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REVIEW ARTICLE

IDENTIFYING KEY FACTORS AFFECTING ESTIMATING GENERAL PRACTITIONER WORKFORCE REQUIREMENTS WITH A SYSTEM DYNAMICS APPROACH: A SCOPING REVIEW

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ABSTRACT

BACKGROUND:

The objective of this study is to identify the key factors influencing approaches to estimating general practitioner workforce requirements through a system dynamics approach. This analysis is essential for understanding workforce dynamics and informing healthcare policy. Consequently, a study was conducted to identify the key factors affecting the estimation of general practitioner numbers using a system dynamics approach.

METHODS:

This study involved a scoping review of articles concerning the healthcare workforce and general practitioners. Relevant articles were obtained from international databases such as PubMed, Scopus, Embase, and Web of Science, covering the period from 2000 to 2024, where full-text access was provided. An inductive approach was utilized to analyze the findings, enabling deeper insights beyond mere aggregation of information.

RESULTS:

Eighteen final studies out of 7,397 initially identified were included in the present research. The findings identified 77 variables and factors as exogenous and indigenous. Exogenous variables in the healthcare domain are classified into two main categories: demographic variables and health system variables. Indigenous variables are categorized into two primary groups: educational and workforce variables.

CONCLUSIONS:

The findings offer a comprehensive framework and identification of variables for this healthcare workforce by integrating demographic changes, labor market dynamics, and professional development. Accurate labor force estimation relies on high-quality data, which presents challenges due to regional differences and ongoing changes, making effective evidence-based workforce planning and policy development crucial through dynamic system thinking.

KEYWORDS
general practitioner, workforce estimates, system workforce, approach, scoping review

BACKGROUND

The rising trend in healthcare costs worldwide can be largely attributed to demographic shifts, continuous advancements in technology, increasing societal expectations, and changing disease patterns [1]. These interconnected factors have created a widespread resource scarcity challenge that healthcare systems around the globe must address [2]. Among these vital inputs are medical equipment and personnel, especially physicians, whose roles are crucial for the effective and efficient delivery of healthcare services. Therefore, they represent one of the most critical elements in healthcare resource allocation [3].

A report from the World Health Organization in 2006 highlighted a critical workforce crisis affecting physicians (including specialist physicians) and nurses in 57 countries, emphasizing the significance of human capital in the health sector. Many analysts contend that overlooking this aspect can lead to the failure of health policies. [4, 5]. Therefore, strategic planning and policymaking in health human resources are essential [6]. Accurate estimation of the necessary number of general practitioners is particularly vital, given the lengthy educational pathways and substantial costs associated with training [7]. In this study we focus specifically on general practitioners (GPs) because they are the main providers of primary care and determine population access, continuity, and first-line response; errors in estimating GP supply or distribution therefore have broader and more immediate system-level consequences than shortages limited to specialist cadres. Although we reviewed variables reported in specialist-focused studies to capture system-level spillovers (e.g. training capacity, remuneration, referral systems), the analysis and dynamic modelling explicitly target the supply and demand of GPs.

While various models and methodologies have been proposed globally over the years to forecast the demand for general practitioners, including the supply model [8], the population-to-healthcare workforce ratio model [9], and needs-based models from healthcare organizations [10], these approaches exhibit varying degrees of effectiveness and applicability. Additional methodologies, such as computational models based on service volume, adjusted needs-based models, and the World Health Organization's own models [11], highlight the breadth of research in this domain. Despite the extensive literature, there is a notable gap in customized approaches that consider the unique socio-economic and healthcare characteristics of Iran.

System dynamics, an advanced estimation and forecasting method that employs mathematical models, provides significant advantages for tackling these challenges [12]. It accurately captures temporal changes and integrates sophisticated algorithms, such as simulation techniques and sensitivity analyses, to pinpoint optimal strategies for health resource management and system optimization. The application of system dynamics results in substantial enhancements in efficiency, quality, and cost-effectiveness [13]. However, the effectiveness of this method is heavily dependent on the assumptions made at its inception, especially regarding the selection of key variables.

This study focuses on identifying the fundamental variables essential for system dynamics modeling in general practitioners. We present a comprehensive scoping review of dynamic systems studies in the medical field, emphasizing the crucial role of general practitioner physicians in this modeling process. A scoping review is a type of research synthesis that aims to map the existing literature on a particular topic, identifying key concepts, theories, sources of evidence, and gaps in research. This method is particularly useful for exploring broad topics or areas where the evidence is still emerging, as it helps clarify the scope of available research and provides a foundation for future investigations [14]. Our approach is unique, addressing a significant gap in the Iranian context, which has yet to implement such comprehensive system dynamics models. By clarifying the relevance and applicability of these models, we aim to encourage researchers and healthcare professionals interested in dynamic modeling to engage more deeply in this vital area of study, ultimately contributing to a more effective healthcare system in Iran.

METHODS

This study conducted a scoping review, and relevant articles were extracted using the databases: PubMed, Scopus, Embase, and Web of Science. Articles included in the present research had to be accessible in full text in English. They were published between 2000 and 2024.The search for articles was performed using related keywords and Boolean operators as follows:

SEARCH STRATEGY

"healthcare workforce" OR "Human resource" OR "Health Personnel" OR "Health Manpower" OR "Health Workforce" AND" Primary care physician" OR "Family physician" OR "family doctor" OR "family practice" OR "General Practitioner" OR "General Practice Physician" OR "General Physician" OR" Physician workforce" OR "GP" AND "Calculate" OR "Model" OR "Modelling" OR "Approach" OR "Forecast" OR "forecasting" OR "Estimation" OR "Estimating" OR "System" OR "Strategy" OR "planning"

The review aimed to identify the key variables and models used in system dynamics within the medical field, particularly focusing on the role of GPs. This comprehensive search and subsequent analysis provide a foundation for understanding the current landscape and future directions of dynamic modeling in healthcare.

To ensure that no relevant studies were missed and to monitor the target content more accurately, manual searching was also employed. Initially, backward searching was utilized, in which the references or works cited in an article were identified and examined. Following this, forward searching was used, where the researcher identified studies that cited an article or primary work after its publication. These processes specifically utilized the Google Scholar and Web of Science databases.

INCLUSION AND EXCLUSION CRITERIA

Articles included in the present research are those for which full text access is available, written in English, published between the years 2000 and 2024, and related to the assessment of general practitioners or specialists using a dynamic systems approach in the health field. Articles that were in a non-English language, lacked full text access, were not published within the specified timeframe, and studies that assessed general practitioners and specialists using other approaches.

DATA EXTRACTION

The study retrieval process for the scoping review involved several stages as follows:

In the first stage, a total of 7,397 articles were identified across scholarly databases. Specifically, 2,032 articles were retrieved from Web of Science, 2,756 from Embase, 5,848 from PubMed, and 4,375 from Scopus. After removing duplicates, 4,086 articles remained. In the second stage, 141 articles met the initial screening criteria, while 3,945 articles were excluded based on predefined inclusion criteria. In the third stage, the full texts of the remaining 141 articles were reviewed. Among these, 123 articles were further excluded based on Inclusion and Exclusion criteria.

Ultimately, 18 studies were included in this research, and the findings extracted from these studies have been elaborated upon. The details of the article retrieval process are illustrated in Figure 1 (PRISMA diagram). The characteristics of the studies included in this research are presented in Table 1. They focused on forecasting estimates from general or specialist physicians using a system dynamics approach in the healthcare domain. Editorial letters, conference papers, and systematic reviews were excluded from this research.

