Review article/Metaanalysis:

Health Manpower Forecasting: A systematic Review for Models and Approaches

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Abstract:

Background: An appropriate planning requires forecasting the demand and supply of health manpower in an accurate manner. ***Objectives:*** The paper objective was to review health manpower forecasting approaches and methods and propose the improvement features for effectiveness of health manpower planning. ***Data sources*****:** A systematic review was conducted for studies published in English from 1970-2014 using Pub Med, Science Direct, Pro Quest, and Google Scholar databases. ***Study eligibility criteria*****:** Review articles, qualitative studies, questionnaire driven surveys, retrospective and prospective studies describing or applying various types of forecasting approaches and methods in health manpower forecasting were included in the review. ***Data collection and study appraisal*****:** Two reviewers (SR and MA) independently appraised the studies to identify relevant ones to be included in the review. ***Results:*** A total of 128 studies were included in the review. As a result, two main categories of approaches (conceptual and analytical) for health manpower forecasting were identified with their strengths and weaknesses. ***Conclusions:*** Future forecasting methods should benefit from advantages of current approaches and overcome some of their main limitations. Applying a method which incorporates a wide range of factors affecting supply and demand, facilitates the collection of good quality data, monitors changing trends over time, considers the uncertainty of health systems and has a dynamic approach is proposed as an improvement roadmap for future forecasting.

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Introduction

Every health care systems are dependent on human resources[1]. To have a well functioning health care system, it is inevitable to have adequate number with proper performance of health manpower[2]. Imbalance in manpower demand and supply increases health care costs through provider induced demand[3,4] while insufficient supply may cause health needs of the population remain unmet or provide with lower quality[4,5]. Therefore policy makers are worry about such imbalances and try to resolve the problem through proper planning[4,6]. Planning health manpower prevents the potential imbalances in health manpower system[7,8]. It actually aims to guarantee that available health manpower is ready to provide services in "the right place at the right time with the right skills"[9-11].

Health human resource planning incorporates assessment of current manpower supply, forecast future requirements and develop appropriate strategies

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to make certain about balance between supply of and demand for manpower[12]. First by estimating current workforce supply, the adequacy of supply will be assessed. This gap analysis identifies proportion of population not covered by health manpower services[6]. Then the workforce requirements will be forecasted to define an optimal size for manpower. After defining an appropriate number of health manpower needed to meet requirements for health services, there would be necessary to develop some policies to keep supply and demand of manpower in a balance[9,10].

There are several forecasting methods with their own strengths and weaknesses[2, 8, 13-48]. Most of them do not have the ability to capture all key factors affecting demand and supply of health manpower. They also lack the ability to consider the dynamic interactions among full range of variables and to make possible scenarios in response to what-if questions[27,33,45,46,49]. To propose a single comprehensive approach incorporating strength point of other methods, it is required to conduct a systematic review on existing approaches, their advantages and limitations. In this way, challenges of such models would be analyzed to determine possible roadmaps for improvement. Almost always, this kind of study has been ignored in the literature and there is rarely a well appraised description of forecasting methods in which both conceptual and analytical approaches are examined together.

This paper aims to provide a comprehensive overview toward human resource forecasting approaches and consequently propose the features that potentially improve the effectiveness of such an approach.

Methods

The study method was structured based on PRISMA statement[50].

Eligibility criteria:

1) *Types of studies:* Reports, books, review articles, qualitative and quantitative studies were included in our study.

2) *Study subjects:* We included in the review those articles or reports describing the conceptual and analytical approaches in health manpower forecasting also those applying various forecasting methods to estimate health manpower supply and demand both in developed and developing countries.

3) *Types of participants:* We included in the review all health care professionals such as: doctors, dentists, nurses, dieticians and pharmacists.

4) *Year of publication:* We included in the review those articles or reports published in 1970-2014.

Information sources

Data bases of Pub Med, Science Direct, Google Scholar and Pro Quest were searched to find articles related to study subject. Reports were also investigated through searching the websites of World Health Organization and international professional associations related to workforce research. Examples for such associations included Canadian Nurses Association and Association of American Medical Colleges. Additionally the references cited by including articles were scanned to identify relevant articles that might have been missed.

