Addressing Mismatched Demand and Supply in Diabetic Care Delivery Systems Under Thailand's Universal Health Coverage

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Introduction

Thailand has successfully implemented Universal Health Coverage (UHC) since 2001(1). However, rapid increases in non-communicable diseases (NCDs) and an aging society have challenged the accessibility to quality healthcare for the population(1). One reason is the insufficient number of facilities designed for chronic and elderly care, resulting in limitations in the first decade of UHC policy implementation(2). NCDs have become the leading cause of death in Thailand, with chronic diseases accounting for 74% of all deaths in 2016(3). The leading causes include stroke, ischemic heart disease, diabetes, and chronic obstructive pulmonary disease(4).

Under Thailand's UHC policy, NCD patients can access treatment without paying for services or medication if they are part of the National Essential Medicines List(5). Patients can access registered healthcare facilities and receive referrals for more complex care, contributing to approximately 3.79% of the country's GDP in health expenditure(5). As Thailand transitions from a lower-middle-income country to an upper-middle-income country and aims for high-income status, its healthcare system may require additional investment to address the epidemiological changes(1). Among chronic NCDs, diabetes poses the most significant burden, being the primary disease for Thai men and the 7th highest burden for Thai women in 2014(6). The prevalence of age-adjusted diabetes increased from 8% in 2003 to 10% in 2013(7).

The increasing burden of NCDs highlights the need to change Thailand's healthcare systems under its UHC policy. Developing more efficient and higher-quality health services is crucial, as merely improving accessibility or increasing health service utilization might not directly improve the population's health, patient experiences, or equitable outcomes(8,9). However, global standards for high-quality healthcare for NCDs in low- and middle-income countries (LMICs) remain underdeveloped(8,9). This lack of precise policy interventions, combined with the rapidly increasing burden of chronic diseases, makes it difficult for many countries, including Thailand, to manage NCDs effectively. The rising burden of NCDs and the limited capacity of healthcare facilities to address the needs of chronic patients in Thailand may be further exacerbated by the COVID-19 pandemic(10). Appropriate policies for managing NCD patients during the pandemic could help reduce morbidity and mortality, such as developing telemedicine services for continuity of care(11). These new services require cooperation among various stakeholders to ensure the successful and sustainable implementation of telemedicine for NCDs in Thailand and other countries facing similar challenges in reforming their healthcare systems for NCD management.

When considering the World Health Organization's "4x4" framework for non-communicable disease control (12), which was later accepted in the United Nations General Assembly's High-Level Meeting on Non-communicable diseases (13), the main focus is on four NCDs: 1) cardiovascular diseases, 2) diabetes, 3) chronic respiratory diseases, and 4) cancers, as well as four risk factors: 1) tobacco use, 2) harmful use of alcohol, 3) unhealthy diets, and 4) physical inactivity. Among all aspects of the 4x4 framework, diabetes is a rapidly increasing non-communicable disease in Thailand (14,15). Hence, the current diabetes management in Thailand's healthcare system is an excellent example of the challenges and limitations in handling chronic diseases, especially in an aging society. Research on diabetes care models can provide lessons applicable to policies or care systems for cardiovascular, respiratory, and cancer diseases.

Although Thailand has implemented a universal health coverage policy since 2011, it still faces challenges due to limited health resources and increased health demands from an aging society. The epidemiological transition in the Thai population has shifted from infectious to non-communicable chronic diseases, along with issues in the quality of existing health service systems (18-22). The 5th Thai National Health Examination Survey (19) revealed at least three limitations in managing chronic diseases within the Thai healthcare system: 1) A large proportion of the Thai population has health risk factors related to type 2 diabetes, especially obesity, without appropriate management to reduce such risks. The prevalence of Thais aged 15 years and older with diabetes risk factors increased from 6.0% in 2009 to 8.9% in 2014; 2) Diabetes screening and diagnosis systems are not comprehensive or effective, as seen in the proportion of undiagnosed cases and newly detected diabetes from the survey, which rose from 31.2% in 2009 to 43.1% in 2014; and 3) The quality of diabetes treatment, which primarily occurs in hospitals, does not meet expectations, resulting in a reduced proportion of patients receiving adequate care and disease control (FBS <130mg/dl), dropping from 28.5% in 2009 to 23.5% in 2014.

Thailand continuously develops diabetes care guidelines through collaborations among the Thai Diabetes Association, the Thai Endocrine Society, the Ministry of Public Health, and the National Health Security Office. These guidelines are regularly updated and align with international standards like the American Diabetes Association (ADA)(20). The unsatisfactory results of diabetes management in Thailand's healthcare system are not due to a lack of clinical knowledge, but rather an implementation gap. A study from 2011 showed that only 21.5% of diabetic patients had eye examinations, and only 45% of those who should receive such services were examined. Additionally, relying on hospitals as the primary healthcare providers for diabetes care instead of specialized chronic disease clinics may contribute to limitations in providing effective and efficient health services for diabetic patients (21-23).

Policymakers can better understand the interrelationships between all system components by considering the healthcare system as part of a complex adaptive system (CAS) and a learning health system (24). Collaborating with various stakeholder groups in health policy laboratories enables a participatory policy development process, such as group model building (GMB) (25,26), which helps to understand the complex system structure and behaviors. This approach can lead to evidence-based and risk-managed policy decisions, multidisciplinary policy alternatives, and research methods supporting systems thinking, such as system dynamics modeling (SD) (27). These models can simulate policy alternatives' outcomes and provide national-level policymakers with a decision-support tool (DCT).

This research aims to create knowledge to address the lack of clear understanding regarding the inefficiency of chronic disease care for elderly patients in Thailand. The objectives are two-fold. First, to apply systems thinking and develop system dynamics models to analyze problems in the healthcare system that led to inefficiency in caring for elderly patients with chronic diseases in Thailand, using diabetes care as a case study. Second, to synthesize policy recommendations to improve chronic disease management in Thailand's aging society within 15 years (2023-2038) and project positive and negative impacts of healthcare system designs to support policy decision-making.

Methods

Study Setting

This research project was conducted by the research team of Mahidol University's Faculty of Medicine Ramathibodi Hospital in collaboration with the 7th Regional Health Office, Thailand's Ministry of Public Health. The project received support from the National Research Council of Thailand and additional support from The Better Health Programme Thailand under the Prosperity Fund managed by the Foreign and Commonwealth Development Office of the United Kingdom.

The study aims to develop decision-making tools for regional policymakers, managers, and practitioners in the local healthcare systems that provide care for chronic disease patients in the context of Thai society's aging population. We chose to work with the 7th Regional Health Office of the Ministry of Public Health and their diabetes care teams, which includes the provider in the provinces of Khon Kaen, Maha Sarakham, Roi Et, and Kalasin. This geographic area was selected because of its high prevalence of diabetes in northeastern Thailand and because its policymakers, managers, practitioners, and stakeholders were willing to collaborate with the research team in the aftermath of the COVID-19 pandemic.

We utilized a system dynamics model (SD) to analyze quantitative data from the database and qualitative data from stakeholders. SD is a mathematical modeling tool commonly used in health policy and systems research, allowing for a better understanding of complex system behavior over time. Unlike other modeling types, such as agent-based models (ABM), which focus on the behavior of individuals, SD targets system-level changes and resource movements over time. The model uses a set of differential equations to simulate changing variables over time and considers feedback loops and delays, allowing researchers to address simultaneous problems or shared causes of system behaviors. Although SD may overlook small details within complex health systems, it provides a way to explore the long-term impacts of strategic changes in patient care systems (28).

Therefore, developing a system dynamics model is suitable for understanding the nature of complex problems related to the inadequate healthcare system for elderly patients with diabetes in Thailand and for designing a healthcare system for this population. The research process for developing the system dynamics model consists of four main steps (29), including 1) problem articulation, which involves reviewing relevant literature on health care system design for the elderly in Thailand and developing dynamic hypotheses that can capture the system's behavior; 2) developing a causal model or causal map, which involves using data from group model building (GMB) sessions to develop a causal loop diagram (CLD) or casual mapping; 3) model formulation, which involves using data from GMB sessions to develop stock and flow diagrams (SFD) to create a system dynamics model and testing the model's validity and consistency; and 4) policy formulation and experimentation, which involves presenting policy options derived from the system dynamics model to policymakers and establishing a health policy laboratory to support the design of a health care system for the elderly in Thailand.

Group Model Building Process and Study Participants

We involved stakeholders in developing a system model for chronic disease patients in the context of an aging society in Thailand using Group Model Building (GMB) (25,26). The study participants included policymakers, managers, healthcare providers, and other stakeholders in the 7th Health Region, including those with knowledge about policy and healthcare management and diabetes care in the region and healthcare providers from all levels of healthcare facilities. A GMB workshop was held on July 8, 2022, in Khon Kaen province, with 39 participants attending our workshop.

The researchers (BL, PK, NI) facilitated the Group Model Building process. The facilitators used GMB scripts (26) to guide the meetings, which were developed based on best practices of group model building from publicly available sources such as Scriptapedia (30). The process included identifying the problem, linking relevant concepts, presenting causal loop diagrams, and analyzing qualitative and quantitative data to build a foundational structure for the system dynamics model.