DATA ANALYSIS

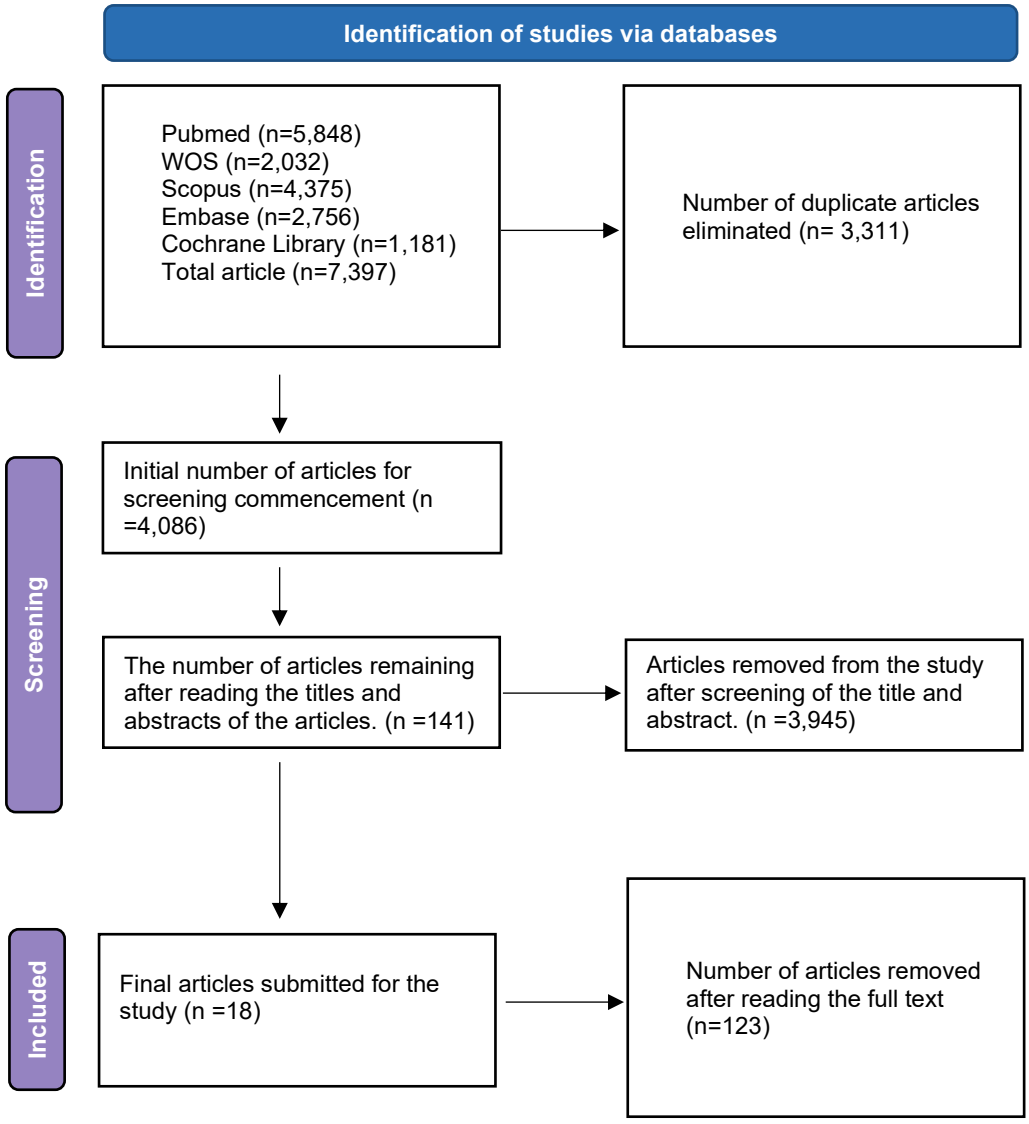
To analyze the findings, a content analysis and inductive approach were utilized. The process unfolded as follows: The research design was established by defining objectives, research questions, and inclusion/exclusion criteria. A list of studies

pertinent to the research topic was carefully selected and thoroughly reviewed. After systematically reviewing the studies, relevant findings were extracted. Similarities and differences among the findings and their themes were identified. Based on these similarities, the data were manually coded and initially categorized. The content of the findings was ultimately categorized and classified according to the research objectives. Subsequently, the results were interpreted. This structured approach ensured a comprehensive analysis of the data, facilitating a thorough understanding and interpretation of the research findings.

FINDINGS

The studies included in the review are categorized by year of publication as follows: 1 study in the period 2010-2006, 6 studies in the period 2011-2015, and 3 studies in the period 2021-2024. It should be noted that no studies were conducted between 2000-2005 on this topic. 8 studies were conducted between 2020-2016.

FIGURE 1: PRISMA FLOW DIAGRAM



The findings obtained from the scoping review were classified into two main tables, exogenous variables and indigenous variables in the healthcare domain.

TABLE1: DEMOGRAPHIC CHARACTERISTICS OF THE EXTRACTED ARTICLES

Article	Author	Year Pub-ished	Year Estimate	Target Population	Setting	Result	Journal	Refer-ence Nº
System dynamics modelling of health workforce planning to address future challenges of Thailand's Universal Health Coverage	Leerapan	2021	20 years	health workforce	Thailand	The simulation modelling found hospital utilisation created a vicious cycle of constantly increasing demands for hospital care and a constant shortage of healthcare providers. Moreover, hospital care was not designed for effectively dealing with the future demands of ageing populations and prevalent chronic illness. Hence, shifting emphasis to professions that can provide primary care, intermediate care, long-term care, palliative care, and end-of-life care can be more effective.	*Human Resources for Health*	*(15)*
A Study on Human Resources Management Based on System Dynamics	Liu	2012	Not applicable	Not applicable	China	Using system dynamics of qualitative analysis, and analyze the combination of principle and method to establish human resource management system quantitative, the model of enterprise human resources management in order to provide scientific basis for the correct decision.	advances in Asian social science	(16)
Theoretical System Dynamics Modeling for Taiwan Pediatric Workforce in an Era of National	Mei-Hwan Wu	2013	43 years	health workforce	Taiwan	Over the past decade in Taiwan, the child-to-pediatrician ratio has strongly correlated with infant mortality rates. Currently at 1742:1,	Pediatrics and Neonatology	(17)

Health Insurance and Low Birth Rates						the model suggests a ratio of 1009:1 based on Millennium Development Goals, projecting a decreasing trend in pediatric workforce and potential supply-demand discrepancies post-2017, which policy incentives could mitigate.		
Forecasting the need for medical specialists in Spain: application of a system dynamics model	Patricia Barber	2010	18 years	43 medical specialties	Spain	In the baseline model with moderate population growth, the shortage of medical specialists is projected to increase from 2% currently (2800 specialists) to 14.3% by 2025 (almost 21,000), with specialties like Anesthesiology, Orthopedic and Traumatic Surgery, Pediatric Surgery, and others facing the most significant deficits in the medium term.	Human Resources for Health	(18)
Forecasting the regional distribution and sufficiency of physicians in Japan with a coupled system dynamics—geographic information system model		2017	period 2010–2030 in 5-year increments.	practicing physicians	Japan	Forecast suggests physician shortage in Hokkaido Prefecture will largely be resolved by 2020. Based on current policies, four SMSAs in Hokkaido are projected to continue experiencing physician shortages beyond that date, with only one SMSA expected to remain understaffed in 2030.		(19)
Forecasting the absolute and relative shortage of physicians in Japan using a system dynamics model approach	Ishikawa T	2013	2008 until 2030	all clinical physicians and OB/GYN specialists.	Japan	The forecast predicted an increase in the number of physicians from 2008 to 2030, with the shortage expected to be resolved by 2026 for all clinical physicians.	Human resources for health	(20)

