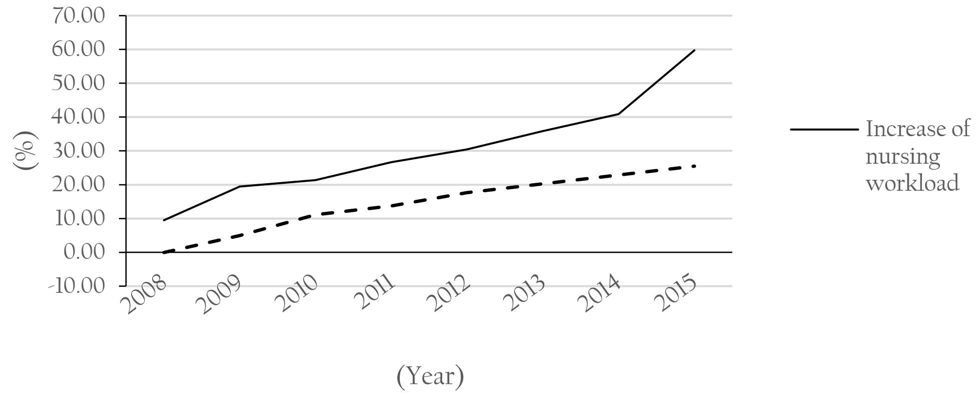


Figure 11 Increase rates of Nursing Workload and Workforce during 2008-2015
Adapted from Sawaengdee (2017)

2.3.2 Downsized Nurse Production during 1999-2005

In 1997, Thailand encountered a financial crisis which resulted in a more cautious fiscal policy in the following years. This included an attempt to reduce the governmental workforce. Subsequently, nurse production was decreased from 6,000 to around 4,200 graduates per year from 1999 to 2005, causing a smaller number of nurses entering the workforce during 2004-2009 (Sawaengdee, 2009).

2.3.3 Loss of Entry-Level Registered Nurses

The financial crisis in 1997 also had an impact on the intention to leave the PSO facilities of the new entry nurses. A number of civil-servant positions were discarded because they were deemed as a long-term financial burden to the government (Sawaengdee, 2017). In addition, the government at the time proposed to exclude public universities from the civil service system in 1999, hence, meaning that nurses working in public hospitals no longer able to obtain a civil-servant status (see section 2.2.2). The impact of such policy began to manifest in 2005 when MOPH did not have vacant civil-servant positions to place the new entry nurses. The result was the loss of around 23% of the nurse cohort (Khunthar, 2014). A survey of registered nurses working in 95 hospitals under MOPH during 2005-2010 showed that the average length of stay for the non-civil-servant nurses was only around 1.2 years (48.68% quitting in the first year and 25.57% in the second year). Though the government decided to allocate around 11,000 more civil-servant positions to PSO for public nursing workforce during 2013-2015, it appeared to still be insufficient (Sawaengdee, 2017).

2.3.4 Loss of Senior Registered Nurses

The inadequacy of civil-servant positions also had an effect on the senior registered nurses (40-50 years old) despite them already being civil servants. Most of the nurses were stuck at the professional level because there were no vacancies and, thus, could not earn higher salaries (Sawaengdee, 2017). This was due to the fact that, as a part of the restricted fiscal policy, governmental agencies had to discard some vacant civil-servant positions in order to gain more higher-level positions (e.g. 3 vacant practitioner-level positions for 1 senior-professional-level position). Since there were also no lower-level vacancies for the nursing profession (see section 2.3.3), it was impossible for MOPH to create new higher-level positions for these senior nurses (Sawaengdee, 2017). The government addressed the issue by elevating the salary ceiling for each level in 2018.

In addition, these older nurses are also oftentimes assigned as mentors for the new entry nurses, along with the normal patient care workload which is also increasing due to the insufficient workforce. These conditions cause these senior nurses several troubles, for example, family, mental and physical health issues. Together with the low opportunity to advance in the career, the morale to stay in the facilities of the nurses can be weakened (Sawaengdee, 2017).

2.4 Intention to Leave

As the losses of young and senior nurses have become an important factor affecting the public nursing workforce age structure, the literature regarding the intention to leave of registered nurses were specifically reviewed.

Tourangeau, Cummings, Cranley L.A., Ferron, & Harvey (2010) proposed eight thematic categories of determinants influencing nurse intention to remain employed resulted from focus groups, including relationships with co-workers, condition of the work environment, relationship with and support from one's manager, work rewards, organizational support and practices, physical and psychological responses to work, patient relationships and other job content, and external factors. The proposition was later generally supported by a survey of over 15,000 nurses in England (Carter & Tourangeau , 2012). In China, seven factors were found to be statistically significant, including normative commitment, economic costs commitment, age, limited alternatives commitment, praise and recognition, professional advancement opportunities and the hospital classification (Wang , Tao, Ellenbecker, & Liu , 2012).

In Thailand, Sawaengdee (2016) found that 15.4 % of Thai registered nurses across the country intended to leave nursing career someday during their employment, whereas Sudjit (2006) showed that 23.7 % of nurses in Bangkok area had the intention to leave and 57.1% thought about the resignation.

Jaiboon, Chiangnangarm, and Kuhirunyaratn (2011) indicated that the highest resignation proportion was among nurses who had a duration of employment between 1-5 years. The major reasons for their resignation in the fiscal year of 2001-2005 were getting a new job, and job transferring whereas the reasons for resignation after 2006 were family reasons. This agrees with the result of Sudjit (2006) and Nasornjai, Nuysri, & Lemsawasdikul (2016) stating that opportunity to select a new job was a significant factor to predict the intention to leave the nursing profession. In addition, welfare services for family members, the timing of night shift, organizational commitment, quality of work life, work experience, and organizational climate were found to be influential factors amongst registered nurses working in public hospitals (Khunthar, Sujijantararat, Thongchareon, Namthep, & Klayklongjit, 2012).

A study with a specific focus on Generation-Y (born between 1981 and 2000) professional nurses found that career advancement opportunity was the only statistically significant factor affecting the intention to leave (Silamom, Deoisres, & Khumyu, 2018).

2.5 Healthcare Service and Nursing Workforce Demands in Public Facilities of Thailand

To provide a realistic context in which the developed model operates, healthcare service and nursing workforce demands are needed. Undoubtedly, number of population of a country is one of the main factors determining aggregate healthcare service demand of the country. For Thailand, the figure has increased by 13.4% in 20 years, from 60.8 million people in 1997 to 69 million people in 2017. Nevertheless, a study revealed that almost 80% of patients opt to go to state hospitals (Viriyathorn, et al., 2017). Using this result, it can be roughly estimated that 55.2 million population were the demand base of the public hospitals in 2017. Using the total number of the nursing workforce in the facilities under PSO (Figure 10), one may calculate the nurse-to-population ratio to be around 18 nurses per 10,000 population. This was below the recommended minimum threshold of 23 nurses per 10,000 population to achieve adequate coverage rates for the key primary health-care interventions, suggested by WHO (World Health Organization, 2010).

Summary of Literature Review

The public nursing workforce in Thailand is a complex system involving several elements and mechanisms which interact and affect each other. Indeed, the increasing healthcare demand has put a lot of pressure on the system, including the need for higher production of nurses. However, history has clearly witnessed that, for the public healthcare facilities, higher input of nurses is a silver-bullet solution. The civil-servant system that Thailand has had for a long time plays an important role in the dynamics of the nursing workforce. Career advancement opportunity and job security have proved to be the factors that affect the intention to leave of the nurses working in the state hospitals. In particular, the sufficiency of civil-servant positions and the opportunity to get promoted to a higher position are the important determinants for entry-level and senior nurses working in public healthcare establishments, respectively. The sudden downsizing of nurse production and reduction in civil-servant positions during 1999-2005 were believed to be the onset of how PSO nursing workforce age structure has evolved until what was observed in 2017. In the public facilities, there was a need for more registered nurses in order to achieve adequate coverage rates for the key primary health-care services.

Chapter 3: Methodology

3.1 System Dynamics

3.1.1 Overview of System Dynamics

Pioneered in the 1950s by Jay W. Forrester, System Dynamics (SD) was originally called Industrial Dynamics as it was initially used to study industrial problems by understanding the influence of interactions between organization structure, policies, and decision and action time delays on the performance of the organization (Forrester, 1961). In 1968, the application of Industrial Dynamics was broadened beyond corporate modeling. In collaboration with John F. Collins, Forrester wrote a book titled Urban Dynamics which identified and described the systemic structure responsible for the dynamics of urban development and decay (Forrester, 1969). This was the first major non-corporate application of SD. Over time, the merits of the approach have been realized by researchers and policymakers as it was widely used to tackle a variety of complex problems in other social systems, for example, population, agriculture, ecological and economic systems.

System Dynamics is often applied to understand the dynamic behavior of social problems and, subsequently, to identify robust policy options for alleviating such problems. To do so, Causal Loop Diagram (CLD) and/or Stock and Flow Diagram (SFD) are built and used as representations of the real systems – often referred to as the models. While a quantitative SD study always involves the construction of quantified SFD(s), a qualitative study can result in merely CLD(s) or unquantified SFD(s). As a result, the use of qualitative SD models can be limited to the understanding of the structure of the systems descriptively. On the other hand, quantitative models (so-called 'simulation models') allow the investigation of how the systems behave under several circumstances through multiple simulations without interfering the real systems. This advantage makes it possible for decision-makers to evaluate and identify the most optimal policy option(s) for dealing with the problems. The reader who is not familiar with how to read the diagrams is encouraged to consult chapter 5 and chapter 6 of Sterman (2000).

Systems Dynamics is a problem-solving approach utilizing systems thinking which assumes that a system's behavior emerges from its underlying structure (Meadows & Wright, 2008). Richardson (2011) explained that the foundation of System Dynamics, which is often implicit and ignored, is the endogenous point of view. With this underlying concept, SD practitioners (so-called 'modelers') are encouraged to build the models that are capable of producing the dynamic behavior of interest solely from variables and interactions within the appropriately chosen system boundary (Richardson G. , 2011). In other words, a good SD model should not depend on exogenous factors to produce dynamic behavior of interest. The characteristic distinguishes SD from other modeling approaches as SD models can be analyzed causally (Barlas, Formal aspects of model validity and validation in system dynamics, 1996) and oftentimes require non-dynamic input data to derive dynamic behavior.

3.1.2 The Fit between System Dynamics and the Research Problem

Illustrated in Chapter 1, the public nursing workforce age structure dynamics can be viewed as a complex system, involving interactions of several elements – e.g. a tremendous number of interacting variables and time delays. In this complexity, it could be doubtful to analyze such system by conventional analytical models. In addition, the purpose of this study is to promote understanding of how the problematic behavior of interest developed and to provide potential policy options which could effectively and efficiently solve the problem. This emphasizes the need for a method that allows observation of the dynamic behavior of the system and experiments. Simulation modeling is, thus, a promising candidate approach for this study. In fact, to explain the problem intuitively, causal-descriptive (structure-oriented) models can be deemed more appropriate than statistical or correlational (data-driven) models (Barlas, 1996).

Axelrod (2003) explained how simulation can be considered as another way of conducting scientific research. Simulation study starts with a set of assumptions, namely the structure of the system of interest. However, it does not aim at proving theories. Instead, the simulation produces some results that could be analyzed inductively (Axelrod, 2003). While inductive study tries to find patterns in observed data to build theories and deductive study concerns testing existing theories, the value of simulation lies in helping the researcher to intuitively understand a phenomenon.

The major approaches (paradigms) in simulation modeling are System Dynamics (SD), Discrete-Event Simulation (DES) and Agent-based modeling (ABM) (Borshchev & Filippov, 2004). Different simulation modeling approaches are implemented differently (e.g. top-down such as SD and DES or bottom up such as ABM) and yield different results in terms of precision and level of aggregation (Richardson K. , 2003). Good modelers choose the model architecture, level of aggregation and simulation method that most properly meet the purpose of the study, under given constraints (Sterman, 2018).

Suggested by (Sumari, Ibrahim, Zakaria, & Ab Hamid, 2013), the rationale behind the choice of System Dynamics for this study is illustrated in Table 1. Comparing the requirement of the simulation model to answer the research problem and the capability of each of the main simulation modeling approaches, the author believes that SD is the most appropriate approach for the current study.

	The capability of each simulation modeling approach		
The requirement of the study	**SD**	**DES**	**ABM**
Enabling scenario analysis and policy testing	Yes	Yes	Yes
Expecting aggregate results rather than entity-level results	Aggregate	Both	Both
Involving time delays	Yes	Yes	Yes
Involving complex feedback processes	High	Low	High
Involving non-linear relationships between variables	High	Low	High

	The capability of each simulation modeling approach		
The requirement of the study	**SD**	**DES**	**ABM**
Involving multiple qualitative variables (so-called 'soft variables')	High	Low	High
Promoting a deep understanding of the complex system (being easily analyzable)	High	Moderate	Moderate
Requiring moderately complex computational operations	Moderate	High	High

Table 1 Suitability of Candidate Modeling Approaches for the Research Problem

3.1.3 The Process

To attain a high-quality scientific model that can serve the purpose of the study, a rigorous modeling process is required.

"Scientific modeling is distinguished from other approaches largely by the quality of evaluation and revision performed and by an insistence upon empirical evidence to support hypotheses and formulations" (Homer , 1996, p. 1)

Moxnes (2009) suggested SD practitioners follow a standard framework consisting of 5 main steps when they conduct SD studies.

The first step is problem formulation which involves defining the problem statement and translating this description into a graph representing the behavior of the problem variable over time. This graph is usually referred to as the reference mode. The reference mode could be based on historical data, or it could be a hypothetical (future) problem development. For the current study, the result of the step is presented in Chapter 1.

The second step is dedicated to formulating a hypothesis in the form of a system structure that is believed to be responsible for the behavior of the reference mode. The system structure is represented by a formal model – namely, a quantified stock and flow diagram. It is suggested that the hypothesis belongs to a class of problems such that previous research can be utilized and such that the results of the study can be generalized. The hypothesis of this study is discussed in Chapter 4. The process of collecting data for the model construction is described in the next section.

The third step consists of two tasks, hypothesis testing and model behavior analysis. Unlike usual statistical modeling research, there are two separate sets of hypothesis tests for structure and behavior of the model, where SD puts an emphasis on structure tests. The process of testing the hypothesis often referred to as model validation process is discussed more in detail in Chapter 6. The analysis of the behavior of the model is covered in Chapter 5. Chapter 6 and Chapter 7.

While the first three steps combine to represent the scientific method used to understand the roots of the problem, the last two steps involve policy design and implementation which can be deemed more of as operations research and management.

The fourth step concerns the generation and evaluation of policies. Given a tested hypothesis (a validated model) that could explain the reference mode, hypotheses about policies that could alleviate the problem are formulated. The above iterative process with hypothesis formulation and analysis is repeated for these policies. However, at this stage, the goal is not to replicate the reference mode, but rather to identify policies, whether it be system parameter changes or structural changes or both, that produce less problematic behaviors. The identified policies are, then, evaluated against a set of pre-defined criteria such as effectiveness and efficiency to reduce the problematic behavior and side effects on other parts of the system. The process and result of policy formulation and analysis are discussed in Chapter 8.

Because the most effective policy in the model might not be the one working best in the real world, the last step involving feasibility study should be conducted to identify the most realistic policy for implementation. Several aspects, e.g. cost, uncertainty, the fairness of outcome distribution and misperception of stakeholders engaged in the problem, should be taken into account. Chapter 9 elaborates more on this matter.

Despite being described in the linear way, it is important to note that the scientific modeling process should be viewed as an iterative process (Homer , 1996). This means that to reach a credible model, one might need to implement the process in multiple rounds. For example, the need to revise the model structure for expanding the boundary of the system might be realized at the policy formulation and analysis stage if the current model cannot help to generate effective solutions. Subsequently, this means the new structure will also need to be revalidated.

3.2 Data Collection

As the main objective of this study is to address the problem of unfavorable public nursing workforce age structure dynamics in Thailand by using a System Dynamics model as an aid to improve understanding and policy formulation, a variety of data are needed for constructing and validating the model. Literature review was the data collection method used in this study to build and validate the model.

To develop the System Dynamics model representing the problem, a literature review was first conducted. A literature review is important for gathering the conceptual knowledge or qualitative data regarding the system being studied and the quantitative data required to operationalize the model. To be precise, these data were mainly used in the first and the second steps of the modeling process described in the previous section.

The literature review process of this study consisted of two phases: a preliminary literature review and an extended literature review.

The first phase involved gathering the literature specific to the nursing shortage and aging nursing workforce problems around the globe and in Thailand. To identify academic papers on the topics, a search was conducted for papers in Google Scholar database to avoid bias in favor of any specific publisher. The search for scientific articles was carried out during February-April 2019 using the search terms such as “nursing shortage”, “aged nursing workforce”, “ag(e)ing nursing workforce”, “older nursing workforce”, and “ag(e)ing nurses”. The results are the overview of the problem, presented in Chapter 1 and Chapter 2, parts of the full model in Chapter 4, and referenced sources for model validation in Chapter 5.

The second phase was mainly conducted during the second step of the modeling process to append the preliminary model obtained from the first phase. As mentioned in the previous section system boundary is an important aspect of SD modeling, the data aimed to collect in this phase have to efficiently correspond to the boundary of the interested system. For this purpose, this extended literature review was done iteratively throughout the model construction process during February-June 2019. The results of this phase are also included in Chapter 2, and parts of the full model described in Chapter 4.

Chapter 4: Model Description

4.1 Model Overview

This section explains the overview of the System Dynamics model developed in this study. The model can be divided into 5 sectors that interact with each other (Figure 12). The connections between sectors indicate information passing and receiving. The explanation for each sector and each connection is summarized in Table 2.

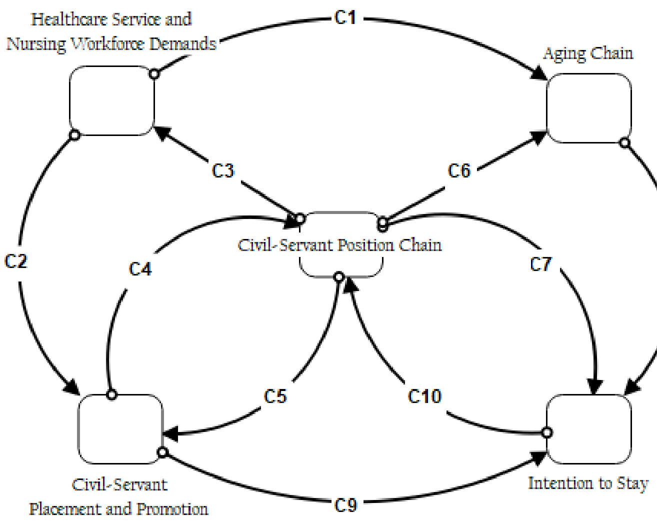


Figure 12 Overview of the Model

Element	Type	Information Sender	Information Receiver	Explanation
Healthcare Service and Nursing Workforce Demands	Sector	N/A	N/A	This sector concerns the number of Thailand's population, how it is translated into nursing workforce demand, and recruitment rate of new nurses.
Aging Chain	Sector	N/A	N/A	This sector concerns the numbers of nurses at different ages, and the process by which nurses age up.
Civil-Servant Position Chain	Sector	N/A	N/A	This sector concerns the numbers of nurses at the different status and/or position levels, and the process by which nurses get placed and promoted, and leave or retire.

Element	Type	Information Sender	Information Receiver	Explanation
Civil-Servant Placement and Promotion	Sector	N/A	N/A	This sector concerns the allocation of vacant civil-servant positions to non-civil-servant or allocation of senior-level positions.
Intention to Leave	Sector	N/A	N/A	This sector concerns the effects of lack of civil-servant positions and training burden (imbalance between young and senior nurses) on the intention to leave of nurses.
C1	Connection	Healthcare Service and Nursing Workforce Demands	Aging Chain	This connection denotes the recruitment rate of new nurses into the nursing workforce aging chain.
C2	Connection	Healthcare Service and Nursing Workforce Demands	Civil-Servant Placement and Promotion	This connection denotes the recruitment rate of new nurses into the allocation of civil-servant positions.
C3	Connection	Civil-Servant Position Chain	Healthcare Service and Nursing Workforce Demands	This connection denotes the current number of total nurses, leaving rates for determining recruitment rate of new nurses.
C4	Connection	Civil-Servant Placement and Promotion	Civil-Servant Position Chain	This connection denotes the current number of total nurses, leaving rates for determining recruitment rate of new nurses.
C5	Connection	Civil-Servant Position Chain	Civil-Servant Placement and Promotion	This connection denotes the current number of total nurses, leaving rates for determining civil-servant position allocation.
C6	Connection	Civil-Servant Position Chain	Aging Chain	This connection denotes the current leaving rates to keep the number of total nurses in the two chains equal.
C7	Connection	Civil-Servant Position Chain	Intention to Leave	This connection denotes the current number of total nurses, leaving rates for determining effects on intention to leave of nurses.

Element	Type	Information Sender	Information Receiver	Explanation
C8	Connection	Aging Chain	Intention to Leave	This connection denotes the proportion of senior nurses to young nurses for determining effects on intention to leave of nurses.
C9	Connection	Civil-Servant Placement and Promotion	Intention to Leave	This connection denotes the career advancement opportunity (vacant positions) for determining effects on intention to leave of nurses.
C10	Connection	Intention to Leave	Civil-Servant Position Chain	This connection denotes the affected leaving rates of nurses after the effects of lack of civil-servant positions and training burden of senior nurses.

Table 2 Explanation of Model Overview Elements

4.2 Model Boundary and Time Horizon

To be able to exhibit the dynamics of public nursing workforce age structure, a quantitative and integrative dynamic model with a suitable boundary, time horizon and realistic interpretation of relevant decision-making mechanisms of the civil-service human resource system and the registered nurses, is essential.

Emphasized throughout the study, the model in this research covers only the relevant systems of the nursing workforce in the healthcare facilities under the Permanent Secretary Office (PSO) of Ministry of Public Health (MOPH) of Thailand. This model, thus, does not involve the nurses working in private healthcare establishments and university-owned hospitals, even if the universities are public.

It is important to note that the model treats the demand side of the system, thus number of visitors to the hospitals, exogenously. In other words, the structure of the model does not include parts to explain the dynamics of the visitors number. Instead, statistical data of population and fraction of them using public facilities were used to estimate the number of visitors to the facilities each year. In addition, the population are assumed to be homogeneous, meaning that all entities have the same qualities, e.g. gender and age.

The model was designed to simulate over a period of 25 years, including 13 years of the historical problematic behavior (from 2005 to 2017) and 12 years of forecasting period (from 2018 to 2030).

4.3 Underlying Assumptions

4.3.1 Exclusion of Expert-Level and Advisory-Level

Although the nursing profession is classified as a knowledge workforce and, according to the civil-service regulation, has 5 levels, there have been, in fact, only very few nurses who were granted an expert-level or an advisory-level (less than 0.5% of the total workforce, see Figure

10 in Chapter 2). Therefore, these levels were excluded from the model since they would not have significant impacts on the model behavior.

4.3.2 Limited Senior-Professional-Level Positions

Since the higher positions are more costly to the government than the lower ones, there is a limit for the number of senior-profession-level positions. Generally, the number is very small, for example, 2-4% of the total nursing workforce. See more detail in section 2.3.4, Chapter 2.

4.3.3 Seniority System

This assumption is mainly applied for both the intermediate civil-servant placement and the promotion from the professional level to senior-professional level. Since there is a limited number of such level positions, nurses are normally promoted according to their seniority. This means that, for example, when there are vacancies for senior-level positions, nurses with a higher number of years' experience will have a higher chance to get promoted. Likewise, the non-civil-servant nurses with more years' experience have a higher chance to get a civil-servant status. See more detail in section 2.2.3, Chapter 2.

4.3.4 No Re-entry and No Intermediate Entry

Thailand's civil-servant system has been well-known for its rigorousness (See section 2.2.1-2.2.3, Chapter 2.) For the civil servants who, once, leave the civil-service system, if they want to re-enter the system, they will have to restart at the practitioner-level regardless of their years' experience through complicated processes, including retaking the civil-service entrance examination. Thus, it was assumed that, once, nurses leave their public hospitals, they will not re-enter. For the same reason, it is impossible for nurses who might have extensive experience working in, for example, private hospitals to enter the public hospitals under PSO without starting at the practitioner level.

4.3.5 Relaxed Regulation of Restart at Practitioner-Level

Although due to the civil-service regulation, non-civil-servant nurses always have to start at practitioner-level if they want to get a civil-servant status (See section 2.2.2 and 2.2.3, Chapter 2), they are assumed in this model to be able to get placed at the civil-servant position levels according to their years' experience. This assumption was made specific to non-civil-servant nurses with 8-12 years' experience such that they can get placed directly at the professional level, once there are open civil servant positions.

This assumption was made so that the aging and the career development processes of nurses correspond to each other. The author believes that this assumption is legitimate in this model for two reasons. First, there have been only a few non-civil-servant nurses who remained in the public hospitals until such stage, according to statistics. Second, there is no position limit at the professional level.

4.3.6 Last Waiting of Non-Civil-Servant

Intention to leave or stay of non-civil-servant nurses depends substantially on the career development opportunity, namely the chance to get civil-servant status. Due to a limited number of civil-servant positions, not all new-entry nurses get a civil-servant status at their entrance. Some of them might have to wait more than 10 years until they get permanent status.

However, they are not hesitant to leave public hospitals if they do not see any such possibility. Therefore, it was assumed that the non-civil-servant nurses will wait for 12 years at maximum before they leave the facilities for private hospitals or changing their careers.

4.3.7 Consistent Leakage of Non-Civil-Servant

Based on the literature review (See section 2.4, Chapter 2), it was assumed that public registered nurses may leave the facilities at any point during their employment, regardless of their accumulated working experience in the facilities. In other words, the probability of leaving the facilities is uniformly distributed over different ages in an age class, for both civil-servant nurses and non-civil-servant nurses. This assumption was used in determining the 100% leakage zone in leaving rates of the model.

4.4 Model Structure

This section explains the SD model in detail. For simplicity purpose, the full SFD is not presented at once. Instead, it is divided into 4 parts which are logically presented and explained. Nevertheless, the reader can find the full model in Appendix I: Full Stock and Flow Diagram. Note that, at this stage, model parameter values are not involved.

4.4.1 Nursing Workforce Aging Chain and Civil-Servant Position Chain

This part of the model involves the backbone structure of the public nursing workforce system in Thailand. This structure consists of two chains: Nursing Workforce Aging Chain, and Civil-Servant Position Chain. These two chains represent different processes, yet with the same entities – i.e. same nursing workforce, simultaneously. This part corresponds to the Aging Chain and Civil-Servant Position Chain sectors described in section 4.1.

a) Nursing Workforce Aging Chain

This chain concerns the process by which the registered nurses working in the facilities under PSO get older over time. Seen in Figure 13, eight stocks are used to represent eight age classes in which the nurses reside, at a given time. New nurses enter the chain through '*Recruitment*' flow. With the assumption of no intermediate entry and no re-entry, this is the only inflow to the chain. Since most nurses graduate from nursing schools when they are 22, the first age class is 23 to 24 years old. While the first stock consists of only nurses with 2-year age variance, the other stocks consist of nurses with 5-year age variance. This classification is due to the availability of parameter values and reference mode data.

The aging process is modeled by the stocks and the flows with names starting with '*Aging*'. After residing in '*Aged 23-24*' stock for 2 years[1], the initially 22-year-old nurses move into '*Aged 25-29*' stock through '*Aging 1*' flow. Likewise, this cohort of nurses will reside in '*Aged 25-29*' stock for 5 years before moving into '*Aged 30-34*' stock through '*Aging 2*' flow. The process continues until the nurse cohort retire from the facilities at 60 through '*Retirement*' flow. The magnitude of '*Retirement*' flow is explained in 4.4.2.

At any stage, the nurses might leave the facilities through the flows with names starting with '*Leaving*'. For example, nurses aged 23-24 leave through '*Leaving 1*' flow. How high the leaving

[1] Stella Architect, the modeling software used in this study, allows users to model precise pipeline delay within a certain type of stock called 'Conveyor'.

flows are, depends on the variables with names starting with '*Fractional Leaving Rate*'. These variables are percentages indicating how much nurses leave, compared to the total nurses residing in the respective age classes in a given year. The magnitudes of these variables are explained in 4.4.2.

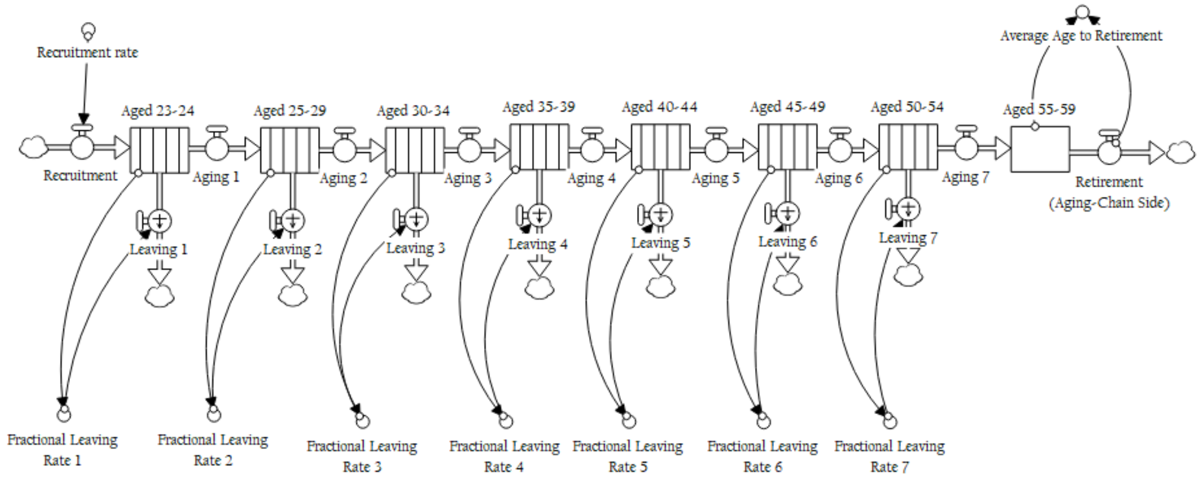


Figure 13 Nursing Workforce Aging Chain

The structure shown in Figure 14 shows how important reference variables are derived from the component variables in Figure 13.

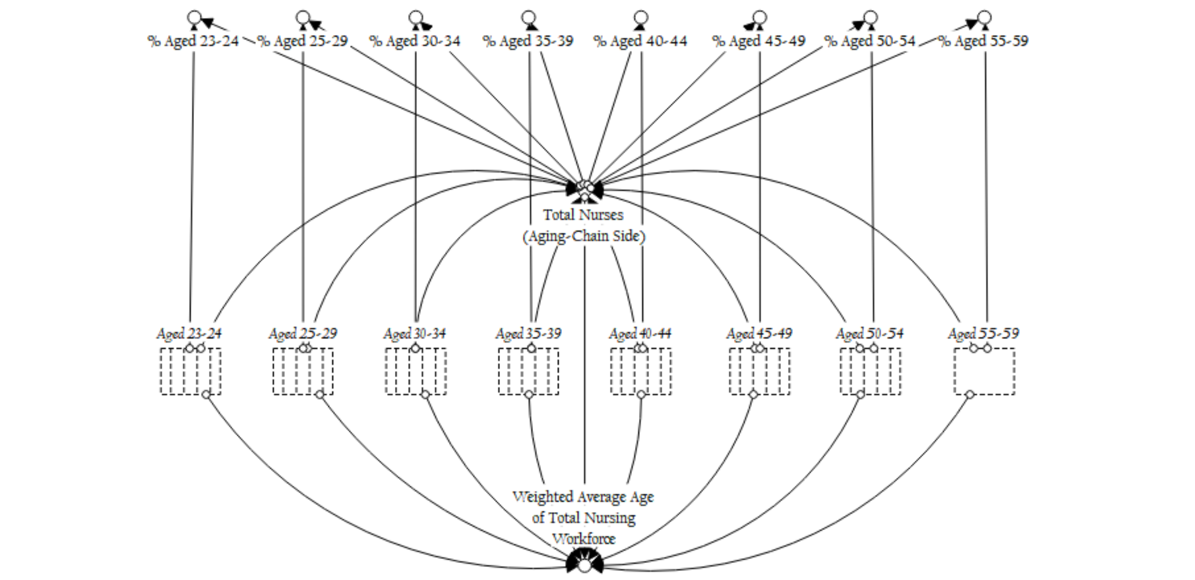


Figure 14 Derivation of Important Reference Variables of the Aging Chain

b) Civil-Servant Position Chain

The other chain of this model involves the career path of nurses working in public hospitals under PSO. Similar to the aging chain, this chain (Figure 15) consists of a number of stocks and flows, representing the process by which the nurses progress in the civil-servant system.

However, this process has 2 sub-chains inside: civil-servant sub-chain in the upper part of the diagram and non-civil-servant sub-chain in the lower part of the diagram.