First, the facilitators helped the study participants co-create causal loop diagrams (CLDs) that could explain the discrepancies between the needs and provisions of care for chronic disease patients in the context of elderly care in Thailand's 7th Health Region. The newly created CLDs captured all dimensions of diabetes care, including healthcare expenditure, payment models, health literacy, communication between physicians and patients, and patient and family culture and beliefs related to diabetes care. The revised and combined and revise CLD reveals the structure of the diabetic care systems, as shown on Figure 1, which include reinforcing loops (R) and balancing loops (B). It also shows four subsystems of diabetic care, including (1) diabetes incidence (R1); (2) capabilities of diabetes care and patient-related driving forces of increased age and death due to diabetes (B1 and B2); (3) continuity of NCD/diabetes care (R3); and (4) care during the transitional phase of the disease (R4). R1 highlighted the importance of public health intervention necessary to address the rapidly increasing demand for diabetes care. Meanwhile, R2, B1, and B2 showed the limitations of diabetes care facilities that may directly impact the quality of diabetes care and patient satisfaction during the care process. R4 and R5 indicated that changes in diabetes care and continuity of care are significant dimensions of chronic care management. Poor coordination between healthcare providers and diabetic patients may result in diabetic patients dropping out of the healthcare system.

Based on the co-created CLDs, the facilitators later elicited the structure of the quantitative stock and flow diagram (SFD) model from the participants. The facilitators enabled the participants to also consider the policy mechanisms within the healthcare system by discussing the structural model of the entire diabetes population in the region and their relevant care policy and management systems. The participants identified variables that could help open or close stock and flow towards improving the efficiency of diabetes care management in the region.

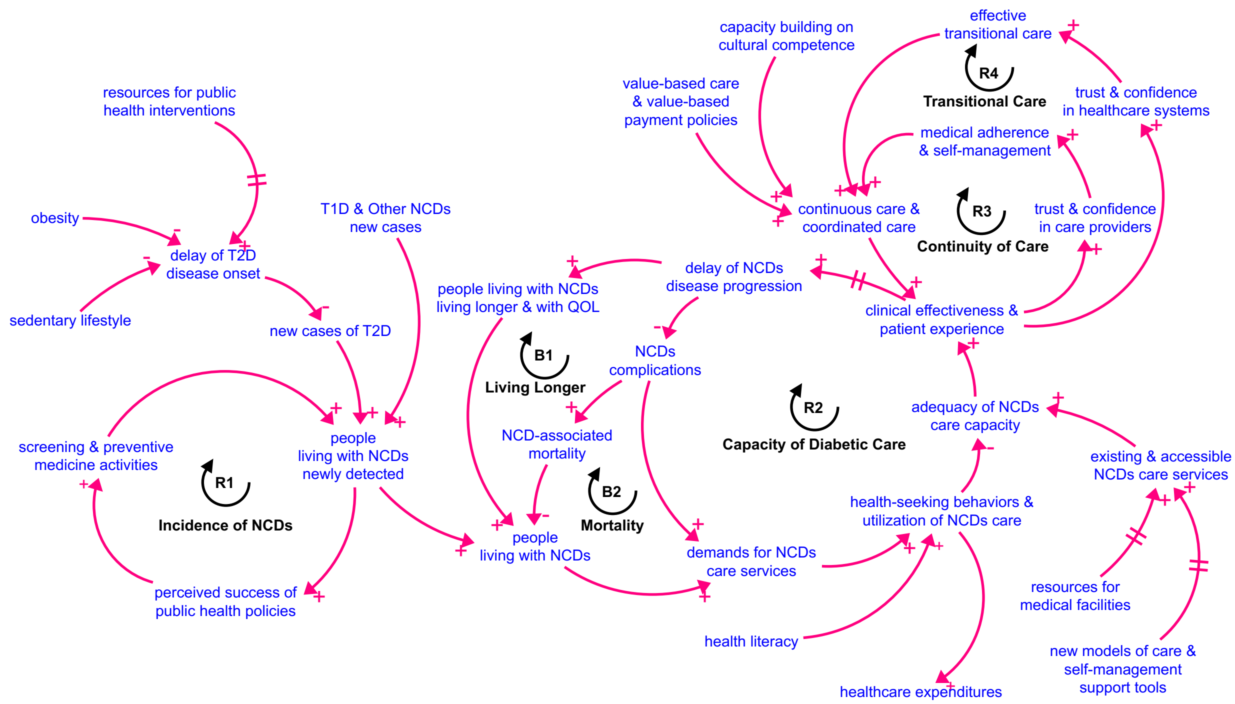


Figure 1 Causal loop diagram of diabetic care systems

Model Structure:

The UN 4 × 4 framework for non-communicable diseases (12, 13) was used as a basis to develop the model structure. The framework focuses on four groups of diseases (cardiovascular diseases, diabetes, chronic respiratory diseases, and cancer) and four sets of behavioral risk factors (smoking, harmful alcohol use, unhealthy diet, and physical inactivity). The model structure combines the diseases of the cardiovascular system and diabetes into one model because they are closely linked and share similar risk factors. The researchers used a Stock and Flow Diagram (SFD) to show the policy management and patient care system for diabetes in the region. The SFD shows the movement of people through each step of the disease process, including those with normal blood sugar levels, prediabetes, uncomplicated diabetes, and complicated diabetes. System's components and their relationships that may lead to inconsistencies in objectives and actions for diabetes patient care are highlighted in each module, as shown in Figure 2.

1) The Behavioral Risk Factors of Diabetes Module, which focuses on the four main behavioral risk factors of smoking, harmful alcohol consumption, unhealthy eating, and

physical inactivity that can affect the incidence of diabetes and cardiovascular diseases. These factors are important input parameters for this module.

2) The Population with Unobserved Diabetes Module, which addresses the hidden needs in diabetes patient care. The health status of the population can be classified into four groups: healthy population, high-risk population for diabetes, non-complex diabetes population, and complex diabetes population. The latter three groups represent the population with undiagnosed diabetes, and diagnosis is crucial for appropriate clinical management, including controlling high blood sugar, blood pressure, and lipids, which can significantly reduce the incidence, progression, and mortality rates of diabetes. Screening and diagnosis play a crucial role in diabetes management, as they can inform appropriate clinical management and facilitate resource allocation for prediabetes and diabetes within the region.
3) The Population with Observed Diabetes and Healthcare Delivery for People Living with Diabetes Module outlines the healthcare needs of individuals with diagnosed diabetes. The model shows that each person may have different health statuses based on the severity of their illness. These health statuses are divided into various groups based on the progress of their diabetes or the development of diabetes-related complications. The model also includes a program for accumulating additional data to represent the population who have been screened for diabetes but not yet diagnosed. The delay in diagnosis may be a significant problem for diabetes care in Thailand.