Strategic Workforce Planning in Healthcare: A multi-methodology approach	Willis G	2018	Horizon 2035	Workforce for healthcare at the national level	England	This paper outlines contributions in healthcare workforce planning models using System Dynamics, integrating multiple methodologies for strategic planning, and facilitating modeling through workshops.	European Journal of Operational Research	(21)
System dynamics modeling for general practitioner workforce forecasting in Kazakhstan	Koichubekov	2021	12 year	general practitioner workforce	Kazahstan	All three scenarios indicate that the current number of graduated General Practitioners will exacerbate the shortage of primary care physicians. In general, the shortage can exceed 2,000 in a population of 18.3 million (2018).	Annali di igiene : medicina preventiva e di comunita	(22)
A dynamic, multi-professional, needs-based simulation model to inform human resources for health planning	MacKenzie A	2019	4 year	Nurses, including nurse practitioners (NPs) and registered nurses (RNs); Physicians—including family physicians (FPs), pediatricians, and psychiatrists; Psychologists; Social workers.	Canada.	The model explicitly identifies two key planning parameters in HRH: distribution of work among different types of HRH and level of clinical focus. These parameters, previously overlooked in HRH literature, greatly impact planning scenarios. Failure to consider them can lead to under- or over-estimation of HRH gaps.	Human Resources for Health	(23)

Modelling the future of the Canadian cardiac surgery workforce using system dynamics	Vanderby	2014	2008-2030	cardiac surgery workforce	Canadian	Simulation results show a cardiac surgeon shortage in Canada by 2025, depending on their response to demand-supply changes. If residency enrollment rates remain at 2009 levels, a significant shortage may develop, reaching nearly 50% of the Canadian cardiac surgical workforce.	Journal of the Operational Research Society	(24)
A retrospective of System Dynamics based workforce modelling at the Centre for Workforce Intelligence	Cave S	2016	2010-2016	health and social care workforce	England	The Centre for Workforce Intelligence (CfWI) has also improved its workforce planning framework through enhancements in elicitation and scenario generation, which are detailed in separate technical papers.	n34th International Conference of the System Dynamics Society	(25)
Comparing health workforce forecasting approaches for healthcare planning: The case for ophthalmologists	Ansah J	2017	2012-2040	ophthalmologists	Singapore	The needs based approach tends to project the largest number of required ophthalmologists, followed by integrated, utilization based and workforce-to-population ratio approaches in descending order. The four different approaches vary widely in their forecasted workforce requirements and reinforce the need to be discerning of the fundamental differences of each approach in order to choose the most appropriate one. Further, health workforce planning should also be approached in a comprehensive and integrated manner that accounts for	International Journal of Healthcare	(26)

						developments in demographic and healthcare systems.		
How many Medical specialists do Ministry of Health- Sri Lanka need by 2025: Use of system dynamics modelling for policy decisions	De Silva MD	2017	2016 -2025	Medical specialists	Sri Lanka	Results By December 2015 there were 1860 clinician medical specialists with an average age of 46.8 years, in the government hospitals in Sri Lanka. In the surgical group of specialties the Proposed Training Rate is more than Current Training Rate while in Medical and Paediatric groups and in Radiology, Anaesthesiology, Psychiatry, Dermatology and Hematology Proposed Training Rate is less than the Current Training Rate.	Ceylon Medical Journal	(27)
Application of a system dynamics model in forecasting the supply and age distribution of physicians	Relić D	2020	2017-2041	physicians	Croatia	The two scenarios showed that Croatia would not face physician shortage in the future. The scenario 1 projected that Croatia would certainly reach the current European Union (EU) average of 360 physicians per 100 000 inhabitants by 2021, and that this figure would increase to 430 per 100 000 inhabitants by 2041. The scenario 2 suggested a similar trend, with Croatia reaching the current EU average by 2021 and the number of physicians increasing to 451 per 100000 inhabitants by 2041. Both scenarios indicated that the Croatian physicians' age distribution	Croatian medical journal.	(28)

						will recover in favor of younger age groups of specialists.		
How many doctors should we train for Sri Lanka? System dynamics modelling of training needs	De Silva	2017	a period of 15 years from 2017 to 2032	doctors	Sri Lanka	The key output parameters were "percentage need met" and the "doctor to population ratio". At present the doctor to population ratio is 1:671 and 91% of the need has been met. This study shows that currently there is a shortage of doctors in the country. However, the supply will match the need by 2025/26. Increasing the number of doctors, will result in oversupply of doctors towards the latter part of the next decade.	The Ceylon medical journal	(29)
Designing a human resource productivity model with a system dynamics approach in the health sector	Baibordy L	2023	2011-2031	human resource in the health sector	East Azerbaijan province.	Factors influencing human resource productivity in the health sector were labor numbers, education, in-service training, geographical health facility coverage, and staff research. A model was created, validated, and simulated to enhance productivity through scenario analysis, emphasizing dynamic improvements in the sector. Expert input and quantitative relationships were pivotal in model development and testing	International Journal of Nonlinear Analysis and Applications	(30)
Transformation of potential medical demand in China: A system dynamics simulation model	Yu W	2015	2014	patients not seeking medical care	China	Decreasing the number of hospitals, increasing the number of CHSs, and raising the proportion of health insurance compensation would effectively increase the	Journal of Biomedical Informatics	(31)

						transformation of potential medical demand. But currently, changes of the outpatient prices didn't play a role in the transformation of potential medical demand		
An Innovative Interactive Modeling Tool to Analyze Scenario-Based Physician Workforce Supply and Demand	Gupta S	2015	2015	health workforces	USA	A model was built to analyze future pathologist supply and demand trends up to 2030, with a focus on workforce dynamics and financial impacts. It offers quantitative forecasting for various effort areas and can test hypotheses regarding pathologist workforce requirements. The model introduces a new pathology practice taxonomy that considers both population-wide and individual patient work, highlighting the need for physician adaptation to evolving payment models.	Academic pathology	(32)

Based on the findings of this study (Tables 2 and 3), exogenous variables in the healthcare domain are classified into two main categories: demographic variables and health system variables, comprising 8 sub-categories and 32 codes. Indigenous variables are categorized into two main groups: educational and variables, and workforce variables, encompassing 8 sub-categories and 45 codes, which will be further detailed below.

EXOGENOUS VARIABLES

External or exogenous variables in healthcare systems are factors that influence community health or the healthcare system but are not entirely under the direct control of healthcare human resource management. These variables are divided into two primary categories: demographic variables and health system variables. Considering these variables in the analysis and assessment of healthcare human resources is essential, as they can help identify external factors and unforeseen interferences affecting the healthcare workforce, thus enabling effective management. Based on conducted studies, eight sub-categories have been identified related to external variables, including demographics, health and needs, sector performance, service provision (prevention level), financing, facilities, and capacity (training capacity).

POPULATION

Population variables are recognized as factors that directly influence health based on the population and its characteristics. These variables can be classified into various forms; in this study, demographic characteristics and health needs are categorized as sub-categories. According to the findings, population size, sex distribution, and geographical location are the most significant factors affecting physician estimation within the healthcare system. Population size can heavily influence physician estimation. For instance, regions with a larger elderly population may require physicians specializing in age-related diseases. Additionally, disparities in gender distribution may indicate the need for specialized healthcare services tailored to both women and men. Healthcare and treatment needs may vary between genders, necessitating tailored physician estimation strategies. The geographical location of populations also significantly impacts physician estimation. Remote or underserved areas lacking adequate healthcare access may require an increased number of physicians and roles to meet local health needs.