Search strategy

We chose a time period from January 1, 1970 to December 30, 2014 for searching process of the study. Similar search terms including "forecasting approaches OR forecasting methods OR predict OR project" AND "demand OR supply" AND "health manpower OR health workforce OR health human resources OR health care professionals" were used for all databases. The search was restricted to articles and reports with full text accessibility published in English during the years 1970-2014.

Study selection

Data base searching led to 2816 documents. After removing duplicates, two reviewers (SR and MA) independently appraised the publications according to the title and abstracts. After this level of filtering, studies were checked to meet the eligibility criteria. In reference to the inclusion criteria of "study type", "study subject" and "types of participants", we included review studies describing conceptual approaches and analytical methods in health manpower forecasting. Original articles applying various forecasting methods to estimate health manpower supply and demand were also considered

to be eligible for inclusion in the review (figure 1). When there were more than one publication with similar method and presented data, authors decided to include only the most recent publication. Detailed information about searching process and final selection of publications is given in bellow table.

Table 1. Study selection process for each data base

Selection process	Pub med	Science Direct	Google Scholar	Pro Quest	Website of WHO or International Professional Associations
Potentially relevant documents identified through the initial search	482	48	263	1983	40
Documents excluded after title and abstract review	285	16	135	992	5
Documents excluded after evaluation on inclusion criteria	118	8	87	830	8
Documents excluded due to similarity in study design and data provided	29	2	23	157	0
Additional articles added from reference list of other publications	2	0	5	0	0
Total included articles from each database	52	22	23	4	27
Total included articles	128				

Data collection

As no systematic review with a similar objective of this study was available to provide an applicable extraction form, authors designed an extraction data sheet based on study questions. This form had been used to collect data on studies references, countries and designs, type of forecasting approaches whether discussed or applied with their strengths and weaknesses (table2). For each study, two authors (SR and MA) completed the sheet independently. Any disagreement was solved through consensus.

Table 2. Data extraction form

Reference number	Study country	Study design	Type of forecasting approach	strengths	weaknesses

Results

In an initial search restricted to language, publication time and full text accessibility 2816 publications were found. Screening documents based on their titles and abstracts revealed 1433 duplicates or non-relevant studies. After reviewing the full texts of remaining studies 1051 of them were excluded because of non consistency with inclusion criteria. Among which 570 did not meet our criteria for study subject, 15 were not compatible with inclusion criteria of study design, 350 studied forecasting approaches among non health workforce and 116 provided no data on strengths and weaknesses of forecasting approaches. 211 documents were also removed due to similarity in method and data provided. Considering the reference lists of remaining studies led to 7 additional publications that met our inclusion criteria and were not the duplication of other studies. Documents' flow in a searching process is depicted in figure 1. As a whole, 128 studies were included in the review both from developed and developing countries. More than 50% of them were published in or after 2000.