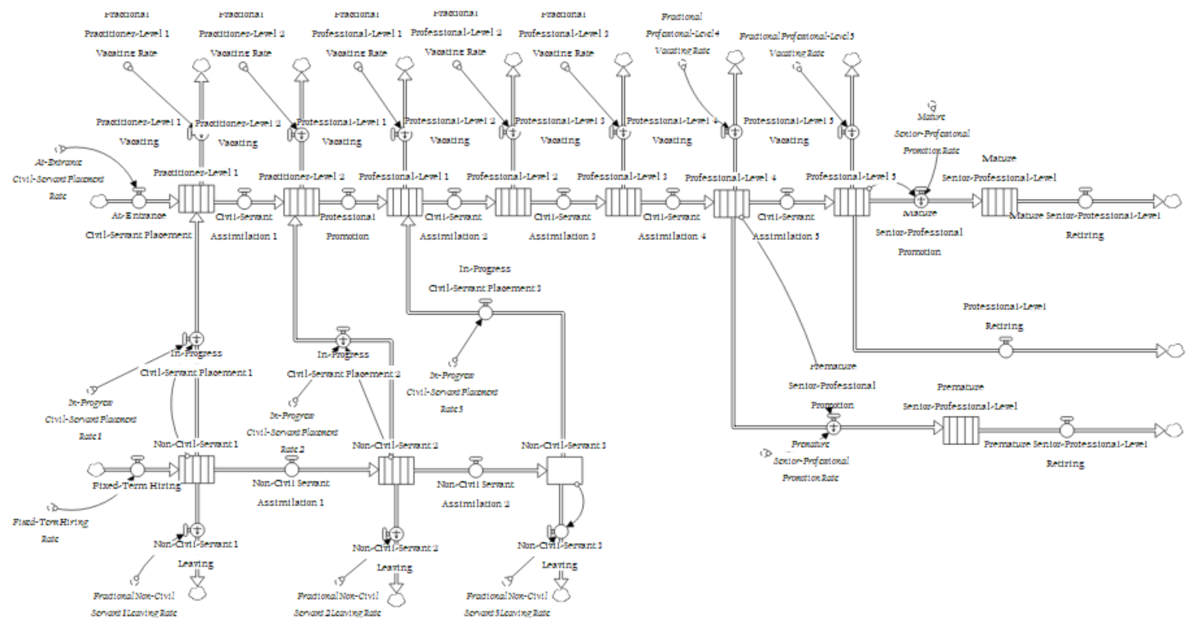


Figure 15 Civil-Servant Position Chain

Civil-servant sub-chain consists of 9 stocks used to represent different civil-servant position levels in which the nurses are. There are 3 main civil-servant position levels: Practitioner-Level, Professional-Level and Senior-Professional-Level. Practitioner-Level and Professional-Level also have sub-stages according to nurses' number of year of experience. For example, the nurses residing in '*Practitioner-Level 1*' stock are with 1-2 years' experience in the nursing profession, whereas the ones residing in '*Professional-Level 2*' stock are with 13-17 years' experience (including practitioner period). Senior-Professional-Level has 2 types: Mature and Premature. The former is the stock containing senior nurses who progressed from '*Professional-Level 5*' stock, the ones with 28-32 years' experience. The latter progressed from '*Professional-Level 4*' stock, the ones with 23-27 years' experience. The reason why there are two types is explained in 4.4.2. Nurses progress one stock to another stock through the flows with names starting with '*Civil-Servant Assimilation*' (gaining experience), or the flows with names ending with '*Promotion*'. For instance, after residing in '*Practitioner-Level 1*' stock for two years, the nurses move into '*Practitioner-Level 2*' stock and after 4 years in '*Practitioner-Level 2*' stock, they move into '*Professional-Level 1*' stock. At '*Professional-Level 4*' and '*Professional-Level 5*', nurses can move into '*Mature Senior-Professional-Level*' or '*Premature Senior-Professional-Level*' under certain conditions explained in 4.4.2.

Non-civil-servant sub-chain consists of only 3 stocks used to represent groups of non-civil-servant nurses with different years' experience. Nurses progress from one stock to another stock through '*Non-Civil-Servant Assimilation 1*' and '*Non-Civil-Servant Assimilation 2*' flows. At any stock in this sub-chain, nurses may move into the civil-servant sub-chain through the flows with names starting with '*In-Progress Civil-Servant Placement*'.

New nurses enter the chain through '*At-Entrance Civil-Servant Placement*' and '*Fixed-Term Hiring*' flows which are determined by '*At-Entrance Civil-Servant Placement Rate*' and '*Fixed-Term Hiring Rate*' variables, respectively. The magnitudes of these variables are explained in 4.4.2.

Nurses retire after working in the facilities for approximately total 37 years through the flows with names ending with '*Retiring*'. However, nurses may also leave beforehand through the flows with names ending with '*Vacating*' *or* '*Leaving*', determined by the variables with names ending with '*Vacating Rate*' or '*Leaving Rate*'. The magnitudes of these variables are explained in 4.4.3.

The structure shown in Figure 16 shows how important reference variables are derived from the component variables in Figure 15.

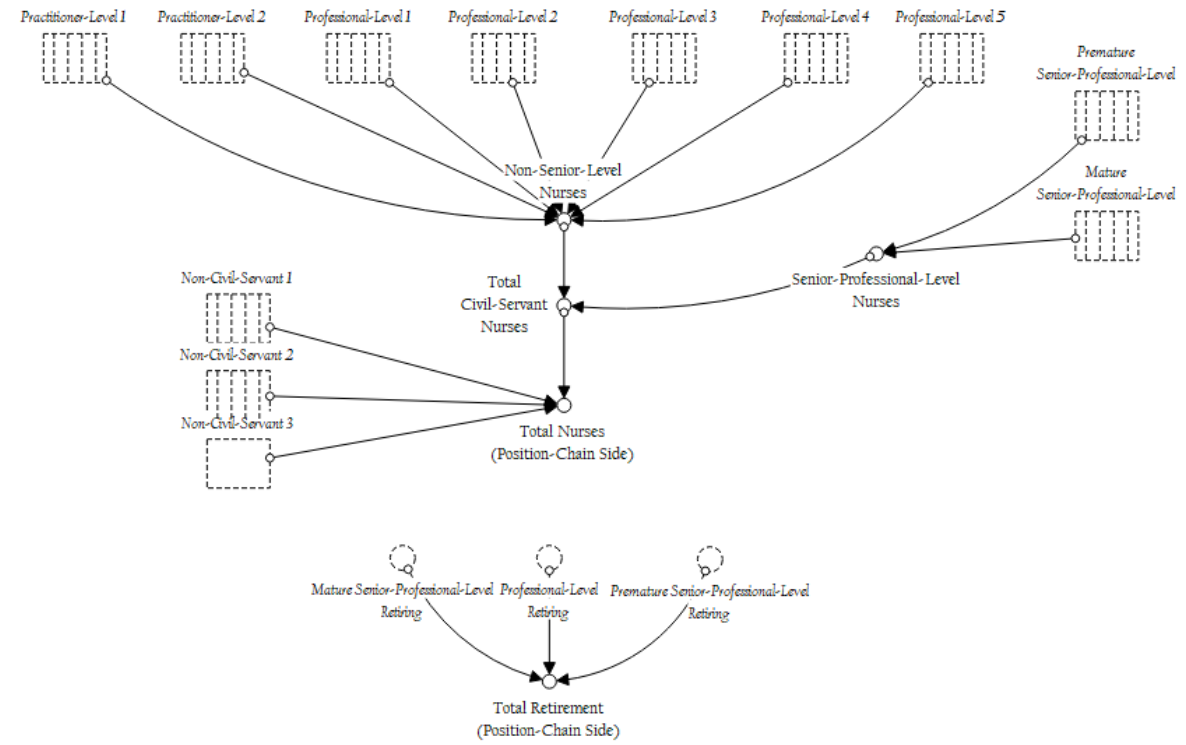


Figure 16 Derivation of Important Reference Variables of the Civil-Servant Position Chain

4.4.2 Mechanisms Behind the Flows

This part mainly describes how the flows in the chains are influenced. This part corresponds to Aging Chain, Civil-Servant Position Chain, and Civil-Servant Placement and Promotion sectors described in section 4.1.

a) **Leaving and Civil-Servant Position Vacating**

To make the two chains work simultaneously and consistently, the outflows of the two chains also need to be synchronized.

The leaving and retirement rates of the aging chain are derived from the civil-servant position chain. Therefore, Figure 17 presents the links between the two chains. For the variables with names starting with '*Fractional Leaving Rate*', their values vary based on the flows with names ending with '*Vacating*' *or* '*Leaving*' from civil-servant position chain and their upstream stocks[2]. The first three leaving rates of the aging chain also incorporate the values of '*Leaving*' from the civil-servant position chain because of the presence of non-civil-servant nurses.

For the '*Retirement*' flow of the aging chain is derived from the sum of the flows with names ending with '*Retiring*' of the civil-servant position chain in each time step.

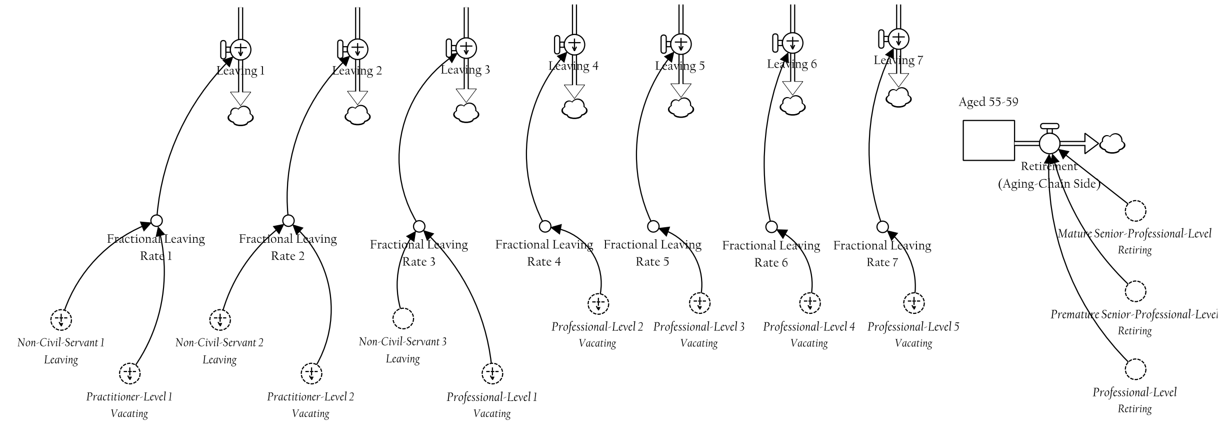


Figure 17 Connections Between the Aging Chain and the Civil-Servant Position Chain

b) Recruitment and Civil-Servant Placement and Promotion

The inflows and interlinking flows between stocks of the two civil-servant position sub-chains involve complex conditional calculations. The reader is suggested to read Figure 18 leftward. '*Max Civil-Servant Positions*' is the constant indicating the maximum number of civil-servant positions in the system. Most of these positions are allocated to non-senior positions (upper branch in the figure) and only a small fraction is for senior positions (lower branch in the figure).

With respect to the non-senior branch, the number of vacant non-senior positions at a point in time is calculated in '*Vacant Non-Senior Positions*' variable. Through times, some nurses leave the facilities, making some positions vacant. Thus, the number of opening positions for non-senior levels is calculated in '*Opening Non-Senior Positions*' by also considering the leaving rates. Having the opening positions, the model, then, allocates them to non-civil-servant and new-entry nurses, respectively. Since there is always a limited number of opening positions, working years' experience in the facilities indicates the priority. The more experienced non-civil-servant nurses are allocated the civil-servant status before the less experienced ones, e.g. '*Non-Civil-Servant 3*' stock is considered before '*Non-Civil-Servant 2*'. The conditions used to allocate the positions are shown in. If there are open positions left for only some of the new-

[2] Instead of using only flows from civil-servant position chain, the values of the upstream stocks are required in this case because the leaving flows from conveyor-type stocks take only fractional values. The calculation of such fractional values is shown in Appendix II: List of Equations and Baseline Parameters.

entry nurses, '*Recruitment*' rate will be divided into '*At-Entrance Civil-Servant Placement Rate*' and '*Fixed-Term Hiring Rate*' used for determining the inflows to the civil-servant position chain.

The same logic is applied to the senior branch. However, the process does not involve recruitment and the onset at which the allocation starts is '*Professional-Level 5*'. Again, professional-level nurses with more years' experience have the priority to get promoted to the senior level.

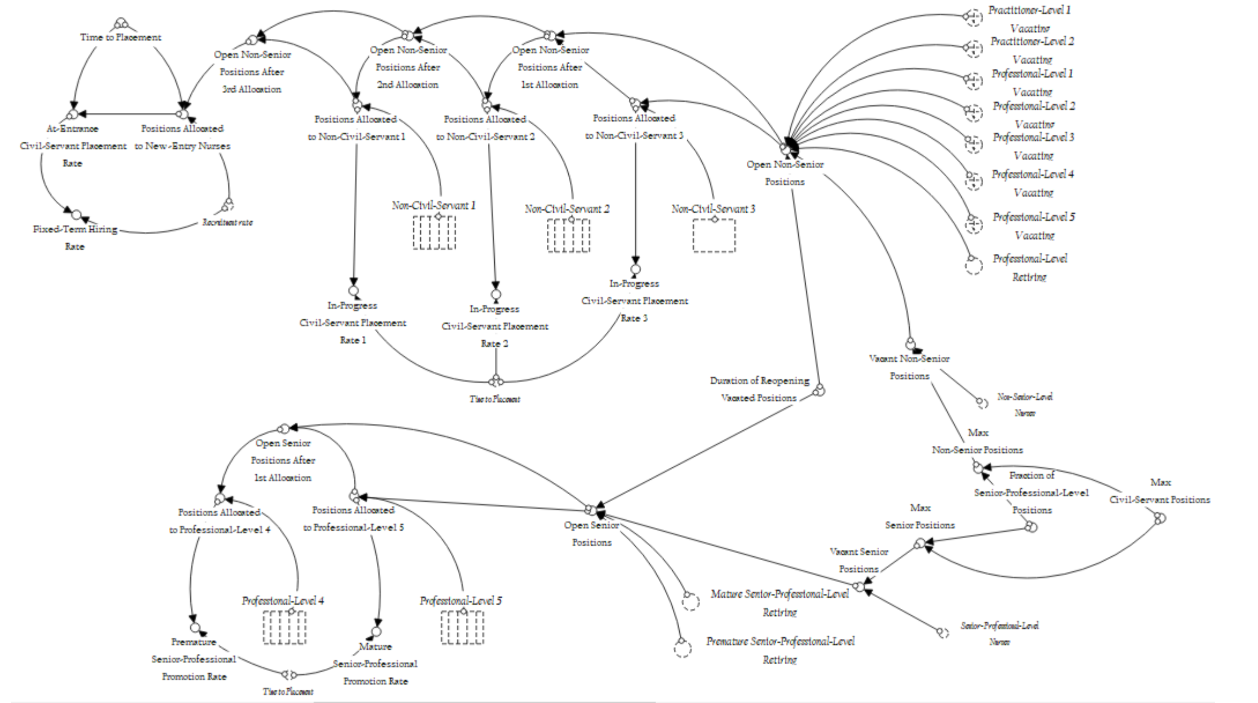


Figure 18 Civil-Servant Placement and Promotion

4.4.3 Nonlinear Relationships

This part mainly describes the effect of career advancement opportunity (civil-servant position availability) and training burden on the intention to leave of nurses. This part corresponds to the Intention to Leave sector described in section 4.1.

a) **Effect of Career Advancement Opportunity on the Intention to Leave of Non-Civil-Servant Nurses**

According to the literature, the opportunity to advance in the career plays an important role to determine nurses' intention to leave from or stay in an organization. Non-civil-servant nurses receive less attractive remuneration package, compared to the civil-servant nurses. In addition, it is impossible for them to ladder up the hierarchy with such temporary status. Therefore, the effect of civil-servant position insufficiency on the intention to leave was included in this model. The mechanism was modeled by imitating the decision-making process of nurses. The willingness to stay in the organization will remain as long as they perceive that there is an opportunity to grow, namely the number of open positions. They compare the number of nurses who are waiting for civil-servant placement and the number of according open positions at a given time and then, they decide whether to leave the

establishments. For example, the non-civil-servant nurses with 1-2 years' experience compare the number of open positions after allocations for the highly experienced ones. If the result of the comparison (number of nurses in *'Non-Civil-Servant 1'* stock divided by number of according open positions, open *'Non-Senior Positions after 2nd Allocation'* variable) is very high, this means that the chance of getting a civil-servant status is very low, resulting in *'Perception of Non-Civil-Servant 1 towards Civil-Servant Placement Opportunity'* variable. This perception is then translated into a numerical factor by a non-linear graphical function which is afterwards multiplied by a reference fractional leaving rate, *'Reference Fractional Non-Civil-Servant 1 Leaving Rate'* variable, to obtain the actual fractional leaving rate, *'Fractional Non-Civil-Servant 1 Leaving Rate'* variable.
The translation of the perception variables to their effects and calculation of the final leaving rate variables are shown in Appendix II: List of Equations and Baseline Parameters

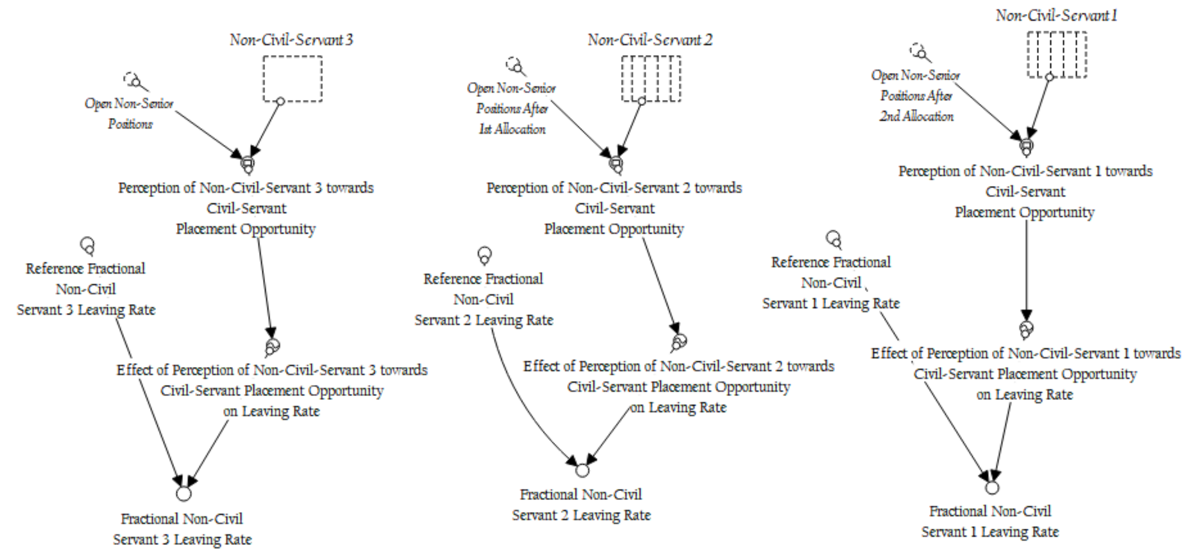


Figure 19 Effect of Career Advancement Opportunity on the Intention to Leave of Non-Civil-Servant Nurse

b) Effect of Training Burden and Senior Career Advancement Opportunity on the Intention to Leave of Professional-Level Nurses

The same mechanisms were used to model the effect of the training burden and senior career advancement opportunity on the intention to leave of professional-level nurses. For example, professional-level nurses with 23-27 years' experience assess the opportunity to get promoted to the senior level by comparing the number of nurses on their levels, *'Professional-Level 4'* stock, and the number of open senior positions after the first allocation to nurses with 28-32 years' experience, *'Open Senior Position after 1st Allocation'* variable. The result of this comparison, *'Perception of Professional-Level 4 towards Career Advancement Opportunity'* variable, is then translated into a numerical factor by a non-linear graphical function which is afterwards multiplied by a reference fractional leaving rate, *'Reference Fractional Professional-Level 4 Vacating Rate'* variable, to obtain the actual fractional leaving rate, *'Fractional Professional-Level 4 Vacating Rate'* variable.

However, there is another factor that affects the intention to leave or to leave of the experienced nurses, namely the extraordinary task of training young nurses. The indicator of the magnitude of this burden is the fraction of aged workforce (45 to 54 years old) to the young nursing workforce (23 to 29 years old), '*Training Burden on Senior Nurses*' variable. This variable is then translated into a numerical factor by a non-linear graphical function which is afterwards added to the effect of career advancement opportunity before calculating the final leaving rate, '*Fractional Professional-Level 4 Vacating Rate*' variable.

The translation of the perception variables to their effects and calculation of the final leaving rate variables are shown in Appendix II: List of Equations and Baseline Parameters.

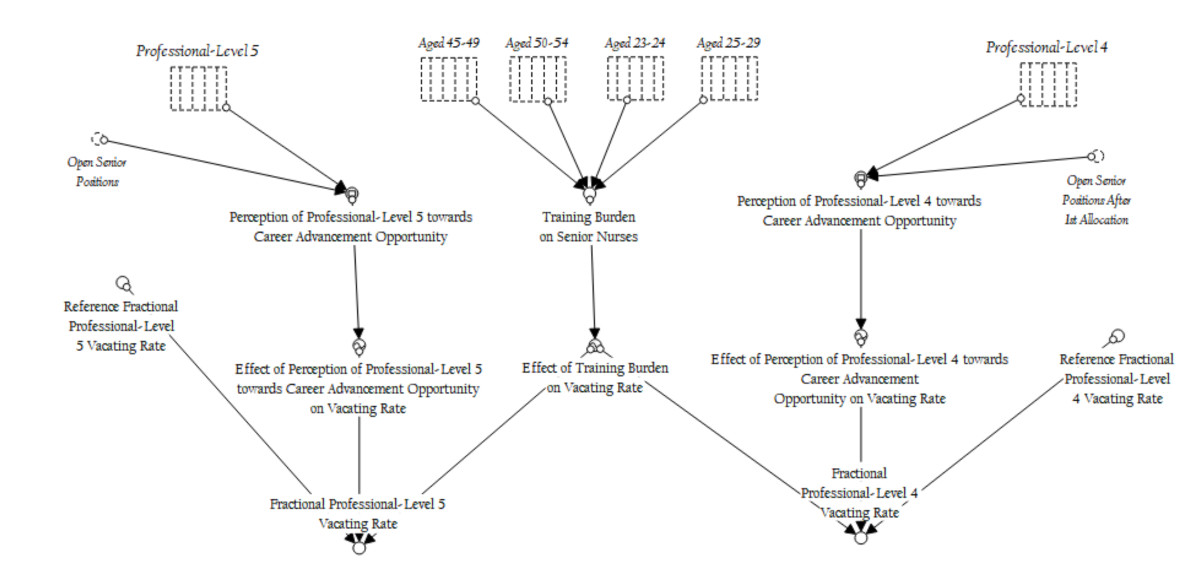


Figure 20 Effect of Training Burden and Senior Career Advancement Opportunity on the Intention to Leave of Professional-Level Nurses

4.4.4 Healthcare Service and Nursing Workforce Demands

To provide a more realistic context than constant healthcare service demand for the nursing workforce system, statistics regarding Thailand's population and percentage of public health facilities use were incorporated. From the top of Figure 21, '*Population*' stock, denoting the total number of population in Thailand at a given time, is changed by '*Net Change in Population*' flow. This flow is influenced by the stock and '*Fractional Change rate in Population*' variable. In this model, the variable is treated exogenously by taking the statistical data of annual Thailand's population changes.

The number of population using public healthcare facilities under PSO, '*Population Using Public Healthcare Facilities*' variable, is calculated from the population stock by using '*Fraction of Population Using Public Healthcare Facilities*' constant. The variable is then multiplied with the nurse-to-patient ratio recommended by WHO, '*Target Nurse-to-Patient Ratio*' constant, resulting in '*Target Public Nursing Workforce*' variable.

The right part of the same figure concerns the calculation of total loss of nursing workforce per year by using other variables of the model, '*Total Loss of Nurses*' variable.

Then, the nursing workforce demand gap is calculated by comparing '*Target Public Nursing Workforce*' variable, '*Total Loss of Nurses*' variable, and '*Total Nurses*' variable. This demand gap is then used to calculate the recruitment rate of new nursing graduates by taking the nurse production time delay and the fraction of nursing graduates opting to start working in public hospitals under PSO into account.

This part corresponds to the Healthcare Service and Nursing Workforce Demands sector described in section 4.1.

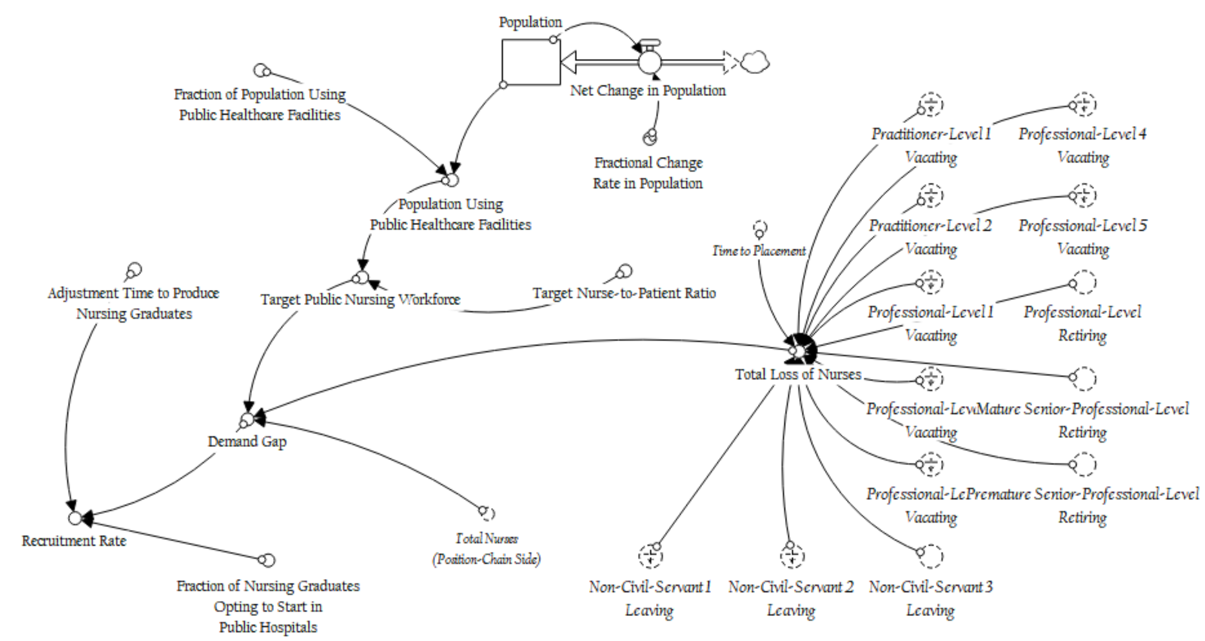


Figure 21 Healthcare Service and Nursing Workforce Demands

4.5 Feedback Analysis

This section explains a general description of the main feedback mechanisms of the model. Richardson & Pugh (1981, p. 4) defined a feedback loop as "a closed sequence of causes and effects, that is, a closed path of action and information". All dynamics arise from the interactions of two types of feedback loops: reinforcing loops (R) that amplify whatever is happening in the system and balancing loops (B) that counteract or oppose changes.

Causal loop diagrams (CLDs) are an important tool for representing the feedback structure of systems (Coyle, 2000). Causal relationships support the clarification of the actual structure of the examined problem, as the clear picture of the problem's structure improves understanding of the observed phenomena (Senge & Forrester, 1980). Thus, this section will present a causal loop diagram representing a simplification of the full model (see Appendix I: Full Stock and Flow Diagram). It is important to note that this CLD might not include all the feedback loops existing in the full model. However, the major feedback loops believed to be responsible for the dynamics hypothesis are captured and explained.

This section will explain each of feedback loops appearing in the aggregate CLD (Figure 22) separately and the next section will explain how the feedbacks may interact with each other to generate the dynamic behavior of the reference problem described in Chapter 1.

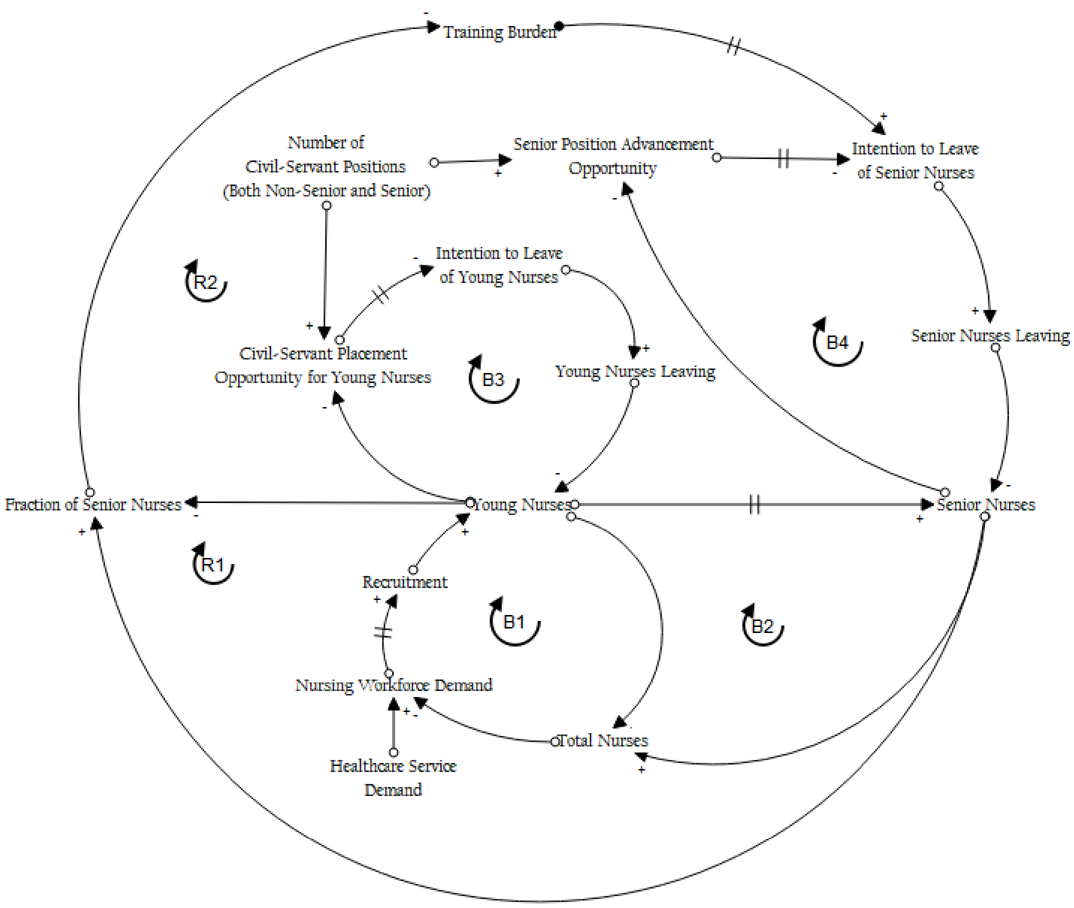


Figure 22 Aggregate CLD

4.5.1 Balancing Loops

a) Loop B1

This loop represents the goal seeking behavior of nurse production and recruitment processes of the Ministry of Public Health. As young nurses are part of the total nursing workforce in facilities under PSO, when there are more (fewer) of these young nurses, the total number of nurses increases (decreases), given all else constant. The total number of the currently available nurses is then compared with healthcare service demand to determine desired recruitment rate. The bigger (smaller) the total number of nurses is, the lower (higher) the recruitment rate of new nurses will be, given all else constant. The recruitment rate affects the number of young nurses in the same direction. The lower (higher) the recruitment rate is, the smaller (bigger) the number of young nurses will be, given all else constant. This loop is a balancing loop because, for example, if it starts with a bigger number of young nurses, its effect will go around the loop and makes the number smaller in the end, given all else constant.

b) **Loop B2**

This loop also represents the goal seeking behavior of nurse production and recruitment processes of the Ministry of Public Health. As senior nurses are part of the total nursing workforce in facilities under PSO, when there are more (fewer) of these young nurses, the total number of nurses increases (decreases), given all else constant. The total number of the currently available nurses is then compared with healthcare service demand to determine desired recruitment rate. The bigger (smaller) the total number of nurses is, the lower (higher) the recruitment rate of new nurses will be, given all else constant. The recruitment rate affects the number of young nurses in the same direction. The lower (higher) the recruitment rate is, the smaller (bigger) the number of young nurses will be, given all else constant. After some time, the young nurses become senior nurses, increasing the number of senior nurses, given all else constant. Therefore, if there are fewer (more) young nurses, there will be fewer (more) senior nurses. This loop is a balancing loop because, for example, if it starts with a bigger number of senior nurses, its effect will go around the loop and makes the number smaller in the end, given all else constant.

c) **Loop B3**

This loop represents the effect of limited civil-servant positions on the intention to leave of young nurses. Number of young nurses compared with limited non-senior civil-servant positions determines civil-servant placement opportunity. The bigger (smaller) the number of young nurses is, the lower (higher) the chance of all young nurses getting placed in civil-servant positions will be, given all else constant. The civil-servant placement opportunity affects the intention to leave of young nurses in the same direction. The lower (higher) the opportunity is, the higher (lower) the intention of leave will be, given all else constant. The higher (lower) intention of leave implies a higher (lower) leaving rate of young nurses. When the leaving rate is high (low), the number of young nurses decreases (increases), given all else constant. This loop is a balancing loop because, for example, if it starts with a bigger number of young nurses, its effect will go around the loop and make the number smaller in the end, given all else constant.

d) **Loop B4**

This loop represents the effect of limited civil-servant positions on the intention to leave of senior nurses. Number of senior nurses compared with limited senior civil-servant positions determines civil-servant career advancement opportunity. The bigger (smaller) the number of senior nurses is, the lower (higher) the chance of all senior nurses getting promoted to senior civil-servant positions will be, given all else constant. The civil-servant career advancement opportunity affects the intention of leave of senior nurses in the same direction. The lower (higher) the opportunity is, the higher (lower) the intention of leave will be, given all else constant. The higher (lower) intention of leave implies a higher (lower) leaving rate of senior nurses. When the leaving rate is high (low), the number of senior nurses decreases (increases), given all else constant. This loop is a balancing loop because, for example, if it starts with a bigger number of senior nurses, its effect will go around the loop and make the number smaller in the end, given all else constant.