HEALTH AND NEEDS

Based on the World Health Organization framework, healthcare system variables were categorized into five sub-categories: performance, service provision, sector financing, and facilities, comprising a total of 23 codes. The nature and type of sector in which general practitioners operate are crucial factors influencing their estimation, extensively discussed in numerous studies. Furthermore, regarding healthcare functions, efficiency and productivity are the primary factors highlighted in various studies. Research has also demonstrated that financial mechanisms within the healthcare system are critically important, particularly in determining physicians' income and the extent to which the services they provide are covered by insurance.

TABLE 2: EXOGENOUS VARIABLES FOR ESTIMATION BASED ON SYSTEM DYNAMICS

Categories	Sub-categories	Codes	Description of the Codes	References
population	demographic	Population size	a key demographic variable that directly influences the healthcare system's workforce estimation. It considers the total number of individuals within a population and serves as a fundamental factor in predicting healthcare needs	(19-21, 24)
		sex distribution	the gender composition of a population and its role in influencing healthcare workforce planning and physician estimation within the healthcare system. Variations in gender distribution among populations can indicate the need for specialized healthcare services tailored to men or women.	(20, 21)
		age distribution	the demographic composition of a population based on various age groups and its critical influence on the demand for healthcare services and workforce planning. Age distribution significantly affects the estimation of physicians, as varying age groups have diverse healthcare needs.	(15, 20, 21, 32)
		sub-populations	specific demographic subgroups within the broader population that influence healthcare needs and resource planning. These subgroups may be defined based on characteristics such as ethnicity, socio-economic status, or other relevant factors. Understanding sub-populations is critical in workforce estimation, as they often exhibit distinct health behaviors, disease patterns, and care requirements.	(17, 32)
		Population Exchange Rate	the dynamics of migration and demographic shifts between regions or countries, influenced by factors such as war, economic opportunity, or environmental changes. Unlike traditional currency exchange rates, this	(21)

			concept focuses on how populations move or are relocated, often under governmental policies or historical circumstances.	
	Health and needs	health literacy	the ability to access, understand, evaluate, and use health information to make informed health decisions. It includes skills such as reading medical texts, interpreting numerical data (like medication dosages), and navigating the healthcare system. High health literacy leads to better health outcomes and increased adherence to treatment, while low health literacy can cause misunderstandings about health information and poorer health management.	(15)
		the population with diseases	groups of individuals within a specific geographic area or community who are affected by various health conditions or illnesses. This concept is often used in public health to study disease prevalence, distribution, and the associated risk factors, in order to inform healthcare strategies, resource allocation, and interventions aimed at improving health outcomes and reducing the burden of disease.	(26, 32, 33)
		the unmet health needs of the population	healthcare demands that are not adequately addressed within a population. This includes individuals who are unable to access necessary medical services due to barriers like geographical constraints, economic limitations, or insufficient healthcare resources. Addressing unmet health needs is crucial for aligning the healthcare workforce with the actual demands of the population. .	(15, 16, 19, 21, 23, 26, 27, 30)
health systems	sector	health sector growth in the country	the expansion of healthcare services through the establishment of new facilities, adoption of technologies, and increased capacity. This growth drives	(27)

			demand for a larger, specialized medical workforce, influenced by policies and initiatives from health ministries and governing bodies.	
		Number of Doctors in the Ministry of Health	the total number of physicians employed by a nation's Ministry of Health. This metric indicates the capacity of the public healthcare system and helps assess the distribution and availability of medical personnel for delivering government health services, aiding in workforce planning to meet healthcare needs.	(29)
		Number of doctors in University academic staff (medically qualified)	the count of medically qualified individuals working as educators in universities, crucial for training and developing healthcare professionals.	(29)
		Number of Doctors in Full time Private sector	the count of licensed doctors working full-time in private healthcare facilities, contributing to non-government medical services.	(29)
	performance	Level of access to excess services	the extent to which individuals can access healthcare services beyond their essential needs.	(30)
		Efficiency(training efficiency)	the effectiveness and resource optimization in medical training programs, impacting workforce supply and healthcare outcomes.	(16, 19, 22, 26, 30)
		the effectiveness of population health interventions	the impact of public health strategies aimed at improving overall community health outcomes.	(15)
		Patient Protection and Affordable	policies or measures aimed at improving healthcare accessibility, affordability, and quality for the population.	(32)
		satisfaction	the level of patient satisfaction with healthcare services, reflecting care quality and overall experience.	(30)
		utilization	the use of healthcare services, such as outpatient visits and hospital admissions, influenced by access, availability, and workforce quality.	(32, 33)
		changes in workforce productivity	variations in healthcare workforce efficiency influenced by training, workload, and systemic factors.	(21, 23, 24, 30)

	Service provision (prevention level)	people's self-care	individuals managing minor health issues and adopting preventive health behaviors to reduce healthcare demand.	(15)
		primary care pediatricians.	pediatricians specializing in providing basic healthcare, early intervention, and preventive care for children.	(17)
		visits	description of the code people's self-care. Write the description very, very briefly	(26)
		size of the labour market in non-hospital care	the workforce size specific to non-hospital healthcare settings, highlighting its capacity and distribution.	(15)
		size of the labour market of hospital care	the workforce scale dedicated to hospital settings, reflecting personnel capacity in providing inpatient and specialized medical services.	(15)
		Published scientific-research articles	scholarly articles that contribute to academic knowledge and support evidence-based practices in the healthcare domain.	(20, 30)
		technologies	innovations and advancements, such as medical devices or telemedicine, that influence healthcare delivery and workforce dynamics.	(25, 32)
		Rate of presentation of innovative and pragmatic projects	the frequency of introducing practical and groundbreaking initiatives in the healthcare system.	(20, 30)
	financing	resources	the financial, infrastructural, and human assets essential for healthcare delivery, training, and workforce retention.	(31)
		income	the financial earnings of healthcare workers, influencing workforce retention and overall healthcare system sustainability.	(33)
		rates of insurance across population groups	the distribution and coverage levels of health insurance among different demographic or socioeconomic populations.	(25, 27, 32, 33)
	facilities provided for the public compared to the expected status		the gap between available healthcare infrastructure and	(30)

		services versus anticipated or ideal levels.	
	current capacity loss rate	the reduction in healthcare system capacity due to factors like workforce attrition, resource constraints, or inefficiencies.	(16, 27)

INDIGENOUS VARIABLES

The term " indigenous variables" refers to factors determined by internal elements of the healthcare system. In this study, education and workforce are identified as two Indigenous variables within the healthcare system. The factor of education three sub-categories: education level, educational features, and education evaluation. The educational attainment level of personnel can significantly influence the quality of healthcare and medical services provided.

For instance, employees with higher education levels may possess the most current medical knowledge and technologies, potentially leading to enhanced healthcare services. The workforce factor pertains to both the quantity and quality of available personnel. To deliver high-quality healthcare services, the workforce must have the necessary expertise and skills. Furthermore, an adequate workforce is crucial to meet the healthcare needs and demands of society. In this context, five sub-categories, including Demographic, Active Workforce, Labor Market, Growth and Excellence, and Specialty, have been highlighted in relevant studies. Human resource training and workforce development, as two intrinsic variables, can directly and indirectly influence the quality, accessibility, and efficiency of the healthcare system. Therefore, healthcare managers and decision-makers must prioritize the management and development of these two variables to ensure the enhancement of overall healthcare performance and services.