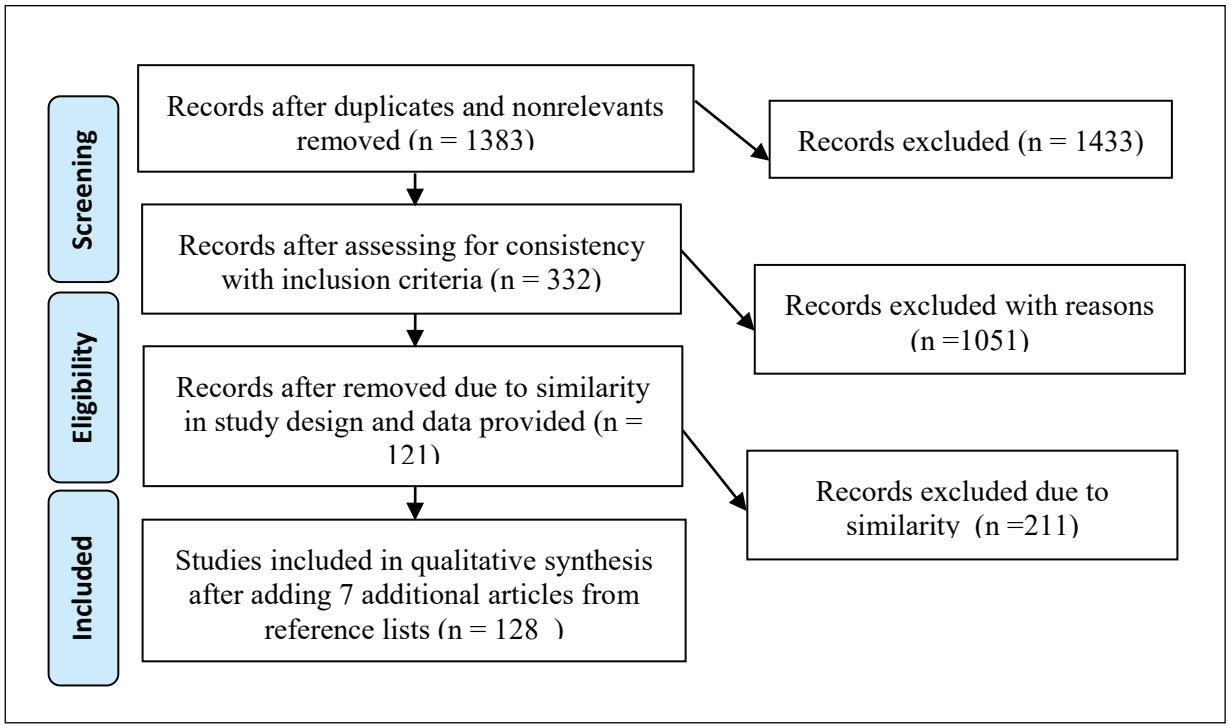

Figure 1. PRISMA flow diagram: Identified studies reviewing the forecasting approaches in health manpower planning

Two main categories of forecasting approaches in health manpower planning were identified [51]. The first category is conceptual approaches which clarify different affecting factors involving in health manpower planning. Each of the approaches relies on specific factors to forecast health manpower supply and demand.

Conceptual approaches

Main conceptual approaches for health manpower forecasting were identified from the review.

Manpower to population ratio

Definition

This is a simple method to forecast future requirements for health manpower by calculating the number of staff needed to serve future population in a way they are currently being served[35]. This ratio is often identified by governmental policy makers, professionals in expert panels or technical agencies like World Health Organization [19]. There are three main assumptions regarding to this approach: current number, skill mixture and of distribution of manpower are adequate; productivity, age and sex pattern of manpower will keep on unchanged in the future; number and demographic specification of manpower alters according to current observed trends over time [39, 52].

Strong sides

This approach is easy to understand and use by simply depending on existing data bases. Applicability of the method in a national context besides its comparability among different regions and countries are other main advantages [4, 19, 24, 26, 45, 53] .

Weak sides

The defined ratio in this approach is supposed to be appropriate and efficient in a way that future estimation should be based on it. This faulty assumption will put a great obstacle in a way of manpower planning improvement [13, 26]. Synonymous of supply to need and considering manpower as a homogeneous category are other faulty assumptions regarding to this approach. In fact, differences in productivity, type of activities manpower perform and population dissimilarities are neither reflected [19]. Explaining health sector functions and ways of increasing manpower productivity are features that are mostly ignored in this approach [17, 25, 26, 36]. Disability to demonstrate distributional imbalances and taking little account to age distribution of the population, the epidemiological features and socio economic conditions are other weakness points [19, 26, 31]. Overall, the real capability of health system and actual needs for services are not taken in to account in this approach [4, 17, 19, 28, 39].

Demand based approach (Requirement model or utilization based approach)

Definition

This approach calculates utilization rates of health services among different population categories and then adjusts the calculated rates to future characteristics of the population in order to find

out service demands. Finally service demand will be converted to required health manpower[25, 26, 54]. The approach is recommended to be used in countries with a dominant private sector and little imbalances of services to different segments of the population[26, 55]. There are three related assumptions: existing demand for health care services is suitable and will be met by present number, skill mixture and manpower distribution; age and sex pattern of manpower will keep on unchanged in the future; number and demographic specification of manpower alters according to current observed trends after a while [4, 39].