4.5.2 Reinforcing Loops

a) **Loop R1**

This loop represents the effect of the fraction of senior nurses to young nurses on the intention to leave of senior nurses. The fraction simply divides the number of senior nurses by the number of young nurses. Subsequently, the bigger (smaller) the number of senior nurses is, the higher (lower) the fraction will be, given all else constant. The fraction implies the amount of training burden to senior nurses in an adverse way. The higher (lower) the fraction is, the less (more) the training burden will be, given all else constant. The amount of training burden affects the intention to leave of senior nurses in the same direction. The decrease (increase) in training burden will decrease (increase) the intention to leave and, thus, lower the leaving rate of senior nurses, given all else constant. Finally, when the leaving rate is low (high), the number of senior nurses increases (decreases), given all else constant. This loop is a reinforcing loop because, for example, if it starts with a bigger number of senior nurses, its effect will go around the loop and make the number bigger in the end, given all else constant.

b) **Loop R2**

This loop also represents the effect of fraction of senior nurses to young nurses on the intention to leave of senior nurses but by a different mechanism. The higher (lower) the number of senior nurses is, the higher the total number of nurses will be, given all else constant. The total number of nurses indicates the recruitment rate of new nurses. The higher (lower) the total number of nurses is, the lower (higher) the recruitment rate will be, given all else constant. The recruitment rate affects the number of young nurses in the same direction. The decrease (increase) in recruitment rate will decrease (increase) the number of young nurses, given all else constant. Subsequently, the smaller (bigger) the number of young nurses is, the higher (lower) the fraction of senior nurses to young nurses will be, given all else constant. The same mechanism explained in the previous loop, then, kicks in. The fraction implies the amount of training burden to senior nurses in an adverse way. The higher (lower) the fraction is, the less (more) the training burden will be, given all else constant. The amount of training burden affects the intention to leave of senior nurses in the same direction. The decrease (increase) in training burden will decrease (increase) the intention to leave and, thus, lower the leaving rate of senior nurses, given all else constant. Finally, when the leaving rate is low (high), the number of senior nurses increases (decreases), given all else constant. This loop is a reinforcing loop because, for example, if it starts with a bigger number of senior nurses, its effect will go around the loop and make the number bigger in the end, given all else constant.

4.6 The Hypothesis

The main hypothesis of this study is that the proposed model structure, described in the previous section, can explain the dynamics of Thailand's nursing workforce age structure seen in section 1.3 of Chapter 1. In particular, the dynamics concerns the unfavorable development of the distribution shape. The transition from the right-skewed normal to the uneven distribution can imply fluctuation in the number of nurses in each age class over time. In other words, without such fluctuation, the distribution should have been maintained in the same shape over time.

The instability in the number of nurses in each age class might be explained by its unstable inflows and outflows, the result of the interaction of the feedback loops described in the previous section. The only inflow to the workforce – namely the recruitment rate, depends on the total number of nurses (as seen in loop B1 and B2). However, the entire workforce comprises of young and senior nurses, which are driven by the recruitment rate and their leaving rates (as seen in loop B3 and B4). The fluctuation may occur due to the competing goals of the balancing feedback loops with the presence of time delays (Sterman, 2000, p. 663). The trigger that activates the counteraction between the loops was hypothesized to be the inadequacy of civil-servant positions which started to be observed since 2005. It is more complicated when some elements of the balancing loops are also parts of the reinforcing feedback loops (as seen in loop R1 and R2), resulting in more intensified competition between the balancing loops.

The hypothesis was tested in the form of behavior analysis and model validation, presented in Chapter 5 and 6, respectively.

Chapter 5: Behavior Analysis

5.1 Model Calibration

Model calibration is the process of estimating the model parameters to obtain a match between observed and simulated behavior. The process may be implemented either 'by hand' or by automation (Lyneis & Pugh , 1996). Statistically based approaches have been adopted from other fields to make the parameter estimation process more rigorous. However, Senge (1977) concluded that econometric approaches might not be useful because SD models have a tendency to violate the ordinary least squares estimation assumptions.

In this study, the model calibration was performed by hand with an emphasis on pattern replication (e.g. periods, frequencies, trends, phase lags, amplitudes), rather than point (event) replication (statistical measures) due to two reasons.

The first reason is that the reference data needed for calibrating statistically (the age structure of nursing over time) were very limited. In fact, even if there were enough data to calibrate the model, statistical replication would not necessarily be the best method for behavior test (Barlas, 1996). This issue is discussed in more detail in Chapter 6.

Second, as introduced in chapter 1, the aim of this model is to help one understand the dynamics of the nursing workforce age structure and propose policies to change the shape of the distribution. The author believes that the precision of reproducing exact data points of the model is not crucially needed to serve the purposes.

The result of the model calibration process was the list of parameter values used in the baseline run. This list is presented in Appendix II: List of Equations and Baseline Parameters.

5.2 Analysis of Baseline Simulation Result

This section presents some of the baseline simulation result and its analysis. Although the main reference mode of the study is the dynamics of the shape of the nursing workforce age structure (Figure 23 and Figure 24), it could be very difficult to analyze because the structure consists of multiple age classes (stocks). As pointed in section 4.6 of Chapter 4, the transition of the age structure implies the fluctuating number of nurses in each age class. Therefore, analyzing the behavior of such fluctuation should help in understanding the age structure dynamics. At this stage, the anaylsis will cover only the historical period (2005-2017).

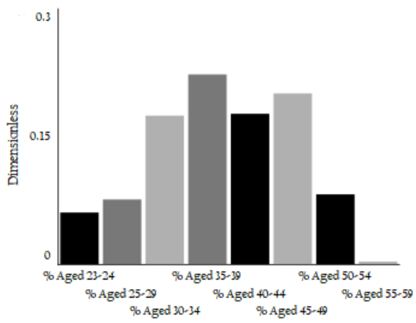


Figure 23 Simulated Behavior of Nursing Workforce Age Structure at t=2010

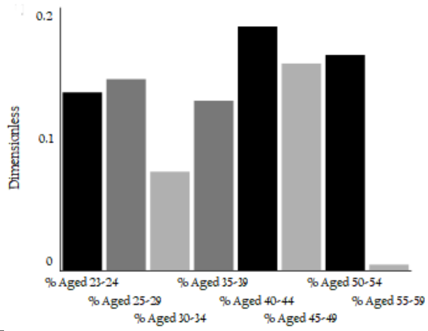


Figure 24 Simulated Behavior of Nursing Workforce Age Structure at t=2017

This analysis focuses on the nurses aged 23-24 years old since, according to literature, their intention to leave can be most sensitive amongst all age classes. In addition, one can expect the behavior of the subsequent age classes to fluctuate if the first age class fluctuates because they should exhibit the same behavior as the first age class but only with time lags, given that there are no drastic changes in between. The analysis covers a period of 12 years, from 2005 to 2017.

Figure 25 shows the simulated behavior of *'Aged 23-24'* stock, representing the number of nurses aged 23-24 years each year. The reader can observe a general uptrend with fluctuation in the development. The development of this stock can be fundamentally explained by its inflow - namely *'Recruitment'* flow, and total outflow (

Figure 26). From 2005, the stock is increasing decreasingly because the inflow remains bigger than the total outflow. Around 2007, the total outflow overtakes and remains higher than the inflow until 2010, resulting in a decrease in the number of nurses during the period. The inflow increases drastically in 2010 and remains constant ever since. This results in the stock increasing due to the total outflow being smaller than the inflow. However, the total outflow gradually climbs up and reaches the inflow again around 2012, resulting in the stagnation of the stock until just before 2014 when the total outflow suddenly drops. The total outflow gradually increases, yet staying beneath the inflow, until 2017, causing the stock to increase over the 4 years period.

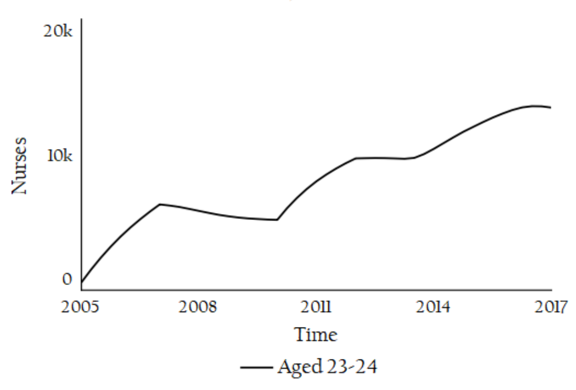


Figure 25 Simulated Behavior of 'Aged 23-24' Stock (Baseline)

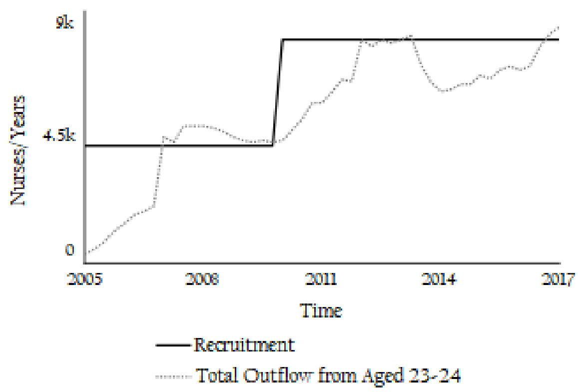


Figure 26 Simulated Behavior of 'Aged 23-24' Stock's Inflow and Total Outflow(Baseline)

Consider the dynamics of the flows. While the inflow consists of only the recruitment, the total outflow is the sum of *'Leaving 1'* and *'Aging 1'* flows.

Figure 27 exhibits the development of the two-component outflows. While 'Aging 1' flow is subject to a constant delay time and *'Aged 23-24'* stock, *'Leaving 1'* flow depends on also the stock and *'Fractional Leaving Rate 1'* variable (

Figure 28). From 2005 to 2007, the variable increases decreasingly, resulting in an increase in *'Leaving 1'* flow during the period. The fractional leaving rate continues to rise until around 2010; however, the leaving flow remains constant in this course of 3 years due to the decrease in the stock. The leaving flow, however, starts to increase again after 2010 as the number of nurses in the stock increases, despite the fractional leaving staying unchanged. The outflow increases until 2013 when the fractional leaving rate dramatically drops. The variable continues to dive, resulting in a drastic decrease in the leaving flow until around 2016.

Figure 27 Simulated Behavior of 'Leaving 1' and 'Aging 1' flows (Baseline)

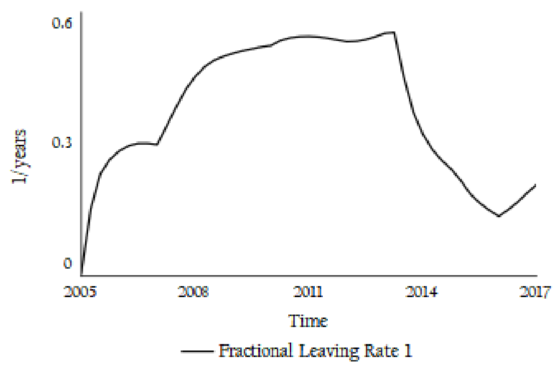


Figure 28 Simulated Behavior of 'Fractional Leaving Rate 1' variable (Baseline)

Consider the dynamics of the fractional leaving rate. The variable is the product of *'Effect of Perception of Non-Civil-Servant 1 towards Civil-Servant Placement Opportunity on Leaving Rate'* variable and *'Reference Fractional Non-Civil Servant 1 Leaving Rate'*, which is a constant. Therefore, the reader can expect similar behavior from the multiplier variable (Figure 29).

'Effect of Perception of Non-Civil-Servant 1 towards Civil-Servant Placement Opportunity on Leaving Rate' variable, in turn, is derived from *'Perception of Non-Civil-Servant 1 towards Civil-Servant Placement Opportunity on Leaving Rate'* variable (Figure 30) by using a non-linear relationship. The resulting variable increases from 2005 to 2013 as the causing variable slowly increases during 2005-2012 and suddenly soars in 2013. The latter, however, dramatically drops in the following year and continues to decrease, causing the former to also plummet until 2016.

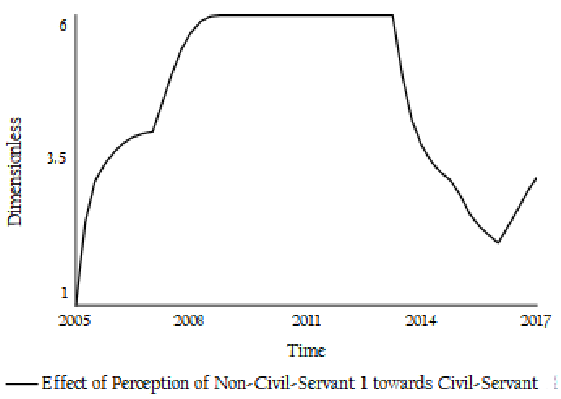


Figure 29 Simulated Behavior of 'Effect of Perception of Non-Civil-Servant 1 towards Civil-Servant Placement Opportunity on Leaving Rate' variable (Baseline)

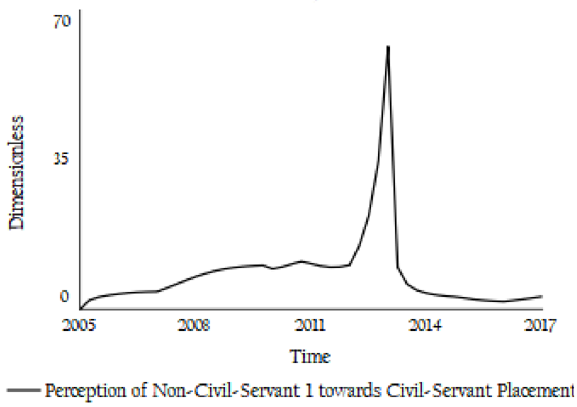


Figure 30 Simulated Behavior of 'Perception of Non-Civil-Servant 1 towards Civil-Servant Placement Opportunity' variable (Baseline)

Consider the dynamics of *'Perception of Non-Civil-Servant 1 towards Civil-Servant Placement Opportunity on Leaving Rate'* variable. The variable is derived from dividing 'Non-Civil-Servant 1' stock by *'Open Non-Senior Positions After 2nd Allocation'* variable. The development of the stock and the variable is shown in Figure 31. During 2005-2011, the perception variable gradually increases because the gap between the numerator and the denominator has become wider. The gap becomes widest around 2013, resulting in the spike of the perception variable at the time. It, however, gradually starts to narrow down in the following year, causing the resulting variable to decrease until 2016.

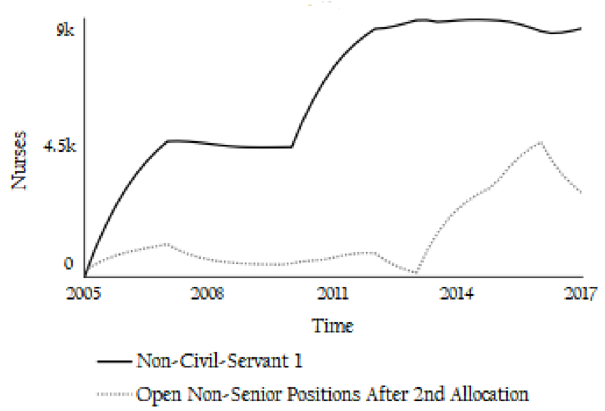


Figure 31 Simulated Behavior of 'Effect of Perception of Non-Civil-Servant 1 towards Civil-Servant Placement Opportunity on Leaving Rate' variable (Baseline)

In summary, the gap between the number of new-entry nurses and the allocated positions implies the inadequacy of civil-servant positions since 2005. Although new positions are added during 2013-2016, there have been a lot of nurses remaining non-civil-servant. The size of the gap influences the leaving rate of nurses in the age class. In general, when the gap is wide, the leaving rate becomes higher, resulting in a decrease in the stock. On the other hand, when the gap becomes narrow, the leaving rate decreases, causing the stock to increase. The dynamics of the leaving rate together with the recruitment of new nurses, in turn, affects the gap size through the changing stock. This mechanism corresponds to Loop B1 and Loop B3 explained in the previous chapter.

Chapter 6: Model Validation

6.1 Overview of Model Validation

One common purpose of SD studies is to initiate strategic changes for solving complex social problems. This can never be achieved if the decision makers do not have confidence in the models. Model validation is, thus, a process of establishing confidence in the models (Senge & Forrester, 1980).

From the objective point of view, since models are basically simplified representations of real-world systems, all models are inherently wrong (Sterman, 2000). However, Barlas and Carpenter (1990) pointed out that the validity of a model cannot be entirely formal or objective. Instead, it should be seen as usefulness with respect to some purpose (Barlas, 1996).

From the purpose-oriented perspective, the validation of an SD model can be a very complicated process as it needs many relevant audiences each of which may have different interests in the model (Senge & Forrester, 1980). For instance, while a scientist may consider a model useful if it can accurately reproduce the past behavior and generate a trustful prediction, a policy-maker may seek for a model that could causally explain why a phenomenon is developing in a certain way and could provide the basis for policy design. As a consequence, a number of confidence building tests need to be carried out to serve all the relevant purposes.

As there is no single test that can solely reach full confidence in SD models, Barlas (1996) proposed a logical sequence as a guideline for carrying out model validity tests in three stages: direct structural tests, structure-oriented tests, and behavior pattern tests. The current study follows this guideline and the procedure for each test is explained further together with its result in the following sections.

6.2 Direct Structure Tests

Direct structure tests aim at assessing the validity of the model by directly comparing the model structure, i.e. stock and flow diagram, with the real system structure (Barlas, 1996). This category consists of four tests: structure-confirmation test, parameter-confirmation test, direct extreme-condition test, and dimensional consistency test.

6.2.1 Structure-confirmation Test

This test compares the equations of the model with the relationships that exist in the real system (Senge & Forrester, 1980). In this study, the conceptual foundation of the model is grounded on the systematic review of the relevant literature during the model-building process (see Chapter 2). To do this, all relationships between variables and their equations were checked against existing research and literature.

The result of this test is shown in Table 3, summarizing the relationships between variables in the model and their supporting and negating literature. In addition, all model equations are explained extensively in Appendix II: List of Equations and Baseline Parameters. According to the result, it can be concluded that the model structure is consistent with the real-world system.

Structure Part/Relationship	Description	Supporting Literature	Negating Literature
Aging Chain of Nursing Workforce (see section 4.4.1a in Chapter 4)	The process by which nurses enter the workforce, age up, leave and retire from the workforce	Common knowledge / Obvious or factual relationships	Not applicable since the part concerns obvious/factual mechanisms or relationships
Civil-Servant Position Chain And (see section 4.4.1b in Chapter 4)	The process by which nurses gain experience, ladder up the position chain and, leave the workforce	See section 2.2 in Chapter 2 for supporting literature	Not applicable since the part concerns obvious/factual mechanisms or relationships
Civil-Servant Position Placement and Promotion (see section 4.4.2 in Chapter 4)	The process describing how civil-servant positions are allocated to non-civil-servant nurses, how senior nurses get promoted under a limited number of senior-level positions, and how nurses leave the workforce	See section 2.2 in Chapter 2 for supporting literature	Not applicable since the part concerns obvious/factual mechanisms or relationships
Relationship of Population and Nursing Workforce Demand (see section 4.4.4 in Chapter 4)	The process by which public health system tries to increase number of nurses in its facilities to meet the recommended nurse-to-population ratio.	See section 2.5 in Chapter 2 for supporting literature	The goal-seeking behavior to approach the recommended nurse-to-population ratio by the government increasing nurse production may depend on other factors, e.g. in economic crisis, the production may be downsized (Sawaengdee, 2017; Khunthar, 2014)
Effect of Civil-Servant Career Advancement Opportunity on the Intention to Leave of Non-Civil-Servant Nurses (see section 4.4.3a in Chapter 4)	The process by which the civil-servant career advancement opportunity affects the intention to leave of non-civil-servant nurses	See section 2.3.3 and 2.4 in Chapter 2 for supporting literature	According to the relevant literature review, there were no empirical studies directly negating the relationships
Effect of Training Burden and Senior Career Advancement Opportunity on the Intention to Leave of Professional-Level Nurses	The process by which the training burden and the senior career advancement opportunity affect the intention to leave of professional-level civil-servant nurses	See section 2.3.4 and 2.4 in Chapter 2 for supporting literature	According to the relevant literature review, there were no empirical studies directly negating the relationships

Structure Part/Relationship	Description	Supporting Literature	Negating Literature
(see section 4.4.3b in Chapter 4)			

Table 3 Structure-confirmation Test

6.2.2 Parameter-confirmation Test

The parameter confirmation test examines whether all constant parameters in the model have real-world counterparts and their values are reasonable (Sterman, 2000). The parameters need to be evaluated against the knowledge available in the literature, both conceptually and numerically (Senge & Forrester, 1980).

The conceptual parameter confirmation was performed by identifying the elements available in the literature that correspond to the parameters of the model. The numerical parameter confirmation was conducted by estimating the numerical value of the parameter with enough accuracy and plausible ranges (Barlas, 1996).

The result of the test is present in Appendix II: List of Equations and Baseline Parameters where the reader can find the meaning and best estimate(s) of each parameter in the real-world system. There are some parameters whose values were calibrated due to unavailability of reliable real data. An emphasis is put on these constants in behavior sensitivity test for checking if their numerical uncertainty is significantly impactful to the model behavior.

6.2.3 Direct extreme-condition Test

Direct extreme-condition testing involves evaluating the validity of model equations under extreme conditions, by assessing the plausibility of the resulting values against the knowledge/anticipation of what would happen under a similar condition in real life (Senge & Forrester, 1980). To do this, extreme values were assigned to input variables for each model equation. Subsequently, the value of the output variable was compared to what would logically happen in the real system under the same extreme condition (Barlas, 1996). It is important to note that direct extreme-condition testing does not involve dynamic simulation; it is applied to each equation in isolation.

Table 4 shows a number of critical equations of the model which were included in this test. These equations were selected because they were deemed to be representing complex processes, i.e. containing more than five unique input variables or involving sophisticated conditional operations. The result indicates that the model passes the test as all critical equations are able to produce logical results under extreme condition.

Variable Name	Equation	Upper Extreme Condition	Response to Upper Extreme Condition	Lower Extreme Condition	Response to Lower Extreme Condition
Process: Non-Senior Civil-Servant Position Allocation					
Positions Allocated To Non-Civil-Servant 3	IF("Open_Non-Senior_Positions">"Non-Civil-Servant_3") THEN ("Non-Civil-Servant_3") ELSE (IF("Open_Non-Senior_Positions">0) THEN ("Open_Non-Senior_Positions") ELSE 0)	"Open_Non-Senior_Positions" = 1000000 "Non-Civil-Servant_3" = 1	Expected: 1 Actual: 1	"Open_Non-Senior_Positions" = 0 "Non-Civil-Servant_3" = 1000000	Expected: 0 Actual: 0
Open Non-Senior Positions After 1st Allocation	MAX(0,"Open_Non-Senior_Positions"-"Positions_Allocated_to_Non-Civil-Servant_3")	"Open_Non-Senior_Positions" = 1000000 " Positions Allocated To Non-Civil-Servant 3" = 1	Expected: 999999 Actual: 999999	"Open_Non-Senior_Positions" = 1 " Positions Allocated To Non-Civil-Servant 3" = 1000000	Expected: 0 Actual: 0
Positions Allocated to Non-Civil-Servant 2	IF("Open_Non-Senior_Positions_After_1st_Allocation">"Non-Civil-Servant_2") THEN ("Non-Civil-Servant_2") ELSE (IF("Open_Non-Senior_Positions_After_1st_Allocation">0) THEN ("Open_Non-Senior_Positions_After_1st_Allocation") ELSE 0)	"Open_Non-Senior_Positions_After_1st_Allocation" = 1000000 Non-Civil-Servant_2 = 1	Expected: 1 Actual: 1	"Open_Non-Senior_Positions_After_1st_Allocation" = 0 Non-Civil-Servant_2 = 1000000	Expected: 0 Actual: 0
Open Non-Senior Positions After 2nd Allocation	MAX(0,"Open_Non-Senior_Positions_After_1st_Allocation"-"Positions_Allocated_to_Non-Civil-Servant_2")	"Open_Non-Senior_Positions_After_1st_Allocation" = 1000000 "Positions_Allocated_to_Non-Civil-Servant_2" = 1	Expected: 999999 Actual: 999999	"Open_Non-Senior_Positions_After_1st_Allocation" = 1 "Positions_Allocated_to_Non-Civil-Servant_2" = 1000000	Expected: 0 Actual: 0

Variable Name	Equation	Upper Extreme Condition	Response to Upper Extreme Condition	Lower Extreme Condition	Response to Lower Extreme Condition
Positions Allocated to Non-Civil-Servant 1	IF("Open_Non-Senior_Positions_After_2nd_Allocation">"Non-Civil-Servant_1") THEN ("Non-Civil-Servant_1") ELSE (IF("Open_Non-Senior_Positions_After_2nd_Allocation">0) THEN ("Open_Non-Senior_Positions_After_2nd_Allocation") ELSE 0)	"Open_Non-Senior_Positions_After_2nd_Allocation"=1000000 "Non-Civil-Servant_1"=1	Expected: 1 Actual: 1	"Open_Non-Senior_Positions_After_2nd_Allocation"= 0 "Non-Civil-Servant_1"=1000000	Expected: 0 Actual: 0
Open Non-Senior Positions After 3rd Allocation	MAX(0, "Open_Non-Senior_Positions_After_2nd_Allocation"-"Positions_Allocated_to_Non-Civil-Servant_1")	"Open_Non-Senior_Positions_After_2nd_Allocation" = 1000000 "Positions_Allocated_to_Non-Civil-Servant_1" = 1	Expected: 999999 Actual: 999999	"Open_Non-Senior_Positions_After_2nd_Allocation" = 1 "Positions_Allocated_to_Non-Civil-Servant_1" = 1000000	Expected: 0 Actual: 0
Positions Allocated to New-Entry Nurses	IF("Open_Non-Senior_Positions_After_3rd_Allocation">Recruitment_Rate*Time_to_Placement) THEN (Recruitment_Rate*Time_to_Placement) ELSE (IF("Open_Non-Senior_Positions_After_3rd_Allocation">0) THEN ("Open_Non-Senior_Positions_After_3rd_Allocation") ELSE 0)	"Open_Non-Senior_Positions_After_3rd_Allocation" = 1000000 Recruitment_Rate = 1 Time_to_Placement = 1	Expected: 1 Actual: 1	"Open_Non-Senior_Positions_After_3rd_Allocation" = 0 Recruitment_Rate = 1000000 Time_to_Placement = 1	Expected: 0 Actual: 0
Process: Senior Civil-Servant Position Allocation					
Positions Allocated to Professional-Level 5	IF(Open_Senior_Positions>"Professional-Level_5") THEN ("Professional-Level_5") ELSE (IF(Open_Senior_Positions>0)	"Open_Senior_Positions" = 1000000 "Professional-Level_5" = 1	Expected: 1 Actual: 1	"Open_Senior_Positions" = 0 "Professional-Level_5" = 1000000	Expected: 0 Actual: 0

Variable Name	Equation	Upper Extreme Condition	Response to Upper Extreme Condition	Lower Extreme Condition	Response to Lower Extreme Condition
	THEN (Open_Senior_Positions) ELSE 0)				
Open Senior Positions After 1st Allocation	MAX(0,Open_Senior_Positions-"Positions_Allocated_to_Professional-Level_5")	"Open_Senior_Positions" = 1000000 "Positions_Allocated_to_Professional-Level_5" = 1	Expected: 999999 Actual: 999999	"Open_Senior_Positions" = 0 "Positions_Allocated_to_Professional-Level_5" = 1000000	Expected: 0 Actual: 0
Positions Allocated to Professional-Level 4	IF(Open_Senior_Positions_After_1st_Allocation >"Professional-Level_4") THEN ("Professional-Level_4") ELSE (IF(Open_Senior_Positions_After_1st_Allocation>0) THEN (Open_Senior_Positions_After_1st_Allocation) ELSE 0)	"Open_Senior_Positions_After_1st_Allocation" = 1000000 "Professional-Level_4" = 1	Expected: 1 Actual: 1	"Open_Senior_Positions_After_1st_Allocation" = 0 "Professional-Level_4" = 1000000	Expected: 0 Actual: 0
Process: Intention to Leave					
Fractional Professional-Level 5 Vacating Rate	"Reference_Fractional_Professional-Level_5_Vacating_Rate"*("Effect_of_Perception_of_Professional-Level_5_towards_Career_Advancement_Opportunity_on_Vacating_Rate"*Effect_of_Fraction_of_Aged_Workforce_on_Vacating_Rate)	"Reference_Fractional_Professional-Level_5_Vacating_Rate" = 0.005 "Effect_of_Perception_of_Professional-Level_5_towards_Career_Advancement_Opportunity_on_Vacating_Rate" = 1 "Effect_of_Fraction_of_Aged_Workforce_on_Vacating_Rate" = 1	Expected: 0.005 Actual: 0.005	"Reference_Fractional_Professional-Level_5_Vacating_Rate" = 0.005 "Effect_of_Perception_of_Professional-Level_5_towards_Career_Advancement_Opportunity_on_Vacating_Rate" = 2 "Effect_of_Fraction_of_Aged_Workforce_on_Vacating_Rate" = 2	Expected: 0.02 Actual: 0.02

Variable Name	Equation	Upper Extreme Condition	Response to Upper Extreme Condition	Lower Extreme Condition	Response to Lower Extreme Condition
Fractional Professional-Level 4 Vacating Rate	"Reference_Fractional_Professional-Level_4_Vacating_Rate"*("Effect_of_Perception_of_Professional-Level_4_towards_Career_Advancement_Opportunity_on_Vacating_Rate"*Effect_of_Fraction_of_Aged_Workforce_on_Vacating_Rate)	"Reference_Fractional_Professional-Level_4_Vacating_Rate" = 0.005 "Effect_of_Perception_of_Professional-Level_4_towards_Career_Advancement_Opportunity_on_Vacating_Rate" = 1 "Effect_of_Fraction_of_Aged_Workforce_on_Vacating_Rate" = 1	Expected: 0.005 Actual:0.005	"Reference_Fractional_Professional-Level_4_Vacating_Rate" = 0.005 "Effect_of_Perception_of_Professional-Level_4_towards_Career_Advancement_Opportunity_on_Vacating_Rate" = 10 "Effect_of_Fraction_of_Aged_Workforce_on_Vacating_Rate" = 2	Expected: 0.1 Actual: 0.1

Table 4 Direct Extreme-condition Test

6.2.4 Dimensional Consistency Test

Dimensional consistency test examines if each equation or variable is consistent in terms of units (Sterman, 2000). A system dynamics model has dimension or unit for each of its variables. The dimension for each variable is specified when the model is built. The test checks if the units between the right-hand side and left-hand side of each equation are the same (Barlas, 1996). The dimensional consistency test has been performed automatically by the modeling software employed for this research (Stella Architect 1.8.1), which notifies if the model has dimensionally inconsistent equations.

The model presented in this study is considered dimensionally consistent since the software did not notify any unit error messages.

6.3 Structure-Oriented Behavior Tests

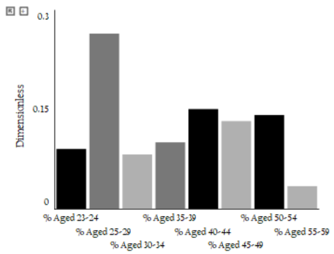
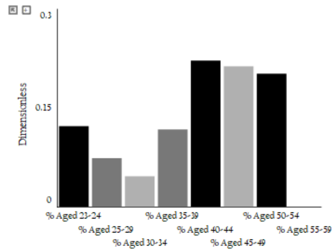
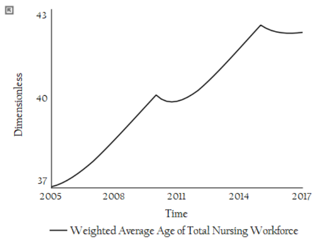
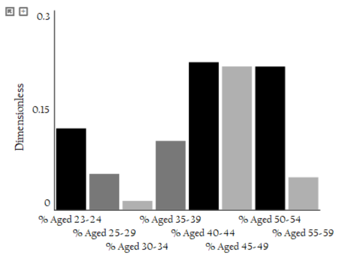
Structure-oriented behavior tests assess the validity of the structure indirectly, by applying certain behavior tests on model-generated behavior patterns (Barlas, 1996). Unlike direct structure tests, simulation is required to perform the tests. However, the simulation will cover only the historical period (2005-2017). This category consists of two tests: extreme-condition test and behavior sensitivity test.