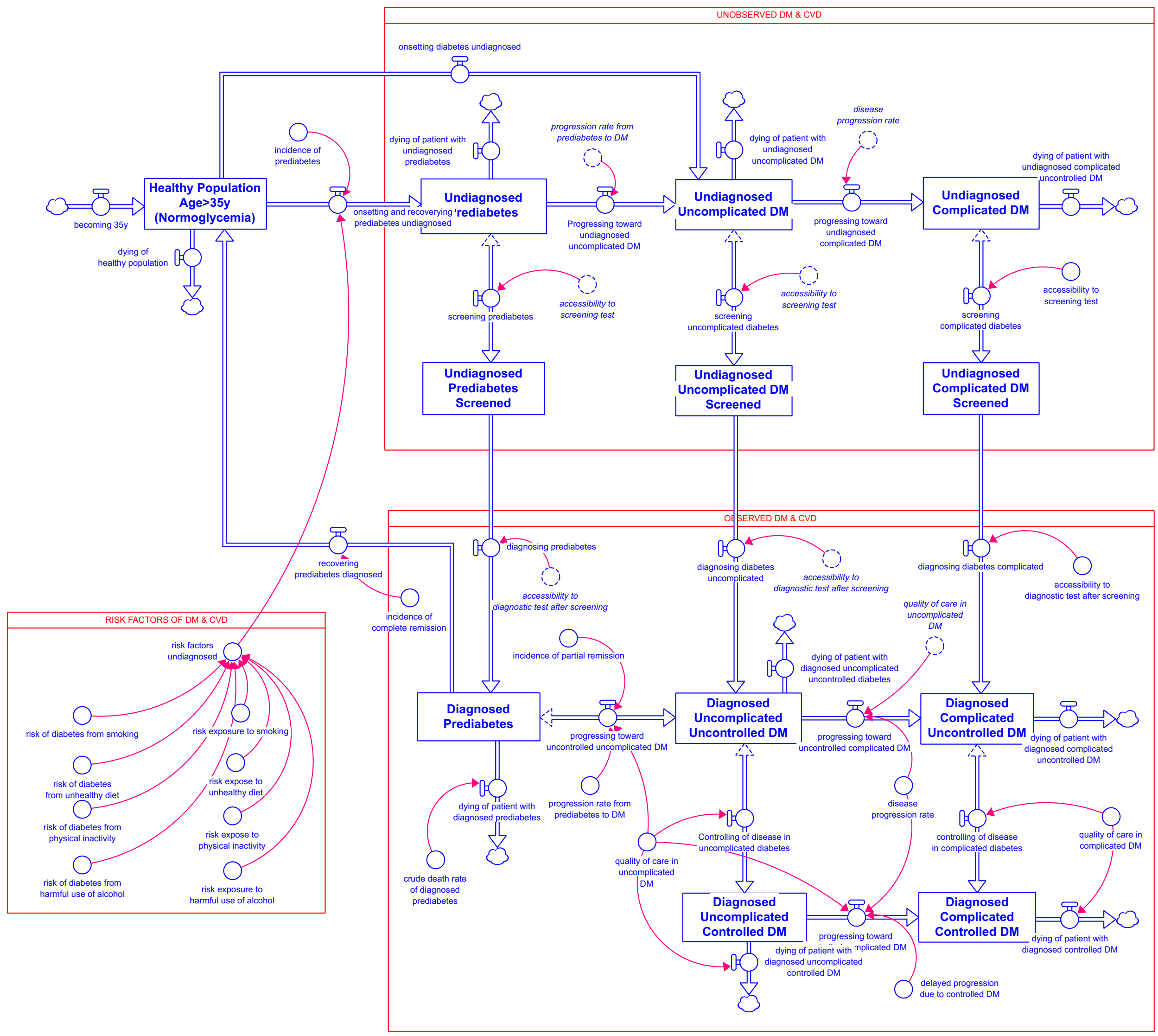


Figure 2 Stock and Flow diagram (SFD) demonstrating the structure of the model

Model Parameters:

The parameters used in the model are shown in Table 1. These parameters are used in the steady state of the model, which represents the balance of the system and is sensitive to the parameters used in the quantitative model. The parameters used in the system dynamics model are important for evaluating policies related to the health outcomes of people with diabetes within the policy management and healthcare system for diabetes patients in the 7th Health Region. The researchers cited data from the model-building process by considering the desired outcomes of the diabetes healthcare system in Thailand. These outcomes can be determined from the health status of the population (e.g., the proportion of healthy individuals), unmet health needs (e.g., the proportion of undiagnosed and uncontrolled diabetes), the quality of diabetes patient care (e.g., the mortality rate of patients, the proportion of well-controlled diabetes), and the costs or resources associated with diabetes patient care.

Most of the participants in the model-building process agreed that data from the Health Data Center (HDC) on the Ministry of Public Health's administrative database, as known as “the 43-folder files” (71), would be suitable for extracting data to develop a system dynamics model to reflect the control and prevention of diabetes in the Health Region. The parameters in the overall population health status model can be expressed as percentages. The parameters in the model that show the overall health status of the population can be represented by the percentage of the population with good health or the "healthy population" or "diabetes-free population," indicating that developing the capacity of the policy management and patient care systems for diabetes in the Health Region requires not only sufficient public health and disease prevention measures but also measures to reduce the risk factors for diabetes. The unmet health needs still reflect the access to necessary diabetes patient care for limited health status. However, researchers cannot use HR-QoL to model the overall health status of the population in the Health Region 7 because there is no such data reported or collected.

The parameters in the model that show the inadequacy of diabetes patient care, whether in terms of low medical service utilization (quantity-based) or poor quality of care (quality-based), not only affect the health status of the population but may also create other problems, such as creating negative patient experiences due to long waiting times in hospitals. In addition, the inadequacy of diabetes patient care can lead to unmet health needs that remain in the system in large numbers, possibly causing hospitals to be overwhelmed with a large number of diabetes patients and leading to uneven access to necessary diabetes patient care. The quality of diabetes patient care, therefore, includes chronic care and primary care for these patients, including emergency care for acute exacerbations/complications of diabetes and treatment.

In the future, the parameters in the model that show the results of the effectiveness in other dimensions of the policy management and patient care systems for diabetes in the Health Region can be added to the model structure. For instance, healthcare costs, which are a major concern of the government that wants to manage policy interventions or management within the healthcare system. The structure of the model can incorporate the costs of policy interventions or management in a new format if such interventions or management are specified by policy makers and stakeholders in the future.

Table 1 Model parameters

Name of Variables	Unit	Initial Value (2014)	Data Sources/References
prevalence of healthy population in northeast Thailand	dimensionless	0.743	Yan, Hanvoravongchai, Aekplakorn, Chariyalertsak, Kessomboon, Assanangkornchai, et al., 2020(43)

Table 1 Model parameters			
Name of Variables	**Unit**	**Initial Value (2014)**	**Data Sources/References**
prevalence of prediabetes in northeast Thailand	dimensionless	0.161	Yan, Hanvoravongchai, Aekplakorn, Chariyalertsak, Kessomboon, Assanangkornchai, et al., 2020(43)
prevalence of diabetes in northeast Thailand	dimensionless	0.0953	Yan, Hanvoravongchai, Aekplakorn, Chariyalertsak, Kessomboon, Assanangkornchai, et al. 2020(43)
prevalence of microvascular & macrovascular complications among people with diabetes	dimensionless	0.200	Estimated by the modellers, with a reference to Tracey, Gilmartin, O'Neill, Fitzgerald, McHugh, Buckley, et al., 2016.(33) (6.5–25.2 % retinopathy; 3.2–32.0 % neuropathy; 2.5-5.2 % nephropathy)
incidence of diabetes	per year	0.004	Estimated by the modellers, with a reference to National Health Exam Survey IV & V(NHES V * NHES V) 2015 (Increased prevalence of DM in Thailand from 6.9% in 2009 to 8.9% in 2014)
incidence of prediabetes	per year	0.0072	Estimated by the modellers, with a reference to National Health Exam Survey V (NHES V) 2014 (Increased prevalence of prediabetes in Thailand from 10.6% in 2009 to 14.2% in 2014)
incidence of partial remission (subdiabetic hyperglycemia)	per year	0.0028	Karter, Nundy, Parker, Moffet, Huang, 2014.(34)
incidence of complete remission (normoglybemia)	per year	0.00024	Karter, Nundy, Parker, Moffet, Huang, 2014.(34)
disease progression rate from prediabetes to diabetes	per year	0.0642	Wutthisathapornchai & Lertwattanarak, 2021(35)

Table 1 Model parameters			
Name of Variables	**Unit**	**Initial Value (2014)**	**Data Sources/References**
disease progression rate toward complicated diabetes	per year	0.095	Estimated by the modellers, with a reference to Boutayeb W, Lamlili ME, Boutayeb A, Derouich, 2015(36)
proportion of controlled diagnosed uncomplicated diabetes	dimensionless	0.1045	HDC Service Stand Reporting System, Ministry of Public Health (MoPH), 2014(31)
proportion of controlled diagnosed complicated diabetes	dimensionless	0.2553	HDC Service Stand Reporting System, Ministry of Public Health (MoPH), 2019(31)
newly controlled diabetes uncomplicated	per year	0.01	Estimated by the modellers
newly controlled diabetes complicated	per year	0.005	Estimated by the modellers
accessibility to screening test	dimensionless	0.670	Yan, Hanvoravongchai, Aekplakorn, Chariyalertsak, Kessomboon, Assanangkornchai, et al., 2020(43)
accessibility to diagnostic test	dimensionless	0.507	Yan, Hanvoravongchai, Aekplakorn, Chariyalertsak, Kessomboon, Assanangkornchai, et al., 2020(43)
healthy population age ≥ 35 year in thailand's 7th health region (normoglycemia)	people	3,7475,43	Estimated by the modellers, with a reference to HDC Service Stand Reporting System, Ministry of Public Health (MoPH) 2014(31) & Yan, Hanvoravongchai, Aekplakorn, Chariyalertsak, Kessomboon, Assanangkornchai, et al., 2020(72) (74.3% of 5,043,799)
unscreened and undiagnosed diabetes	people	92,302	Estimated by the modellers, with a reference to HDC Service Stand Reporting System,