Strong sides

Availability of data and the assumption that providers currently deliver services in accordance with societal values are among the advantages can be mentioned for [16, 22]. The approach can capture future forces of increasing number and ageing population on amount of health care services demanded [4, 19, 24, 39, 45, 53, 56].

Weak sides

The main problem of this approach is neglecting the consequences of errors arising from its faulty assumptions. It is notable that utilization of services is dependent to supply, therefore any incorrect estimation of service requirements will lead to changes in the number of health manpower per capita population [45, 53]. There is also an interaction between demand, need and supply which is ignored in this approach[45]. Second issue is that demand for services is not a proper representation for health care services need; somewhat it is a measure for perceived need[8,10,17,29]. The third invalid assumption is that demand based approach considers current utilization rate efficient which can be regarded as a basis for future demand estimation[28]. As a result, such approach may assign current injustice and insufficiencies in to the future[18, 19, 21, 35]. The fourth issue is that professional, economic, political, technological and socio cultural factors are rarely well intended[27, 33]. Another disadvantage is the assumption that there is no excess use in the utilization pattern of the population and people use only the amount of health care services which is needed to maintain or maximize their health condition[22]. Finally the approach assumes that there is no room for health improvement of population and the health status is optimal and should be maintained in a same way in the future[22].

Need based (Epidemiological) approach

Definition

This approach defines and predicts health deficiencies of a population and level of appropriate services needed to make best standard of health status possible[4, 34, 39]. This method has three main assumptions: all health care needs are possible and supposed to be met[53], allocating resources for the purpose of meeting all health needs of the population is a cost effective approach regardless of other needs existing in different sectors of the country, methods of dealing with needs are clarified and can be recognized without facing any difficulty, and finally health care resources are always employed in reference to actual amount of need[39, 53].

Strong sides

When health needs are defined, this approach can identify a normative standard for manpower supply to meet service requirements of a population[25, 26]. The method is more practical for planning services with defined standards of need for specific population characteristics[24, 40]. It is also useful in comparing burden of illness among different population of an area [24]. Change in health care delivery and work styles among providers are considered in this approach[28, 40, 41, 52]. Unlike utilization based approach, needs based planning assumes that current number and distribution of manpower are not necessarily optimal[30, 38]. Method also includes unmet needs in the estimation process and is useful in planning preventive and national public health programs. The approach is mostly suitable for planning in countries with a high public awareness and sound planning capacity.

Weak sides

These standards are mainly based on expert panels and technical opinion of a group of professionals and do not rely on objective techniques for identifying health service requirement {Weiner, 1987 #36;Roberfroid, 2009 #23;Solutions., 2013 #35}. The approach does not reflect the capability and eagerness of population to pay amount of money needed for health services[46,57]. Although the approach seems rational but it is most difficult to performed. Defining health needs is very challenging. Measurement of needs is also a major difficulty. The problem may be even more critical when there are no established norms yet[19, 24, 39, 40]. There is a fact that health needs change dramatically over time and there is a necessity to monitor these changes over time[10,19]. Needs based approach often neglects the effects of new developments such as technological advances on their estimates[10]. The approach also ignores the efficiency in resource allocation between health care and other activities. Therefore considering a connection between principles of needs based

approach and economic values such as opportunity costs of resources have a great importance[53].

Benchmarking

Definition

This approach uses health manpower to population ratio as a proxy for need[13, 18, 23, 26] and relies on identifying a service standard in a health system which is supposed to perform appropriately and provide affordable and sustainable health care services. Then the standard would be applied to a comparable population[22, 40, 43, 44]. The approach assumes that current condition continues in to future to estimate health manpower requirements[39]. The second assumption confirms that defined ratio is the finest and most valid possible in providing suitable health care services for a new population[46, 58]. It is also believed that desirable health for a population can be met with equal number of manpower after modifying for demographic characteristics of a population [24, 39].

Strong sides

This approach is simple to perform and able to compare manpower resources between regions with same health care system characteristics[16, 22, 23, 39, 40].