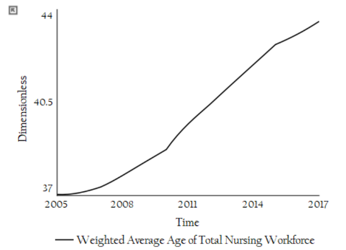
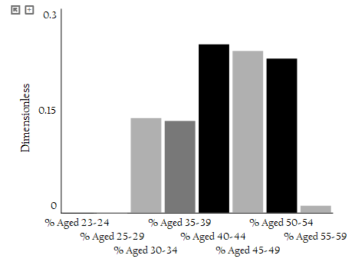
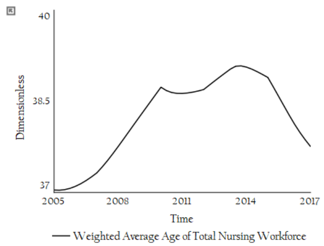
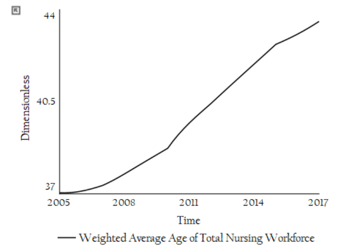
6.3.1 Extreme-Condition Test

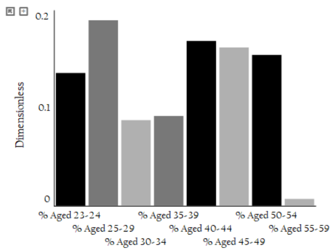
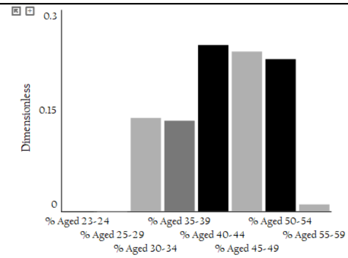
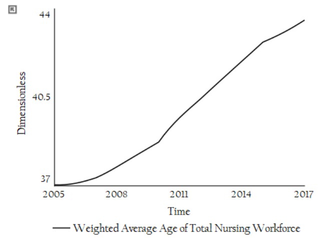
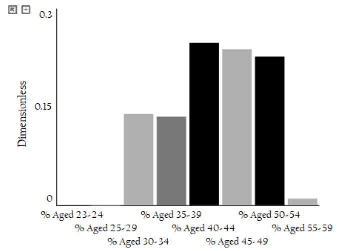
Extreme-condition (indirect) test involves assigning extreme values to selected parameters and comparing the model-generated behavior to the observed or anticipated behavior of the real system under the same "extreme condition" (Barlas, 1996). For this study, nine input parameters were included in the test.

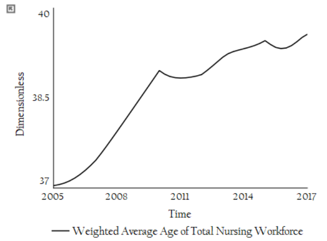
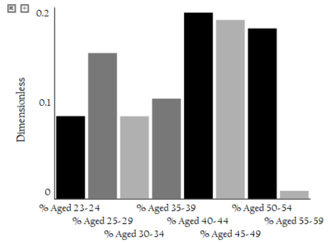
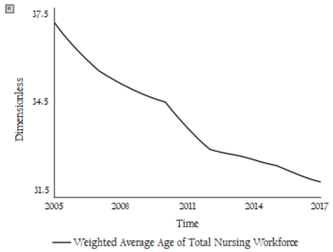
Table 5 presents the result of the test, comparing the model-generated behavior and the observed or anticipated behavior of the real system under each extreme condition of the input variables. The result indicates that the model passes the test since the model-generated behavior is in agreement with the predefined expected behavior in every test scenario.

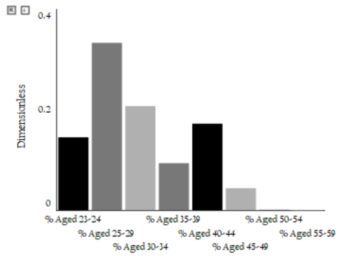
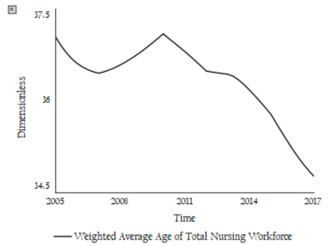
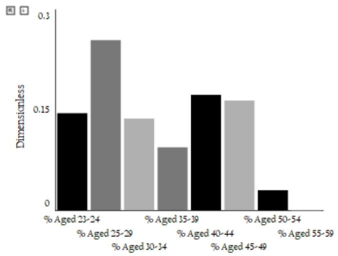
Selected Parameter	Upper Extreme Condition	Anticipated System Behavior in Response to Upper Extreme Condition	Simulated System Behavior in Response to Upper Extreme Condition	Lower Extreme Condition	Anticipated System Behavior in Response to Lower Extreme Condition	Simulated System Behavior in Response to Lower Extreme Condition
Max Civil-Servant Positions	1000000	The average age of the workforce shall generally stay low due to high retainability of young nurses. The age structure shall become more or less evenly distributed.	 (Average age of the workforce)	0	The average age of the workforce should become relatively high due to the high leaving rate of the new nurses. The age structure shall become left-skewed.	 (Average age of the workforce)

Selected Parameter	Upper Extreme Condition	Anticipated System Behavior in Response to Upper Extreme Condition	Simulated System Behavior in Response to Upper Extreme Condition	Lower Extreme Condition	Anticipated System Behavior in Response to Lower Extreme Condition	Simulated System Behavior in Response to Lower Extreme Condition
			 (Age structure at t=2017)			 (Age structure at t=2017)
Fraction of Senior-Professional-Level Positions	1	The age structure shall become left-skewed in long run due to the abundance of available senior civil-servant positions and lack of non-senior positions. The average age of the workforce should become relatively high.	 (Average age of the workforce)  (Age structure at t=2017)	0	There should be no significant difference, compared to the baseline result (at 0.02).	There is no significant difference, compared to the baseline result.

Selected Parameter	Upper Extreme Condition	Anticipated System Behavior in Response to Upper Extreme Condition	Simulated System Behavior in Response to Upper Extreme Condition	Lower Extreme Condition	Anticipated System Behavior in Response to Lower Extreme Condition	Simulated System Behavior in Response to Lower Extreme Condition
Fraction of Population Using Public Healthcare Facilities	1	There should be no significant difference, compared to the baseline result (at 0.8).	There is no significant difference, compared to the baseline result.	0	The age structure shall be left-skewed in long run due to lower recruitment rate. The average age of the workforce should become relatively high.	 (Average age of the workforce)  (Age structure at t=2017)
Target Nurse-to-Patient Ratio	1	The recruitment rate should become enormous. However, the shape of the age structure should not significantly differ from the baseline result due to the limited number of civil-servant positions and its effect on the intention to leave.	 (Average age of the workforce)	1/10000	The recruitment rate should shrink. The average age of the workforce should become relatively high. The age structure shall become left-skewed due to fewer new nurse graduates. The average age of the workforce should become relatively high.	 (Average age of the workforce)

Selected Parameter	Upper Extreme Condition	Anticipated System Behavior in Response to Upper Extreme Condition	Simulated System Behavior in Response to Upper Extreme Condition	Lower Extreme Condition	Anticipated System Behavior in Response to Lower Extreme Condition	Simulated System Behavior in Response to Lower Extreme Condition
			 (Age structure at t=2017)			 (Age structure at t=2017)
Fraction of Nursing Graduates Opting to Start in Public Hospitals	1	There should be no significant difference, compared to the baseline result (at 0.8).	There is no significant difference, compared to the baseline result.	0	The recruitment rate should shrink. The age structure shall become left-skewed in the long run. The average age of the workforce should become relatively high.	 (Average age of the workforce)  (Age structure at t=2017)

Selected Parameter	Upper Extreme Condition	Anticipated System Behavior in Response to Upper Extreme Condition	Simulated System Behavior in Response to Upper Extreme Condition	Lower Extreme Condition	Anticipated System Behavior in Response to Lower Extreme Condition	Simulated System Behavior in Response to Lower Extreme Condition
Fractional Practitioner-Level 1 Vacating Rate	1	The leaving rate of practitioner-level 1 nurses should become high, resulting in a smaller inflow of new nurses to the workforce. The age structure will become left-skewed in the long run. The average age of the workforce should become relatively high.	 (Average age of the workforce)  (Age structure at t=2017)	0	There should be no significant difference, compared to the baseline result (at 0.005).	There is no significant difference, compared to the baseline result.
Reference Fractional Professional-Level 4 Vacating Rate	1	The average age of the workforce should generally decrease due to the relatively high leaving rate of senior nurses. The age structure, thus, shall become right-skewed.	 (Average age of the workforce)	0	There should be no significant difference, compared to the baseline result (at 0.005).	There is no significant difference, compared to the baseline result.

Selected Parameter	Upper Extreme Condition	Anticipated System Behavior in Response to Upper Extreme Condition	Simulated System Behavior in Response to Upper Extreme Condition	Lower Extreme Condition	Anticipated System Behavior in Response to Lower Extreme Condition	Simulated System Behavior in Response to Lower Extreme Condition
			 (Age structure at t=2017)			
Reference Fractional Professional-Level 5 Vacating Rate	1	The average age of the workforce should generally decrease due to the relatively high leaving rate of senior nurses. The age structure, thus, shall become right-skewed.	 (Average age of the workforce)  (Age structure at t=2017)	0	There should be no significant difference, compared to the baseline result (at 0.005).	There is no significant difference, compared to the baseline result.

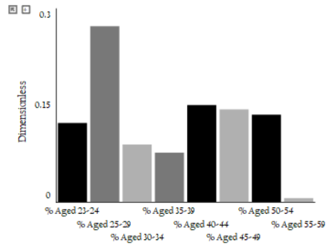
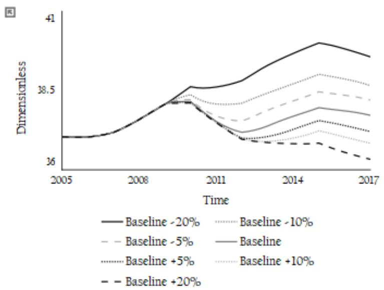
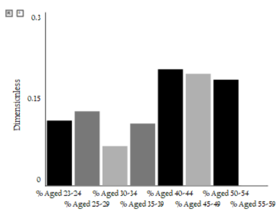
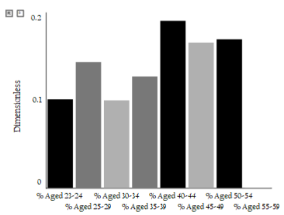
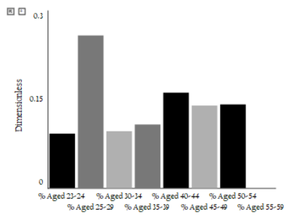
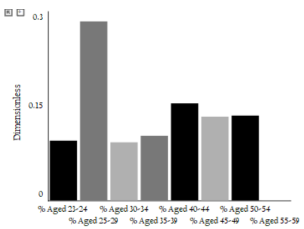
Selected Parameter	Upper Extreme Condition	Anticipated System Behavior in Response to Upper Extreme Condition	Simulated System Behavior in Response to Upper Extreme Condition	Lower Extreme Condition	Anticipated System Behavior in Response to Lower Extreme Condition	Simulated System Behavior in Response to Lower Extreme Condition
Reference Fractional Non-Civil Servant 1 Leaving Rate	1	There should be no significant difference, compared to the baseline result (at 0.1).	There is no significant difference, compared to the baseline result.	0	The average age of the workforce should generally decrease due to the absence of the youngest non-civil-servant nurses. The age structure, however, shall not change significantly because the nurses may leave the later stages.	 (Average age of the workforce)  (Age structure at t=2017)

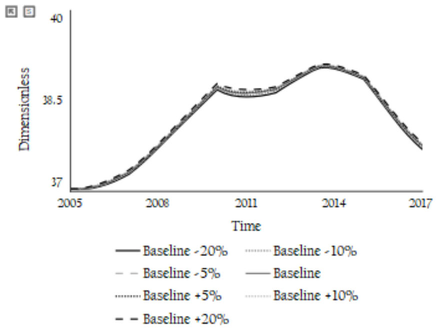
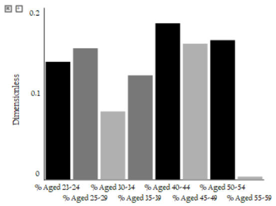
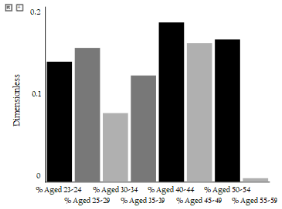
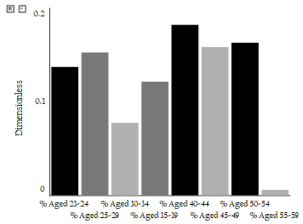
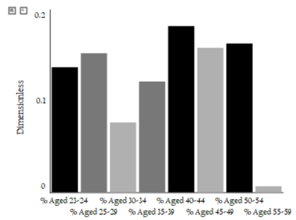
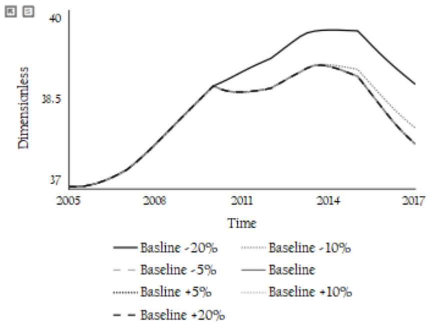
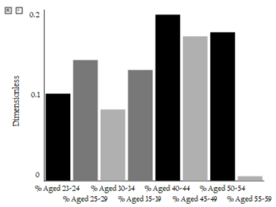
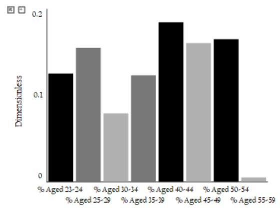
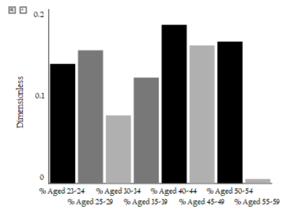
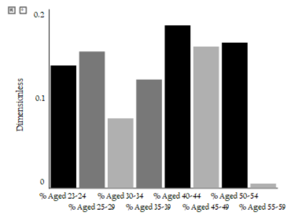
Table 5 Extreme-Condition Test

6.3.2 Behavior Sensitivity Test

Behavior sensitivity test involves identifying those parameters to which the system behavior is highly sensitive (Barlas, 1996). This test could provide a basis for policy formulation as it implicitly asks what factors in the real system are leverage points and should be intervened. For models that require fairly high precision in outputs, this test provides a suggestion as to which parameters might need highly reliable or precise data. To achieve this, each input parameter value was changed within a numerical range from minus to plus 20 per cent of the baseline value. For graphical functions, the non-linear relationships were tested only in different shapes. The change in upper and lower limits of the graphical functions were not included since they were calibrated to imitate the behavior of the reference mode due to limited data of the relevant non-linear relationships. Note that in this test parameters and graphical functions were tested in isolation. The combinations of such changes are discussed in Chapter 7.

The results of behavior sensitivity test on selected parameters, shown in Table 6, indicate that the system is relatively sensitive to *Max Civil-Servant Positions*, *Fraction of Population Using Public Healthcare Facilities*, *Target Nurse-to-Patient Ratio*, *Fraction of Nursing Graduates Opting to Start in Public Hospitals*, and *Reference Fractional Non-Civil Servant 1 Leaving Rate* parameters, compared to the others.

	System Behavior Under Different Parameter Variants				
Parameter	Average Age of the Workforce	Age Structure (at t=2017) Baseline -20%	Age Structure (at t= 2017) Baseline -10%	Age Structure (at t= 2017) Baseline +10%	Age Structure (at t= 2017) Baseline +20%
Max Civil-Servant Positions (Baseline: 93000)					

<table>
<tr><td></td><td colspan="5">System Behavior Under Different Parameter Variants</td></tr>
<tr><td>Parameter</td><td>Average Age of the Workforce</td><td>Age Structure
(at t=2017)
Baseline -20%</td><td>Age Structure
(at t= 2017)
Baseline -10%</td><td>Age Structure
(at t= 2017)
Baseline +10%</td><td>Age Structure
(at t= 2017)
Baseline +20%</td></tr>
<tr><td>Fraction of Senior-Professional-Level Positions
(Baseline: 0.02)</td><td>
</td><td></td><td></td><td></td><td></td></tr>
<tr><td>Fraction of Population Using Public Healthcare Facilities
(Baseline: 0.8)</td><td>
</td><td></td><td></td><td></td><td></td></tr>
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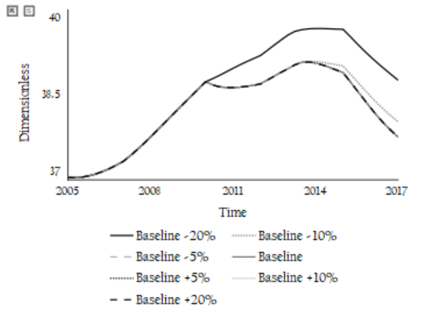
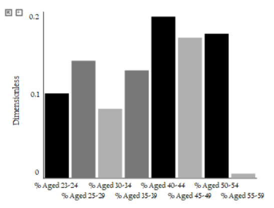
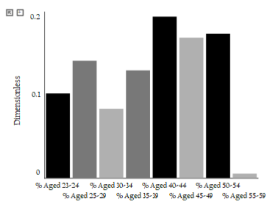
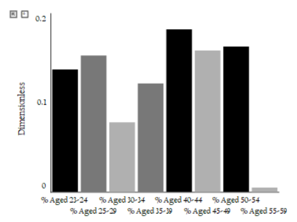
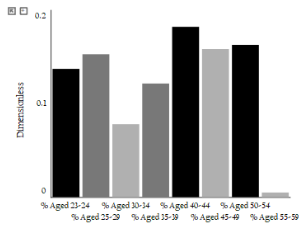
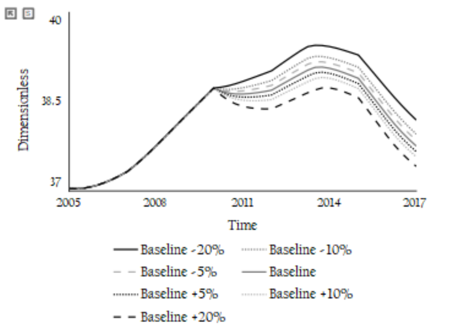
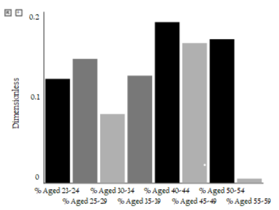
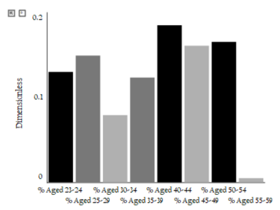
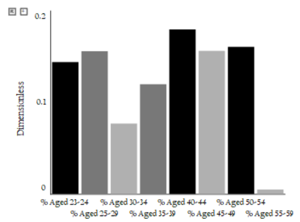
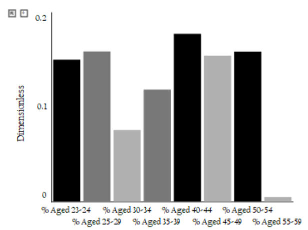
	System Behavior Under Different Parameter Variants				
Parameter	Average Age of the Workforce	Age Structure (at t=2017) Baseline -20%	Age Structure (at t= 2017) Baseline -10%	Age Structure (at t= 2017) Baseline +10%	Age Structure (at t= 2017) Baseline +20%
Target Nurse-to-Patient Ratio (Baseline: 0.0025)					
Fraction of Nursing Graduates Opting to Start in Public Hospitals (Baseline: 0.8)					

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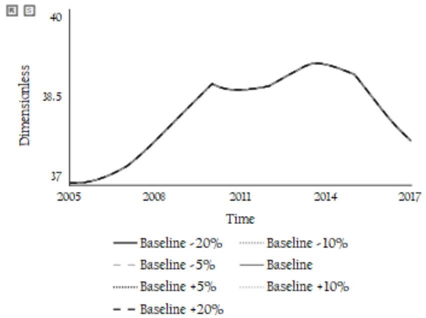
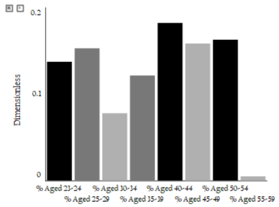
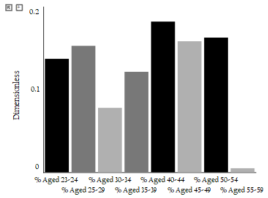
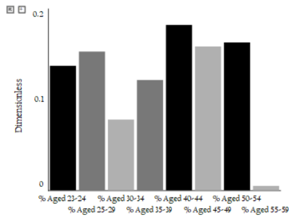
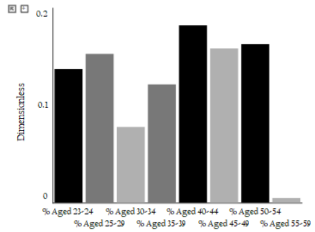
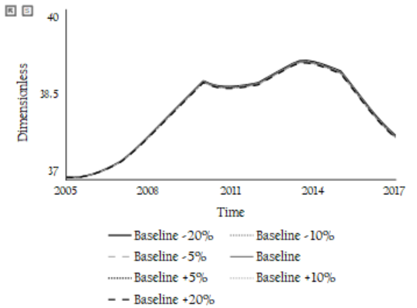
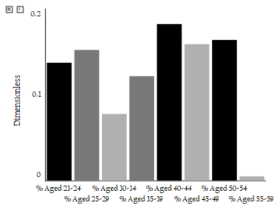
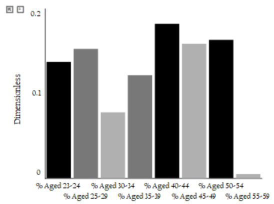
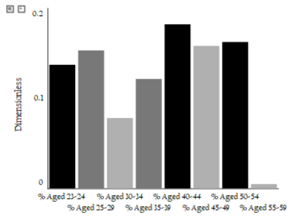
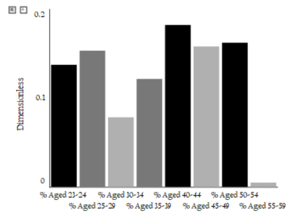
<tr><td>Parameter</td><td>Average Age of the Workforce</td><td>Age Structure
(at t=2017)
Baseline -20%</td><td>Age Structure
(at t= 2017)
Baseline -10%</td><td>Age Structure
(at t= 2017)
Baseline +10%</td><td>Age Structure
(at t= 2017)
Baseline +20%</td></tr>
<tr><td>Fractional Practitioner-Level 1 Vacating Rate
(Baseline: 0.005)</td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Reference Fractional Professional-Level 4 Vacating Rate
(Baseline: 0.005)</td><td></td><td></td><td></td><td></td><td></td></tr>
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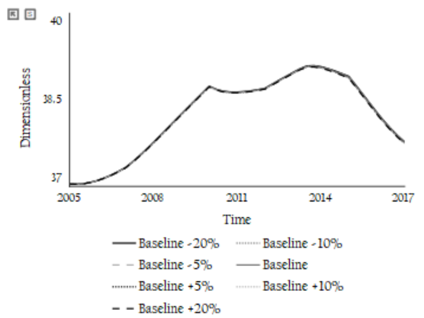
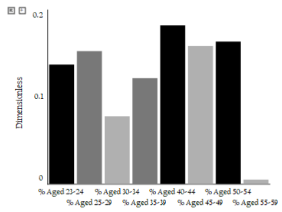
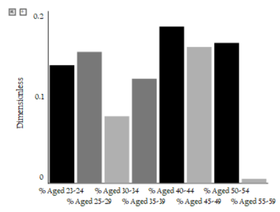
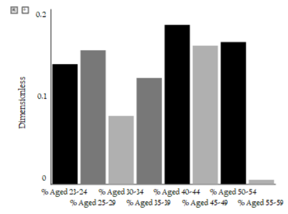
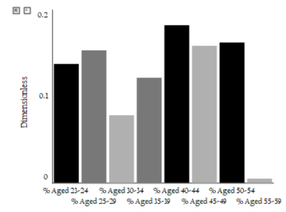
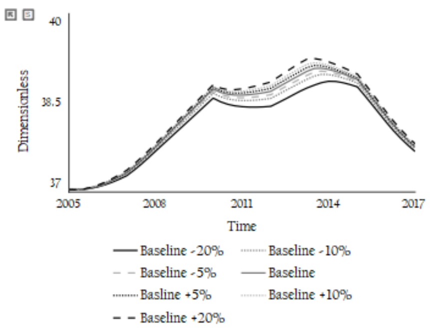
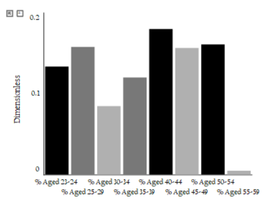
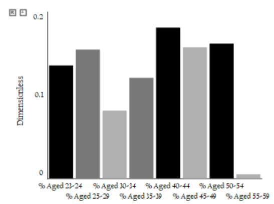
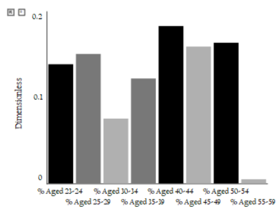
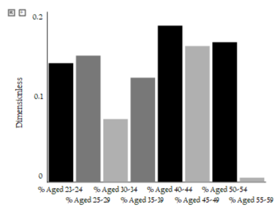
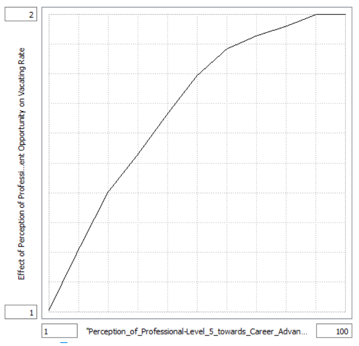
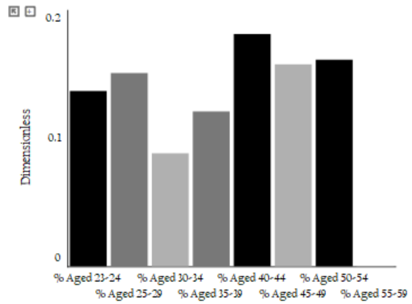
	System Behavior Under Different Parameter Variants				
Parameter	Average Age of the Workforce	Age Structure (at t=2017) Baseline -20%	Age Structure (at t= 2017) Baseline -10%	Age Structure (at t= 2017) Baseline +10%	Age Structure (at t= 2017) Baseline +20%
Reference Fractional Professional-Level 5 Vacating Rate (Baseline: 0.005)					
Reference Fractional Non-Civil Servant 1 Leaving Rate (Baseline: 0.1)					

Table 6 Parameter Behavior Sensitivity Test

The results of behavior sensitivity test on all graphical functions, shown in Table 7, indicate that the system is not significantly sensitive to the change in shape of the graphical functions, compared to the change in parameters. However, during the calibration process, the change in upper and lower bounds of the graphical functions have shown to have significant impacts on the behavior of the system.

		System Behavior Under Different Parameter Variants	
Graphical Function	Graphical Function Shape Variant	Average Age of the Workforce	Age Structure (at t= 2017)
Effect of Perception of Professional-Level 5 towards Career Advancement Opportunity on Vacating Rate	 (Baseline)		

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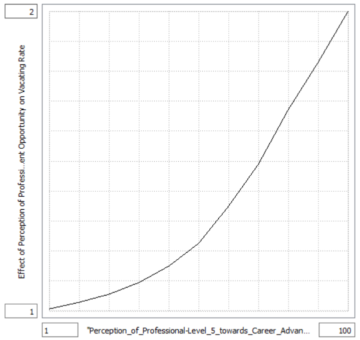
(at t= 2017)</td></tr>
<tr><td rowspan="2"></td><td>
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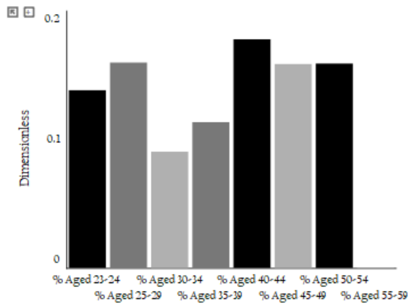
</td><td>
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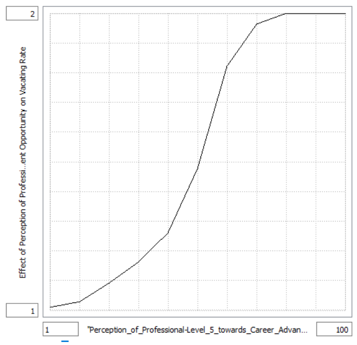
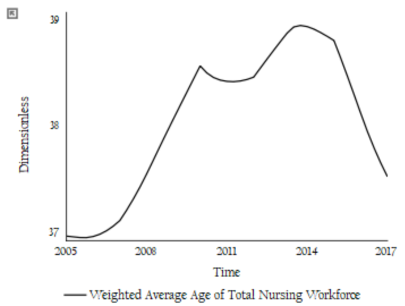
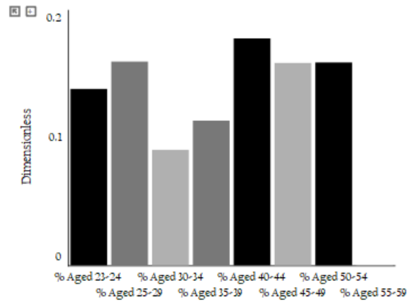
<tr><td>
</td><td>
</td><td>
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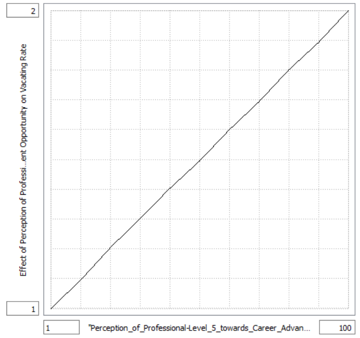
(at t= 2017)</th></tr>
<tr><td></td><td>
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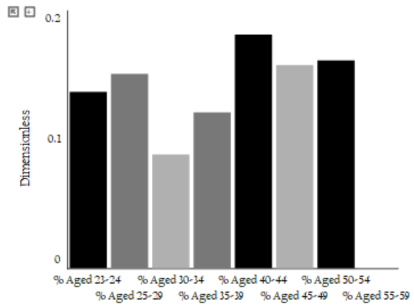
</td><td>
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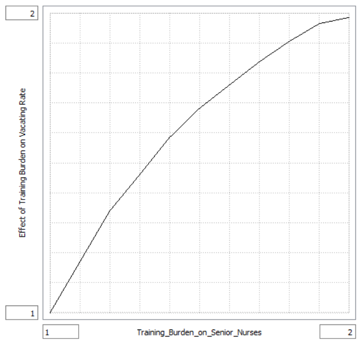
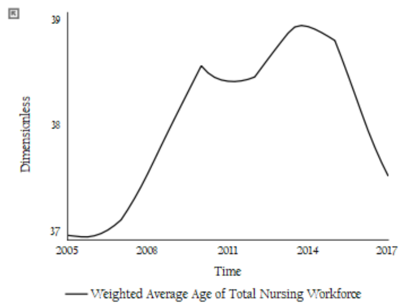
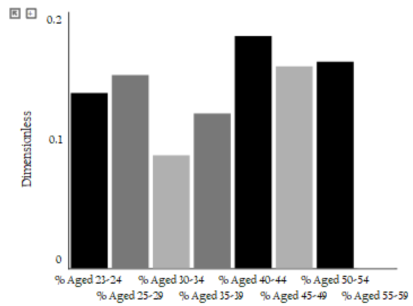
<tr><td>Effect of Training Burden on Vacating Rate</td><td>

(Baseline)</td><td>
</td><td>
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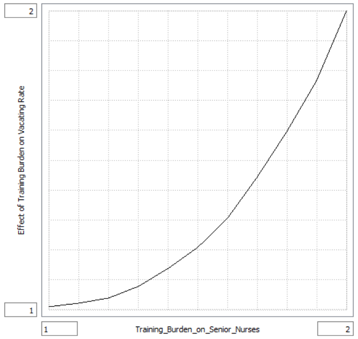
(at t= 2017)</th></tr>
<tr><td rowspan="2"></td><td>
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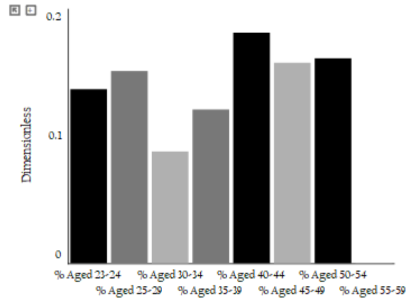
</td><td>
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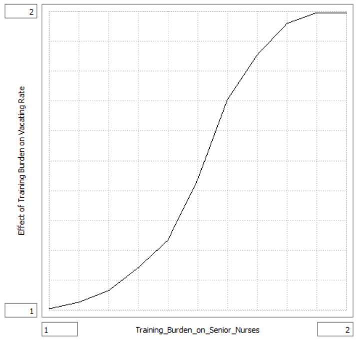
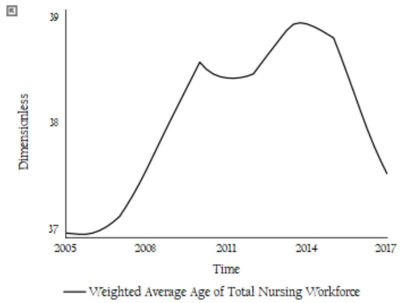
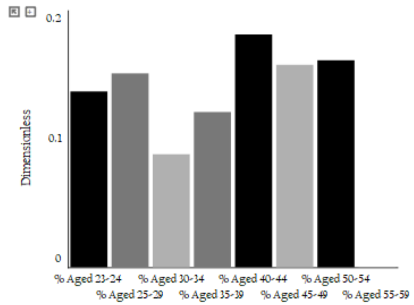
<tr><td>
</td><td>
</td><td>
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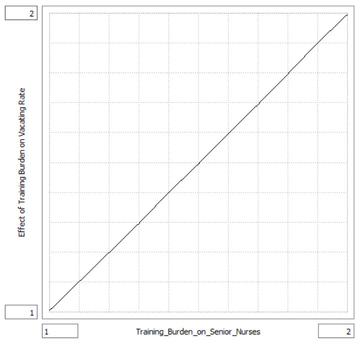
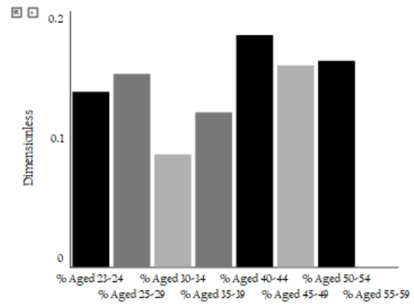
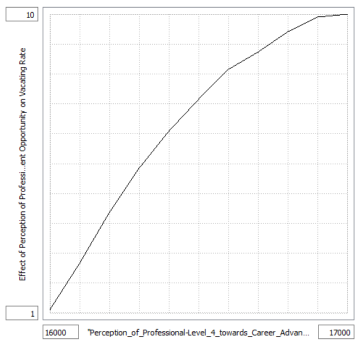
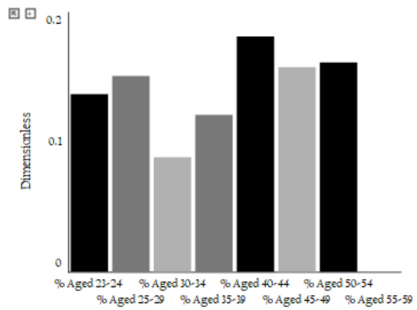
<tr><th>Graphical Function</th><th>Graphical Function Shape Variant</th><th>Average Age of the Workforce</th><th>Age Structure
(at t= 2017)</th></tr>
<tr><td></td><td></td><td></td><td></td></tr>
<tr><td>Effect of Perception of Professional-Level 4 towards Career Advancement Opportunity on Vacating Rate</td><td>
(Baseline)</td><td></td><td></td></tr>
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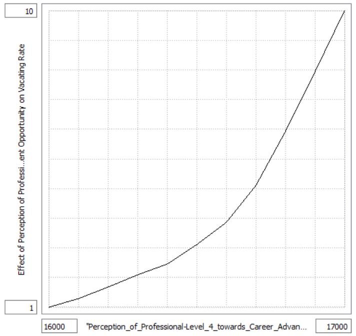
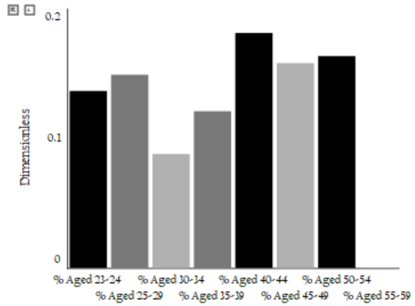
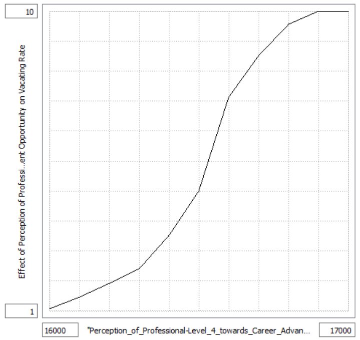
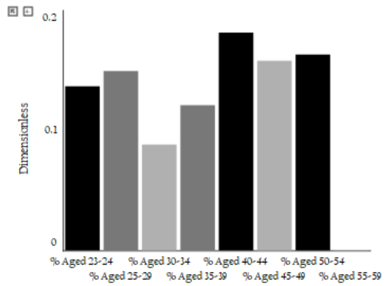
		System Behavior Under Different Parameter Variants	
Graphical Function	Graphical Function Shape Variant	Average Age of the Workforce	Age Structure (at t= 2017)
			