Table 1 Model parameters			
Name of Variables	Unit	Initial Value (2014)	Data Sources/References
(prediabetes + uncomplicated diabetes + complicated diabetes)			Ministry of Public Health (MoPH), 2014(31) & Yan, Hanvoravongchai, Aekplakorn, Chariyalertsak, Kessomboon, Assanangkornchai, et al., 2020(43) (1.83% x 5,043,799)
screened but undiagnosed (prediabetes, uncomplicated diabetes, complicated diabetes)	people	160,392	Estimated by the modellers, with a reference to HDC Service Stand Reporting System, Ministry of Public Health (MoPH), 2014(31) & Yan, Hanvoravongchai, Aekplakorn, Chariyalertsak, Kessomboon, Assanangkornchai, et al., 2020(43) (3.18% x 5,043,799)
undiagnosed prediabetes	people	34,336	Estimated by the modellers, with a reference to HDC Service Stand Reporting System, Ministry of Public Health (MoPH), 2014 (31) & Yan, Hanvoravongchai, Aekplakorn, Chariyalertsak, Kessomboon, Assanangkornchai, et al., 2020(43) (37.2% of 92,302)
undiagnosed uncomplicated diabetes	people	46,373	Estimated by the modellers, with a reference to HDC Service Stand Reporting System, Ministry of Public Health (MoPH), 2014(31) & Tracey, Gilmartin, O'Neill, Fitzgerald, McHugh, Buckley, et al., 2016(33) (80% of 62.8% of 92,302)
undiagnosed complicated diabetes	people	11,593	Estimated by the modellers, with a reference to HDC Service Stand Reporting System, Ministry of Public Health (MoPH), 2014(31) & Tracey, Gilmartin, O'Neill, Fitzgerald, McHugh, Buckley, et al., 2016.(33) (20% of 62.8% of 92,302)
undiagnosed prediabetes screened	people	59,666	Estimated by the modellers, with a reference to HDC Service Stand Reporting System,

Table 1 Model parameters			
Name of Variables	**Unit**	**Initial Value (2014)**	**Data Sources/References**
			Ministry of Public Health (MoPH), 2014 (31) & Yan, Hanvoravongchai, Aekplakorn, Chariyalertsak, Kessomboon, Assanangkornchai, et al., 2020(43) (37.2% of 160,392)
undiagnosed uncomplicated diabetes screened	people	80,581	Estimated by the modellers, with a reference to HDC Service Stand Reporting System, Ministry of Public Health (MoPH), 2014(31) & Tracey, Gilmartin, O'Neill, Fitzgerald, McHugh, Buckley, et al., 2016(33) (80% of 62.8% of 160,392)
undiagnosed complicated diabetes screened	people	20,145	Estimated by the modellers, with a reference to HDC Service Stand Reporting System, Ministry of Public Health (MoPH), 2014(31) & Tracey, Gilmartin, O'Neill, Fitzgerald, McHugh, Buckley, et al., 2016(33) (20% of 62.8% of 160,392)
diagnosed prediabetes	people	133,437	HDC Service Stand Reporting System, Ministry of Public Health (MoPH), 2014(31)
diagnosed diabetes (uncomplicated, complicated, controlled, uncontrolled)	people	369,398	HDC Service Stand Reporting System, Ministry of Public Health (MoPH), 2015(31)
diagnosed uncomplicated uncontrolled diabetes	people	264,637	Estimated by the modellers, with a reference to HDC Service Stand Reporting System, Ministry of Public Health (MoPH), 2014(71)& Yan, Hanvoravongchai, Aekplakorn, Chariyalertsak, Kessomboon, Assanangkornchai, et al., 2020(43) & Tracey, Gilmartin, O'Neill,

Table 1 Model parameters			
Name of Variables	**Unit**	**Initial Value (2014)**	**Data Sources/References**
			Fitzgerald, McHugh, Buckley, et al., 2016(33) (80.0% of 89.55% of 369,398)
diagnosed uncomplicated controlled diabetes	people	30,881	Estimated by the modellers, with a reference to HDC Service Stand Reporting System, Ministry of Public Health (MoPH), 2014(31)& Yan, Hanvoravongchai, Aekplakorn, Chariyalertsak, Kessomboon, Assanangkornchai, et al., 2020(43) & Tracey, Gilmartin, O'Neill, Fitzgerald, McHugh, Buckley, et al., 2016(33) (80.0% of 10.45% of 369,398)
diagnosed complicated uncontrolled diabetes	people	55,018	Estimated by the modellers, with a reference to HDC Service Stand Reporting System, Ministry of Public Health (MoPH), 2014(31)& Yan, Hanvoravongchai, Aekplakorn, Chariyalertsak, Kessomboon, Assanangkornchai, et al., 2020(43) & Tracey, Gilmartin, O'Neill, Fitzgerald, McHugh, Buckley, et al., 2016(33) (20.0% of 74.47% of 369,398)
diagnosed complicated controlled diabetes	people	18,861	Estimated by the modellers, with a reference to HDC Service Stand Reporting System, Ministry of Public Health (MoPH), 2014(31)& Yan, Hanvoravongchai, Aekplakorn, Chariyalertsak, Kessomboon, Assanangkornchai, et al., 2020(43) & Tracey, Gilmartin, O'Neill, Fitzgerald, McHugh, Buckley, et al., 2016(33) (20.0% of 25.53% of 369,398)
risk of diabetes from smoking	dimensionless	1.40	The U.S. Department of Health and Human Services(37) (1.3 – 1.4x healthy population age ≥ 35 yr)

Table 1 Model parameters			
Name of Variables	**Unit**	**Initial Value (2014)**	**Data Sources/References**
risk of diabetes from unhealthy diet	dimensionless	1.30	Merino, Guasch-Ferré, Li, Chung, Hu, Ma, et al., 2022(38) (1.3x of healthy population age ≥ 35 yr)
risk of diabetes from physical inactivity	dimensionless	1.67	Hamburg, McMackin, Huang, Shenouda, Widlansky, Schulz, et al., 2007(39) (1.67x of healthy population age ≥ 35 yr)
risk of diabetes from harmful use of alcohol	dimensionless	1.80	Suebsamran, Choenchoopon, Rojanasaksothorn, Loiha, Chamnan, 2016(43) (1.47-1.80x of healthy population age ≥ 35 yrX
risk of expose to smoking	dimensionless	0.22	Estimated by the modellers, with a reference to the United Nations Department of Economics and Social Affairs' World Population Prospects, 2022(40)
risk of expose to unhealthy diet	dimensionless	0.10	Estimated by the modellers
risk of expose to physical inactivity	dimensionless	0.05	Estimated by the modellers
risk of expose to harmful use of alcohol	dimensionless	0.10	Estimated by the modellers
crude birth and net migration rate of Thailand's 7th health region	per year	0.0111	Estimated by the modellers, with a reference to the United Nations Department of Economics and Social Affairs' World Population Prospects, 2014(40)
delayed progression due to diabetic care	dimensionless	0.33	Estimated by the modellers
delayed disease progression of disease due to controlled diabetes	dimensionless	0.33	Estimated by the modellers

Table 1 Model parameters			
Name of Variables	**Unit**	**Initial Value (2014)**	**Data Sources/References**
effect of glycaemic control on mortality	dimensionless	0.455	Estimated by the modellers, with a reference to Landman, van Hateren, Kleefstra, Groenier, Gans, Bilo, 2010(41)
crude death rate of healthy population (normoglycemia)	per year	0.00732	Ares, Valdés, Botas, Sánchez-Ragnarsson, Rodríguez-Rodero, Morales-Sánchez, et al., 2019(42)
crude death rate of diagnosed prediabetes	deaths/ person-years	0.01164	Ares, Valdés, Botas, Sánchez-Ragnarsson, Rodríguez-Rodero, Morales-Sánchez, et al., 2019(42)
crude death rate of diagnosed uncomplicated uncontrolled diabetes	deaths/ person-years	0.02142	Ares, Valdés, Botas, Sánchez-Ragnarsson, Rodríguez-Rodero, Morales-Sánchez, et al., 2019(42)
crude death rate of diagnosed complicated uncontrolled diabetes	deaths/ person-years	0.03472	Ares, Valdés, Botas, Sánchez-Ragnarsson, Rodríguez-Rodero, Morales-Sánchez, et al., 2019(42)
crude death rate of undiagnosed prediabetes	deaths/ person-years	0.01280	Estimated by the modellers, with a reference to Ares, Valdés, Botas, Sánchez-Ragnarsson, Rodríguez-Rodero, Morales-Sánchez, et al., 2019(42) (1.1 x 0.01164)
crude death rate of undiagnosed uncomplicated diabetes	deaths/ person-years	0.03213	Estimated by the modellers, with a reference to Ares, Valdés, Botas, Sánchez-Ragnarsson, Rodríguez-Rodero, Morales-Sánchez, et al., 2019(42) (1.5 x 0.02142)
crude death rate of undiagnosed complicated diabetes	deaths/ person-years	0.06944	Estimated by the modellers with a reference to Ares, Valdés, Botas, Sánchez-Ragnarsson, Rodríguez-Rodero, Morales-Sánchez, et al., 2019(42) (2.0 x 0.03472)

Table 1 Model parameters			
Name of Variables	**Unit**	**Initial Value (2014)**	**Data Sources/References**
crude death rate of diagnosed uncomplicated controlled diabetes	deaths/ person-years	0.01161	Estimated by the modellers, with a reference to Ares, Valdés, Botas, Sánchez-Ragnarsson, Rodríguez-Rodero, Morales-Sánchez, et al., 2019(42) (0.75 x 0.02142)
crude death rate of diagnosed complicated controlled diabetes	per year	0.01580	Estimated by the modellers, with a reference to Ares, Valdés, Botas, Sánchez-Ragnarsson, Rodríguez-Rodero, Morales-Sánchez, et al., 2019(42) & Landman, van Hateren, Kleefstra, Groenier, Gans, Bilo, 2010(41) (0.455 x 0.03472)
effects of improving the effectiveness of public health interventions on risk exposure	dimensionless	0.50 (0.10-0.75)	Estimated by the modellers
effects of expanding the coverage of diagnostic test among the target population on diagnosis of prediabtes and diabetes	dimensionless	0.30 (0.10-0.50)	Estimated by the modellers
effects of modernising and enhancing quality performance of diabetic care on newly complete remission	dimensionless	0.25 (0.05-0.50)	Estimated by the modellers
effects of modernising and enhancing quality performance of	dimensionless	0.50 (0.05-0.50)	Estimated by the modellers