Education

The variable of human resource training and education plays a vital role in enhancing the quality of healthcare and medical services provided by general practitioners. In this study, 13 codes were identified that relate to the specialized and scientific education a general practitioner may acquire. Among the factors associated with the sub-category of education level, residency training has been emphasized in numerous articles as a significant determinant influencing the performance of healthcare personnel. Studies have examined the transition of general practitioners into specialized and residency training levels to understand their impact. Within the sub-category of educational features, the duration and stages of training have been recognized as key factors in human resource development in many articles. Additionally, enrollment criteria and methods have garnered significant attention in educational evaluations across various studies. Furthermore, the gender and age of physicians have been referenced in several studies as well.

Workforce

The workforce factor in the assessment of general practitioners encompasses a range of elements that influence the selection, training, development, and ranking of these professionals. These elements include demographic characteristics of the active workforce, labor market dynamics, considerations of growth and excellence, and specialization. They are crucial factors in evaluating general practitioners within the medical field. Given the substantial impact of medical services on community health, effective strategies for attracting, retaining, and enhancing skills and knowledge among general practitioners to address societal needs are critically important. In this study, 32 codes were identified related to workforce factors, focusing on aspects such as the utilization of trained personnel, their full-time engagement, and their active participation in healthcare delivery. Key elements within the human resource market include workforce demographics, dynamics of workforce size, attrition rates including migration and retirement, and the effects of retirement and migration on the workforce system. Within the specialty sub-category, most studies have focused on the role of general practitioners, with fewer investigations into specialized areas.

Table 3: Indigenous variables for estimation based on system dynamics

Categories	Sub-categories	Codes	Description of the codes	References
Education	Education level	General educational level	the overall academic attainment of individuals, which influences their qualifications and readiness for further training.	(30, 33)
		Student	individuals enrolled in medical education programs, representing the initial stage of the healthcare workforce pipeline.	(24)
		Training personnel number	the count of individuals undergoing training programs aimed at entering or advancing within the healthcare workforce.	59, (18, 19)
		Graduate students number	the count of students who have successfully completed their higher education programs, particularly in medical and healthcare-related fields.	(19, 23, 24), 58, ,
		Past graduation numbers	the count of individuals who have completed educational or training programs in the past.	(20)
		Residencies	postgraduate training programs for medical graduates specializing in specific fields to enhance their skills and qualifications.	57, ,(17, 19, 24)
		Fellowship & subspecialty	advanced medical training programs undertaken after residency to obtain expertise in specialized areas of practice.	(17, 24)
	Educational features	Education attrition	the dropout rates or discontinuation of students from educational or training programs.	(23)
		Stages and duration of the training	dropout rates in training programs, while "stages and duration of the training" pertain to the distinct phases and timeframes of medical education.	(23, 24, 27, 28)
	Education evaluation	The number of enrolled	the count of individuals registered in educational or training programs.	(23, 24, 28)
		Entrants	individuals newly admitted into educational or training programs.	(23)
		National exam	standardized exams that assess qualifications for entry into medical training or licensing.	(19, 20)

		Rates of passing	the proportion of candidates successfully passing national or other relevant healthcare exams.	(19)
Workforce	Demographic	The age medical population	the age distribution of individuals in the medical workforce.	(19)
		Sex medical population	the gender composition within the medical workforce.	(19)
	Active workforce	The current number of members of that profession currently licensed to practice	the total currently certified professionals eligible to practice in their field.	(23)
		Unemployed	the number of healthcare professionals not currently engaged in any active employment within the medical workforce.	(24)
		Active employees	healthcare professionals currently engaged in the workforce.	(30)
		Full-time	healthcare professionals engaged in full-time work within the medical workforce.	(18)
		Rate of staying	the retention rate of healthcare professionals within the workforce.	(19)
		Working pressure on staff in the healthcare system	the workload and stress levels healthcare professionals experience in their roles.	(30)
	Labor market	The number of new providers entering that stock (either as new graduates or in-migrants from other jurisdictions)	the influx of healthcare professionals, including newly graduated or migrating providers, entering the workforce.	(23)
		Population workforce size	the total number of individuals working in the healthcare sector.	(24, 30)
		Exits from the health workforce due to another reason	workforce departures caused by factors other than retirement or migration.	(22, 23)
		Immigration rate	the rate of healthcare professionals moving across borders or jurisdictions.	(18, 22, 23)
		Rates of retirement	the proportion of healthcare workers leaving the workforce due to retirement.	(18-20, 22, 30)
		Workforce Demand	the need for healthcare professionals based on population health requirements and service demand.	(21)

		Workforce Supply	the availability of healthcare professionals to meet system demands.	(21)
	Growth and excellence	The actual capacity value and the difference between the expectation values	the comparison between a workforce's current capacity and the expected or required capacity.	(16, 29)
		Training rate	the pace at which healthcare professionals undergo training within a specific timeframe.	(16, 27)
		Career option rate	the frequency at which individuals select specific career paths in healthcare.	(20)
		Roles	the specific functions or responsibilities assigned to healthcare professionals within the workforce.	(23, 32)
		Participation	the active involvement of healthcare professionals in delivering services within the workforce.	(23)
		Norms	the standard practices and behaviors that influence staff motivation and applied skills in the healthcare workforce.	(27)
		Staff motivation	factors that inspire and influence healthcare staff to achieve their goals and enhance performance.	(30)
		Level of applied skills in human resources	the practical competencies demonstrated by healthcare personnel in their roles.	(30)
	Specialty	Change of specialty	the transition of healthcare professionals from one medical specialty to another.	(20)
		Consultants	specialized healthcare professionals offering expert advice and services in their respective fields.	(29)
		Dentists	healthcare professionals specialized in oral health and dental services.	(19)
		Pharmacists	healthcare professionals specializing in the preparation and dispensing of medications.	(19)
		Physicians	medical professionals responsible for diagnosing and treating illnesses to ensure patient health.	(19, 20, 29, 30)

		Specialty	The code "specialty" refers to a specific field of medical practice chosen by healthcare professionals.	(20, 27)
		Surgeon	medical professionals specializing in performing surgical procedures to treat injuries, diseases, and disorders.	(24)
		Hospital staff	healthcare professionals providing medical and support services within a hospital setting.	(17)
		Other specialty	medical fields outside the primary categories, encompassing diverse specialized practices.	(19)

DISCUSSION

This scoping review offers a comprehensive framework of key variables analyzed in studies modeling the dynamic system for forecasting the necessary medical workforce, including GPs. Identifying these variables is a crucial step toward creating accurate and dynamic models to predict future healthcare workforce requirements.

EXOGENOUS VARIABLES

Population

Demographic factors emerge as fundamental drivers of healthcare needs, influencing both the demand for and the allocation of the medical workforce. Population size, growth trends, and structural characteristics such as age and gender distribution are pivotal in workforce planning [32]. For instance, an aging population necessitates a stronger focus on geriatric care and chronic disease management, while diverse demographic subgroups may require culturally adapted care to ensure equitable outcomes [34, 35]. Furthermore, geographical factors—such as urban/rural distribution and access to education and healthcare facilities—play a critical role in shaping the accessibility and availability of healthcare services. Addressing these disparities is essential for ensuring the equitable distribution and strategic allocation of the workforce across various regions [36].

Health literacy levels within the population further underline the demand for healthcare services [37]. Higher health literacy fosters better self-care practices, improves adherence to treatments, and enhances the effectiveness of preventive measures, reducing dependence on healthcare resources. Conversely, lower health literacy necessitates additional resources and specialized communication strategies.