			

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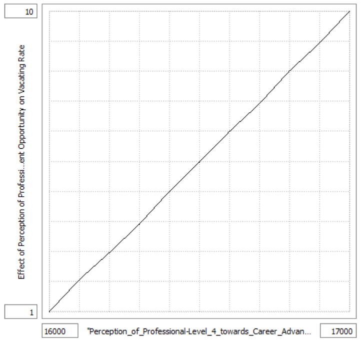

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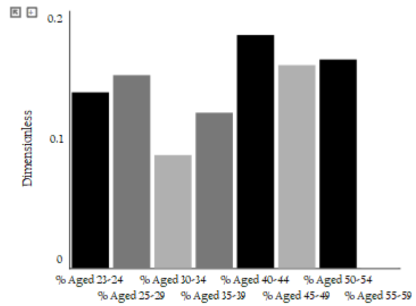

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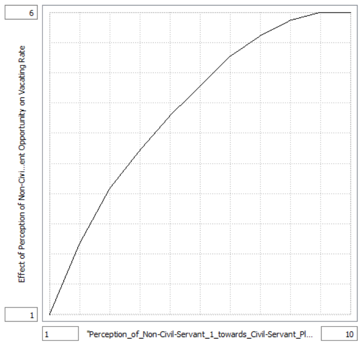
<tr><td>Effect of Perception of Non-Civil-Servant 1 towards Civil-Servant Placement Opportunity on Vacating Rate</td><td>



(Baseline)</td><td>

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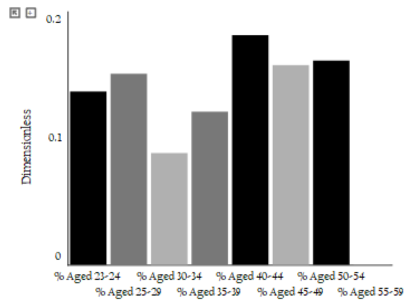

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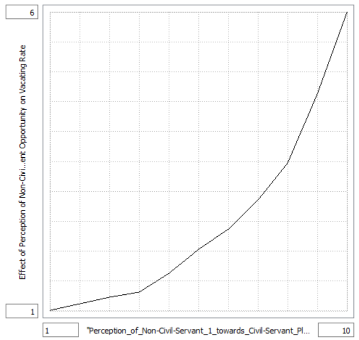
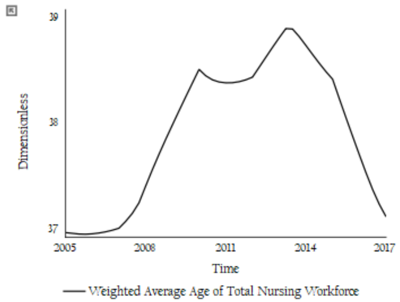
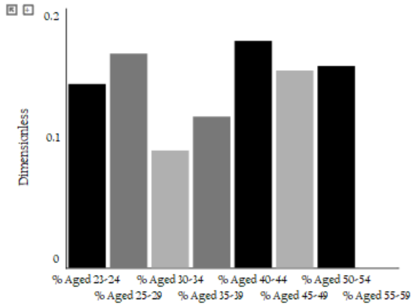
(at t= 2017)</th></tr>
<tr><td rowspan="2"></td><td></td><td>
</td><td>
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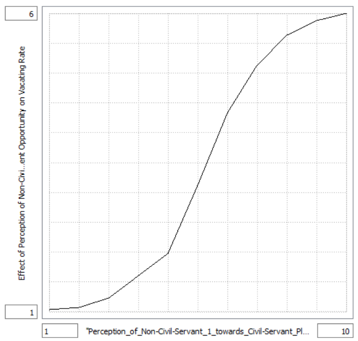
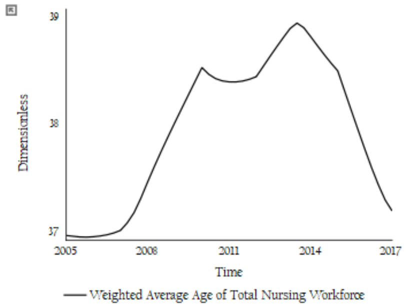
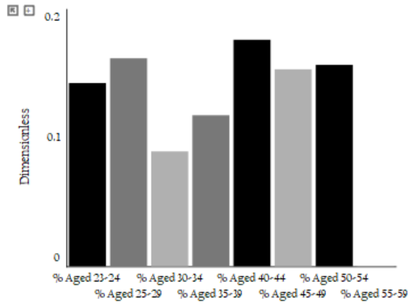
<tr><td></td><td>
</td><td>
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		System Behavior Under Different Parameter Variants	
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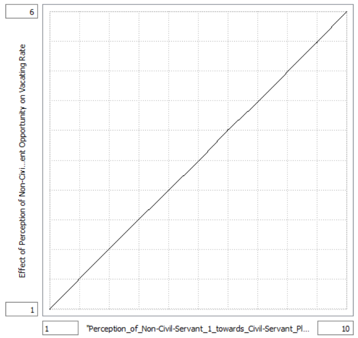
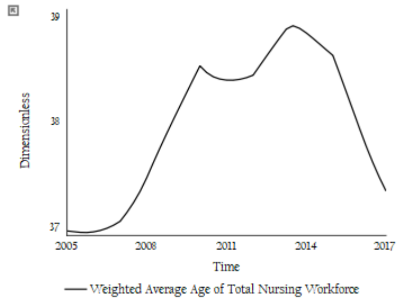
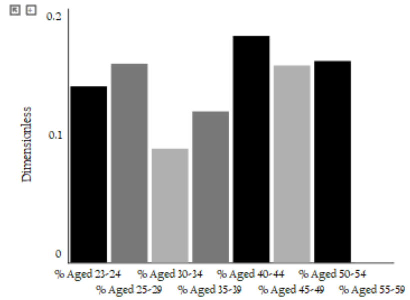
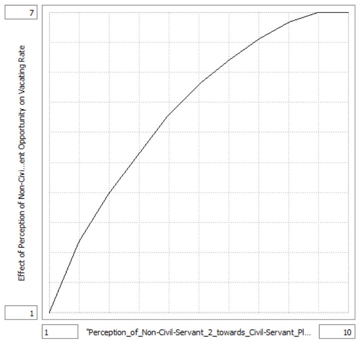
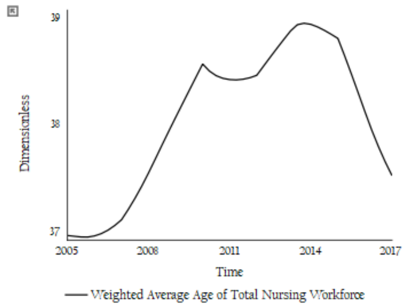
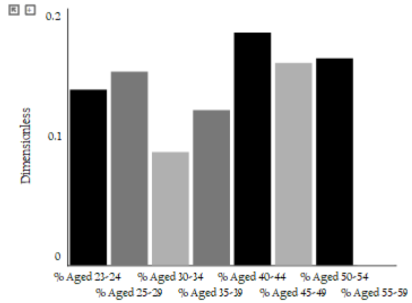
			
Effect of Perception of Non-Civil-Servant 2 towards Civil-Servant Placement Opportunity on Vacating Rate	 (Baseline)		

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	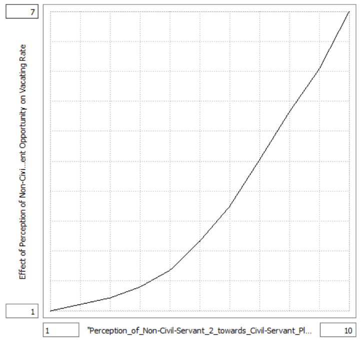	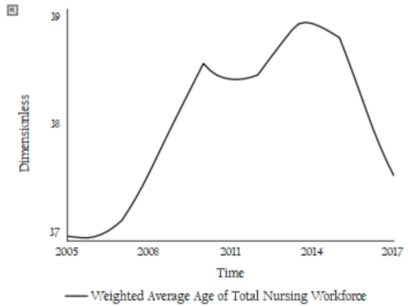	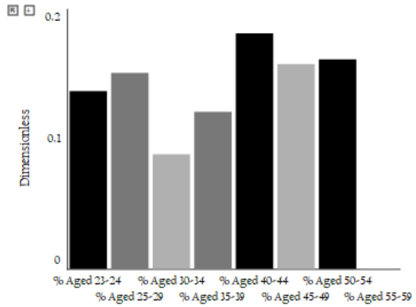
	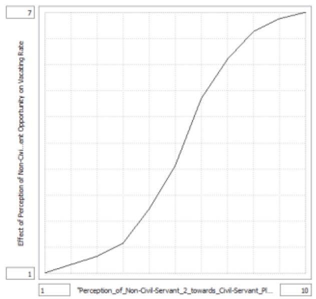	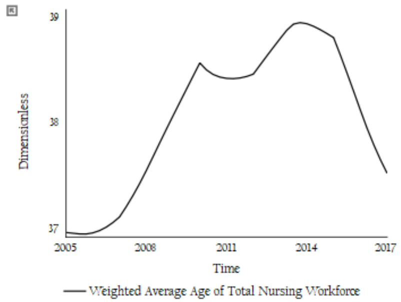	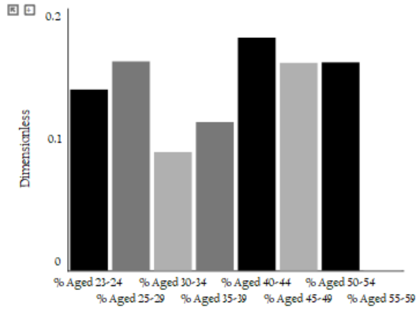

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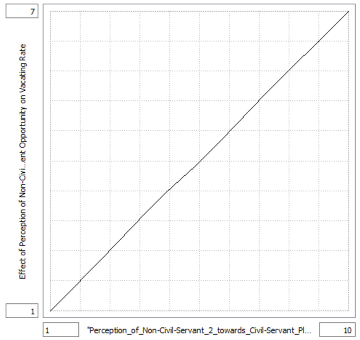
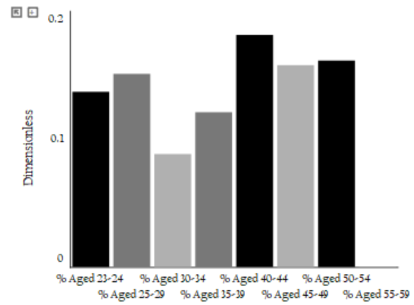
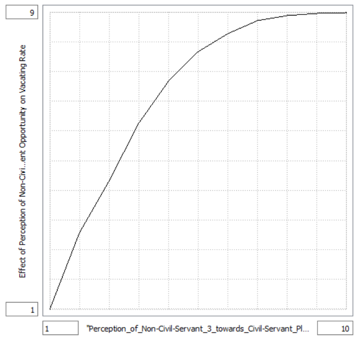
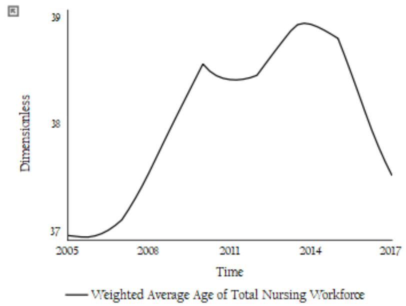
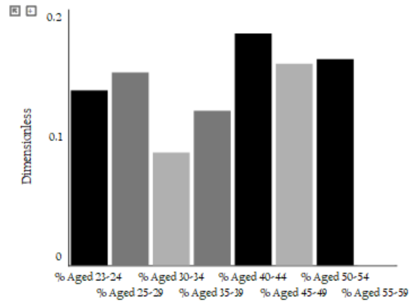
			
Effect of Perception of Non-Civil-Servant 3 towards Civil-Servant Placement Opportunity on Vacating Rate	 (Baseline)		

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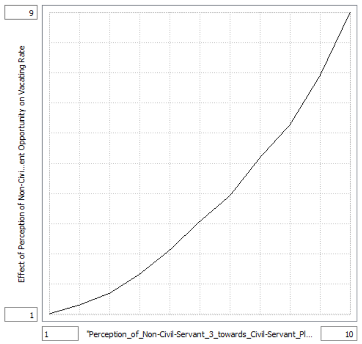
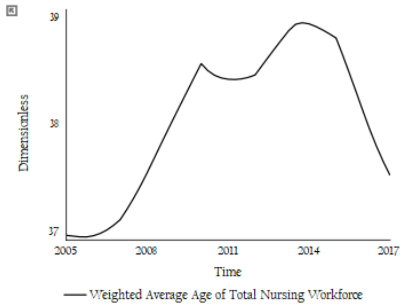
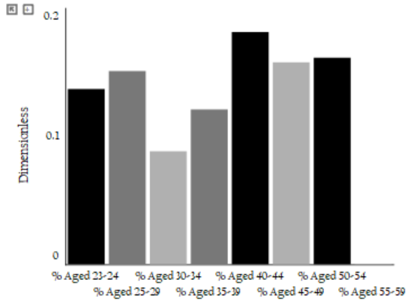
(at t= 2017)</td></tr>
<tr><td rowspan="2"></td><td>
</td><td>
</td><td>
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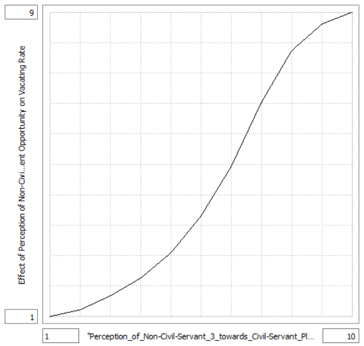
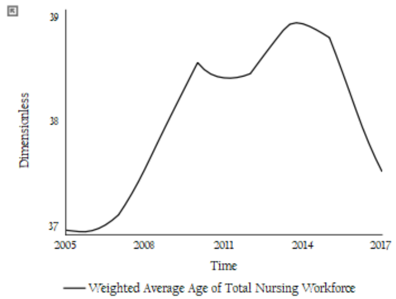
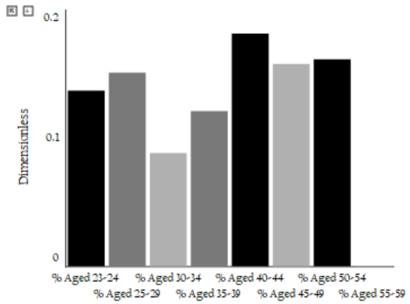
<tr><td>
</td><td>
</td><td>
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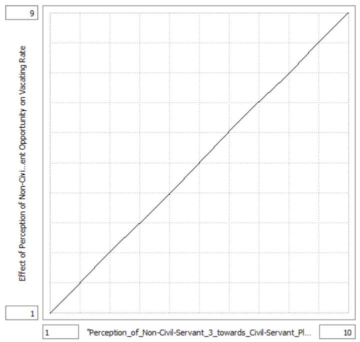
<tr><td></td><td></td><td colspan="2">System Behavior Under Different Parameter Variants</td></tr>
<tr><td>Graphical Function</td><td>Graphical Function Shape Variant</td><td>Average Age of the Workforce</td><td>Age Structure
(at t= 2017)</td></tr>
<tr><td></td><td>
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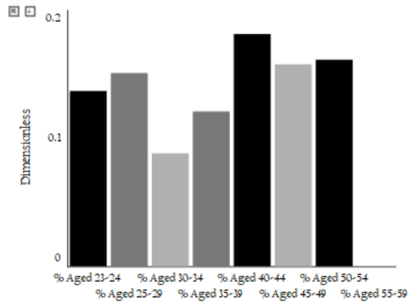
</td><td>
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Table 7 Graphical Function Behavior Sensitivity Test

6.4 Behavior Pattern Tests

As confidence has been built in the validity of the model structure, one can start applying certain tests designed to measure how accurately the model can reproduce the behavior patterns exhibited in the reference mode. Suggested by the name, it is crucial to note that the emphasis is on pattern reproduction (e.g. periods, frequencies, trends, phase lags, amplitudes etc.), rather than point (event) reproduction.

In this study, the behavior aimed to reproduce is the dynamics of Thailand's nursing workforce age structure. Unlike traditional behavior pattern test, one that compares real-world behavior and model-generated behavior over time, the test of this study compares only the shape of the actual workforce age structure observed in 2017 to the shape of model-generated age structure at t=2017, due to limited data collected by the country. The validity of the model behavior is, thus, based on the replicability of the age structure shape which inherently reflects the dynamics of multiple stocks – i.e.percentage of nurses in age classes. Figure 32 shows the result of comparison. The model could produce the age structure at t=2017, similar to the one exhibited in reference mode in certain aspects. The largest portion of the structure is the 40-44 age class at around 19%. An obvious trough could been seen in the 30-34 age class. However, the percentages of 23-24, 45-49, 50-54, and 55-59 age classes have suggested the need for a more accurate calibration and more precise data.

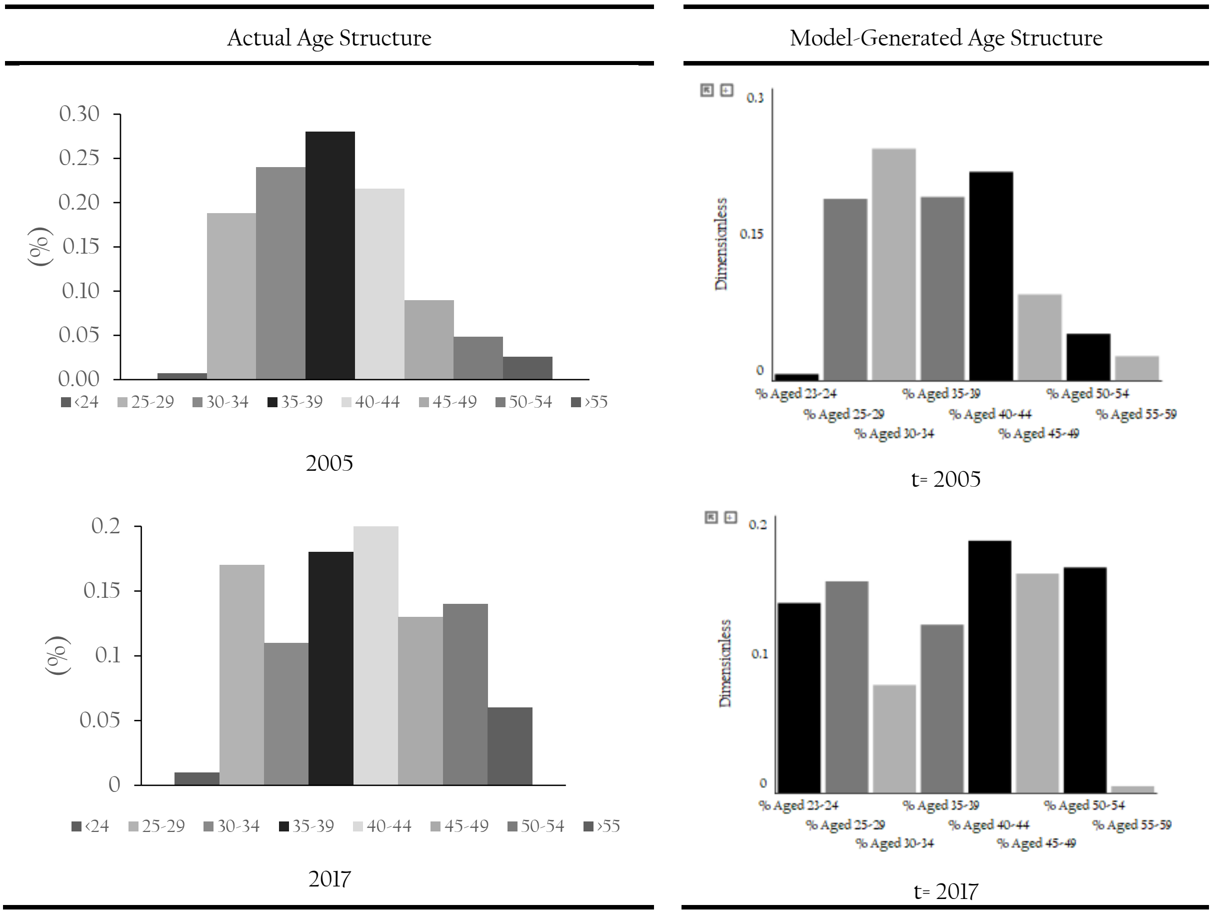

Figure 32 Behavior Pattern Test

Although the model could not precisely reproduce the behavior observed in the reference mode, it has shown that it could satisfy the hypothesis raised in Chapter 4 by generating the dynamics of the nursing workforce age structure without relying on dynamic external variables.

Summary of Model Validity Tests

Model validation is a process of establishing confidence in the models. The validity of an SD model can be seen as usefulness with respect to its purpose In this study, a number of tests have been carried, covering structure tests, structure-oriented behavior tests, and behavior pattern tests. The model has satisfied the direct structure tests and built the confidence that the model has been constructed based on the real-world system, both in conceptual structure and parameters. As a result of structure-oriented behavior tests, the model has shown to produce sensible behavior under extreme conditions. Certain parameters have shown to be relatively influential on the system behavior, including *Max Civil-Servant Positions*, *Fraction of Population Using Public Healthcare Facilities*, *Target Nurse-to-Patient Ratio*, *Fraction of Nursing Graduates Opting to Start in Public Hospitals*, and *Reference Fractional Non-Civil Servant 1 Leaving Rate* parameters, compared to the other parameters. The model could generally exhibit the dynamics of the age structure from 2005 to 2017. The model could produce the age structure, similar to the one exhibited in reference mode in certain aspects. However, the more accurate calibration and more precise data may be needed for the model to more precisely reproduce the reference mode.

Chapter 7: Scenario Analysis

7.1 Overview of Scenario Analysis

This chapter presents the model-simulated behavior of the system under various circumstances. Each scenario is a combination of model parameters with their values differing from the baseline simulation. The scenarios were selected based on the possible development of the relevant parameters at the time when the study was being conducted. At this stage, the simulation will explore the possible future scenarios in a period of 13 years (2018-2030).

	Short Description	Rationale
Scenario 1	Thailand's population continues to grow at a very low rate. The government does not allow new civil-servant positions to the nursing profession during the 13-year period. The aging population causes extraordinary healthcare service demands and thus increasing demand of the healthcare workforce. More of new nursing graduates opt to start their careers in non-public hospitals.	Statistics have shown that Thailand's population was growing at a decreasing rate (United Nations, Department of Economic and Social Affairs, Population Division, 2017). However, the current government at the time had initiatives to motivate the citizens to give more births, for example, the child tax credit launched in 2018. Due to bad economic climates, the government tried to cut public expenditure by not creating new civil-servant positions to the nursing profession. The civil-servant position reduction policy had been introduced since around 2000 after the financial crisis in 1997 and was brought to the table again in 2017 (The Secretariat of the Cabinet, 2017). The lack of career advancement and new career opportunities may sway new nursing graduates from working in public hospitals (see section 2.4, Chapter 2).
Scenario 2	Thailand's population stops growing in 2022. The government does not allow new civil-servant positions to the nursing profession during the 13-year period. The aging population causes extraordinary healthcare service demands and thus increasing demand of the healthcare workforce.	Statistics have shown that Thailand's population was growing at a decreasing rate (United Nations, Department of Economic and Social Affairs, Population Division, 2017). Due to bad economic climates, the government tried to cut public expenditure by not creating new civil-servant positions to the nursing profession. The civil-servant position reduction policy had been introduced since around 2000 after the financial crisis in 1997 and was brought to the table again in 2017 (The Secretariat of the Cabinet, 2017).
Scenario 3	Thailand's population continues to grow at a very low rate. The government allows new civil-servant positions to the nursing profession during the 13-year period. The aging population causes extraordinary healthcare service demands and thus increasing demand of the healthcare workforce.	Statistics have shown that Thailand's population was growing at a decreasing rate (United Nations, Department of Economic and Social Affairs, Population Division, 2017). However, the current government at the time had initiatives to motivate the citizens to give more births, for example, the child tax credit launched in 2018. Although the policy to reduce civil-servant positions has been reintroduced, the requests put forward by the nursing workforce have been constantly satisfied in the past (Sawaengdee, 2017).

Table 8 Selected Scenarios

7.2 Scenario 1

7.2.1 Scenario Setting

<table>
<tr><th>Parameter</th><th>Historical Value (2005-2017)</th><th>Scenario 1 Value (2018-2030)</th></tr>
<tr><td>Fractional Change Rate in Population</td><td>
<table>
<tr><th>Year</th><th>Value</th></tr>
<tr><td>2005</td><td>0.00649</td></tr>
<tr><td>2006</td><td>0.006</td></tr>
<tr><td>2007</td><td>0.00563</td></tr>
<tr><td>2008</td><td>0.00528</td></tr>
<tr><td>2009</td><td>0.005</td></tr>
<tr><td>2010</td><td>0.00488</td></tr>
<tr><td>2011</td><td>0.00477</td></tr>
<tr><td>2012</td><td>0.00464</td></tr>
<tr><td>2013</td><td>0.0044</td></tr>
<tr><td>2014</td><td>0.004</td></tr>
<tr><td>2015</td><td>0.0035</td></tr>
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<tr><td>2017</td><td>0.0025</td></tr>
</table>
</td><td>
<table>
<tr><th>Year</th><th>Value</th></tr>
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<tr><td>2019</td><td>0.005</td></tr>
<tr><td>2020</td><td>0.005</td></tr>
<tr><td>2021</td><td>0.005</td></tr>
<tr><td>2022</td><td>0.005</td></tr>
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<tr><td>2024</td><td>0.005</td></tr>
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<tr><td>2026</td><td>0.005</td></tr>
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<tr><td>2028</td><td>0.005</td></tr>
<tr><td>2029</td><td>0.005</td></tr>
<tr><td>2030</td><td>0.005</td></tr>
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<tr><td>Max Civil-Servant Positions</td><td>
<table>
<tr><th>Year</th><th>Value</th></tr>
<tr><td>2005-2013</td><td>81000</td></tr>
<tr><td>2014</td><td>84900</td></tr>
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<tr><th>Year</th><th>Value</th></tr>
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<tr><td>Target Nurse-to-Patient Ratio</td><td>0.0025 (1:400)</td><td>
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<tr><th>Year</th><th>Value</th></tr>
<tr><td>2018-2022</td><td>0.00267 (1:375)</td></tr>
<tr><td>2022-2030</td><td>0.0028 (1:350)</td></tr>
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<tr><td>Fraction of Nursing Graduates Opting to Start in Public Hospitals</td><td>0.8</td><td>
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<tr><th>Year</th><th>Value</th></tr>
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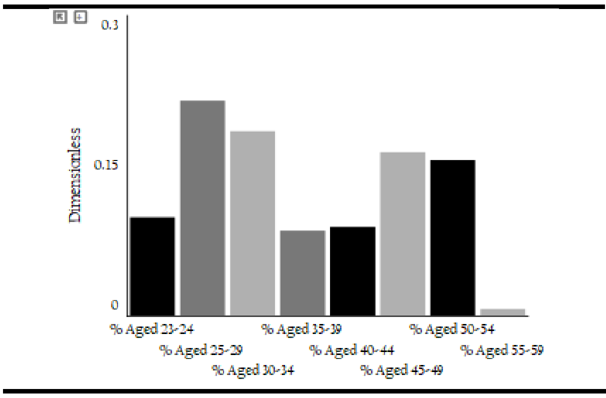
Table 9 Scenario 1: Parameter Setting

7.2.2 Simulation Results



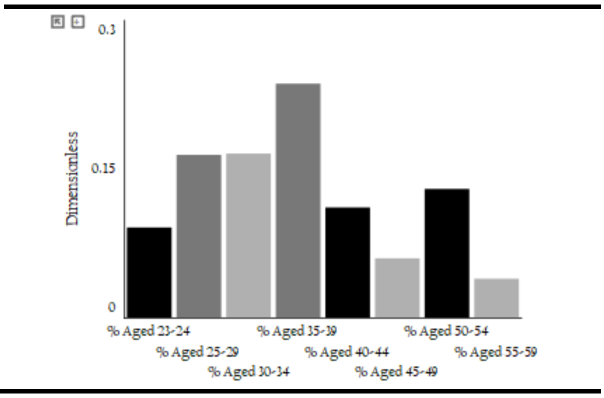


Figure 33 Scenario 1: Simulated Behavior of Nursing Workforce Age Structure at t=2022 and t=2030 (left to right)

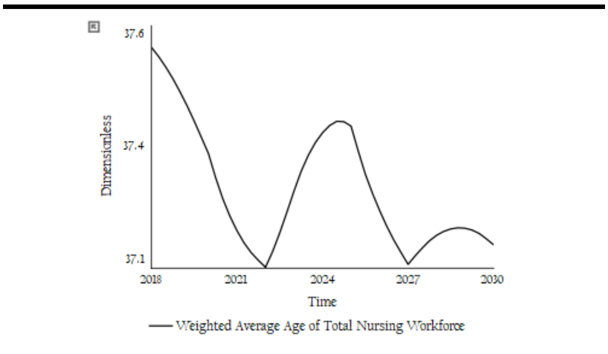


Figure 34 Scenario 1: Weighted Average Age of Nursing Workforce

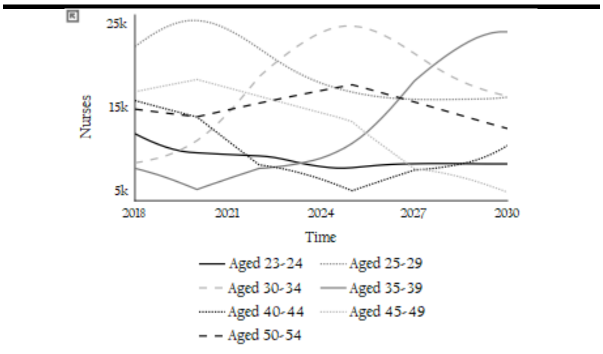


Figure 35 Scenario 1: Development of Age Classes

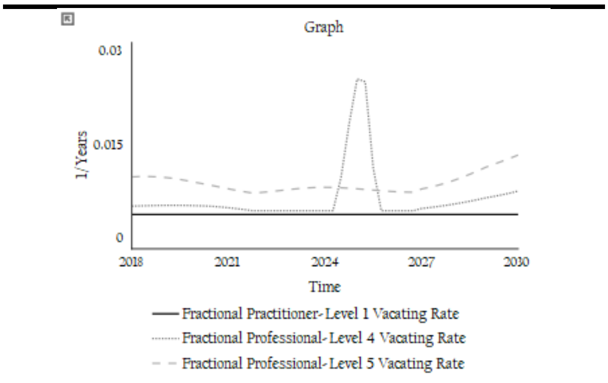


Figure 36 Scenario 1: Development of Fractional Leaving Rates of Selected Age Classes of Civil-Servant Nurses