Weak sides

Such models are mostly criticized because of the faulty assumption that health condition of a particular population is desirable for other areas and can be met after some adjustments in demographic characteristics. Considering the defined ratio as the finest and most valid possible is also a doubtful assumption that endangers the utility of the approach. Similar to manpower to population ratio, this approach also neglects changing in productivity, age and sex pattern of providers over time. In fact benchmarking is not a suitable approach for regions with infrastructure differences and does not take in to account the geographic distribution of population [14, 24, 31, 47].

Service Target Approach

Definition

Service target approach links manpower provision to specific health care services that are mentioned as an objective to be produced for a specific number of population or for a defined region [2, 26, 58]. It assumes that needs are the same among populations and there is no heterogeneity in productivity and practice style of providers[19, 26].

Strong sides

This approach is politically appealing and most suitable to be used at a local level[32, 45]. The advantages of this method is easy separation of health services into component parts and simplification of cost estimates also providing an active approach towards health services improvement. Being flexible and requisite of modest data are another advantages that could be mentioned[19].

Weak sides

Standard setting in this approach is based on desires rather than reality and this is one of the shortcomings of the approach as errors of judgment would occur consequently. In fact, targets are not clearly confirmed in all situations and may only be a sign of experts' opinions; therefore suffer from subjective manner [19]. Ignoring the heterogeneity among populations and providers is also a notable weak point regarding to this approach[19, 26].

Mixed approach

Definition

Since different forecasting approaches have their own strengths and limitations and vary in assumptions, mixed models are introduced to be useful in estimating health human manpower in a most effective way. In this approach an efficient number of required manpower is determined by integrating several factors of health human resource conceptual approaches and creating a single comprehensive model. In reality, however mix (combined) models are used in projections[32, 39].

Strong sides

Mixed approach considers a variety of economic, social, political and technological factors influencing health manpower forecasting. The dynamic nature of population health needs and providers' characteristics is taken in to account by the model. To estimate future requirements for health manpower the interaction between supply and demand factors is fully considered. Model can be applied in both national and local levels and provides an opportunity to investigate different health policies before putting them in to action[6, 10, 27, 34, 49, 53, 59].

Weak sides

Demanding varied sources of data and somehow complexity of the approach are the main limitations of the method[33, 53].

Different mixed approaches

The most common mix approach relates supply and demand based parameters in a way to build a supply to health care utilization ratio[15, 20, 42]. Another mix model is effective demand based approach in which economic values harmonize the epidemiological concerns related to need based approach[53, 60]. As there are clear possibilities for resource tradeoffs, it is not wise to ignore financial resource constraints in forecasting. This approach ensures that human

resources are organized efficiently[29].

A conceptual model "dynamic system based framework" was introduced as a mix model by O' Brien, et al considering:1) health levels related to population (needs based factors), 2) health care utilization rates (utilization factors), and 3) economic, social, environmental and political factors affecting health expenses (effective demand based)[4]. This model integrates two main methodological approaches of needs and demand based to introduce a comprehensive model[32, 53.]

Effective infrastructure approach is another mixed approach which is based on needs based parameters added to infrastructure variables[4]. In this approach, physical facilities of a health system should be clarified to make use of workforce according to available infrastructure[4, 21].

Integrating Markov population model with principles related to benchmarking approach is another mix approach which was used for projecting endocrinologists in USA[37, 39].

Analytical approaches

There are some analytical methods used in manpower forecasting. The methods are useful in decision making and supporting plans and policies related to manpower system[35, 39]. As conceptual methods are different, analytical approaches are also varied. A desired outcome expected from analytical methods is to provide practical and easy to understand information for managers, planners and policy makers. These approaches must have the capacity for longitudinal analyses. They must take in to account the inherent uncertainties in manpower supply and demand variables and use high-quality databases to achieve viable data also capable for scenario planning using a variety of techniques[46]. Analytical methods in health manpower forecasting are categorized in to some main groups: extrapolative methods including trend analysis, explanatory variable methods such as econometric models and regression analysis, operations research methods including Markov model, linear and non linear programming, queuing theory, simulation and system dynamic and finally workload indicators of staffing needs developed by WHO[10, 32, 35, 46, 59].