In addition, the prevalence and distribution of diseases or specific health conditions directly influence the composition and skill set required of the healthcare workforce [38, 39]. For example, populations with significant infectious disease burdens demand public health interventions and specialized skills among healthcare providers, emphasizing the need for targeted workforce strategies.

Diverse healthcare needs, ranging from preventive to rehabilitative care, underline the necessity of a dynamic workforce capable of addressing multifaceted health demands [10]. Conducting assessments of population health requirements ensures alignment between medical workforce supply and healthcare service demand. Such evaluations foster a better understanding of resource needs and guide planning efforts for preventive, therapeutic, and rehabilitative care.

Health Systems

The factors influencing the healthcare system provide a multifaceted perspective on the variations impacting the demand and utilization of the medical workforce. The growth of the healthcare sector has been notably stimulated by the establishment of new medical facilities, advancements in technology, and enhanced service capacity. These developments have significantly increased the need for a larger and more specialized medical workforce to manage the complexity of modern healthcare systems [40, 41] . Moreover, the role of health ministries and governing bodies remains pivotal in setting policies and standards, which define the framework within which workforce requirements are determined. These organizations directly influence healthcare service accessibility and efficiency, further shaping the demand for medical professionals. The formulation of clear policies by these bodies ensures that both public and private healthcare institutions can strategically address workforce challenges while aligning with national and regional health priorities [42, 43].

Access to and the capacity of educational institutions, along with their active faculty members, are critical for the continuous training of a specialized healthcare workforce and for addressing workforce needs. The establishment of adequate infrastructure, including a sufficient number of medical schools and well-equipped universities supported by experienced and committed educators, facilitates the development of a skilled next generation of physicians [44]. These educational systems form the backbone of human resource development in healthcare, ensuring a steady supply of qualified professionals to meet growing societal demands.

The private healthcare sector, in addition to government facilities, plays a significant role in workforce dynamics. Its expansion has heightened the need for specialized workforce strategies to meet increased demand. For instance, Sri Lanka provides a notable example, where the private healthcare sector has alleviated skilled workforce shortages since the 1980s. Private hospitals in Colombo, despite operating in a monopolistic framework, have significantly contributed to addressing such shortages by attracting and retaining skilled healthcare professionals who might have otherwise pursued opportunities abroad [29].

Comprehensive workforce management also requires maintaining equitable access to healthcare services and monitoring accessibility rates to specialists, as these are key performance indicators directly linked to workforce distribution [45]. The quality and effectiveness of medical education programs—measured through graduation rates, efficiency, and economic feasibility—underscore how vital these factors are in shaping the healthcare workforce [46]. Ensuring alignment between training programs and workforce needs will enhance not only supply but also the overall efficiency of resource use within the sector.

Healthcare interventions and service delivery align closely with the competencies of the current workforce. These elements contribute directly to achieving societal health outcomes and ensuring that workforce skills meet population needs [47]. Investments in capacity building, ongoing training, and competency monitoring improve service efficiency and lay the foundation for continuous improvement. Collaborative efforts between educational institutions and healthcare providers further validate workforce competencies, ensuring that training aligns with real-world requirements [47]. Furthermore, emphasizing care quality, patient safety, and cost-effectiveness often necessitates additional workforce-centric interventions, such as targeted education or incentive-based policies.

Patient satisfaction serves as an indirect indicator of workforce performance, reflecting crucial aspects like communication, care quality, and the overall patient experience [48]. Utilization rates of healthcare services, such as outpatient visits, hospital admissions, and preventive care, provide further insights into workforce supply and demand imbalances, highlighting areas of shortage or overcapacity [49]. Encouraging population self-care can relieve pressure on the healthcare workforce while promoting preventive practices to reduce demand for medical services.

Primary care accessibility is another vital consideration. The distribution of primary care physicians [22], including pediatricians, ensures basic healthcare, enables preventative efforts, and reduces the need for specialized and emergency services. Similarly, the capacity and distribution of non-hospital healthcare facilities—such as community

health centers and clinics—affect workforce demand by diversifying healthcare environments. Hospitals also require a greater skilled workforce for specialized treatments and complex care delivery.

Research activities and the adoption of new technologies represent transformative forces within the healthcare landscape. Innovations such as telemedicine [50] and digital health tools [51] redefine workforce roles, expand skill requirements, and shift distribution strategies. Establishing a forward-thinking, innovative ecosystem fosters [52] continuous adaptation, creating long-term workforce needs that emphasize the dynamic evolution of skills.

Finally, financial resources, infrastructure, and human resource availability significantly influence an institution's ability to train, employ, and retain skilled professionals. Socio-economic factors, such as income levels, healthcare affordability, and socio-economic status, drive demand for services, shaping workforce needs. Furthermore, the coverage of health insurance schemes impacts care accessibility patterns, ensuring sustainable resource use while influencing workforce allocation.

INDIGENOUS VARIABLES

Education

The identified educational factors encompass a comprehensive array of diverse stages and processes within the medical education, which are essential components for accurately modeling the healthcare workforce supply [53]. Variables such as the number of enrolled students, dropout rates, postgraduate career pathways, and licensure attainment act as critical indicators for estimating the specialized healthcare workforce [53]. By explicitly considering potential dropout rates at various stages, through metrics such as dropout rates and pass rates in examinations, modeling capabilities for estimating effective outputs entering the workforce are significantly enhanced. This level of detail addresses the limitations of some previous workforce models that relied on oversimplified assumptions about educational dynamics within the training.

The inclusion of a temporal dimension—such as the duration of training courses—in workforce supply models is crucial for valid predictions regarding the supply of general practitioners in the healthcare system [54, 55]. Accounting for the time intervals between a student's initial admission and their final licensing as specialists allows for a more accurate representation of the medical education process [55]. Unlike models that primarily focus on macro metrics such as graduation rates, the identified educational factors provide a more granular and phased representation of the medical education process.

This level of detail holds considerable value, as it takes into account the complex dynamics and interactions among various components of the medical education system over time. Incorporating a systemic dynamic approach enables a comprehensive and evolving understanding of how educational factors influence the healthcare workforce [55]. In contrast to models that focus solely on overall educational attainment, this systemic approach integrates feedback loops and intricate interactions among components, providing a more realistic and actionable depiction of medical education dynamics and its downstream effects on the supply of general practitioners.

Such an approach ensures that workforce supply models are not only evidence-based but also adaptive, permitting policy interventions to address emerging workforce challenges. The focus on nuanced variables enhances planning, making it possible to better sync the medical education with future workforce needs and healthcare demands.

Workforce

The factors related to the healthcare workforce encompass a broad range of variables that collectively illustrate the intricate dynamics shaping both the status and future outlook of the medical workforce. Demographic variables, such as age and gender composition, serve as pivotal indicators for predicting retirement rates, labor force participation rates, and workforce alignment with population age structures. Such demographic shifts profoundly influence supply-demand dynamics. For example, women in medical professions often exhibit preferences for part-time arrangements or extended maternity leave compared to their male counterparts, underscoring the significance of designing workforce planning and retention strategies that address these unique needs and support work-life balance [56, 57].

Variables tied to the licensed and active workforce immediately reflect current supply capacity. However, additional factors, such as unemployment rates and workload pressures, often uncover imbalances between labor supply and demand. For instance, an oversupply of surgeons has led to challenges, including unemployment and unfilled residency positions, triggering debates about potentially reducing training opportunities in specific specialties. Workload-related aspects, such as job fatigue and volume, also have a pronounced influence, as they directly impact workforce performance, employee retention, and the overall sustainability of the workforce [24, 58].