Table 1 Model parameters			
Name of Variables	Unit	Initial Value (2014)	Data Sources/References
diabetic care on newly complete remission			
effects of modernising and enhancing quality performance of diabetic care on delayed onset of diabetes and diabetic complications	dimensionless	0.50 (0.05-0.50)	Estimated by the modellers
effects of modernising and enhancing quality performance of diabetic care on newly controlled diabetes uncomplicated	dimensionless	0.50 (0.05-0.50)	Estimated by the modellers
effects of modernising and enhancing quality performance of diabetic care on newly complicated	dimensionless	0.25 (0.05-0.50)	Estimated by the modellers

Policy Options and Policy Experimentation:

The researchers used data from a modeling process generated by a synthetic group as policy options for testing policies on a situation model under five scenarios, each with parameters that vary over time. The scenarios include:

1) Scenario 1: the Business-as-usual (BAU) Scenario, where all main policies remain unchanged, including the efficiency of diabetes patient care and healthcare interventions for diabetes patients in Thailand's Health Region 7, throughout the 15-year period (2023-2038)
2) Scenario 2: Improving the effectiveness of healthcare interventions (Policy #1), which involves additional public funding, regulatory changes, and upgrading healthcare

personnel management to improve the effectiveness of healthcare interventions to address behavioral risk factors associated with diabetes, such as reducing smoking, alcohol consumption, unhealthy eating, and lack of physical activity, thereby reducing the risk of diabetes.

3) Scenario 3: Expanding diabetes screening among high-risk populations (Policy #2): This policy intervention focused on expanding screening for diabetes among high-risk populations starting from 2023. Access to diabetes diagnosis improved after screening.
4) Scenario 4: Improving quality of diabetes care in primary care units and hospitals (Policy #3): This policy intervention aimed to improve the quality of clinical services and increase the quantity and quality of diabetes care in primary care units and hospitals since 2023. The policy emphasized modernization and digitalization of primary care services and expanding public funding for diabetes care by private health providers. As a result, the proportion of diabetes controlled after treatment improved.
5) Scenario 5: Improving quality of care for diabetes and high-risk populations (Policy #4): This policy intervention aimed to improve the quality of diabetes care in primary care units and hospitals while focusing on comprehensive care for people at risk of developing diabetes. The number of high-risk individuals diagnosed with diabetes decreased over time, and the number of patients in complete remission increased.

Model Validation:

The developed healthcare system model has been validated using unit consistency, structural validity, and behavioral replication tests. The unit consistency test was conducted using the Stella Architect software to ensure that each parameter and variable has a meaningful and consistent interpretation throughout the model. The structural validity test was conducted during a practical workshop with policy makers, healthcare professionals, and researchers, who agreed that the model's structure reflects the real situation. The behavioral replication test was conducted using reference mode, which compared the model's output to real-world data from health surveys and statistics. The model showed a close approximation to the actual number of diabetic patients receiving healthcare in the health district and demonstrated a trend of increasing numbers over time.

Results

Simulated findings

The simulation model provide a prediction of the future scenario of the burden of diabetes and its cardiovascular complications (heart disease, and stroke) in the public health system for the next 15 years (2023-2038) as following.

1) Healthy Population: Without any policy intervention or additional management changes during 2566-2580 (run#1), the model predicted that 75.6% of the population in public health region 7 would live without chronic diseases in 2038. The decreasing trend of the proportion of healthy population corresponds to the increasing trend of the elderly

population, leading to a higher risk of diabetes in the region. The model results also showed that policy option 2 (run#3), which emphasizes expanding coverage of diagnostic testing in the targeted population, seems to be the most effective. It increased the predicted proportion of the healthy population in the health region without chronic diseases in 2038 to 76.3%, , as shown in Figure 3.

2) Population with Undiagnosed Diabetes or Prediabetes: The model predicted the prevalence of chronic diseases (diabetes and heart disease) among the population in the 7th Health Region in the next 15 years. In the absence of policy interventions or changes, the model predicts that 85.5% of the population living in Health Zone 7 with diabetes or heart disease will remain undiagnosed and untreated in 2038. Thus, 14.5% of the population will have unmet health needs due to undiagnosed diabetes. Using policy option #2 (run#3), which focuses on expanding screening and diagnosis for diabetes, the model predicts a reduction in unmet health needs by 11.5% in 2038, with an estimated 34,000 people remaining undiagnosed. This is lower than the 168,000 people estimated in the baseline scenario (BUA). The trend in unmet health needs is expected to decrease in the following years, as shown in Figure 4.
3) Well-controlled diabetes: The model predicted that without policy interventions or additional management changes, only 18.2% of the population in the Health Region with diagnosed diabetes or prediabetes will have well-controlled diabetes by 2580. However, implementing policies #3 and #4 to improve the quality of diabetes care can increase the proportion of well-controlled patients to 21.4%. Considering both undiagnosed and poorly controlled diabetes as indicators of health system quality or provider performance, the model estimates a high unmet health need among diabetes patients. In contrast, policy intervention #2, which aims to increase diabetes screening, can lead to a lower unmet need (17.3%) than the BAU scenario (18.2%). However, the trend of well-controlled diabetes patients in the health system in Zone 7 is expected to increase over time, leading to a decrease in unmet health needs.

4) Case-fatality Rate of Diabetes Patients If there is no policy intervention or additional management changes during 2566-2580, the model predicts a case-fatality rate of 1.86% for diabetes patients in the region in 2038. However, if we consider the case-fatality rate of both diagnosed and undiagnosed patients, it is expected to slightly decrease to 1.76% in 2038, as shown in figure 5.