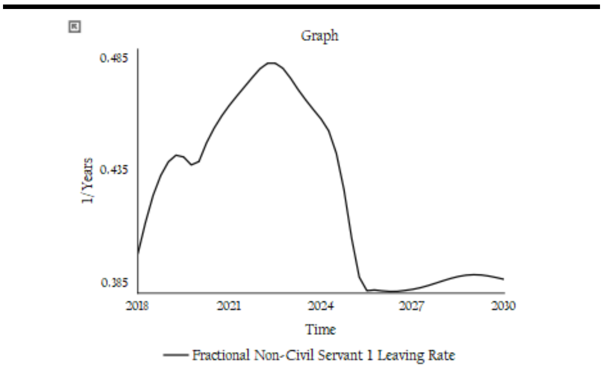


Figure 37 Scenario 1: Development of Fractional Leaving Rates of Non-Civil Servant 1

7.3 Scenario 2

7.3.1 Scenario Setting

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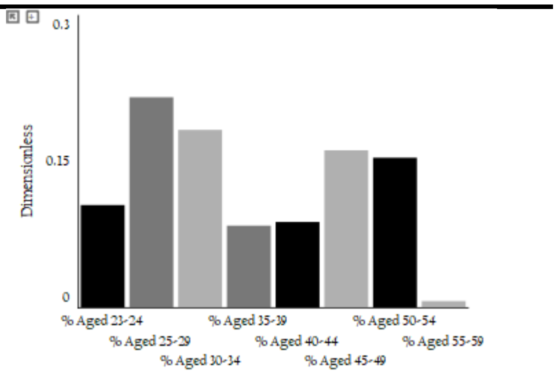
Table 10 Scenario 2: Parameter Setting

7.3.2 Simulation Results



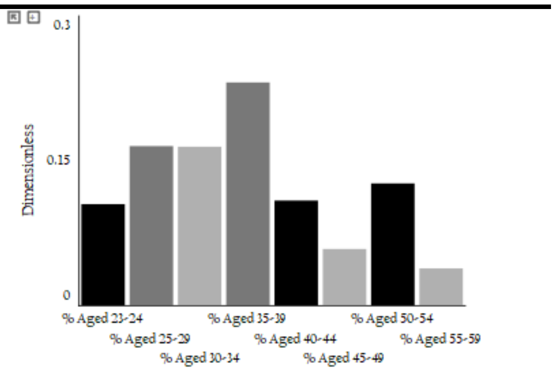


Figure 38 Scenario 2: Simulated Behavior of Nursing Workforce Age Structure at t=2022 and t=2030 (left to right)

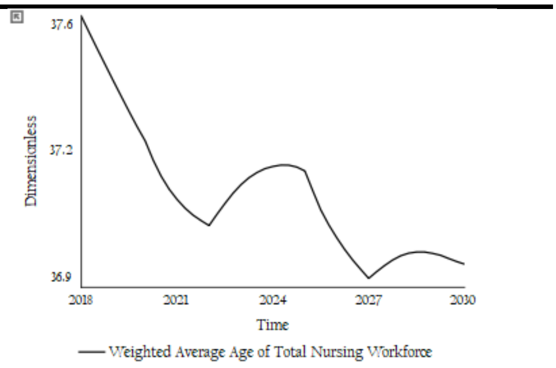


Figure 39 Scenario 2: Weighted Average Age of Nursing Workforce

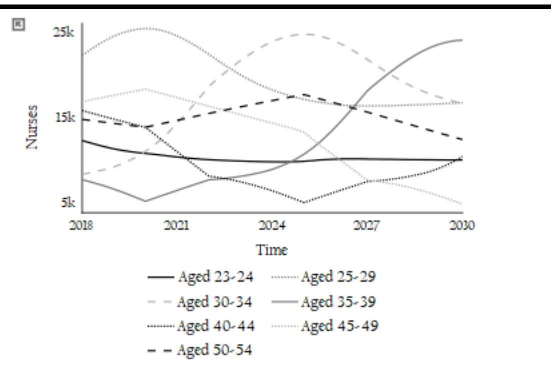


Figure 40 Scenario 2: Development of Age Classes

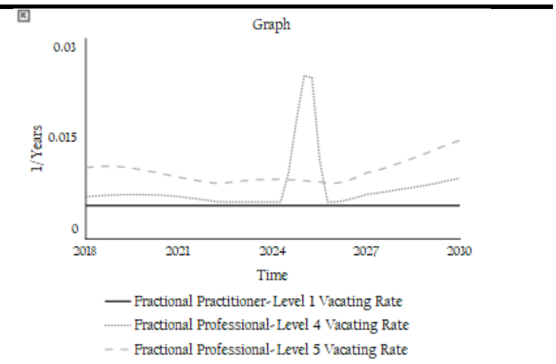


Figure 41 Scenario 2: Development of Fractional Leaving Rates of Selected Age Classes of Civil-Servant Nurses

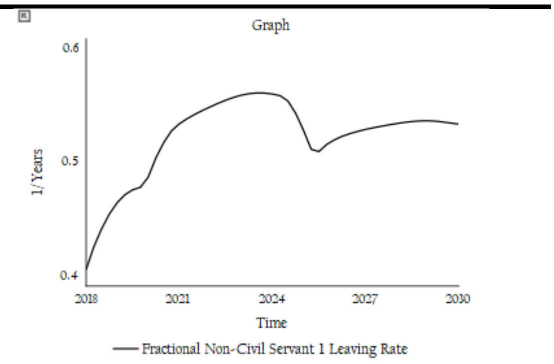


Figure 42 Scenario 2: Development of Fractional Leaving Rates of Non-Civil Servant 1

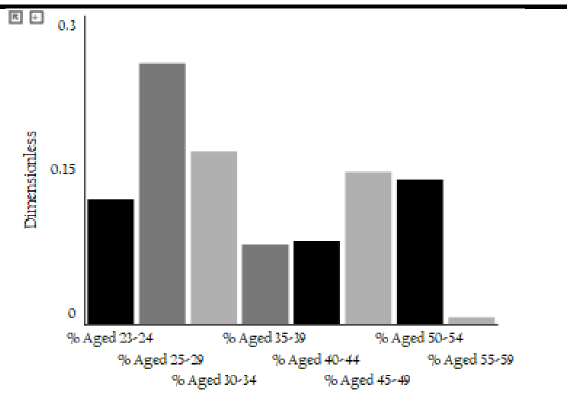
7.4 Scenario 3

7.4.1 Scenario Setting

<table>
<tr><th>Parameter</th><th>Historical Value (2005-2017)</th><th>Scenario 1 Value (2018-2030)</th></tr>
<tr><td>Fractional Change Rate in Population</td><td>
<table>
<tr><th>Year</th><th>Change Rate</th></tr>
<tr><td>2005</td><td>0.00649</td></tr>
<tr><td>2006</td><td>0.006</td></tr>
<tr><td>2007</td><td>0.00563</td></tr>
<tr><td>2008</td><td>0.00528</td></tr>
<tr><td>2009</td><td>0.005</td></tr>
<tr><td>2010</td><td>0.00488</td></tr>
<tr><td>2011</td><td>0.00477</td></tr>
<tr><td>2012</td><td>0.00464</td></tr>
<tr><td>2013</td><td>0.0044</td></tr>
<tr><td>2014</td><td>0.004</td></tr>
<tr><td>2015</td><td>0.0035</td></tr>
<tr><td>2016</td><td>0.00299</td></tr>
<tr><td>2017</td><td>0.0025</td></tr>
</table>
</td><td>
<table>
<tr><th>Year</th><th>Change Rate</th></tr>
<tr><td>2018</td><td>0.005</td></tr>
<tr><td>2019</td><td>0.005</td></tr>
<tr><td>2020</td><td>0.005</td></tr>
<tr><td>2021</td><td>0.005</td></tr>
<tr><td>2022</td><td>0.005</td></tr>
<tr><td>2023</td><td>0.005</td></tr>
<tr><td>2024</td><td>0.005</td></tr>
<tr><td>2025</td><td>0.005</td></tr>
<tr><td>2026</td><td>0.005</td></tr>
<tr><td>2027</td><td>0.005</td></tr>
<tr><td>2028</td><td>0.005</td></tr>
<tr><td>2029</td><td>0.005</td></tr>
<tr><td>2030</td><td>0.005</td></tr>
</table>
</td></tr>
<tr><td>Max Civil-Servant Positions</td><td>
<table>
<tr><th>Year</th><th>Max Civil-Servant Positions</th></tr>
<tr><td>2005-2013</td><td>81000</td></tr>
<tr><td>2014</td><td>84900</td></tr>
<tr><td>2015</td><td>88800</td></tr>
<tr><td>2016</td><td>92700</td></tr>
<tr><td>2017</td><td>93000</td></tr>
</table>
</td><td>
<table>
<tr><th>Year</th><th>Value</th></tr>
<tr><td>2018-2020</td><td>98000</td></tr>
<tr><td>2021-2025</td><td>103000</td></tr>
<tr><td>2026-2030</td><td>108000</td></tr>
</table>
</td></tr>
<tr><td>Target Nurse-to-Patient Ratio</td><td>0.0025 (1:400)</td><td>
<table>
<tr><th>Year</th><th>Value</th></tr>
<tr><td>2018-2022</td><td>0.00267 (1:375)</td></tr>
<tr><td>2022-2030</td><td>0.0028 (1:350)</td></tr>
</table>
</td></tr>
</table>

Table 11 Scenario 3: Parameter Setting

7.4.2 Simulation Results



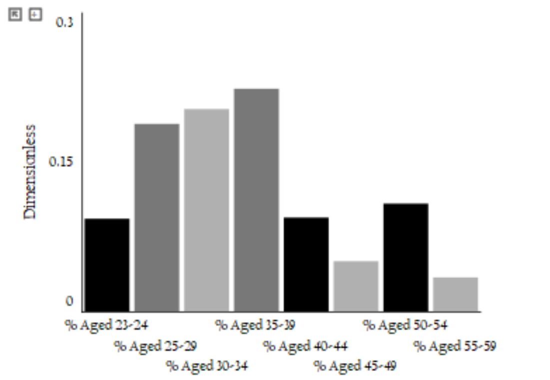


Figure 43 Scenario 3: Simulated Behavior of Nursing Workforce Age Structure at t=2022 and t=2030 (left to right)

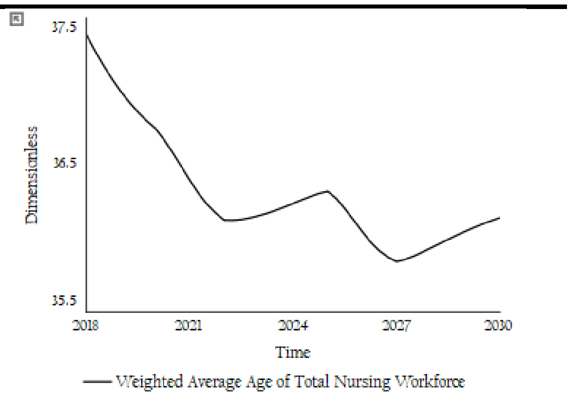


Figure 44 Scenario 3: Weighted Average Age of Nursing Workforce

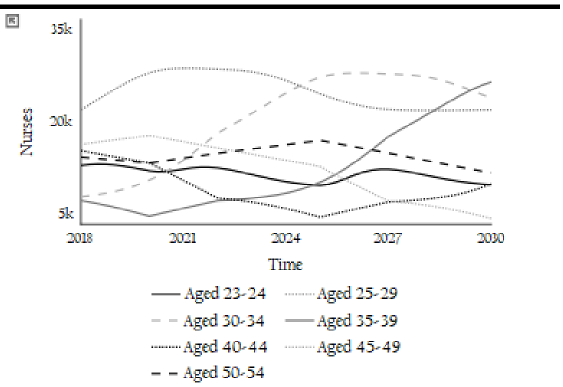


Figure 45 Scenario 3: Development of Age Classes

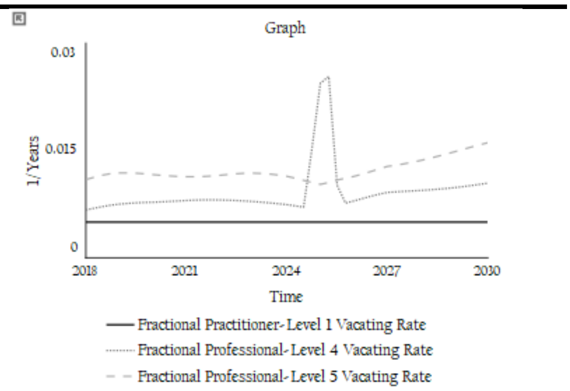


Figure 46 Scenario 3: Development of Fractional Leaving Rates of Selected Age Classes of Civil-Servant Nurses

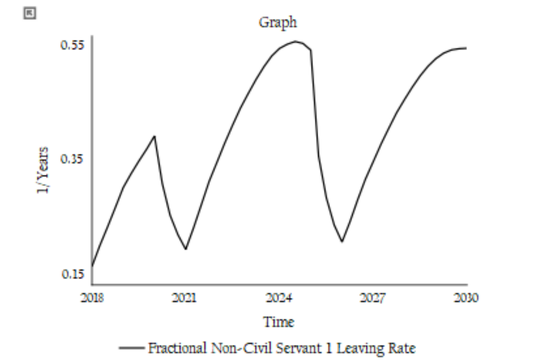


Figure 47 Scenario 3: Development of Fractional Leaving Rates of Non-Civil Servant 1

7.5 Analysis of Scenario Simulation Results

Seen in Figure 33, Figure 38, and Figure 43, the workforce age structure in all scenarios share a similar shape with some different details. At t=2022, the age distribution appears to be more uneven with an obvious trough amongst the middle age classes. This can be roughly explained by the relatively small number of nurses in 30-34 and 35-39 age classes in 2017 becoming the middle-aged workforce (35-44 years old) in 2022. At t=2030, the age structure appears to be right-skewed with a relatively small number of senior nurses This can be roughly explained by the relatively small number of nurses in 35-39 and 40-44 age classes in 2022 becoming the senior workforce (45-59 years old) in 2030. Unlike the age structure in 2017, the distribution in 2030 shows that the system is able to retain more young nurses (23-34 years old), compared to 2017. This will be explained by the dynamics of leaving rates below. As a result, the average age of the workforce becomes relatively low in all scenarios (Figure 34, Figure 39, and Figure 44)

The stocks of nurses in different age classes appear to be oscillating over time (Figure 35, Figure 40, and Figure 45), similar to what has been seen in the historical period (see section 5.2, Chapter 5). However, the behavior appears to be less oscillatory in Scenario 3. The fluctuation can be explained by the development of the inflow(s) and outflow(s) of each stock in the same way as in section 5.2 of Chapter 5). This analysis will focus on the dynamics of the inflows, namely the leaving rates of the nurses.

While the fractional leaving rates of nurses with a civil-servant status in all cases are resembling, one can spot significant differences amongst the fractional leaving rates of non-civil-servant nurses (Figure 37, Figure 42, and Figure 47).

Table 12 presents the simulation results of factors affecting the development of the fractional leaving rate in all three cases. In Scenario 3, the fractional leaving rate appears to be oscillating. The development of the leaving rate in the scenario can be simply explained by the dynamics of *Effect of Perception of Non-Civil-Servant 1 towards Civil-Servant Placement Opportunity on Vacating Rate* and *Perception of Non-Civil-Servant 1 towards Civil-Servant Placement Opportunity* variables. The latter is driven by the difference between *Non-Civil-Servant 1* and *Open Non-Senior Positions After 2nd Allocation* variables. When the gap is large, meaning that there is a lack of civil-servant positions, the perception variable will increase. However, in this case, the oscillation of *Open Non-Senior Positions After 2nd Allocation* variable is a consequence of the scenario setting - namely, the increasing number of maximum civil-servant positions which constantly adds up *Open Non-Senior Positions* variable.

In Scenario2, the fractional leaving rate climbs up until around t=2024 as the gap between *Non-Civil-Servant 1* and *Open Non-Senior Positions After 2nd Allocation* variables has enlarged. It, then, slightly decreases during 2024-2025 due to the gap getting slightly narrower. It, however, rises again in 2027 and stays between 0.5 and 0.55 until t=2030 as the gap increases again during the last 5 years.

In Scenario 1, the fractional leaving rate climbs up until around t=2022 as the gap between *Non-Civil-Servant 1* and *Open Non-Senior Positions After 2nd Allocation* variables has enlarged. The gap, however, becomes smaller after then due to a significant decrease in recruitment rate. The consequence is the drastic decline of the fractional leaving rate until late 2025.

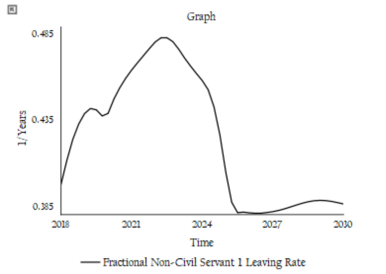
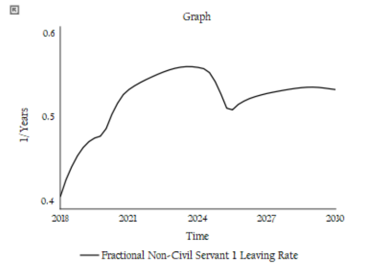
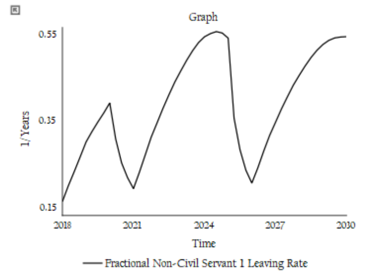
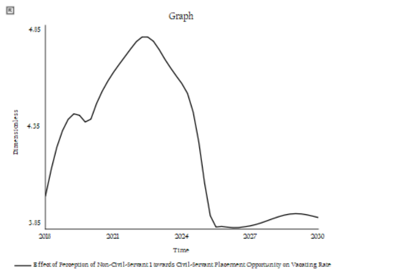
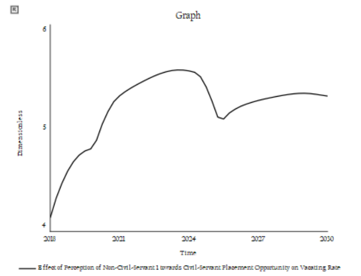
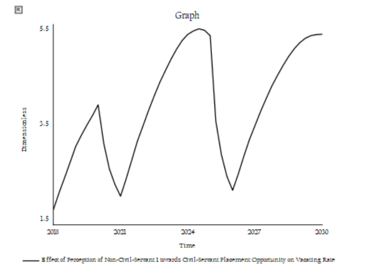
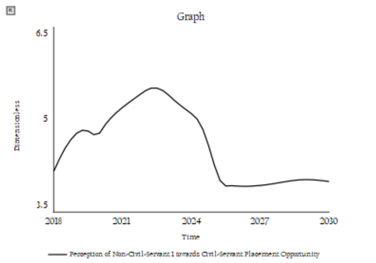
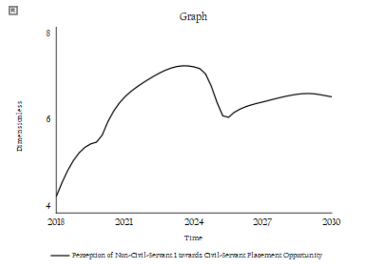
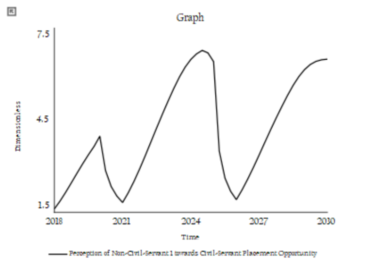
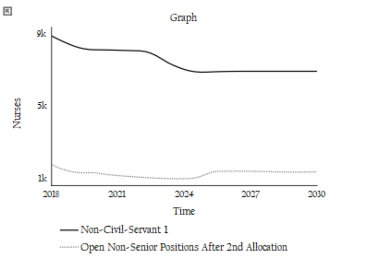
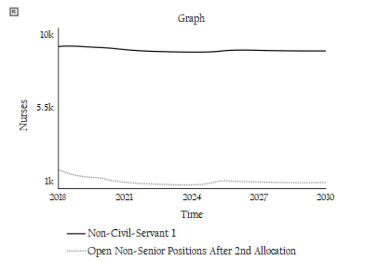
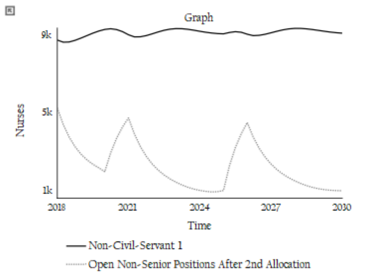
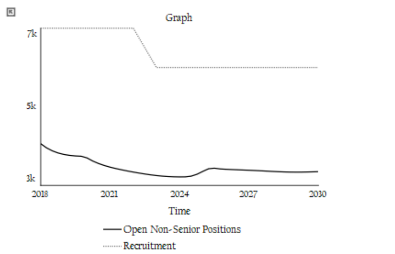
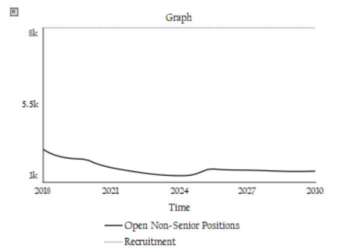
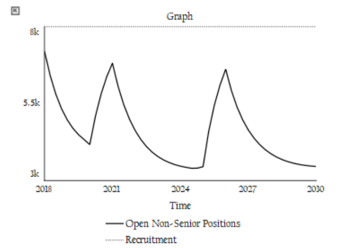
Reference Variable	Scenario 1	Scenario 2	Scenario 3
Fractional Leaving Rates of Non-Civil Servant 1			
Effect of Perception of Non-Civil-Servant 1 towards Civil-Servant Placement Opportunity on Vacating Rate			
Perception of Non-Civil-Servant 1 towards Civil-Servant Placement Opportunity			
Non-Civil-Servant 1 And Open Non-Senior Positions After 2nd Allocation			
Open Non-Senior Positions And Recruitment			

Table 12 Analysis of Fractional Non-Civil Servant 1 Leaving Rate in Different Scenarios

Chapter 8: Policy Formulation and Analysis

8.1 Overview of Policy Formulation and Analysis

This chapter utilizes the analysis results from the previous chapters to formulate and analyze policy alternatives attempted to solve the problem of instability of the nursing workforce age structure. First, the common policy suggested by a number of studies is introduced into the model and its simulation results are analyzed whether it can reform the workforce age structure into the favorable shape (Grund & Westergård-Nielsen, 2008). Second, as the preliminary policy appears not to be able to reshape the age structure unilaterally, the cause of unsolved instability is analyzed. An additional policy is proposed to complement the preliminary policy and tested. The simulation results of the new combined policy are analyzed and presented.

8.2 The Preliminary Policy

The preliminary policy simply follows the common suggestion to increase the number of civil-servant positions so that all nurses have a civil-servant status (Sawaengdee, 2017; Khunthar, 2014). The rationale behind this policy option is the belief that when nurses can perceive higher job security and have a reasonable remuneration package, they will intend to stay longer in the public facilities and, therefore, the workforce age structure should be stabilized. In parallel, the number of senior-professional-level positions should also increase to retain senior nurses.

8.2.1 Policy Setting

The policy involves adjusting two existing parameters in the model: *Max Civil-Servant Positions* and *Fraction of Senior-Professional-Level Positions*. Table 13 presents the policy configuration in the model.

Parameter	**Historical Value (2005-2017)**		**Policy Value**	
	Year	Value	Year	Value
Max Civil-Servant Positions	2005-2013	81000	From 2018	999999
	2014	84900		
	2015	88800		
	2016	92700		
	2017	93000		
Fraction of Senior-Professional-Level Positions	2005-2017	0.02	From 2018	0.05

Table 13 Preliminary Policy: Parameter Setting

8.2.2 Policy Simulation Results

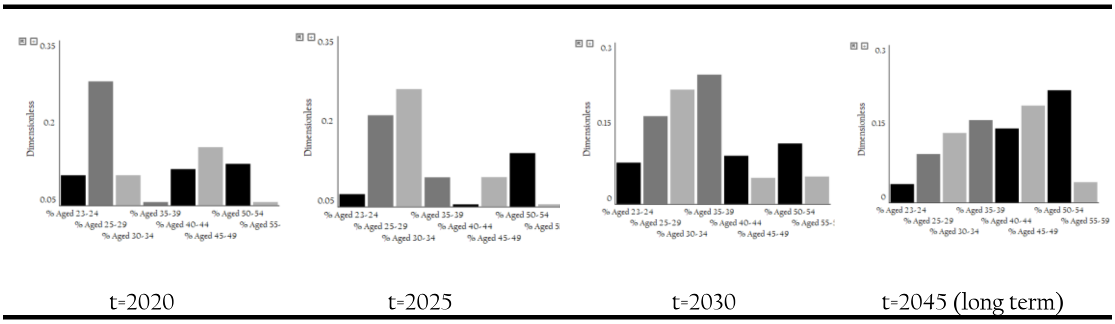


Figure 48 Preliminary Policy: Simulated Behavior of Nursing Workforce Age Structure

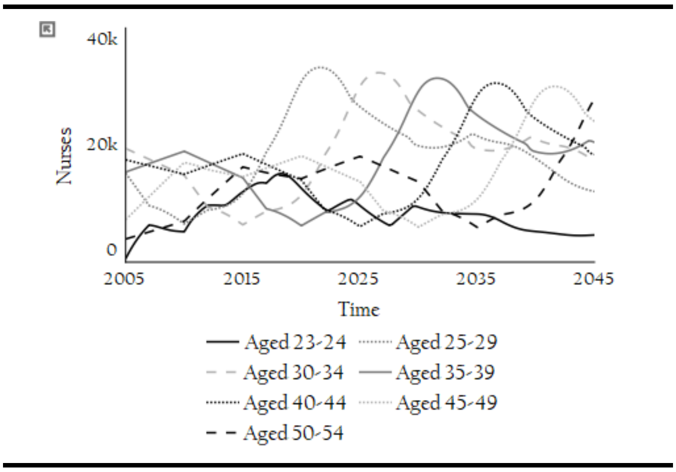


Figure 49 Preliminary Policy: Development of Age Classes

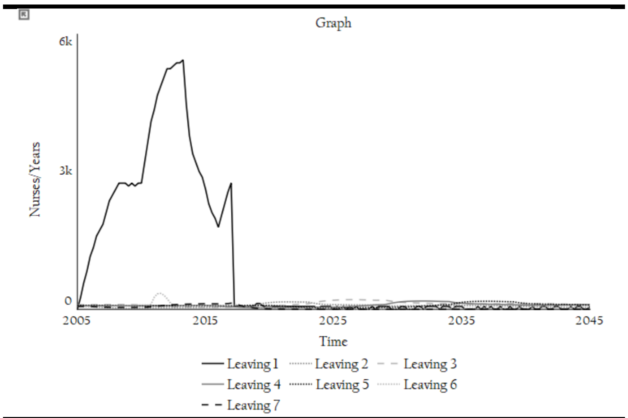


Figure 50 Preliminary Policy: Leaving Rates of Nurses

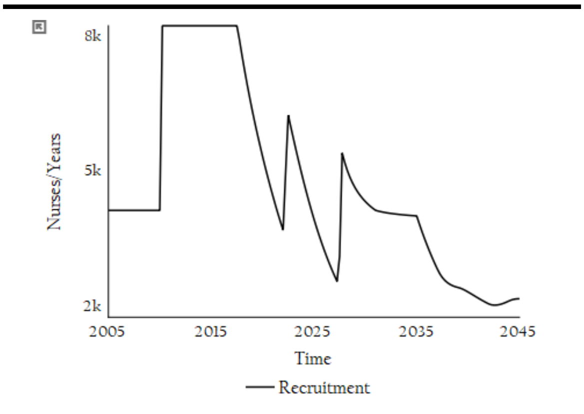


Figure 51 Preliminary Policy: Recruitment Rate

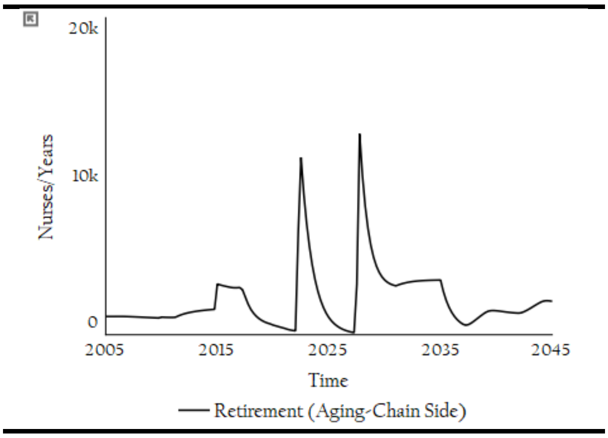


Figure 52 Preliminary Policy: Total Retirement

8.2.3 Analysis of the Results

Seen in Figure 48, the age structure appears to become right-skewed with the highest percentage of nurses in the 35-39 age class at t=2030. Therefore, the preliminary policy appears not to be able to reshape the age structure, either within the target period or in the long term. Furthermore, after 2030, the age structure seems to shift from being right-skewed to left-skewed, warning that the workforce will become an aged workforce in 20-30 years.

As explained in the analysis of baseline simulation result (Chapter 6), the instability in the age structure roots from the oscillations in age-class stocks (Figure 49). To investigate the cause of the oscillations, two important factors are analyzed: the leaving rates of nurses in different age classes and the recruitment rate.

After introducing the preliminary policy to the model at t=2017, the leaving rates decrease and stabilize at near-zero level (Figure 50), indicating that the preliminary policy can solve the problem of high intention to leave in every age class. Therefore, the leaving rates are not the cause of the oscillations as it was before 2017.

On the other side, the recruitment rate of nurses appears to be fluctuating after the preliminary policy is introduced (Figure 51). From the system structure, the recruitment rate relies heavily on the total number of active nurses in the system and the total loss of nurses each year (leaving and retiring). Since the leaving rates are no longer problematic as described above, the focus is, then, on the retirement rate. Clearly seen in Figure 52, the total retirement rate starts to fluctuate after 2017, therefore, causing the recruitment rate to also be oscillatory. The fluctuating retirement rate can be explained by the fact that, at the point where the leaving rate problem is solved (by the preliminary policy at t=2017), the age structure is still uneven. Therefore, there will be higher retirement rates in some years and lower ones in the others afterwards. And once, the recruitment rate fluctuates, the workforce age structure will inevitably remain uneven and, thus again, result in oscillatory retirement rate.

8.3 The Complementary Policy

Although the problem of high leaving rates can be solved by the preliminary policy of giving all nurses a civil-servant status, the instability of the workforce age structure will keep persisting as long as the retirement rate and the recruitment rate reinforce each other to oscillate (Figure 53). Seen in the loop, stabilizing either the retirement rate or the recruitment rate should be sufficient to solve the issue. However, as the recruitment rate is the one that is more easily controllable in nature, therefore, a complementary policy is proposed to damp the oscillation of the recruitment rate by setting the recruitment rate constant, instead of depending on the retirement rate. Note that this complementary policy can be deemed appropriate in this case as Thailand's population is not changing significantly, thus less dynamic healthcare service demand, and maintaining the recruitment rate stable also makes it easier for the government to plan the budget for nurse production.

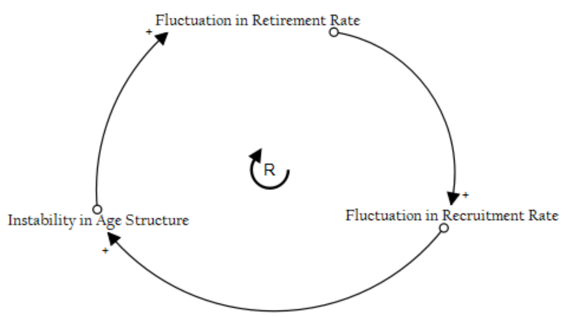


Figure 53 Cause of Age Structure Instability after Preliminary Policy

8.3.1 Policy Setting

On top of the preliminary policy, the *Recruitment Rate* variable is adjusted. Table 14 presents the configuration of the variable.