Trend Models

Definition

These models correlate historical data trends to project future requirements for manpower based on different scenarios and altering key assumptions[46]. Trend models also called supply projection models consider current amount of health care services offered by health manpower. The model defines need as a number of manpower necessary to add current supply to maintain or attain a pre-determined level of service[4, 39]. Consequently, manpower requirements are not calculated on the basis of population health needs [35, 61-64]. This approach assumes that current size, skill mix and distribution of manpower are adequate and their productivity will remain constant in the future[4, 53]. Another assumption is that the number of manpower and their demographic characteristics changes over time in a current observed trend[29,41,53,65-67]. In such models it is assumed that entry, re entry and attrition rates of manpower from current supply would remain the same in the future[68].

Strong sides

The advantage of this approach is that forecasting is easily possible by using historical data and retrospective trend analysis[62, 69].

Weak sides

The shortcoming is that the forecast only reflects the historic trends of manpower supply not the actual number existing in the future. The model incorrectly assumes that past trends in health manpower supply or demand continue in to the future[39, 62, 70-72]. However relying on historical trend and considering the growth rate dependent on the start and end points of time intervals is fully problematic and the assumption of a long-term trend is also impractical[73].

Econometric Models

Definition

This statistical technique suggests that the number of health manpower required is a consequent of population's demand for health services which is related to economic factors such as health service utilization, access to services, consumer health preferences, income or set of market variables[35, 65].

Strong sides

Econometric approach including regression models is useful in examining the relationships between stock, wages, demand and budgets. These analyses can be used for forecasting population demand for manpower considering future growth in national income of a country [35, 51.]

Weak sides

Model often ignores political/socio/economic variables, changing health system and the relative outcomes[32]. Similar to trend models, econometric approach does not consider changes in assumptions and data flows. In fact the model is not comprehensive and able to capture full range of variables and dynamic interactions among them. Another limitation is that model is not self regulating to allow for output

changes as a result of manipulation in some variables or changing their power of importance [46, 74-76].

Artificial Neural Networks

Definition

This method allows for nonlinear connections between input and output variables and for learning patterns in data[77-79]. Artificial neural networks are consisted of a range of variables connected to each other in different layers in a way that one layer obtain input from the former layer and passes the output to the following one[80].

Strong sides

Neural networks are able to simulate system behavior and capture many features of real situation as networks when input and output variables are clearly identified. They can also provide high precise results comparing to regression models and do not necessitate modelers to have special knowledge or understanding of modeling[80]. The method can solve some of the limitations related to former models such as linear regression by estimating nonlinear relations as well[81]. The accuracy of these models can be evaluated by mean squared error[80].

Weak sides

One of the shortcomings of the model is that it needs a lot of data to be run correctly and its accuracy is largely dependent on data quality. Second, it is difficult to define analytical relationship between input and output variables of the model. Likewise, as the model finds any relationship between each set of independent and dependant variables there is a risk of finding unreal associations[82]. Finally the model is not able to automatically adopt itself to environmental changes; thus in response to any alteration the network must be restructured[80, 83, 84].

Markov Models

Definition

Estimating the supply of manpower in a region using Markov and semi Markov methods includes flows of manpower in supply forecasts. In this type of method, fluctuations in labor levels are projected using historical transition rates[85]. These fluctuations are projected by analyzing historical trends in staff retention or movement, and keep it in to the future with the same trends of the past[86].

Strong sides

This method has commonly been used in studies to forecast recruitment requirements of manpower in a local level, but it is also possible to aggregate this information across a nation and provide an overall estimation. Such models increase the precision of forecasting, and are appealing because they can be analytically solved[53]. They are able to give a variety of parameter values, also use confidence intervals and test statistical significance for different estimates[45]. Ability to simulate the consequence of different policy changes is another characteristic can be mentioned for[39, 45, 86-89].

Weak sides

The main weakness of these models is that they assume current behavior and health care delivery patterns will be constant in to the future and project future supply in compliance with current number and age profile of manpower[88]. Trends are considered to keep on developing according to the past. The model also requires major generalization of a problem to make it fit for the projection purpose[53]. Uncertainties in inflow and outflow parameters are often ignored and calculation of statistical confidence intervals is impossible. Inability to capture dynamic variables and the interaction between them is also a shortcoming of the model[14, 89, 90.]