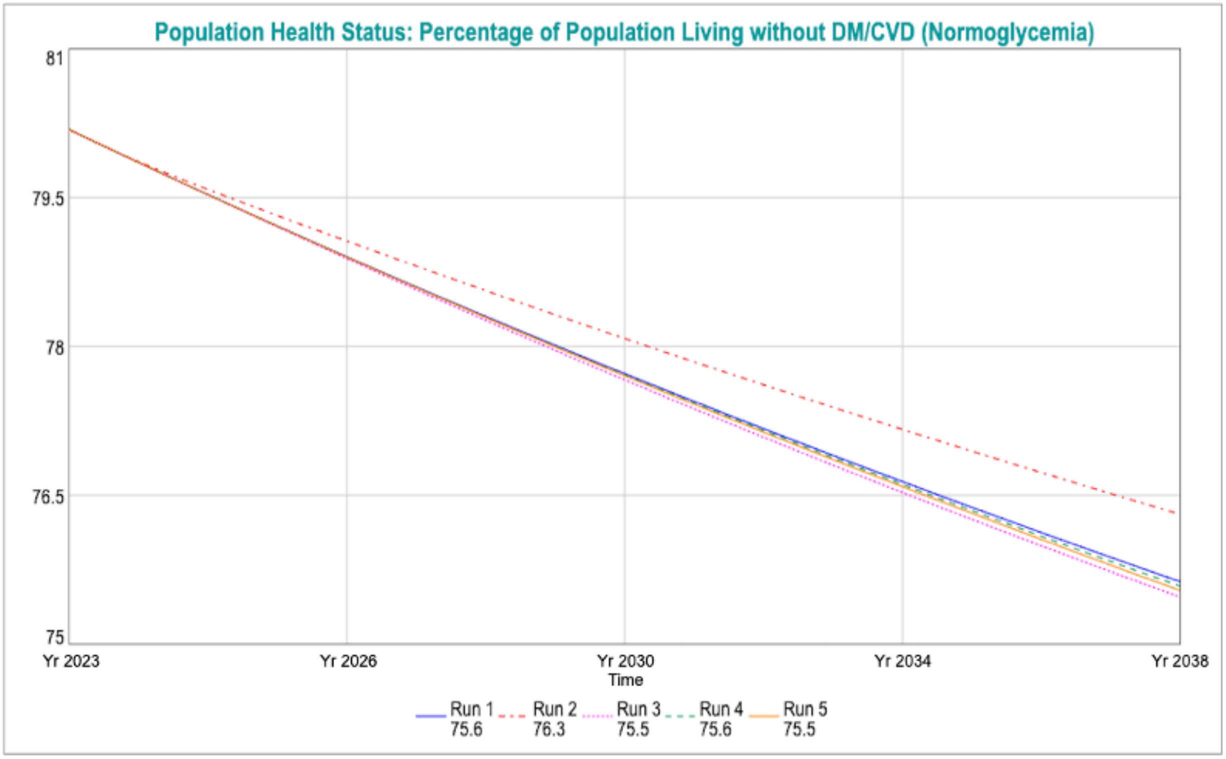


Figure 3 Predicted population living without diabetes

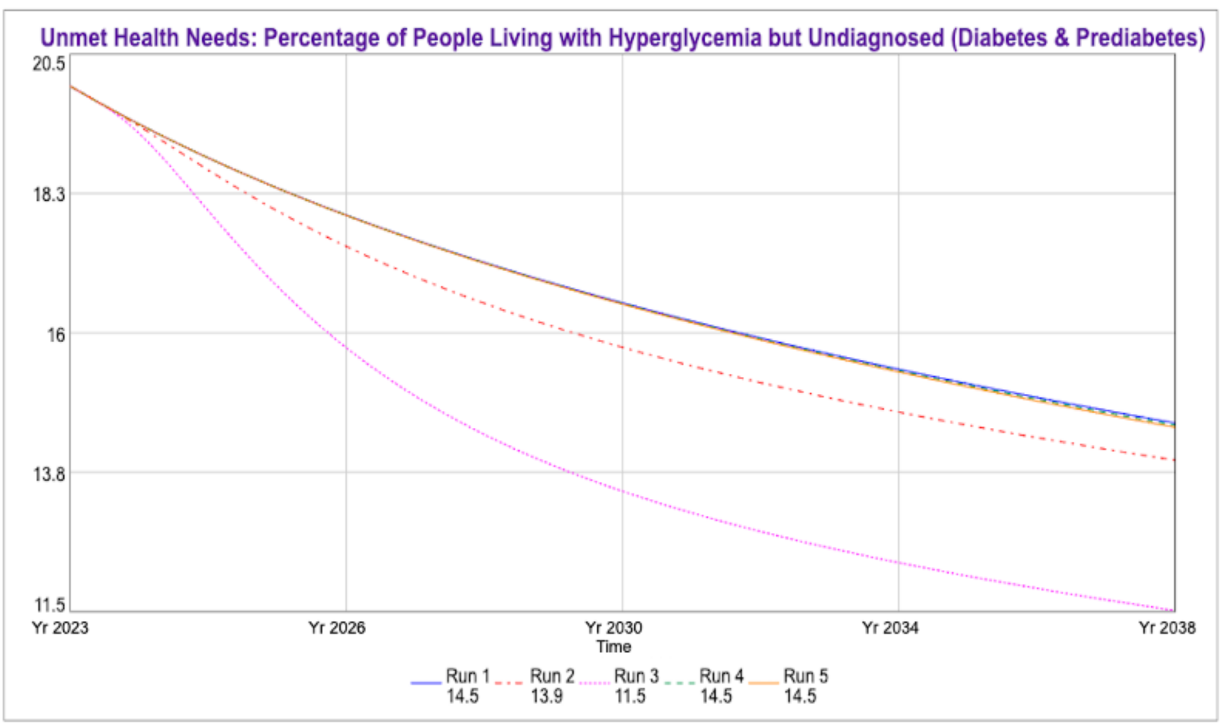


Figure 3 Predicted population living without diabetes

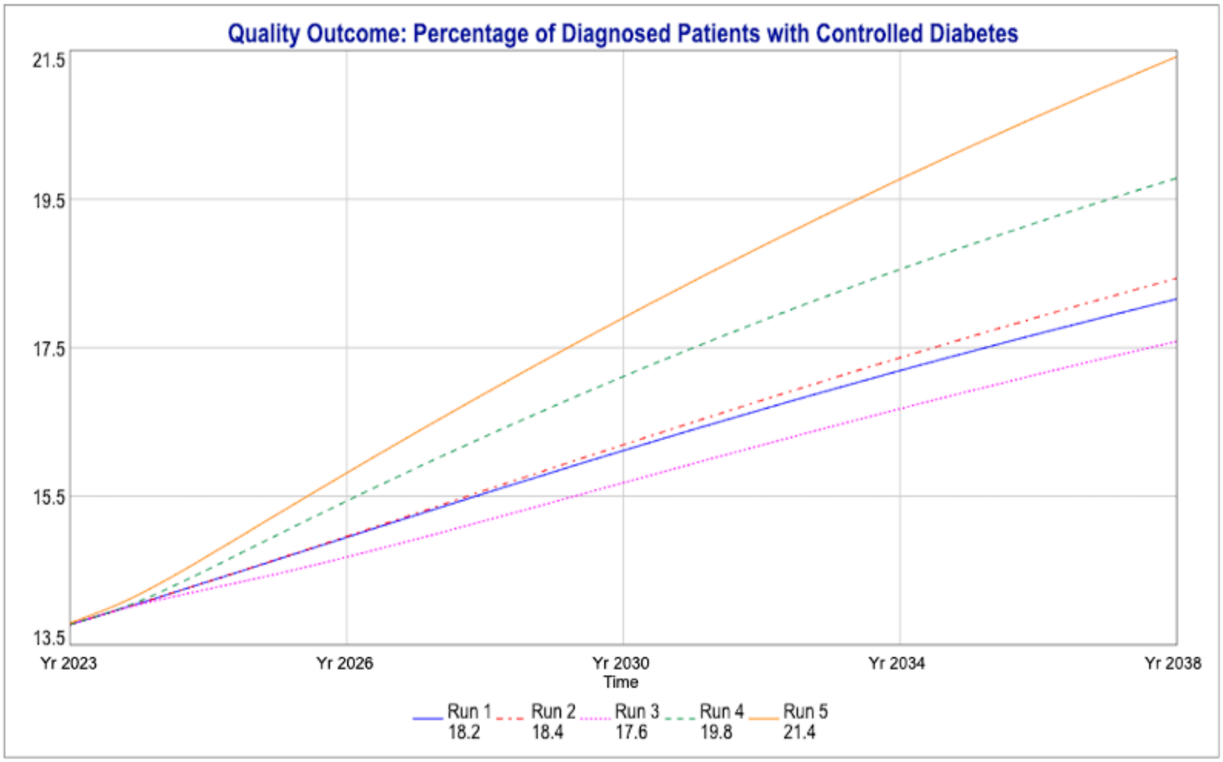


Figure 4 Predicted population with controlled diabetes

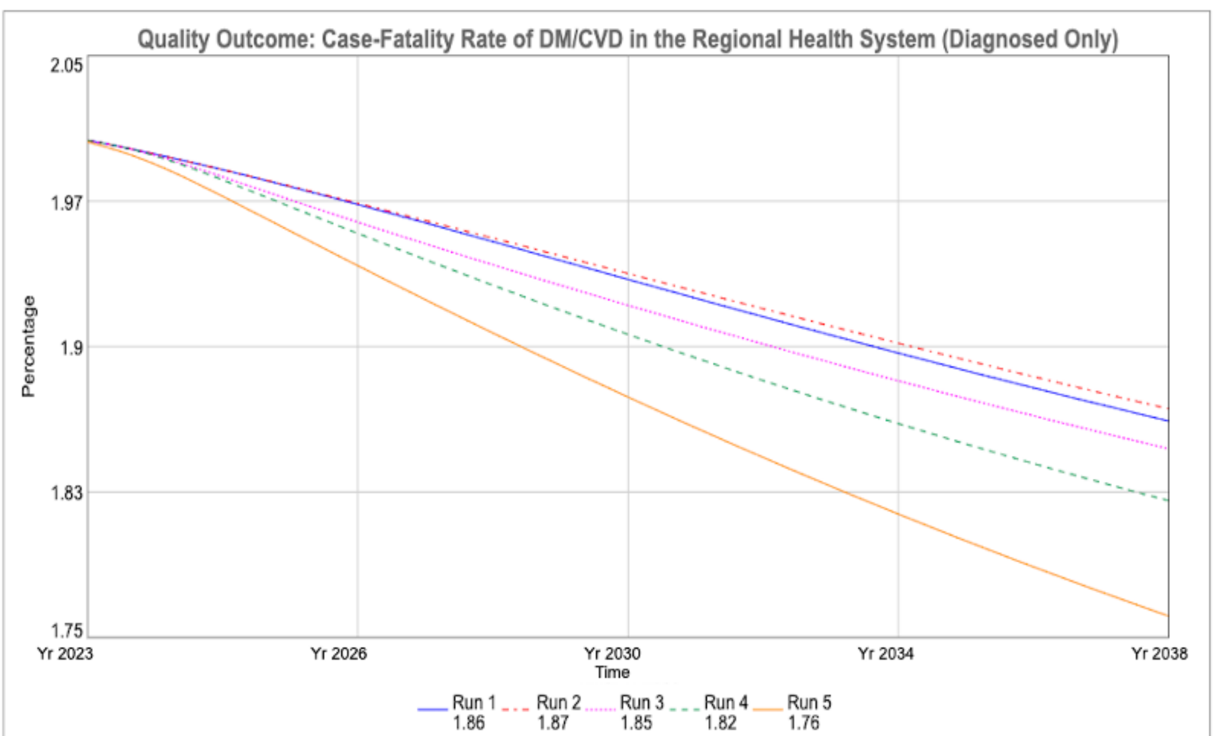


Figure 5 Predicted Case-fatality Rate of Diabetes Patients

Sensitivity Analysis

As the simulation model of the healthcare system can be used as a strategic decision-making tool for policy makers, it is important to evaluate the model's sensitivity to policy interventions or management changes that may occur in the actual healthcare system. In addition, the model can also forecast future events under different scenarios. The results of the model should be validated against historical data to increase decision-makers' confidence in the model. However, the model's results may not always be validated against all relevant indicators and there may be data gaps or inconsistencies that limit the ability of researchers to validate the model against all historical data. Therefore, we considered the best practice to address this issue is to conduct a sensitivity analysis on the most sensitive parameters that affect the model's results the most.
We tested the parameters that were problematic due to data limitations to reduce the risk of biased parameter estimation by the model's creator, and found that the effectiveness of each policy in each scenario may be greater or less than expected, and may have the greatest sensitivity and impact on the most important policy aspects such as unmet health needs and well-controlled diabetes patients, as shown in Figure 5A, 5B, 5C.