Labor market indicators, such as the influx of new graduates, domestic and international migration rates, and workforce attrition due to emigration or retirement, represent crucial metrics for forecasting labor supply. These metrics offer critical support for mathematical models aimed at analyzing workforce inputs and outputs over time. Accurate forecasts grounded in a thorough analysis of these indicators are essential for long-term workforce planning, economic projections, and evidence-based policy formulation [18, 22].

Dynamic system modeling further highlights influential factors such as professional development, competency alignment, and the identification of skill gaps. These elements reinforce the necessity of closing the gap between individual abilities and workforce expectations. Addressing training opportunities, career pathways, and employee motivation forms the backbone of strategies to nurture a skilled and adaptable workforce [16, 59]. This comprehensive approach enables the workforce to respond effectively to the evolving healthcare demands of diverse populations.

In addition to broader workforce variables, dynamic system models include specialty-specific considerations encompassing physicians, surgeons, dentists, pharmacists, and counselors, thereby enabling a more precise understanding of workforce composition and skill distribution. For instance, in Japan, it has been observed that specialty choices among general practitioners influence labor distribution across various medical fields. Should a significant number of practitioners opt for further specialization, shortages in general physician supply could become exacerbated [20]. By capturing these intricacies, the model reveals areas where shortages or surpluses are likely to arise, informing the development of targeted interventions to balance workforce dynamics effectively.

This in-depth, system-oriented framework offers a highly detailed representation of healthcare workforce challenges, enabling healthcare policymakers and planners to address labor market dynamics comprehensively. The integration of demographic trends, labor market variables, and specialty-specific factors into these models supports robust, data-driven decision-making and planning for sustainable workforce development.

STUDY LIMITATIONS AND STRENGTH

The current study represents one of the pioneering comprehensive examinations that employ a dynamic systems approach to investigate the key variables for forecasting both general and specialist physicians. It aims to aid researchers in identifying state variables and rates as essential steps in the dynamic systems approach, despite the existence of numerous studies focused on physician forecasting.

Regarding the limitations of this study, it is possible that related research in non-English languages exists, which was not included due to the criteria for data input and output. Various models and frameworks may also be available for categorizing the findings of this study, which future research could utilize. The primary focus of the current research has been on extracting key variables for physician forecasting and has not explored other steps in the dynamic systems approach to physician forecasting, which future studies could investigate.

CONCLUSION

In contrast to older models that depend on general figures or fixed assumptions, the factors considered within the new framework of system dynamics provide a more comprehensive representation of the healthcare workforce. This scoping review, which adopted a systems dynamics approach, provides a comprehensive map of the key variables influencing

the estimation of general practitioners' workforce and organizes them into two main categories: "exogenous" (demographic and health system-related) and "endogenous" (education and human resources). Focusing on general practitioners revealed that accurate estimation of their supply and demand, particularly in the context of structural population changes, disease burden, financial shifts, and advancements in health technologies, is crucial for accessibility, continuity of care, and the responsiveness of the frontline health system.

The findings highlight that valid modeling and effective policymaking are not feasible without considering the concurrent dynamics of the supply pathway (training capacity and efficiency, stages and duration of training programs, dropout rates, entry into the workforce, migration, retirement, and retention), the demand pathway (age-sex population structure, unmet needs, utilization patterns), and the functional characteristics of the health system (geographical distribution, skill mix, productivity, payment mechanisms and insurance coverage, private sector capacity, and primary care level). The framework derived from this study can serve as a minimum list of variables for developing dynamic models of general practitioners, reducing the risk of reliance on oversimplified assumptions or static macro-level indicators.

ETHICS APPROVAL AND CONSENT TO PARTICIPATE

The study was approved by the Ethics Committee of Kerman University of Medical Sciences (KUMS) with the Approval ID IR.KMU.REC.1403.045.

AVAILABILITY OF DATA AND MATERIAL

If requested by the authors for valid and logical reasons, all datasets analyzed during the current study are available upon request.

COMPETING INTERESTS

The authors declare that they have no conflict of interest.

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AUTHORS' CONTRIBUTIONS

MI and MHM conducted the search and retrieval of resources, data collection, and its coding; AAH assisted in data analysis; MRA proposed the search strategy, subject, and study design. All authors have read and approved the final version and are responsible for the final content of this article.

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References

1. Homeniuk R, Collins CJBo. How COVID-19 has affected general practice consultations and income: general practitioner cross-sectional population survey evidence from Ireland. 2021;11(4):e044685.
2. Dussault G, Buchan J, Sermeus W, Padaiga Z. Assessing future health workforce needs: World Health Organization Copenhagen; 2010.
3. Glenngård AH, Hjalte F, Svensson M, Anell A, Bankauskaite V, transit. WHOJHs. Health systems in transition: Sweden. 2005.
4. Al-Hanawi MK, Khan SA, Al-Borie HMJPhr. Healthcare human resource development in Saudi Arabia: emerging challenges and opportunities—a critical review. 2019;40:1-16.
5. Karan A, Negandhi H, Nair R, Sharma A, Tiwari R, Zodpey SJBo. Size, composition and distribution of human resource for health in India: new estimates using National Sample Survey and Registry data. 2019;9(4):e025979.
6. Roche W, O'Riordan JJA. The reform of human resource management in the Irish public service. 2020;68(4):97-119.