Variable	Historical Equation (2005-2017)	Policy Equation
Recruitment Rate	From 2005-2010: 4200 From 2010-2017: MIN(10000,MAX(0, Demand_Gap/Adjustment_Time_to_Produce_Nursing_Graduates))*Fraction_of_Nursing_Graduates_Opting_to_Start_in_Public_Hospitals	From 2018: 10000* Fraction_of_Nursing_Graduates_Opting_to_Start_in_Public_Hospitals Note: 6000 is the production level that can close the demand gap in the long term (see Figure 59)

Table 14 Complementary Policy: Variable Setting

8.3.2 Policy Simulation Results

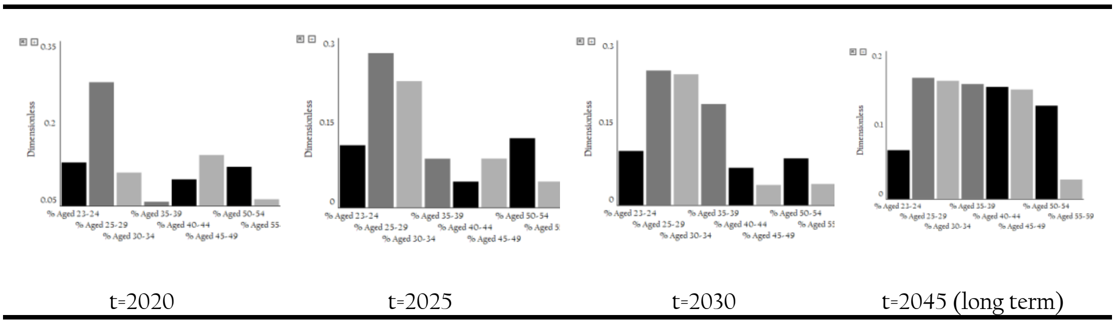


Figure 54 Combined Policy: Simulated Behavior of Nursing Workforce Age Structure

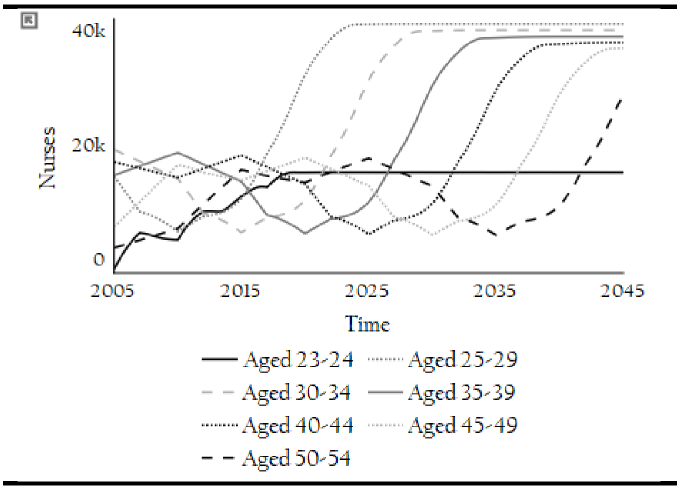


Figure 55 Combined Policy: Development of Age Classes

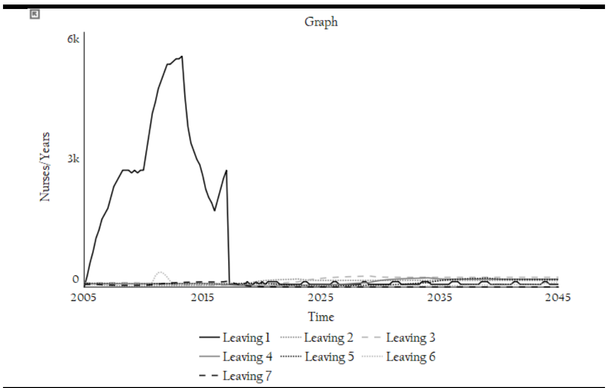


Figure 56 Combined Policy: Leaving Rates of Nurses

Figure 57 Combined Policy: Recruitment Rate

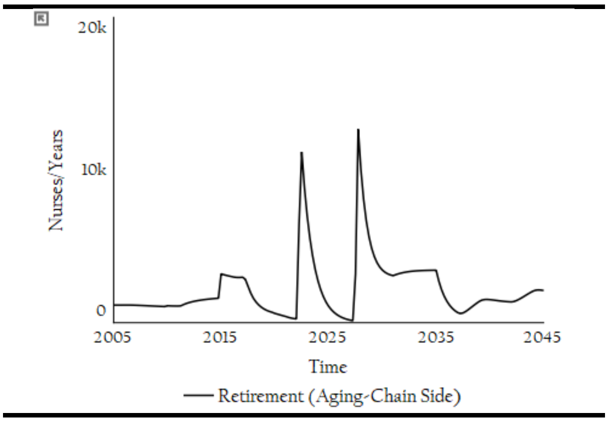


Figure 58 Combined Policy: Total Retirement

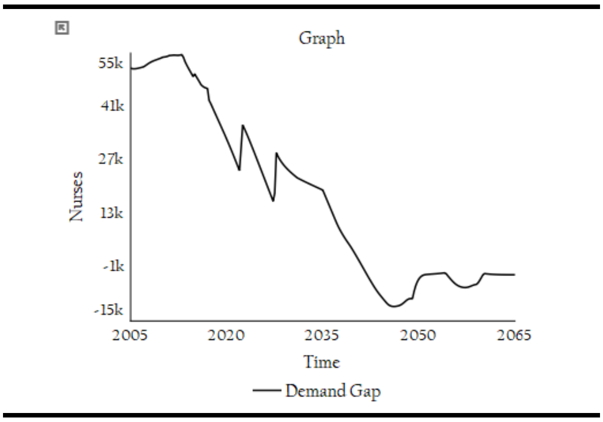


Figure 59 Combined Policy: Nurse Demand Gap in Public Hospitals

8.3.3 Analysis of the Results

The simulation results show that the combined policy can successfully reshape the nursing age structure into the near-uniform shape. However, it indicates that it can take more than 20 years to reach the desired shape due to the huge delay in the aging chain process. The recruitment rate also appears to be able to close the demand gap in public hospitals.

It may be possible to shorten the reshaping time by two additional policies. The first involves laying off a number of nurses at some ages before their retirement to rebalance the entire workforce. However, this policy can be controversial from an implementation perspective as there will be many people affected in a negative way. In addition, it is not logical to lay off nurses when the demand gap remains to be seen. The second one is to recruit external nurses with specific ages to fill up the age classes that have a relatively lower number of nurses. Although this policy can be deemed less controversial, it can still be questioned about practicalities, for instance, what ranks or positions these intermediate-entry nurses should obtain.

Chapter 9: Discussion and Conclusion

9.1 Contribution of the Research

The contribution of this study is twofold. First, it provides a clear picture of how the public nursing workforce age structure in Thailand has been developing and serves as a tool for policymakers to test policies without the need to change the real-world systems. The model developed in this study points out that the commonly suggested policy of increasing number of civil-servant positions might not be able to achieve the goal of uniform age structure unilaterally.

Second, the results of the hypothesis testing have provided the insights as to how the design of a workforce structure in an organization might have an effect on the turnover and age structure of the workforce which, in turn, can jeopardize the organization productivity. In particular, the model developed in this study has shown that organizations implementing temporary employment schemes are prone to encountering the problem of uneven age structure if effective employee retention measures are not in place.

9.2 Model and Study Limitations

9.2.1 Limited Data for Behavior Pattern Tests

The model has passed all the direct structure and structure-oriented behavior tests and could produce behavior (nursing workforce age structure) close to the reference mode at the two reference points in time. However, the credibility of the model could have been increased if there were more datasets against which the model could be validated (see more detail in section 6.4, Chapter 6)

9.2.2 Simplified Demand-Side Boundary of the System

Certainly, the argument that the availability and density of healthcare workforces might have a significant impact on a nation's health outcomes (Nguyen, Mirzoev , & Le , 2016) is valid. This may affect the population growth and survival rates, which, in turn, determine the healthcare service and workforce demands. However, due to limited time and the current model already being able to explain the dynamics, the demand-side of the nursing workforce system in this study was treated exogenously. To be precise, the population number, which is the foundation of healthcare service demand and, thus, nursing workforce demand, was modeled based on statistical data.

9.2.3 Aggregation of Nationwide Nursing Workforce

This study treated the nursing workforce at the national level, thus, assumed that the workforce has been distributed proportionately across the country. However, in fact, unequitable healthcare workforces' distribution has also been another issue in Thailand (Khunthar, 2014). Therefore, the result of this study should be interpreted with this precaution.

9.2.4 Model Assumptions

The model in this study was constructed with a set of assumptions which were deemed appropriate to be made for the system of interest. Therefore, the user of this model should be aware of the assumptions and how the model might be affected if there are drastic changes in system structure or parameters. For example, if the government decides to designate a significant number of expert-level or advisory-level positions for the nursing profession, there should be a significant amendment to the aging chain and the civil-servant position chain. Another example could be that the current model limits the number of senior-professional-level positions. If the government does not limit the number anymore, there should be a major change to the promotion flows and decision rules.

9.3 Recommendations for Further Research

9.3.1 Boundary Expansion

Incorporating Aging Chain of Population and the Heterogeneity of Healthcare Demand

As explained in the previous section, the demand-side of the nursing workforce system in this study was treated exogenously. There is an opportunity to expand the model boundary to include the aging chain of population. This can complicate the matter because each population age class will certainly have different levels of healthcare demand which, in turn, can affect the nursing workforce demand and dynamics of the workforce age structure, respectively.

Incorporating Other Effects on Intention to Leave

In this study, only the career advancement opportunity and the additional workload due to the training burden of senior nurses were taken into account as influences on intention to leave of nurses. There are still other factors that might be included to make the model more realistic, for example, the timing of night shift, organizational commitment, quality of work life, work experience, and organizational climate (Khunthar, Sujijantararat, Thongchareon, Namthep, & Klayklongjit, 2012). However, incorporating such factors may involve a considerable boundary expansion. In addition, the boundary expansion might expose the model to new possibilities of policy intervention.

9.3.2 Group Model Building for Effective Policy Implementation

Neglecting stakeholder involvement in policy formulation might hinder the implementation of the policy and result in failed decisions. Stakeholder participation in the decision-making process has proved to be the most successful decision-making tactic (Nutt, 1999). Group Model Building can be utilized to gain deep understanding, consensus and commitment on the problem or policy option(s) and, thus, increases the success rate of the policy implementation (Vennix, 1996).

In addition, involving stakeholders may result in a boundary expansion, making the model able to incorporate other possible policy options or making the policy evaluation more sophisticated (e.g. financial impacts of implementing policies on the government).

9.3.3 Validation of the Gained Insight against Other Workforces

The model developed in this study provides an insight that organizations that deploy temporary employment schemes might be more likely to encounter the problem of uneven age structure if effective employee retention policies are not in place. The model developed in this study can be replicated and adapted to other workforces experiencing the same problem to validate the insight gained from this study. Empirical studies may be needed to assert the generalization of the insight.

9.4 Conclusion

Nurses are an important component of the healthcare system workforce as they deliver the highest percentage of patient care. Similar to other professions, more years' experience enables these nurses to work more productively as their knowledge and expertise build up. Unlike other professions, nursing also requires physical strength and stamina which normally deteriorate as they age up. Therefore, a balance between young nurses and senior nurses in a country or healthcare service facility's nursing workforce is an important factor affecting its productivity. Subsequently, the uniform distribution suggested by Grund & Westergård-Nielsen (2008) was conceived as the ideal age structure to optimize the workforce productivity. In Thailand, the age structure of the public nursing workforce has been concerned by public health scholars as its shape appears to be abnormally problematic, compared to nursing workforces in other countries. The development of the country's workforce age structure over time has suggested that there have been difficulties in retaining nurses in the public healthcare system.

This study investigated the problem through a systematic lens with the ultimate aim of proposing an effective policy to reshape the currently unfavorable age structure of Thailand's public nursing workforce. A quantitative SD model was built based on literature to represent Thailand's nursing workforce system. The model has gone through a number of validity tests and was populated with actual data from statistics and existing studies to build confidence that it could serve the purpose of the study.

The analysis of the simulation results supported the existing studies that the unfavorable development of the workforce age structure roots from the design of the civil-servant employment system and the insufficient number of civil-servant positions which adversely affect the intention to leave of new nurses and some of senior nurses.

The model, however, the commonly suggest policy of increasing the number of civil-servant positions to reduce high turnover rate of nurses might not be able to unilaterally reshape the workforce age structure as previous studies suggested. A complementary policy was proposed to stabilize the recruitment rate and retirement rate by controlling the nurse production to be at an optimal level. The combined policy appeared to be able to change the workforce age distribution from the current unfavorable shape to the near-optimal shape. However, it indicated that, without additional ad-hoc restructuring measures, it may take a considerable amount of time before the desired shape would arrive.

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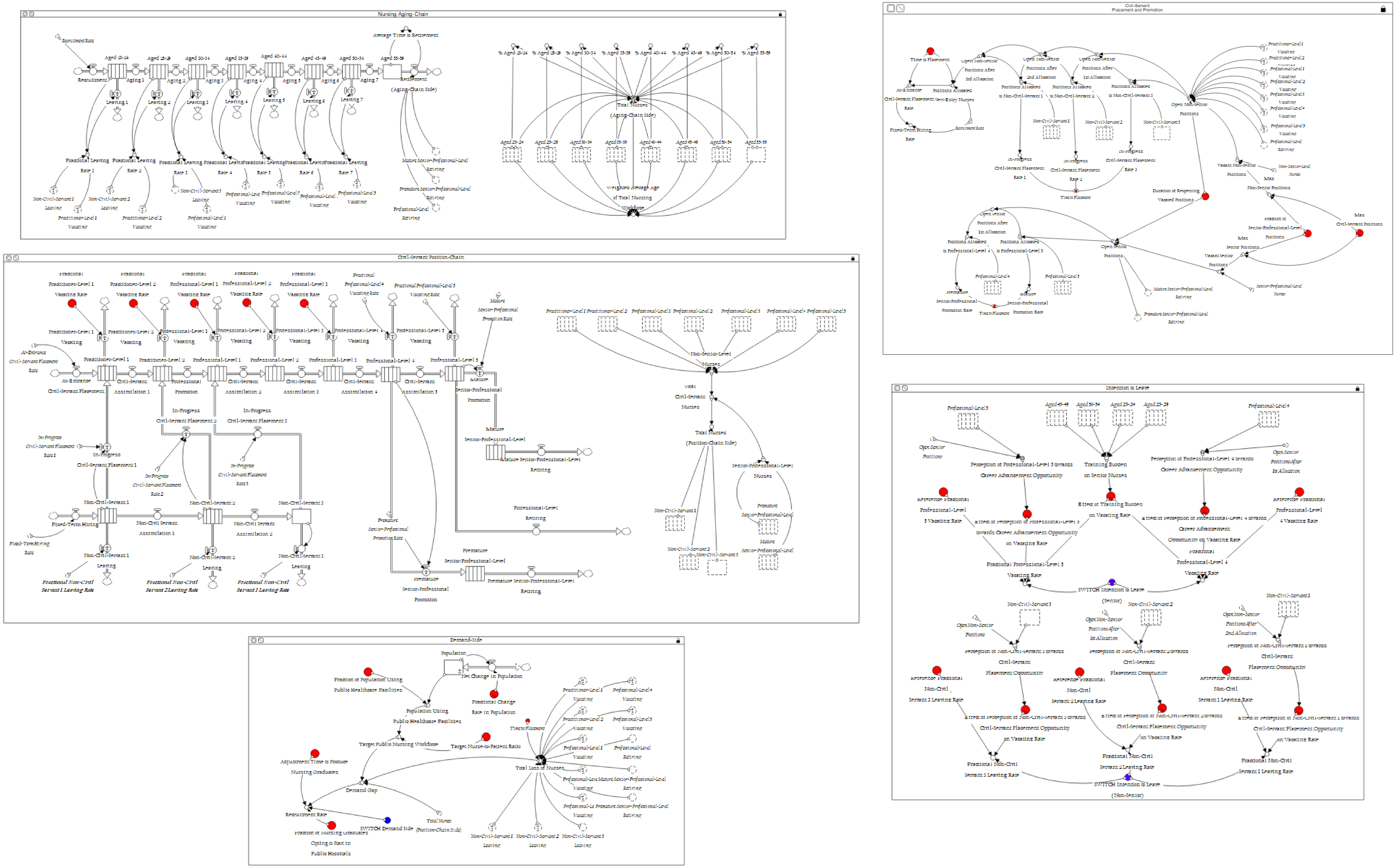
Appendices

Appendix I: Full Stock and Flow Diagram



Appendix II: List of Equations and Baseline Parameters

Name of element	Type	Equation / Value	Unit	Description	Source
DT	System Parameter	1/64			
%_Aged_23-24	Variable	Aged_23-24/Total_Nurses_(Aging-Chain_Side)	Dimensionless	Fraction of registered nurses aged 23-24, working in the facilities under PSO at a given time	Obvious calculation / General fact
%_Aged_25-29	Variable	Aged_25-29/Total_Nurses_(Aging-Chain_Side)	Dimensionless	Fraction of registered nurses aged 25-29, working in the facilities under PSO at a given time	Obvious calculation / General fact
%_Aged_30-34	Variable	Aged_30-34/Total_Nurses_(Aging-Chain_Side)	Dimensionless	Fraction of registered nurses aged 30-34, working in the facilities under PSO at a given time	Obvious calculation / General fact
%_Aged_35-39	Variable	Aged_35-39/Total_Nurses_(Aging-Chain_Side)	Dimensionless	Fraction of registered nurses aged 35-39, working in the facilities under PSO at a given time	Obvious calculation / General fact
%_Aged_40-44	Variable	Aged_40-44/Total_Nurses_(Aging-Chain_Side)	Dimensionless	Fraction of registered nurses aged 40-44, working in the facilities under PSO at a given time	Obvious calculation / General fact
%_Aged_45-49	Variable	Aged_45-49/Total_Nurses_(Aging-Chain_Side)	Dimensionless	Fraction of registered nurses aged 45-49, working in the facilities under PSO at a given time	Obvious calculation / General fact
%_Aged_50-54	Variable	Aged_50-54/Total_Nurses_(Aging-Chain_Side)	Dimensionless	Fraction of registered nurses aged 50-54, working in the facilities under PSO at a given time	Obvious calculation / General fact
%_Aged_55-59	Variable	Aged_55-59/Total_Nurses_(Aging-Chain_Side)	Dimensionless	Fraction of registered nurses aged 55-59, working in the facilities under PSO at a given time	Obvious calculation / General fact
Adjustment_Time_to_Produce_Nursing_Graduates	Constant	4	Years	Time needed to produce new nursing graduates	Typical length of nursing education in Thailand
Aged_23-24 (t)	Stock (Conveyor)	Aged_23-24(t - dt) + (Recruitment - Aging_1 - Leaving_1) * dt Initial value = 575 Transit time = 2	Nurses	Number of registered nurses working in the facilities under PSO aged from 23 to 24 at a given time	Sawaengdee (2009) http://social.nesdb.go.th/social/
Recruitment	Inflow	Recruitment_Rate	Nurses/Years	Number of newly registered nurses entering the facilities under PSO in a given year	Obvious calculation / General fact
Aging_1	Conveyor Outflow and Inflow	*Depends on transit time of its source stock*	Nurses/Years	Number of registered nurses working in the facilities under PSO, aged from 23 to 24, aging up in a given year	Obvious calculation / General fact
Leaving_1	Leakage Outflow	LEAKAGE FRACTION = Fractional_Leaving_Rate_1	Nurses/Years	Number of registered nurses working in the facilities under PSO, aged from 23 to 24, leaving the profession in a given year	Obvious calculation / General fact
Aged_25-29 (t)	Stock (Conveyor)	Aged_25-29(t - dt) + (Aging_1 - Aging_2 - Leaving_2) * dt Initial value = 15228 Transit time = 5	Nurses	Number of registered nurses working in the facilities under PSO aged from 25 to 29 at a given time	Sawaengdee (2009) http://social.nesdb.go.th/social/

Name of element	Type	Equation / Value	Unit	Description	Source
Aging_2	Conveyor Outflow and Inflow	*Depends on transit time of its source stock*	Nurses/Years	Number of registered nurses working in the facilities under PSO, aged from 25 to 29, aging up in a given year	Obvious calculation / General fact
Leaving_2	Leakage Outflow	LEAKAGE FRACTION = Fractional_Leaving_Rate_2	Nurses/Years	Number of registered nurses working in the facilities under PSO, aged from 25 to 29, leaving the profession in a given year	Obvious calculation / General fact
Aged_30-34 (t)	Stock (Conveyor)	Aged_30-34(t - dt) + (Aging_2 - Aging_3 - Leaving_3) * dt Initial value = 19423 Transit time = 5	Nurses	Number of registered nurses working in the facilities under PSO aged from 30 to 34 at a given time	Sawaengdee (2009) http://social.nesdb.go.th/social/
Aging_3	Conveyor Outflow and Inflow	*Depends on transit time of its source stock*	Nurses/Years	Number of registered nurses working in the facilities under PSO, aged from 30 to 34, aging up in a given year	Obvious calculation / General fact
Leaving_3	Leakage Outflow	LEAKAGE FRACTION = Fractional_Leaving_Rate_3	Nurses/Years	Number of registered nurses working in the facilities under PSO, aged from 30 to 34, leaving the profession in a given year	Obvious calculation / General fact
Aged_35-39 (t)	Stock (Conveyor)	Aged_35-39(t - dt) + (Aging_3 - Aging_4 - Leaving_4) * dt Initial value = 15390 Transit time = 5	Nurses	Number of registered nurses working in the facilities under PSO aged from 35 to 39 at a given time	Sawaengdee (2009) http://social.nesdb.go.th/social/
Aging_4	Conveyor Outflow and Inflow	*Depends on transit time of its source stock*	Nurses/Years	Number of registered nurses working in the facilities under PSO, aged from 35 to 39, aging up in a given year	Obvious calculation / General fact
Leaving_4	Leakage Outflow	LEAKAGE FRACTION = Fractional_Leaving_Rate_4	Nurses/Years	Number of registered nurses working in the facilities under PSO, aged from 35 to 39, leaving the profession in a given year	Obvious calculation / General fact
Aged_40-44 (t)	Stock (Conveyor)	Aged_40-44(t - dt) + (Aging_4 - Aging_5 - Leaving_5) * dt Initial value = 17487 Transit time = 5	Nurses	Number of registered nurses working in the facilities under PSO aged from 40 to 44 at a given time	Sawaengdee (2009) http://social.nesdb.go.th/social/
Aging_5	Conveyor Outflow and Inflow	*Depends on transit time of its source stock*	Nurses/Years	Number of registered nurses working in the facilities under PSO, aged from 40 to 44, aging up in a given year	Obvious calculation / General fact
Leaving_5	Leakage Outflow	LEAKAGE FRACTION = Fractional_Leaving_Rate_5	Nurses/Years	Number of registered nurses working in the facilities under PSO, aged from 45 to 49, leaving the profession in a given year	Obvious calculation / General fact
Aged_45-49 (t)	Stock (Conveyor)	Aged_45-49(t - dt) + (Aging_5 - Aging_6 - Leaving_6) * dt Initial value = 7241 Transit time = 5	Nurses	Number of registered nurses working in the facilities under PSO aged from 45 to 49 at a given time	Sawaengdee (2009) http://social.nesdb.go.th/social/
Aging_6	Conveyor Outflow and Inflow	*Depends on transit time of its source stock*	Nurses/Years	Number of registered nurses working in the facilities under PSO, aged from 45 to 49, aging up in a given year	Obvious calculation / General fact

Name of element	Type	Equation / Value	Unit	Description	Source
Leaving_6	Leakage Outflow	LEAKAGE FRACTION = Fractional_Leaving_Rate_6	Nurses/Years	Number of registered nurses working in the facilities under PSO, aged from 45 to 49, leaving the profession in a given year	Obvious calculation / General fact
Aged_50-54 (t)	Stock (Conveyor)	Aged_50-54(t - dt) + (Aging_6 - Aging_7 - Leaving_7) * dt Initial value = 3944 Transit time = 5	Nurses	Number of registered nurses working in the facilities under PSO aged from 50 to 54 at a given time	Sawaengdee (2009) http://social.nesdb.go.th/social/
Aging_7	Conveyor Outflow and Inflow	*Depends on transit time of its source stock*	Nurses/Years	Number of registered nurses working in the facilities under PSO, aged from 50 to 54, aging up in a given year	Obvious calculation / General fact
Leaving_7	Leakage Outflow	LEAKAGE FRACTION = Fractional_Leaving_Rate_7	Nurses/Years	Number of registered nurses working in the facilities under PSO, aged from 50 to 54, leaving the profession in a given year	Obvious calculation / General fact
Aged_55-59 (t)	Stock	Aged_55-59(t - dt) + (Aging_7 - Retirement_(Aging-Chain_Side)) * dt Initial value = 2073	Nurses	Number of registered nurses working in the facilities under PSO aged from 55 to 59 at a given time	Sawaengdee (2009) http://social.nesdb.go.th/social/
Retirement_(Aging-Chain_Side)	Outflow	Mature_Senior-Professional-Level_Retiring +Professional-Level_Retiring +Premature_Senior-Professional-Level_Retiring	Nurses/Years	Number of registered nurses working in the facilities under PSO retiring in a given year	Obvious calculation / General fact
At-Entrance_Civil-Servant_Placement_Rate	Variable	Positions_Allocated_to_New-Entry_Nurses/Time_to_Placement	Nurses/Years	Number of newly registered nurses entering facilities under PSO and placed at practitioner-level civil-servant positions in a given year.	Section 2.2.3, Chapter 2
Average_Time_to_Retirement	Variable	Aged_55-59/MAX(1, Retirement_(Aging-Chain_Side)	Years	Observed average time to retirement of nurses aged 55-59	Obvious calculation / General fact
Demand_Gap	Variable	(Target_Public_Nursing_Workforce-Total_Nurses_(Position-Chain_Side)+Total_Loss_of_Nurses)	Nurses	Number of registered nurses required to reach target Nurse-to-Patient ratio at a given point	Obvious calculation / General fact
Duration_of_Reopening_Vacated_Positions	Constant	0.1	Years	Time used to vacate civil-servant positions for new placements	Assumption/Calibration
Effect_of_Perception_of_Non-Civil Servant_1_towards_Civil-Servant_Placement_Opportunity_on_Vacating_Rate	Graphical Function	GRAPH(Perception_of_Non-Civil-Servant_1_towards_Civil-Servant_Placement_Opportunity) (1.000, 1.000), (1.900, 2.177), (2.800, 3.087), (3.700, 3.718), (4.600, 4.289), (5.500, 4.786), (6.400, 5.272), (7.300, 5.612), (8.200, 5.867), (9.100, 6.000), (10.000, 6.000)	Dimensionless	Non-linear relationship between the perception of civil-servant placement opportunity of non-civil-servant nurses with 1-2 years experience and the effect on their fractional vacating rate	Assumption/Calibration
Effect_of_Perception_of_Non-Civil-Servant_2_towards_Civil-Servant_Placement_Opp	Graphical Function	GRAPH(Perception_of_Non-Civil-Servant_2_towards_Civil-Servant_Placement_Opportunity) (1.000, 1.000), (1.900, 2.427), (2.800, 3.388), (3.700, 4.175), (4.600, 4.961), (5.500, 5.558), (6.400, 6.039), (7.300,	Dimensionless	Non-linear relationship between the perception of civil-servant placement opportunity of non-civil-servant nurses with 3-7 years experience and the effect on their fractional vacating rate	Assumption/Calibration

Name of element	Type	Equation / Value	Unit	Description	Source
ortunity_on_Vacating_R ate		6.461), (8.200, 6.796), (9.100, 7.000), (10.000, 7.000)			
Effect_of_Perception_of_ Non-Civil-Servant_3_towards_Civil - Servant_Placement_Opp ortunity_on_Vacating_R ate	Graphical Function	GRAPH(Perception_of_Non-Civil-Servant_3_towards_Civil-Servant_Placement_Opportunity) (1.000, 1.000), (1.900, 3.058), (2.800, 4.456), (3.700, 6.010), (4.600, 7.136), (5.500, 7.932), (6.400, 8.417), (7.300, 8.767), (8.200, 8.903), (9.100, 8.961), (10.000, 8.981)	Dimensionless	Non-linear relationship between the perception of civil-servant placement opportunity of non-civil-servant nurses with 8-12 years experience and the effect on their fractional vacating rate.	Assumption/Calibration
Effect_of_Perception_of_ Professional-Level_4_towards_Career _Advancement_Opportu nity_on_Vacating_Rate	Graphical Function	GRAPH(Perception_of_Professional-Level_4_towards_Career_Advancement_O pportunity) (16000, 1.109), (16100, 2.507), (16200, 4.036), (16300, 5.369), (16400, 6.483), (16500, 7.444), (16600, 8.340), (16700, 8.864), (16800, 9.476), (16900, 9.913), (17000, 10.000)	Dimensionless	Non-linear relationship between the perception of career advancement opportunity to senior-professional-level of professional-level nurses with 23-27 years experience and the effect on their fractional vacating rate.	Assumption/Calibration
Effect_of_Perception_of_ Professional-Level_5_towards_Career _Advancement_Opportu nity_on_Vacating_Rate	Graphical Function	GRAPH(Perception_of_Professional-Level_5_towards_Career_Advancement_O pportunity) (1.00, 1.005), (10.90, 1.209), (20.80, 1.403), (30.70, 1.529), (40.60, 1.665), (50.50, 1.794), (60.40, 1.883), (70.30, 1.927), (80.20, 1.959), (90.10, 1.998), (100.00, 2.000)	Dimensionless	Non-linear relationship between the perception of career advancement opportunity to senior-professional-level of professional-level nurses with 28-32 years experience and the effect on their fractional vacating rate	Assumption/Calibration
Effect_of_Training_Burd en_on_Vacating_Rate	Graphical Function	GRAPH(Training_Burden_on_Senior_Nur ses) (1.000, 1.000), (1.100, 1.170), (1.200, 1.340), (1.300, 1.461), (1.400, 1.585), (1.500, 1.682), (1.600, 1.760), (1.700, 1.837), (1.800, 1.905), (1.900, 1.964), (2.000, 1.985)	Dimensionless	Non-linear relationship between the training burden of senior nurses and the effect on their fractional vacating rate	Assumption/Calibration
Fixed-Term_Hiring_Rate	Variable	Recruitment_Rate - At-Entrance_Civil-Servant_Placement_Rate	Nurses/Years	Number of newly registered nurses entering facilities under PSO without civil-servant status in a given year	Section 2.2.2-2.2.3, Chapter 2
Fraction_of_Nursing_Gr aduates_Opting_to_Start _in_Public_Hospitals	Constant	0.8	Dimensionless	Percentage of nursing graduates who opt to start their careers in public hospital under PSO	RESYST (2016)
Fraction_of_Population_ Using_Public_Healthcar e_Facilities	Constant	0.8	Dimensionless	Fraction of Thailand's population using public health facilities	(Viriyathorn, et al., 2017)
Fraction_of_Senior-Professional-Level_Positions	Constant	0.02	Dimensionless	Percentage of designated senior-professional-level positions to total civil-servant positions	Assumption/Calibration
Fractional_Change_Rate _in_Population	Graphical Function	GRAPH(TIME) (0.00, 0.00649), (1.00, 0.006), (2.00, 0.00563), (3.00, 0.00528), (4.00, 0.005), (5.00, 0.00488), (6.00, 0.00477), (7.00,	1/years	Percentage of change in Thailand's population	Year 2005-2017 : https://data.worldbank.org Year 2018-2030 : Assumption

Name of element	Type	Equation / Value	Unit	Description	Source
		0.00464), (8.00, 0.0044), (9.00, 0.004), (10.00, 0.0035), (11.00, 0.00299), (12.00, 0.0025), (13.00, 0.002), (14.00, 0.0015), (15.00, 0.001), (16.00, 0.0005), (17.00, 0.0), (18.00, 0.0), (19.00, 0.0), (20.00, 0.0), (21.00, 0.0), (22.00, 0.0), (23.00, 0.0), (24.00, 0.0), (25.00, 0.0), (26.00, 0.0), (27.00, 0.0), (28.00, 0.0), (29.00, 0.0), (30.00, 0.0)			
Fractional_Leaving_Rate _1	Variable	(Non-Civil-Servant_1_Leaving+Practitioner-Level_1_Vacating)/Aged_23-24	1/years	Percentage of registered nurses working in facilities under PSO, aged from 23 to 24, leaving the profession in a given year	Obvious calculation / General fact
Fractional_Leaving_Rate _2	Variable	(Practitioner-Level_2_Vacating+Non-Civil-Servant_2_Leaving)/Aged_25-29	1/years	Percentage of registered nurses working in facilities under PSO, aged from 25 to 29, leaving the profession in a given year	Obvious calculation / General fact
Fractional_Leaving_Rate _3	Variable	(Professional-Level_1_Vacating+Non-Civil-Servant_3_Leaving)/Aged_30-34	1/years	Percentage of registered nurses working in facilities under PSO, aged from 30 to 34, leaving the profession in a given year	Obvious calculation / General fact
Fractional_Leaving_Rate _4	Variable	Professional-Level_2_Vacating/Aged_35-39	1/years	Percentage of registered nurses working in facilities under PSO, aged from 35 to 39, leaving the profession in a given year	Obvious calculation / General fact
Fractional_Leaving_Rate _5	Variable	Professional-Level_3_Vacating/Aged_40-44	1/years	Percentage of registered nurses working in facilities under PSO, aged from 40 to 44, leaving the profession in a given year	Obvious calculation / General fact
Fractional_Leaving_Rate _6	Variable	Professional-Level_4_Vacating/Aged_45-49	1/years	Percentage of registered nurses working in facilities under PSO, aged from 45 to 49, leaving the profession in a given year	Obvious calculation / General fact
Fractional_Leaving_Rate _7	Variable	Professional-Level_5_Vacating/Aged_50-54	1/years	Percentage of registered nurses working in facilities under PSO, aged from 50 to 54, leaving the profession in a given year	Obvious calculation / General fact
Fractional_Non-Civil_Servant_1_Leaving_Rate	Variable	IF (SWITCH_Intention_to_Leave_(Non-Senior)<>0) THEN Reference_Fractional_Non-Civil_Servant_1_Leaving_Rate*Effect_of_Perception_of_Non-Civil-Servant_1_towards_Civil-Servant_Placement_Opportunity_on_Vacating_Rate ELSE Reference_Fractional_Non-Civil_Servant_1_Leaving_Rate	1/Years	Percentage of non-civil-servant registered nurses leaving the facilities under PSO with 1-2 years experience in a given year	Obvious calculation / General fact
Fractional_Non-Civil_Servant_2_Leaving_Rate	Variable	IF (SWITCH_Intention_to_Leave_(Non-Senior)<>0) THEN Reference_Fractional_Non-Civil_Servant_2_Leaving_Rate*Effect_of_Perception_of_Non-Civil-Servant_2_towards_Civil-Servant_Placement_Opportunity_on_Vaca	1/Years	Percentage of non-civil-servant registered nurses leaving the facilities under PSO with 3-7 years experience in a given year	Obvious calculation / General fact