We focused on the sensitivity of the policy interventions' effectiveness on diabetes patients, particularly on unmet health needs and the proportion of well-controlled patients. We randomly sampled 500 scenarios, varying the effectiveness of each policy intervention from 0% to 100% and found that the projected percentage of diabetes patients with unmet health needs could range from 53.8% to 75.8%, while the proportion of well-controlled diabetes patients could range from 12.7% to 18.1%.

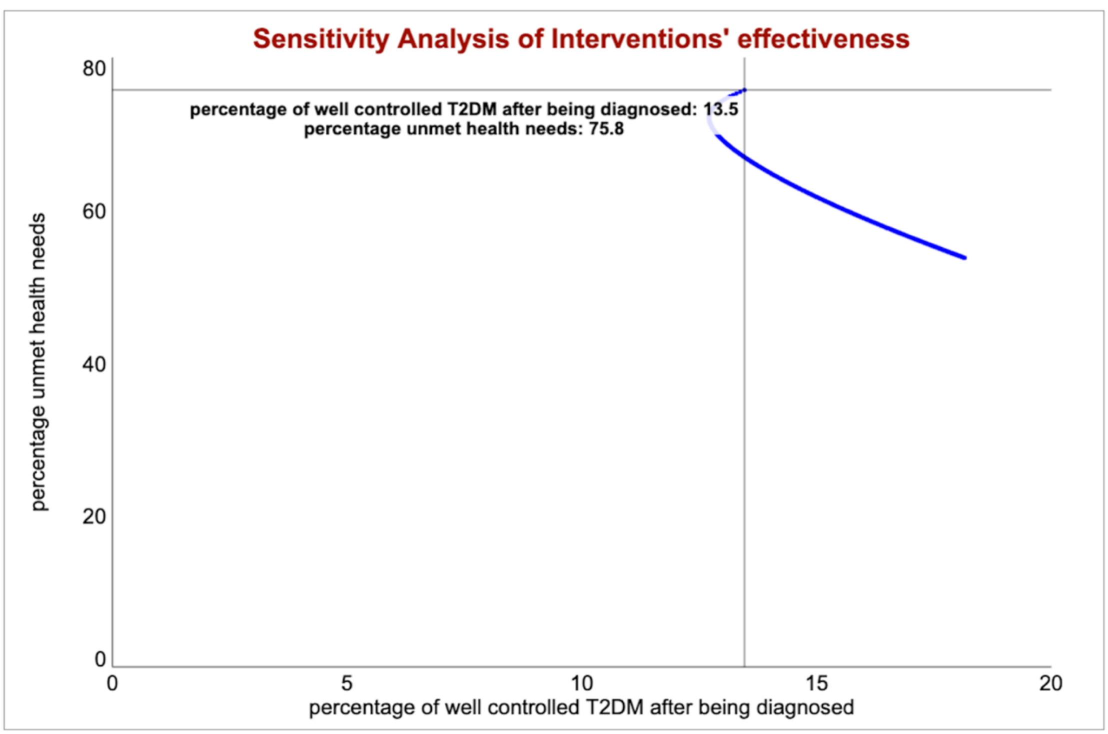
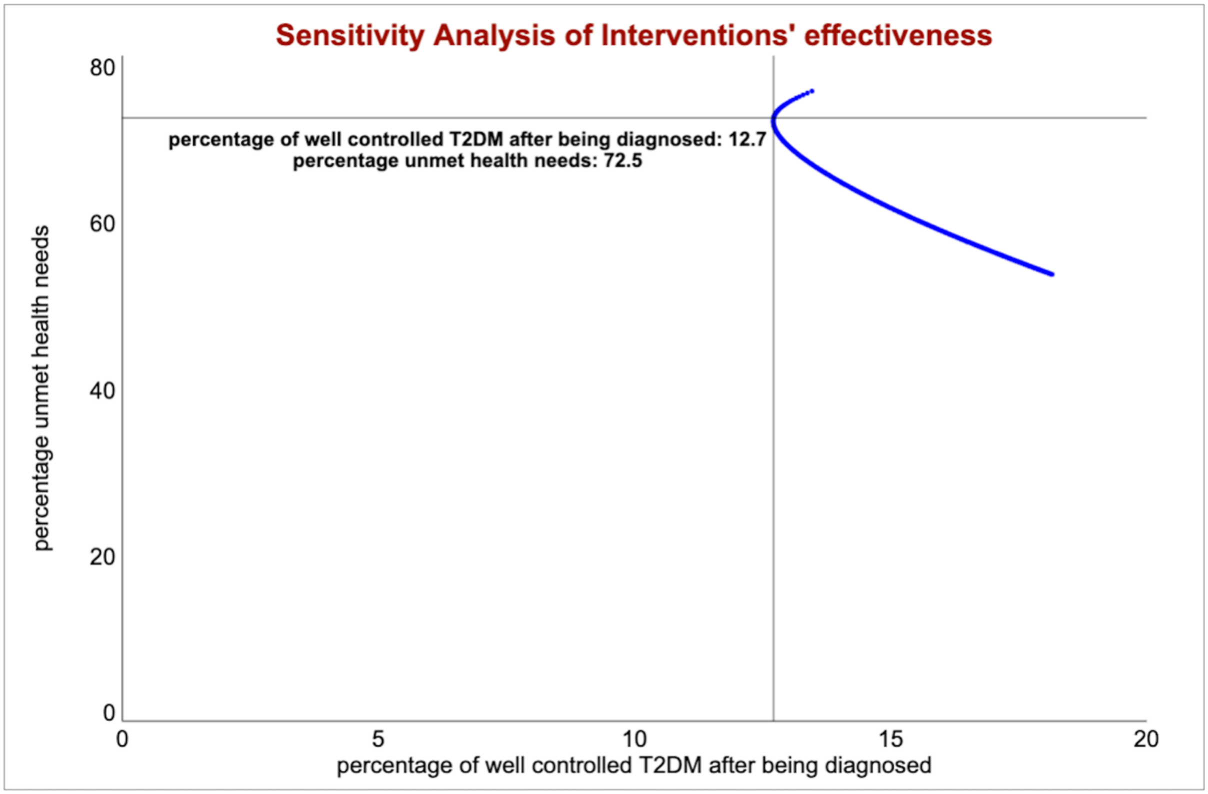


Figure 5A Sensitivity of the policy interventions' effectiveness on diabetes patients