7. Apornak A, Raissi S, Keramati A, Khalili-Damghani KJIJoHM. Optimizing human resource cost of an emergency hospital using multi-objective Bat algorithm. 2021;14(3):873-9.
8. RAZAVI SM, LABBAF GR, HEYDARZADEH A, MOHAGHEGHI MA, BANAZADEGAN R, AGHAHI N, et al. Analysis of needs estimated to clinical subspecialists & fellowships in the country for the next 10 years (since 2019). 2010.
9. Dolea C, Stormont L, Braichet J-MJBotWHO. Evaluated strategies to increase attraction and retention of health workers in remote and rural areas. 2010;88(5):379-85.
10. McClean SJEJoOR. Manpower planning models and their estimation. 1991;51(2):179-87.
11. HADIAN M, NADERI M. Factors affecting the demand for general practitioners and forecasting it by 2001. 2007.
12. Farzadi F, Mohammad K, Maftoon F, Ghasemi RL, Dezfoli NTJP. General practitioner supply: family physician program and medical workforce. 2009;8(4):415-21.
13. Furukawa KJPT, Practice. Human resource challenges for physical therapists in Japan: a hybrid time-series and system dynamics analyses for the near, mid and long-term horizons. 2023;39(3):504-17.
14. Munn Z, Peters MD, Stern C, Tufanaru C, McArthur A, Aromataris EJBmrm. Systematic review or scoping review? Guidance for authors when choosing between a systematic or scoping review approach. 2018;18:1-7.
15. Leerapan B, Teekasap P, Urwannachotima N, Jaichuen W, Chiangchaisakulthai K, Udomaksorn K, et al. System dynamics modelling of health workforce planning to address future challenges of Thailand's Universal Health Coverage. 2021;19:1-16.
16. Liu X, Long T, Xue CJAiASS. A study on human resources management based on system dynamics. 2012;3(3):680-5.
17. Wu M-H, Yu J-Y, Huang C-HJP, Neonatology. Theoretical system dynamics modeling for Taiwan pediatric workforce in an era of national health insurance and low birth rates. 2013;54(6):389-96.
18. Barber P, López-Valcárcel BGJHrfh. Forecasting the need for medical specialists in Spain: application of a system dynamics model. 2010;8:1-9.
19. Ishikawa T, Fujiwara K, Ohba H, Suzuki T, Ogasawara KJHrfh. Forecasting the regional distribution and sufficiency of physicians in Japan with a coupled system dynamics—geographic information system model. 2017;15:1-9.
20. Ishikawa T, Ohba H, Yokooka Y, Nakamura K, Ogasawara KJHrfh. Forecasting the absolute and relative shortage of physicians in Japan using a system dynamics model approach. 2013;11:1-10.
21. Willis G, Cave S, Kunc MJEJoOR. Strategic workforce planning in healthcare: A multi-methodology approach. 2018;267(1):250-63.
22. Koichubekov B, Kharin A, Sorokina M, Korshukov I, Omarkulov BJAI. System dynamics modeling for general practitioner workforce forecasting in Kazakhstan. 2021;33(3):242-53.
23. MacKenzie A, Tomblin Murphy G, Audas RJHRfH. A dynamic, multi-professional, needs-based simulation model to inform human resources for health planning. 2019;17:1-13.
24. Vanderby SA, Carter MW, Latham T, Feindel CJJotORS. Modelling the future of the Canadian cardiac surgery workforce using system dynamics. 2014;65(9):1325-35.
25. Cave S, Willis G, Woodward A, editors. A retrospective of system dynamics based workforce modelling at the centre for workforce intelligence. 34th International Conference of the System Dynamics Society Delft, Netherlands; 2016.
26. Ansah J, Koh V, De Korne D, Bayer S, Pan C, Jayabaskar T, et al. Comparing health workforce forecasting approaches for healthcare planning: The case for ophthalmologists. 2017;3(1):84-96.
27. De Silva MJCMJ. How many Medical specialists do Ministry of Health-Sri Lanka need by 2025: Use of system dynamics modelling for policy decisions. 2017;62(3).
28. Relić D, Božikov JJCmj. Application of a system dynamics model in forecasting the supply and age distribution of physicians. 2020;61(3):100-6.
29. De Silva D. How many doctors should we train for Sri Lanka? System dynamics modelling of training needs. 2017.
30. Baibordy L, Bafandeh Zendeh A, Aali SJIJoNA, Applications. Designing a human resource productivity model with a system dynamics approach in the health sector. 2023;14(1):557-73.
31. Yu W, Li M, Ge Y, Li L, Zhang Y, Liu Y, et al. Transformation of potential medical demand in China: A system dynamics simulation model. 2015;57:399-414.
32. Gupta S, Black-Schaffer WS, Crawford JM, Gross D, Karcher DS, Kaufman J, et al. An innovative interactive modeling tool to analyze scenario-based physician workforce supply and demand. 2015;2(4):2374289515606730.

33. Rafiei S, Mohebbifar R, Hashemi F, Ezzatabadi MR, Farzianpour FJEp. Approaches in health human resource forecasting: a roadmap for improvement. 2016;8(9):2911.
34. Dumitrache L, Nae M, Simion G, Cazacu CJHGJoS, Geography RiH. Geographic maldistribution of the physician workforce in Romania: urban-rural divide and need for better planning and retention strategies. 2023;17(1).
35. Nwankwo ON, Ugwu CI, Nwankwo GI, Akpoke MA, Anyigor C, Obi-Nwankwo U, et al. A qualitative inquiry of rural-urban inequalities in the distribution and retention of healthcare workers in southern Nigeria. 2022;17(3):e0266159.
36. Dubois C-A, Singh DJHrfh. From staff-mix to skill-mix and beyond: towards a systemic approach to health workforce management. 2009;7:1-19.
37. Vamos S, Yeung PJPiHP. Development of a core online health literacy course in Canada. 2017;3(2):90-9.
38. Chehade M, Gill T, Kopansky-Giles D, Schuwirth L, Karnon J, McLiesh P, et al. Building multidisciplinary health workforce capacity to support the implementation of integrated, people-centred Models of Care for musculoskeletal health. 2016;30(3):559-84.
39. Gailey S, Bruckner TA, Lin TK, Liu JX, Alluhidan M, Alghaith T, et al. A needs-based methodology to project physicians and nurses to 2030: the case of the Kingdom of Saudi Arabia. 2021;19(1):55.
40. Maynou L, McGuire A, Serra-Sastre V. Exploring the Impact of New Medical Technology on Workforce Planning. 2019.
41. Cao L, Lei H, Wang Y, Li L, Liu Q, Zeng R, et al. Navigation of the Evolving Medical Science Landscape to Enhance Teaching Capacities in Vocational Medical Education.
42. Lim MYH, Lin VJHRfH. Governance in health workforce: how do we improve on the concept? A network-based, stakeholder-driven approach. 2021;19:1-10.
43. Barbazza E, Langins M, Kluge H, Tello JJHP. Health workforce governance: Processes, tools and actors towards a competent workforce for integrated health services delivery. 2015;119(12):1645-54.
44. Cohen JJJAJoE. Medical education meets health care reform. 2009;11(11):896-9.
45. Liu J, Eggleston KJSir. The association between health workforce and health outcomes: a cross-country econometric study. 2022;163(2):609-32.
46. Witter S, Hamza MM, Alazemi N, Alluhidan M, Alghaith T, Herbst CHJHRfH. Human resources for health interventions in high-and middle-income countries: findings of an evidence review. 2020;18(1):43.
47. Russell D, Mathew S, Fitts M, Liddle Z, Murakami-Gold L, Campbell N, et al. Interventions for health workforce retention in rural and remote areas: a systematic review. 2021;19(1):103.
48. Wang Y, Liu C, Wang PJFiph. Patient satisfaction impact indicators from a psychosocial perspective. 2023;11:1103819.
49. Indicators AHOJG, Switzerland: WHO Document Production Services. Monitoring the building blocks of health systems. 2010.
50. Host BK, Turner AW, Muir JJC, Optometry E. Real-time teleophthalmology video consultation: an analysis of patient satisfaction in rural Western Australia. 2018;101(1):129-34.
51. Socha-Dietrich KJOHWP. Empowering the health workforce to make the most of the digital revolution. 2021(129):0_1-67.
52. Alyani N. Formulating digital right-skilling in the Gulf's Healthcare 4.0 ecosystem to enhance professional capabilities. Nationalization of Gulf Labour Markets: Higher Education and Skills Development in Industry 40: Springer; 2023. p. 149-77.
53. Landry MD, Hack LM, Coulson E, Freburger J, Johnson MP, Katz R, et al. Workforce projections 2010–2020: annual supply and demand forecasting models for physical therapists across the United States. 2016;96(1):71-80.
54. Lopes MA, Almeida ÁS, Almada-Lobo BJHrfh. Handling healthcare workforce planning with care: where do we stand? 2015;13:1-19.
55. Castro Lopes S, Guerra-Arias M, Buchan J, Pozo-Martin F, Nove AJHrfh. A rapid review of the rate of attrition from the health workforce. 2017;15:1-9.
56. Böheim R, Horvath T, Leoni T, Spielauer MJPR, Review P. The impact of health and education on labor force participation in aging societies: Projections for the United States and Germany from dynamic microsimulations. 2023;42(3):39.
57. Montes J. CBO's Projection of Labor Force Participation Rate. 2018.
58. De Hert SJL, anesthesia r. Burnout in healthcare workers: prevalence, impact and preventative strategies. 2020:171-83.

59. Organization WH. WHO guideline on health workforce development, attraction, recruitment and retention in rural and remote areas: World Health Organization; 2021.