Name of element	Type	Equation / Value	Unit	Description	Source
		ting_Rate ELSE Reference_Fractional_Non-Civil_Servant_2_Leaving_Rate			
Fractional_Non-Civil_Servant_3_Leaving_Rate	Variable	IF (SWITCH_Intention_to_Leave_(Non-Senior)<>0) THEN Reference_Fractional_Non-Civil_Servant_3_Leaving_Rate*Effect_of_Perception_of_Non-Civil-Servant_3_towards_Civil-Servant_Placement_Opportunity_on_Vacating_Rate ELSEReference_Fractional_Non-Civil_Servant_3_Leaving_Rate	1/Years	Percentage of non-civil-servant registered nurses leaving the facilities under PSO with 8-12 years experience in a given year	Obvious calculation / General fact
Fractional_Practitioner-Level_1_Vacating_Rate =	Constant	0.005	1/Years	Percentage of civil-servant registered nurses at practitioner level with 1-2 years experience leaving the facilities under PSO in a given year	Assumption/Calibration
Fractional_Practitioner-Level_2_Vacating_Rate =	Constant	0.005	1/Years	Percentage of civil-servant registered nurses at practitioner level with 3-6 years experience leaving the facilities under PSO in a given year	Assumption/Calibration
Fractional_Professional-Level_1_Vacating_Rate	Constant	0.005	1/Years	Percentage of civil-servant registered nurses at professional level with 7-12 years experience leaving the facilities under PSO in a given year	Assumption/Calibration
Fractional_Professional-Level_2_Vacating_Rate	Constant	0.005	1/Years	Percentage of civil-servant registered nurses at professional level with 13-17 years experience leaving the facilities under PSO in a given year	Assumption/Calibration
Fractional_Professional-Level_3_Vacating_Rate	Constant	0.005	1/Years	Percentage of civil-servant registered nurses at professional level with 18-22 years experience leaving the facilities under PSO in a given year	Assumption/Calibration
Fractional_Professional-Level_4_Vacating_Rate	Variable	IF (SWITCH_Intention_to_Leave_(Senior)<>0) THEN Reference_Fractional_Professional-Level_4_Vacating_Rate*(Effect_of_Perception_of_Professional-Level_4_towards_Career_Advancement_Opportunity_on_Vacating_Rate*Effect_of_Training_Burden_on_Vacating_Rate) ELSE Reference_Fractional_Professional-Level_4_Vacating_Rate	1/Years	Percentage of civil-servant registered nurses at professional level with 23-27 years experience leaving the facilities under PSO in a given year	Section 2.2.4, 2.4, Chapter 2
Fractional_Professional-Level_5_Vacating_Rate	Variable	IF (SWITCH_Intention_to_Leave_(Senior)<>0) THEN Reference_Fractional_Professional-Level_5_Vacating_Rate*(Effect_of_Perception_of_Professional-Level_5_towards_Career_Advancement_Opportunity_on_Vacating_Rate*Effect_of_T	1/Years	Percentage of civil-servant registered nurses at professional level with 28-32 years experience leaving the facilities under PSO in a given year	Section 2.2.4, 2.4, Chapter 2

Name of element	Type	Equation / Value	Unit	Description	Source
		raining_Burden_on_Vacating_Rate) ELSE Reference_Fractional_Professional-Level_5_Vacating_Rate			
In-Progress_Civil-Servant_Placement_Rate_1	Variable	Positions_Allocated_to_Non-Civil-Servant_1/Time_to_Placement	Nurses/Years	Number of non-civil-servant registered nurses working in facilities under PSO with 1-2 years experience placed in practitioner-level civil-servant positions in a given year	Section 2.2.2-2.2.3, Chapter 2
In-Progress_Civil-Servant_Placement_Rate_2	Variable	Positions_Allocated_to_Non-Civil-Servant_2/Time_to_Placement	Nurses/Years	Number of non-civil-servant registered nurses working in facilities under PSO with 3-7 years experience placed in practitioner-level civil-servant positions in a given year	Section 2.2.2-2.2.3, Chapter 2
In-Progress_Civil-Servant_Placement_Rate_3	Variable	Positions_Allocated_to_Non-Civil-Servant_3/Time_to_Placement	Nurses/Years	Number of non-civil-servant registered nurses working in facilities under PSO with 8-12 years experience placed in practitioner-level civil-servant positions in a given year	Section 2.2.2-2.2.3, Chapter 2
Mature_Senior-Professional_Promotion_Rate	Variable	Positions_Allocated_to_Professional-Level_5/Time_to_Placement	Nurses/Years	Number of professional nurses working in facilities under PSO with 28-32 years experience promoted to senior-professional positions in a given year	Section 2.2.3, Chapter 2
Mature_Senior-Professional-Level (t)	Stock (Conveyor)	Mature_Senior-Professional-Level(t - dt) + (Mature_Senior-Professional_Promotion - Mature_Senior-Professional-Level_Retiring) * dt Initial value = 2073 Transit time = 5	Nurses	Number of civil-servant registered nurses working in facilities under PSO at senior-professional level with more experience, at a given time	Section 2.2.3, Chapter 2
Mature_Senior-Professional_Promotion	Leakage Outflow	LEAKAGE FRACTION = Mature_Senior-Professional_Promotion_Rate/Professional-Level_5	Nurses/Years	Number of civil-servant registered nurses working in facilities under PSO and getting promoted from professional-level (28-32 years experience) to senior-professional-level positions in a given year	Section 2.2.3, Chapter 2
Mature_Senior-Professional-Level_Retiring	Conveyor Outflow/Inflow	*Depends on transit time of its source stock*	Nurses/Years	Number of civil-servant registered nurses at mature senior-professional level retiring in a given year	Section 2.2.4, Chapter 2
Max_Civil-Servant_Positions	Graphical Function	GRAPH(TIME) (0.00, 81000.0), (1.00, 81000.0), (2.00, 81000.0), (3.00, 81000.0), (4.00, 81000.0), (5.00, 81000.0), (6.00, 81000.0), (7.00, 81000.0), (8.00, 81000.0), (9.00, 84900.0), (10.00, 88800.0), (11.00, 92700.0), (12.00, 93000.0), (13.00, 93000.0), (14.00, 93000.0), (15.00, 93000.0), (16.00, 93000.0), (17.00, 93000.0), (18.00, 93000.0), (19.00, 93000.0), (20.00, 93000.0), (21.00, 93000.0), (22.00, 93000.0), (23.00, 93000.0), (24.00, 93000.0), (25.00, 93000.0)	Nurses	Maximum number of civil-servant positions for nursing profession	https://www.ocsc.go.th/ Sawaengdee (2017)

Name of element	Type	Equation / Value	Unit	Description	Source
Max_Non-Senior_Positions	Variable	Max_Civil-Servant_Positions*(1-Fraction_of_Senior-Professional-Level_Positions)	Nurses	Maximum number of non-senior civil-servant positions for nursing profession	Obvious calculation / General fact
Max_Senior_Positions		Max_Civil-Servant_Positions*(Fraction_of_Senior-Professional-Level_Positions)	Nurses	Maximum number of senior civil-servant positions for nursing profession	Obvious calculation / General fact
Non-Civil-Servant_1 (t)	Stock (Conveyor)	Non-Civil-Servant_1(t - dt) + (Fixed-Term_Hiring - Non-Civil_Servant_Assimilation_1 - In-Progress_Civil-Servant_Placement_1 - Non-Civil-Servant_1_Leaving) * dt Initial value = 1 Transit time = 2	Nurses	Number of non-civil-servant registered nurses working in facilities under PSO with 1-2 years experience, at a given time	Section 2.2.2, Chapter 2
Fixed-Term_Hiring	Inflow	Fixed-Term_Hiring_Rate	Nurses/Years	Number of newly registered nurses entering facilities under PSO and without civil-servant status in a given year	Section 2.2.2-2.2.3, Chapter 2
Non-Civil_Servant_Assimilation_1	Conveyor Outflow and Inflow	*Depends on transit time of its source stock*	Nurses/Years	Number of non-civil-servant registered nurses leaving the facilities under PSO with 1-2 years experience gaining experience in a given year	Section 2.2.2-2.2.3, Chapter 2
In-Progress_Civil-Servant_Placement_1	Leakage Outflow	LEAKAGE FRACTION = In-Progress_Civil-Servant_Placement_Rate_1/MAX(1, Non-Civil-Servant_1)	Nurses/Years	Number of non-civil-servant registered nurses working in facilities under PSO with 1-2 years experience placed in civil-servant positions in a given year	Section 2.2.2-2.2.3, Chapter 2
Non-Civil-Servant_1_Leaving	Leakage Outflow	LEAKAGE FRACTION = Fractional_Non-Civil_Servant_1_Leaving_Rate	Nurses/Years	Number of non-civil-servant registered nurses leaving the facilities under PSO with 1-2 years experience in a given year	Section 2.3.3, 2.4, Chapter 2
Non-Civil-Servant_2(t)	Stock (Conveyor)	Non-Civil-Servant_2(t - dt) + (Non-Civil_Servant_Assimilation_1 - Non-Civil_Servant_Assimilation_2 - In-Progress_Civil-Servant_Placement_2 - Non-Civil-Servant_2_Leaving) * dt Initial value = 1 Transit time = 5	Nurses	Number of non-civil-servant registered nurses working in facilities under PSO with 3-7 years experience, at a given time	Section 2.2.2-2.2.3, Chapter 2
Non-Civil_Servant_Assimilation_2	Conveyor Outflow and Inflow	*Depends on transit time of its source stock*	Nurses/Years	Number of non-civil-servant registered nurses leaving the facilities under PSO with 3-7 years experience gaining experience in a given year	Section 2.2.2-2.2.3, Chapter 2
In-Progress_Civil-Servant_Placement_2	Leakage Outflow	LEAKAGE FRACTION = In-Progress_Civil-Servant_Placement_Rate_2/MAX(1, Non-Civil-Servant_2)	Nurses/Years	Number of non-civil-servant registered nurses working in facilities under PSO with 3-7 years experience placed in civil-servant positions in a given year	Section 2.2.2-2.2.3, Chapter 2
Non-Civil-Servant_2_Leaving	Leakage Outflow	LEAKAGE FRACTION = Fractional_Non-Civil_Servant_2_Leaving_Rate	Nurses/Years	Number of non-civil-servant registered nurses leaving the facilities under PSO with 3-7 years experience in a given year	Section 2.3.3, 2.4, Chapter 2

Name of element	Type	Equation / Value	Unit	Description	Source
Non-Civil-Servant_3(t)	Stock	Non-Civil-Servant_3(t - dt) + (Non-Civil_Servant_Assimilation_2 - Non-Civil-Servant_3_Leaving - In-Progress_Civil-Servant_Placement_3) * dt Initial value = 1	Nurses	Number of non-civil-servant registered nurses working in facilities under PSO with 8-12 years experience, at a given time	Section 2.2.2-2.2.3, Chapter 2
Non-Civil-Servant_3_Leaving	Outflow	Non-Civil-Servant_3*Fractional_Non-Civil_Servant_3_Leaving_Rate	Nurses/Years	Number of non-civil-servant registered nurses leaving the facilities under PSO with 8-12 years experience in a given year	Section 2.3.3, 2.4, Chapter 2
In-Progress_Civil-Servant_Placement_3	Outflow and Inflow	In-Progress_Civil-Servant_Placement_Rate_3	Nurses/Years	Number of non-civil-servant registered nurses working in facilities under PSO with 8-12 years experience placed in civil-servant positions in a given year	Section 2.2.2-2.2.3, Chapter 2
Non-Senior-Level_Nurses	Variable	Practitioner-Level_1+Practitioner-Level_2+Professional-Level_1+Professional-Level_2+Professional-Level_3+Professional-Level_4+Professional-Level_5	Nurses	Total number of civil-servants nurses with practitioner level and professional level, implying number of fulfilled practitioner-level and professional level positions at a given time	Obvious calculation / General fact
Open_Non-Senior_Positions	Variable	Vacant_Non-Senior_Positions+(Practitioner-Level_1_Vacating+Practitioner-Level_2_Vacating+Professional-Level_1_Vacating+Professional-Level_2_Vacating+Professional-Level_3_Vacating+Professional-Level_4_Vacating+Professional-Level_5_Vacating+Professional-Level_Retiring)*Duration_of_Reopening_Vacated_Positions	Nurses	Total number of vacant civil-servant non-senior positions available for new placement in a given year	Obvious calculation / General fact
Open_Non-Senior_Positions_After_1st_Allocation	Variable	MAX(0, Open_Non-Senior_Positions-Positions_Allocated_to_Non-Civil-Servant_3)	Nurses	Number of vacant civil-servant non-senior positions available for non-civil-servant registered nurses working in facilities under PSO with 3-7 years experience in a given year	Section 2.2.2-2.2.3, Chapter 2
Open_Non-Senior_Positions_After_2nd_Allocation	Variable	MAX(0, Open_Non-Senior_Positions_After_1st_Allocation-Positions_Allocated_to_Non-Civil-Servant_2)	Nurses	Number of vacant civil-servant non-senior positions available for non-civil-servant registered nurses working in facilities under PSO with 1-2 years experience in a given year	Section 2.2.2-2.2.3, Chapter 2
Open_Non-Senior_Positions_After_3rd_Allocation	Variable	MAX(0, Open_Non-Senior_Positions_After_2nd_Allocation-Positions_Allocated_to_Non-Civil-Servant_1)	Nurses	Number of vacant civil-servant non-senior positions available for new-entry registered nurses in a given year	Section 2.2.2-2.2.3, Chapter 2
Open_Senior_Positions =	Variable	MAX(1, Vacant_Senior_Positions+(Mature_Senior-Professional-Level_Retiring+Premature_Senior-Professional-	Nurses	Total number of vacant civil-servant senior positions available for new placement in a given year.	Obvious calculation / General fact

Name of element	Type	Equation / Value	Unit	Description	Source
		Level_Retiring)*Duration_of_Reopening_Vacated_Positions)			
Open_Senior_Positions_After_1st_Allocation	Variable	MAX(0, Open_Senior_Positions-Positions_Allocated_to_Professional-Level_5)	Nurses	Number of vacant senior positions available for professional-level nurses working in facilities under PSO with 23-27 years experience in a given year	Section 2.2.2-2.2.3, Chapter 2
Perception_of_Non-Civil-Servant_1_towards_Civil-Servant_Placement_Opportunity =	Variable	Non-Civil-Servant_1/MAX(1, Open_Non-Senior_Positions_After_2nd_Allocation)	Dimensionless	The perception of non-civil-servant nurses with 1-2 years experience towards the civil-servant placement opportunity	Section 2.4, Chapter 2
Perception_of_Non-Civil-Servant_2_towards_Civil-Servant_Placement_Opportunity	Variable	Non-Civil-Servant_2/MAX(1, Open_Non-Senior_Positions_After_1st_Allocation)	Dimensionless	The perception of non-civil-servant nurses with 3-7 years experience towards the civil-servant placement opportunity	Section 2.4, Chapter 2
Perception_of_Non-Civil-Servant_3_towards_Civil-Servant_Placement_Opportunity	Variable	Non-Civil-Servant_3/MAX(1, Open_Non-Senior_Positions)	Dimensionless	The perception of non-civil-servant nurses with 8-12 years experience towards the civil-servant placement opportunity	Section 2.4, Chapter 2
Perception_of_Professional-Level_4_towards_Career_Advancement_Opportunity	Variable	Professional-Level_4/MAX(1, Open_Senior_Positions_After_1st_Allocation)	Dimensionless	The perception of professional-level nurses with 23-27 years experience towards the career advancement (to senior-professional-level) opportunity	Section 2.4, Chapter 2
Perception_of_Professional-Level_5_towards_Career_Advancement_Opportunity	Variable	Professional-Level_5/MAX(1, Open_Senior_Positions)	Dimensionless	The perception of professional-level nurses with 28-32 years experience towards the career advancement (to senior-professional-level) opportunity	Section 2.4, Chapter 2
Population(t)	Stock	Population(t - dt) + (Net_Change_in_Population) * dt Initial value = 65425000	People	Number of Thailand's population	https://data.worldbank.org
Net_Change_in_Population	Flow	Population*Fractional_Change_Rate_in_Population	People/Years	Net change in Thailand's population in a given year	Obvious calculation / General fact
Population_Using_Public_Healthcare_Facilities	Variable	Population*Fraction_of_Population_Using_Public_Healthcare_Facilities	People	Number of Thailand's population using public healthcare facilities under PSO	Obvious calculation / General fact
Positions_Allocated_to_New-Entry_Nurses	Variable	IF(Open_Non-Senior_Positions_After_3rd_Allocation>Recruitment_Rate*Time_to_Placement) THEN (Recruitment_Rate*Time_to_Placement)	Nurses	Number of vacant civil-servant non-senior positions allocated to new-entry registered nurses in a given year	Section 2.2.2-2.2.3, Chapter 2

Name of element	Type	Equation / Value	Unit	Description	Source
		ELSE (IF(Open_Non-Senior_Positions_After_3rd_Allocation>0) THEN (Open_Non-Senior_Positions_After_3rd_Allocation) ELSE 0)			
Positions_Allocated_to_Non-Civil-Servant_1	Variable	IF(Open_Non-Senior_Positions_After_2nd_Allocation>Non-Civil-Servant_1) THEN (Non-Civil-Servant_1) ELSE (IF(Open_Non-Senior_Positions_After_2nd_Allocation>0) THEN (Open_Non-Senior_Positions_After_2nd_Allocation) ELSE 0)	Nurses	Number of vacant civil-servant non-senior positions allocated to non-civil-servant registered nurses working in facilities under PSO with 1-2 years experience in a given year	Section 2.2.2-2.2.3, Chapter 2
Positions_Allocated_to_Non-Civil-Servant_2	Variable	IF(Open_Non-Senior_Positions_After_1st_Allocation>Non-Civil-Servant_2) THEN (Non-Civil-Servant_2) ELSE (IF(Open_Non-Senior_Positions_After_1st_Allocation>0) THEN (Open_Non-Senior_Positions_After_1st_Allocation) ELSE 0)	Nurses	Number of vacant civil-servant non-senior positions allocated to non-civil-servant registered nurses working in facilities under PSO with 3-7 years experience in a given year	Section 2.2.2-2.2.3, Chapter 2
Positions_Allocated_to_Non-Civil-Servant_3	Variable	IF(Open_Non-Senior_Positions>Non-Civil-Servant_3) THEN (Non-Civil-Servant_3) ELSE (IF(Open_Non-Senior_Positions>0) THEN (Open_Non-Senior_Positions) ELSE 0)	Nurses	Number of vacant civil-servant non-senior positions allocated to non-civil-servant registered nurses working in facilities under PSO with 8-12 years experience in a given year	Section 2.2.2-2.2.3, Chapter 2
Positions_Allocated_to_Professional-Level_4	Variable	IF(Open_Senior_Positions_After_1st_Allocation>Professional-Level_4) THEN (Professional-Level_4) ELSE (IF(Open_Senior_Positions_After_1st_Allocation>0) THEN (Open_Senior_Positions_After_1st_Allocation) ELSE 0)	Nurses	Number of senior-professional positions allocated to professional-level nurses working in facilities under PSO with 23-27 years experience in a given year	Section 2.2.2-2.2.3, Chapter 2
Positions_Allocated_to_Professional-Level_5	Variable	IF(Open_Senior_Positions>Professional-Level_5) THEN (Professional-Level_5) ELSE (IF(Open_Senior_Positions>0) THEN (Open_Senior_Positions) ELSE 0)	Nurses	Number of senior-professional positions allocated to professional-level nurses working in facilities under PSO with 28-32 years experience in a given year	Section 2.2.2-2.2.3, Chapter 2
Practitioner-Level_1(t)	Stock (Conveyor)	Practitioner-Level_1(t - dt) + (At-Entrance_Civil-Servant_Placement + In-Progress_Civil-Servant_Placement_1 - Civil-Servant_Assimilation_1 - Practitioner-Level_1_Vacating) * dt Initial value = 575	Nurses	Number of civil-servant registered nurses working in facilities under PSO at practitioner level with 1-2 years experience, at a given time	Office of the Civil Service Commission (2018) Office of the Civil Service Commission Website

Name of element	Type	Equation / Value	Unit	Description	Source
		Transit time = 2			
At-Entrance_Civil-Servant_Placement	Inflow	At-Entrance_Civil-Servant_Placement_Rate	Nurses/Years	Number of newly registered nurses entering facilities under PSO and placed at practitioner-level civil-servant positions in a given year	Section 2.2.2-2.2.3, Chapter 2
Civil-Servant_Assimilation_1	Conveyor Outflow/Inflow	*Depends on transit time of its source stock*	Nurses/Years	Number of civil-servant registered nurses at practitioner level with 1-2 years experience gaining experience in a given year	Section 2.2.2-2.2.3, Chapter 2
Practitioner-Level_1_Vacating	Leakage Outflow	LEAKAGE FRACTION = Fractional_Practitioner-Level_1_Vacating_Rate	Nurses/Years	Number of civil-servant registered nurses at practitioner level with 1-2 years experience leaving the facilities under PSO in a given year	Obvious calculation / General fact
Practitioner-Level_2(t)	Stock (Coveyor)	Practitioner-Level_2(t - dt) + (Civil-Servant_Assimilation_1 + In-Progress_Civil-Servant_Placement_2 - Professional_Promotion - Practitioner-Level_2_Vacating) * dt Initial value = 15228 Transit time = 4	Nurses	Number of civil-servant registered nurses working in facilities under PSO at practitioner-level with 3-6 years experience, at a given time	Office of the Civil Service Commission (2018) Office of the Civil Service Commission Website
Professional_Promotion		*Depends on transit time of its source stock*	Nurses/Years	Number of civil-servant registered nurses working in facilities under PSO and getting promoted from practitioner-level to professional-level positions in a given year	Section 2.2.2-2.2.3, Chapter 2
Practitioner-Level_2_Vacating	Leakage Outflow	LEAKAGE FRACTION = Fractional_Practitioner-Level_2_Vacating_Rate	Nurses/Years	Number of civil-servant registered nurses at practitioner level with 3-6 years experience leaving the facilities under PSO in a given year	Obvious calculation / General fact
Premature_Senior-Professional_Promotion_Rate	Variable	Positions_Allocated_to_Professional-Level_4/Time_to_Placement	Nurses/Years	Number of professional nurses working in facilities under PSO with 23-27 years experience promoted to senior-professional positions in a given year	Obvious calculation / General fact
Premature_Senior-Professional-Level(t)	Stock (Coveyor)	Premature_Senior-Professional-Level(t - dt) + (Premature_Senior-Professional_Promotion - Premature_Senior-Professional-Level_Retiring) * dt Initial value = 0 Transit time = 10	Nurses	Number of civil-servant registered nurses working in facilities under PSO at senior-professional level with less experience, at a given time	Office of the Civil Service Commission (2018) Office of the Civil Service Commission Website
Premature_Senior-Professional_Promotion	Leakage Outflow	LEAKAGE FRACTION = Premature_Senior-Professional_Promotion_Rate/Professional-Level_4	Nurses/Years	Number of civil-servant registered nurses working in facilities under PSO and getting promoted from professional-level (18-22 years experience) to senior-professional-level positions in a given year	Section 2.2.2-2.2.3, Chapter 2
Premature_Senior-Professional-Level_Retiring	Conveyor Outflow	*Depends on transit time of its source stock*	Nurses/Years	Number of civil-servant registered nurses at premature senior-professional level retiring in a given year	Section 2.2.4, Chapter 2
Professional-Level_1(t)	Stock (Coveyor)	Professional-Level_1(t - dt) + (Professional_Promotion + In-Progress_Civil-Servant_Placement_3 -	Nurses	Number of civil-servant registered nurses working in facilities under PSO at professional level with 7-12 years experience, at a given time	Office of the Civil Service Commission (2018)

Name of element	Type	Equation / Value	Unit	Description	Source
		Civil-Servant_Assimilation_2 - Professional-Level_1_Vacating) * dt Initial value = 19423 Transit time = 6			Office of the Civil Service Commission Website
Civil-Servant_Assimilation_2	Conveyor Outflow/Inflow	*Depends on transit time of its source stock*	Nurses/Years	Number of civil-servant registered nurses at professional level with 7-12 years experience gaining experience in a given year	Section 2.2.2-2.2.3, Chapter 2
Professional-Level_1_Vacating	Leakage Outflow	Fractional_Professional-Level_1_Vacating_Rate	Nurses/Years	Number of civil-servant registered nurses at professional level with 7-12 years experience leaving the facilities under PSO in a given year	Obvious calculation / General fact
Professional-Level_2(t)	Stock (Conveyor)	Professional-Level_2(t - dt) + (Civil-Servant_Assimilation_2 - Civil-Servant_Assimilation_3 - Professional-Level_2_Vacating) * dt Initial value = 15390 Transit time = 5	Nurses	Number of civil-servant registered nurses working in facilities under PSO at professional level with 13-17 years experience, at a given time	Office of the Civil Service Commission (2018) Office of the Civil Service Commission Website
Civil-Servant_Assimilation_3	Conveyor Outflow/Inflow	*Depends on transit time of its source stock*	Nurses/Years	Number of civil-servant registered nurses at professional level with 13-17 years experience gaining experience in a given year	Section 2.2.2-2.2.3, Chapter 2
Professional-Level_2_Vacating	Leakage Outflow	Fractional_Professional-Level_2_Vacating_Rate	Nurses/Years	Number of civil-servant registered nurses at professional level with 13-17 years experience leaving the facilities under PSO in a given year	Obvious calculation / General fact
Professional-Level_3(t)	Stock (Conveyor)	Professional-Level_3(t - dt) + (Civil-Servant_Assimilation_3 - Civil-Servant_Assimilation_4 - Professional-Level_3_Vacating) * dt Initial value = 17487 Transit time = 5	Nurses	Number of civil-servant registered nurses working in facilities under PSO at professional level with 18-22 years experience, at a given time	Office of the Civil Service Commission (2018) Office of the Civil Service Commission Website
Civil-Servant_Assimilation_4	Conveyor Outflow/Inflow	*Depends on transit time of its source stock*	Nurses/Years	Number of civil-servant registered nurses at professional level with 18-22 years experience gaining experience in a given year	Section 2.2.2-2.2.3, Chapter 2
Professional-Level_3_Vacating	Leakage Outflow	Fractional_Professional-Level_3_Vacating_Rate	Nurses/Years	Number of civil-servant registered nurses at professional level with 18-22 years experience leaving the facilities under PSO in a given year	Obvious calculation / General fact
Professional-Level_4(t)	Stock (Conveyor)	Professional-Level_4(t - dt) + (Civil-Servant_Assimilation_4 - Civil-Servant_Assimilation_5 - Professional-Level_4_Vacating - Premature_Senior-Professional_Promotion) * dt Initial value = 7241 Transit time = 5	Nurses	Number of civil-servant registered nurses working in facilities under PSO at professional level with 23-27 years experience, at a given time	Office of the Civil Service Commission (2018) Office of the Civil Service Commission Website

Name of element	Type	Equation / Value	Unit	Description	Source
Civil-Servant_Assimilation_5	Conveyor Outflow/Inflow	*Depends on transit time of its source stock*	Nurses/Years	Number of civil-servant registered nurses at professional level with 23-27 years experience gaining experience in a given year	Section 2.2.2-2.2.3, Chapter 2
Professional-Level_4_Vacating	Leakage Outflow	Fractional_Professional-Level_4_Vacating_Rate	Nurses/Years	Number of civil-servant registered nurses at professional level with 23-27 years experience leaving the facilities under PSO in a given year	Obvious calculation / General fact
Professional-Level_5(t)	Stock (Conveyor)	Professional-Level_5(t - dt) + (Civil-Servant_Assimilation_5 - Professional-Level_Retiring - Professional-Level_5_Vacating - Mature_Senior-Professional_Promotion) * dt Initial value = 3944 Transit time = 5	Nurses	Number of civil-servant registered nurses working in facilities under PSO at professional level with 28-32 years experience, at a given time	Office of the Civil Service Commission (2018) Office of the Civil Service Commission Website
Professional-Level_Retiring	Conveyor Outflow	*Depends on transit time of its source stock*	Nurses/Years	Number of civil-servant registered nurses at professional level retiring in a given year	Section 2.2.4, Chapter 2
Professional-Level_5_Vacating	Leakage Outflow	Fractional_Professional-Level_45Vacating_Rate	Nurses/Years	Number of civil-servant registered nurses at professional level with 28-32 years experience leaving the facilities under PSO in a given year	Obvious calculation / General fact
Recruitment_Rate	Variable	IF(SWITCH_Demand_Side<>0) THEN MIN(10000, MAX(0, Demand_Gap/Adjustment_Time_to_Produce_Nursing_Graduates))*Fraction_of_Nursing_Graduates_Opting_to_Start_in_Public_Hospitals ELSE 4200	Nurses/Years	Number of newly registered nurses entering the facilities under PSO in a given year	Assumption/Calibration
Reference_Fractional_Non-Civil_Servant_1_Leaving_Rate	Constant	0.1	1/Years	Percentage of non-civil-servant registered nurses at professional level with 1-2 years experience leaving the facilities under PSO when they perceive sufficient opportunity of career advancement in a given year	Assumption/Calibration
Reference_Fractional_Non-Civil_Servant_2_Leaving_Rate	Constant	0.1	1/Years	Percentage of non-civil-servant registered nurses at professional level with 3-7 years experience leaving the facilities under PSO when they perceive sufficient opportunity of career advancement in a given year	Assumption/Calibration
Reference_Fractional_Non-Civil_Servant_3_Leaving_Rate	Constant	0.1	1/Years	Percentage of non-civil-servant registered nurses at professional level with 8-12 years experience leaving the facilities under PSO when they perceive sufficient opportunity of career advancement in a given year	Assumption/Calibration
Reference_Fractional_Professional-Level_4_Vacating_Rate	Constant	0.005	1/Years	Percentage of civil-servant registered nurses at professional level with 23-27 years experience leaving the facilities under PSO when they perceive sufficient opportunity of career advancement in a given year	Assumption/Calibration
Reference_Fractional_Professional-Level_5_Vacating_Rate	Constant	0.005	1/Years	Percentage of civil-servant registered nurses at professional level with 28-32 years experience leaving the facilities under PSO when they perceive sufficient opportunity of career advancement in a given year	Assumption/Calibration

Name of element	Type	Equation / Value	Unit	Description	Source
Senior-Professional-Level_Nurses	Variable	Premature_Senior-Professional-Level+Mature_Senior-Professional-Level	Nurses	Total number of civil-servants nurses with senior-professional level, implying number of fulfilled senior-professional level positions at a given time	Obvious calculation / General fact
SWITCH_Demand_Side	Constant	0+STEP(1, 5)	Dimensionless	Switch to activate demand calculation based on population	N/A
SWITCH_Intention_to_Leave_(Non-Senior)	Constant	1	Dimensionless	Switch to activate intention to leave effect for non-senior level nurses	N/A
SWITCH_Intention_to_Leave_(Senior)	Constant	1	Dimensionless	Switch to activate intention to leave effect for senior-level nurses	N/A
Target_Nurse-to-Patient_Ratio	Constant	1/400	Nurses/People	Target ratio of number of registered nurses to population	(World Health Organization, 2010)
Target_Public_Nursing_Workforce	Variable	Population_Using_Public_Healthcare_Facilities*Target_Nurse-to-Patient_Ratio	Nurses	Target number of registered nurses in public healthcare facilities under PSO	Obvious calculation / General fact
Time_to_Placement	Constant	1	Years	Time used to hire and place nurses	Assumption/Calibration
Total_Civil-Servant_Nurses	Variable	Non-Senior-Level_Nurses+Senior-Professional-Level_Nurses	Nurses	Total number of civil-servant nurses, implying total number of fulfilled civil-servant positions at a given time	Obvious calculation / General fact
Total_Loss_of_Nurses	Variable	(Practitioner-Level_1_Vacating+Practitioner-Level_2_Vacating+Professional-Level_4_Vacating+Professional-Level_1_Vacating+Professional-Level_2_Vacating+Professional-Level_3_Vacating+Non-Civil-Servant_3_Leaving+Professional-Level_5_Vacating+Professional-Level_Retiring+Mature_Senior-Professional-Level_Retiring+Premature_Senior-Professional-Level_Retiring+Non-Civil-Servant_2_Leaving+Non-Civil-Servant_1_Leaving)*Time_to_Placement	Nurses	Total number of nurses leaving or retiring from public healthcare facilities under PSO in a given year	Obvious calculation / General fact
Total_Nurses_(Aging-Chain_Side)	Variable	Aged_23-24+Aged_25-29+Aged_30-34+Aged_35-39+Aged_40-44+Aged_45-49+Aged_50-54+Aged_55-59	Nurses	Total number of registered nurses working in facilities under PSO at a given time, calculated from aging chain mechanism	Obvious calculation / General fact
Total_Nurses_(Position-Chain_Side)	Variable	Total_Civil-Servant_Nurses+Non-Civil-Servant_1+Non-Civil-Servant_2+Non-Civil-Servant_3	Nurses	Total number of nurses working in the facilities under PSO, calculated from position chain side	Obvious calculation / General fact
Training_Burden_on_Senior_Nurses	Variable	(Aged_23-24+Aged_25-29)/(Aged_45-49+Aged_50-54)	Dimensionless	Average number of junior nurses per senior nurse for on-the-job training, indicating training burden on senior nurses	Obvious calculation / General fact
Vacant_Non-Senior_Position	Variable	MAX(0, Max_Non-Senior_Positions-Non-Senior-Level_Nurses)	Nurses	Number of vacant civil-servant non-senior positions at a given time	Obvious calculation / General fact
Vacant_Senior_Positions	Variable	MAX(0, Max_Senior_Positions-Senior-Professional-Level_Nurses)	Nurses	Number of vacant civil-servant senior positions at a given time	Obvious calculation / General fact

Name of element	Type	Equation / Value	Unit	Description	Source
Weighted_Average_Age_of_Total_Nursing_Workforce	Variable	(Aged_23-24*23.5+Aged_25-29*27+Aged_30-34*32+Aged_35-39*37+Aged_40-44*42+Aged_45-49*47+Aged_50-54*52+Aged_55-59*57)/Total_Nurses_(Aging-Chain_Side)	Dimensionless	Weighted average age of total nursing workforce working in facilities under PSO	Obvious calculation / General fact