Linear programming

Definition

This method analyzes fluctuations in labor levels using an objective function as well as organizational and environmental constraints[39, 91]. Optimal number of manpower recruitment is identified in a way that total cost of planning including recruitment, promotion, overstaffing, wastage and retention are minimal[92].

Strong sides

This method helps to use available resources in a best manner and is appropriate in problems with objective and constraint functions in a linear equation form.

Weak sides

Linearity of objective and constraint functions as one of the model assumptions is not true in real life conditions. As model variables and parameters increase, the number of equations and difficulty to perform the models would raise dramatically. Uncertainty is one of the factors neglected in this model. It also lacks the possibility to perform scenario making and ignores political, technological and socio cultural features in the modeling process[91-94]. Failure to incorporate as much as variables related to manpower supply and demand also the correlation among them is a remarkable shortcoming of the model.

Queuing Theory

Definition

Queuing theory is a mathematical model to facilitate service providing in an organized manner. To apply this method, it is necessary to know the distribution

of arrival time, service time and the queue discipline[73,92,95]. The situation with characteristics of a Poisson arrival process, an exponential distribution of service times, a first come first served queue discipline and a service arrangement of multiple services acting in parallel is suitable for applying queuing theory[73, 96, 97].

Strong sides

Queuing theory can be used in manpower planning and is able to identify how many staff is required to give adequate services to a population. Comparing to simulation, this analytical tool is simpler and needs much less data to answer health manpower planning dilemmas. The results of the model can be solved analytically and are applicable at different scales including individual units/departments, healthcare facilities and healthcare systems in district level[53].

Weak sides

One of the shortcomings of the model is that it uses an average of variables instead of real numbers[73]. It also supposes that system operates in a steady state, times spent for service delivery and service rate are known and the latter is greater than arrival rate also time spent for services is stated by "negative exponential probability distribution"[73]. In fact the method fails to consider the dynamic nature of health system. The other weakness is that the method is not appropriate in complex cases related to national levels. Model also fails to consider full range of variables to reflect the complexity of real life situation[73, 98, 99].

Nonlinear programming

Definition

Nonlinear programming is the course of action in terms of various constraints and a set of variables along with an objective function to be maximized or minimized where they are not in a linear form[100, 101].

Strong sides

Most of the situations in real world are consistent with nonlinear programming. The model has the ability to capture the complexity and nonlinear interactions between system components which is regarded as its main strength point[92, 100, 102-104].

Weak sides

Nonlinear programming solutions are often local optimums[92, 100]. Neglecting the effect of wide range of variables, dynamic interactions among them and uncertainty inherent to the variables are among the main shortcomings of this method[92, 100, 102-104].

Simulation

Definition

Simulation is a method of designing model for a real world phenomenon with the intention of understanding its behavior or assessing the effect of different strategies on it without having to manipulate real world systems. This method models the real system through mathematical relations between variables and their likelihood distributions.

Strong sides

The model provides the opportunity for modelers to understand the system behavior or evaluate different strategies without having to manipulate real world systems. The ability to evaluate system behavior under various scenarios is its important usage in policy making in response to different situations. The method is easier to perform, requires less simplifying assumptions and provides more reasonable reproduction of system than mathematical methods[2,64,65,105]. Facilitating sensitivity analysis over the model variables also involving stakeholders in the process of modeling are among other features of simulation[106]. There are two related approaches used to assess uncertainty in health system forecasts: "deterministic sensitivity analysis and stochastic simulation". Stochastic simulation generates more realistic and meaningful forecasts than deterministic sensitivity analysis. Where there is no systematic data for some features of the problem, stochastic modeling can be useful to take uncertainty in to account by means of random variables[4, 39, 107-109.]

Weak sides

The necessity to use more detailed data makes this method costly to be applied[2, 64, 65]. Simulation is not a precise method able to achieve accurate solutions or single determined answers. Instead, it generates multiple system's responses to different running conditions[110]. As there is no standardized approach for simulation, models generated by different modelers may vary extensively[105]. As the number of parameters increases, model faces with difficulty to find the best possible answer. To ensure the accuracy of the model, validation methods are required[111].