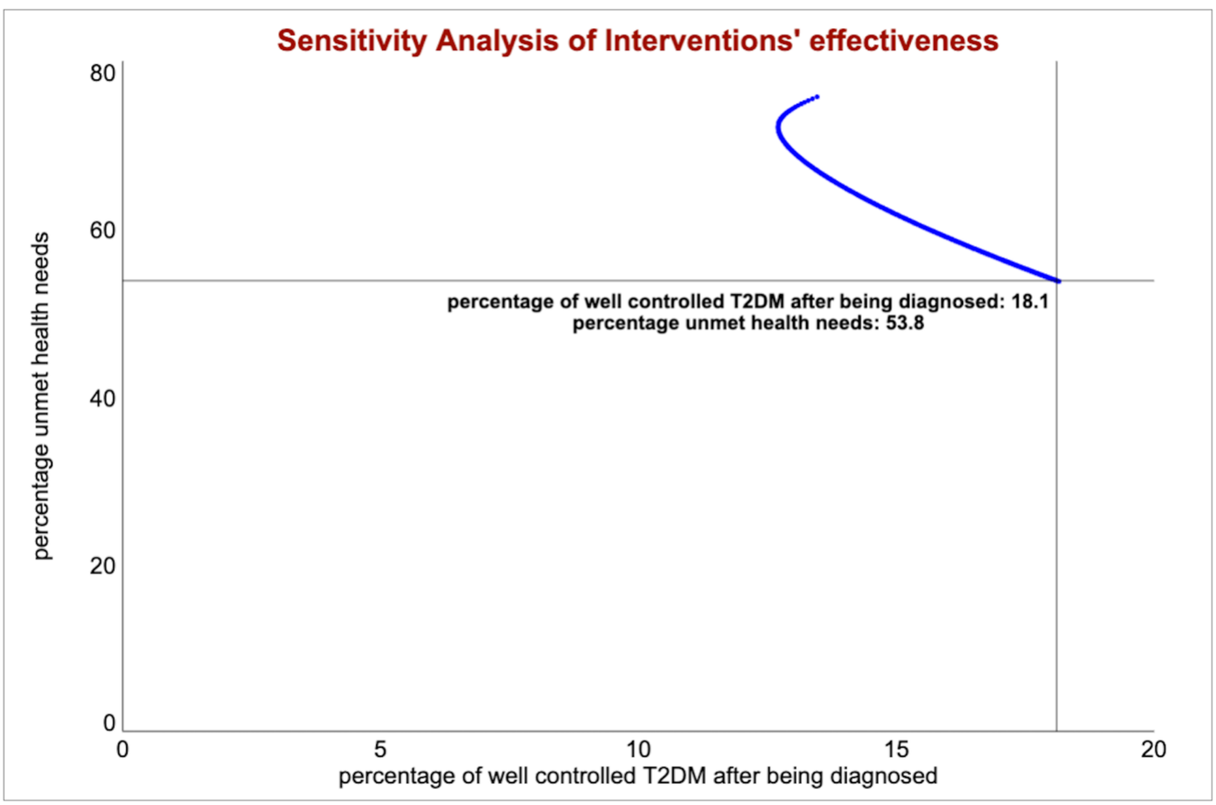


Figure 5B, 5C Sensitivity of the policy interventions' effectiveness on diabetes patients

Discussion and conclusion

The structure of the developed SD model allows for policy experimentation and prediction of the impact of each policy on the diabetes patient healthcare system over the next 15 years (2023-2037). The outcome measures include the proportion of the population without diabetes or related complications, the proportion of the population with prediabetes or undiagnosed diabetes, the proportion of well-controlled diabetes cases, and the mortality rate of diabetes patients.

In Scenario 1, we evaluated the results of the business-as-usual (BAU) policy on diabetes care in Thailand's 7th Health Region, considering all policy parameters, including the effectiveness of diabetes patient care and the delivery of health services to all diabetes patients in the region. The system dynamics model predicted a continuous decrease in the proportion of the healthy population without diabetes or cardiovascular disease over the simulated period from 2013 to 2037. However, the incidence and prevalence of diabetes are expected to increase due to the aging population, which is a risk factor for the disease.

The most significant observation regarding managing diabetes care in the region is the low rate of diabetes diagnosis following diabetes screening. Therefore, expanding the coverage of diabetes screening to targeted populations appears to be the most effective policy alternative to reduce unmet health needs. Alternatively, policymakers could implement policy options #2, #3, and #4 to improve diabetes care and reduce the number of diabetes patients who have not received proper care. Ultimately, policymakers can reduce the proportion of unmet health needs by choosing policy alternatives that address the low diagnosis rate and improve diabetes care.

The model shows the impact of implementing policy measures in Scenario 2, which focuses on improving the effectiveness of interventions in the health sector to reduce the risk factors for diabetes such as reducing smoking, alcohol consumption, unhealthy diets, and lack of exercise. This is aimed at reducing the burden of diabetes on the healthcare system, which may still be manageable. However, if there is an increase in diagnosis of diabetes, the number of patients in the healthcare system may exceed its capacity. Therefore, it is necessary to implement systemic management to improve the quality of healthcare services and increase healthcare providers in accordance with Policy Options #3 and #4. Otherwise, there may be a capacity overload res7ulting in a decrease in the quality of healthcare services.

In addition, the model reflects the imbalance between the supply of healthcare services for diabetic care in the region and the demand or need for healthcare services. This mismatch of demand and supply of diabetic can be considered representative of the overall healthcare system in Thailand, and hence it is necessary to have policies to improve resource management to focus on working efficiently according to policies that increase work efficiency. For example, accelerating the diabetes screening policy currently being implemented by the Ministry of Public Health, which is included as one of the performance indicators of the regional health systems performance evaluation, may not be very beneficial if it does not help reduce the proportion of the population with unmet health needs. The current bottleneck in the system is the low rate of diagnosis after diabetes screening, which is only about 50%, indicating that the system's capacity is still far too low.

Our study can be considered a health policy laboratory that policy makers and stakeholders were given the opportunity to jointly evaluate the appropriateness of health data from the administrative databases of the Ministry of Public Health for analysis and planning of healthcare services for NCD care in each health region. The system dynamics model showed an overall assessment of the performance of the healthcare system and helped identify policy questions about necessary health data or indicators for collecting and linking health data. The study revealed that policy makers currently collect various indicators on health databases but may lack a comprehensive perspective on how each indicator is linked to others and contributes to the overall performance of the healthcare system. This may lead to data collection and presentation of indicators in a fragmented or "siloed" manner, which may limit the ability to develop quality and equitable healthcare systems. To address this issue, we suggested applying a systems thinking approach and developing a group model in health policy laboratories to analyze how the components of the healthcare system are interconnected and how the system changes over time. This can provide a deeper understanding of the causes and effects of the system, leading to more comprehensive and effective healthcare management for diabetes and other NCDs in the future.

While collecting the model parameters, the researchers reviewed administrative databases from the Ministry of Public Health and studied the recording of the results of diabetes indicators in the 7th Health Region. We found that the Ministry of Public Health could apply the concept of "care cascade" (44) to data collection for diabetes indicators, but some data may still not be sufficient for analyzing and planning health service policies. Thus, we suggest creating a model to see the connection and flow of data between indicators to address issues in using data from indicators. Two main issues identified in the routine reporting data were the lack of analysis of the flow of data within the same system and the lack of consistency in the data when comparing variables with the same definition. If policymakers rely solely on the administrative data from the Ministry of Public Health, they may not be able to analyze the data to answer important questions such as "Is the governance mechanisms for diabetic patients in the region currently lead to a quality performance?" or "Does the implementation of the Ministry of Public Health's service plan contribute to improving the health and promoting health equity among the population?".

The findings from our research process also align with the concept of "Learning Health Systems" proposed by the WHO’s Alliance for Health Policy and Systems Research(12), which consists of three dimensions: 1) the level of the learner (individual, team, organization, and inter-organizational), 2) the level of learning (single loop, double loop, triple loop), and 3) the method of learning (learning from available data, learning from connecting past and future factors, and learning from practice). If policymakers and stakeholders can clearly define the learning objectives in these three dimensions and utilize data in the model to inform policy-making and policy monitoring within the region, it may develop the necessary data collection and analysis skills and align with the system thinking approach. This may foster learning at all levels of the health system, from frontline workers to policymakers, to lead to sustainable health system development.

The public health interventions to reduce the risk of diabetes is still important, although the results from the simulation model do not clearly show the impact on the population's health or the quality outcomes compared to other policy options. Future studies could consider using digital health solutions to support clinical management in healthcare units, with a focus on the Multiple Health Behavior Change Intervention Paradigm (MHBC) to promote health behaviors related to weight management in patients with NCDs (45, 46). Also, this study has not considered the impact of the COVID-19 pandemic on the continuity of healthcare services for diabetic patients. However, research in other countries has shown that normal chronic disease care services during large epidemics have been disrupted due to COVID-19, such as reduced healthcare staff due to caring for COVID-19 patients, quarantine policies, or lockdowns (47, 48). This may hinder the care of NCDs patients with complex health conditions, elderly patients, or those with intellectual or sensory impairments. Therefore, it is recommended to develop digital health solutions, such as telemedicine, that can be used to manage NCDs remotely.

There are some limitations to research due to the nature of our model development. This study focus on Thailand's 7th Health Region and lacks observational data from other regions of Thailand. There are also issues of the reliability of health data in the administrative database of the Ministry of Public Health. Therefore, caution should be exercised when interpreting the results of this modeling study, and the sensitivity analysis of the results should also be emphasized. In addition, the findings from the development of the model also have limitations due to time and resource constraints, as well as other limitations of research during the COVID-19 pandemic in Thailand. Future research should focus on collecting a more comprehensive data from the perspectives of all stakeholders, including diabetes patients who accessed to health care in the private sector, or the suppliers or producers of digital health solutions for NCDs patients.

Conclusion

The present study applies a systems thinking and system dynamics modeling approach to work with policymakers and stakeholders to address the ineffective management of diabetic care in Thailand. The findings highlight the root causes of problems in Thai health system, such as the inadequate allocation of resources and low rates of diabetes screening. By considering positive and negative impacts, the study found that expanding the scope of disease screening in the target population is the most effective policy to reduce unmet health needs for chronic disease patients. The study also emphasizes the need to develop skills in systems thinking and learning health systems to improve health policy and information management in Thailand. Therefore, this research serves as a good starting point for developing a "health policy laboratory". The development of policy decision processes that use systemic thinking and model-based policy decision support tools is promising and should be institutionalized.

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