System Dynamic Modeling

Definition

System dynamics (SD) initiated by Forrester (1961) is a modeling method consisted of causal loops and stock-flow diagrams depicting interactions among variables and the structure of a system flow[112,113]. Stock variables represent the current situation of system; while flow variables explain changes constantly occur in the stock[112-114]. Method is used to identify the organization, performance and behavior of complex systems.

Strong sides

The method enables us to simulate real systems

with complicated structure and understand their feedback interrelationships and dynamic nature of variables[113,115]. Interaction among system components causes the dynamic behavior of systems over time which is able to be considered in SD modeling. Method allows for capturing dynamic impacts related to time delays and feedback relations of a system[113]. In fact, managers profit from the interactive environment created by system dynamics[113, 114, 116-119]. Also ability of the model to depict effects of different policies makes it a useful method for better policy making in different decision areas including manpower planning[113, 118]. By reviewing manpower projections and altering assumptions when appropriate, possible surpluses or shortages in future manpower can be recognized[113, 116]. Experiencing long term effects in a short time by testing what-if scenarios can help modelers to design better strategies for system development. The model is useful for forecasting purposes in medium to long term periods of time [113]. The main advantage of the method is its capability of being operated in a fast manner which is suitable for decision makers to effectively plan for the future in a proper time and minimum risks[114]. Furthermore, qualitative data can be modeled in this approach[114,120].

Weak sides

To test the method validity, each parameter should have an equivalent in the real world. Obtaining information on these parameters, variables and potential interactions among them is not a simple process. Additionally, drawing doubtful and hypothesized feedback loops might generate a model that does not characterize real world behavior. Model is also in danger of becoming complicated as a result of growing in number of variables or considering multiple interactions[113, 121].

Workload Indicators of staffing needs (WISN)

Definition

This method has been introduced in 1998 by World Health Organization for determining activity norms for each category of health professionals and converting them into relative workloads in order to obtain a method for defining health manpower requirements [35, 122, 123]. By dividing the actual number of manpower to the required level, WISN can be calculated[35, 123, 124].

Strong sides

The method is a helpful management guide to make valid decisions about employment, distribution and development of health sector manpower[124]. The method is a combination of both expert judgment and measurement of activity standards to define workload norms for each category of health manpower[124]. Deciding on manpower allocation through geographical areas and their functional deployment to achieve an optimal number and staffing pattern are other uses of the method[123].

Weak sides

WISN is estimated by means of annual data available for work activities done in a health care facility. Thus, accuracy of the method is dependent on the accuracy of annual data[124]. When there is a poor information system in a facility, results of the method will be incorrect. It is mostly neglected that low level of workload in a health facility might be the result of lacking materials[124]. Shortages of supplies, poor services, inconvenient location of facilities, short hours and their potential effects are usually ignored in this method[123, 125-127]. Considering a wide range of variables related to manpower supply and demand, their correlation and dynamic nature are not possible in this method[123, 125-127].

more effective method in health manpower forecasting

Most of the health manpower forecasting methods do not regard entire dynamic variables playing important role in manpower forecasting and their causal relations. They also lack the capability of making scenario to help policy makers in effective decision making[128].

Modern forecasting approaches need to meet the key features found in the literature in order to develop a dynamic and comprehensive method necessary for today complex health care systems[32, 46, 129]. Some of the key features are: taking in to account full range of dynamic variables affecting manpower supply and demand, considering their inherent uncertainty and complex interactions, having a system level perspective with a dynamic approach and ability to scenario making useful for policy making purposes[128]. Our study recommends using a dynamic model which meets following features[4, 39, 128].

Incorporating all relative factors with dominant effect on manpower supply and demand, monitoring trends of these factors over time, considering complex interactions among these factors, applying what if scenarios helpful for policy making purposes.

Providing high quality and longitudinally data around the key factors are the essentials in making a valid and reliable manpower forecast[8, 29, 32, 37, 128-133]. Considering the impact of emerging technologies, socio cultural evolutions, economic changes, political incentives, demographic and epidemiological trends on health system capacity to meet these requirements are the

examples emphasizing the importance of monitoring trends in affecting factors over time[32, 46, 130, 134]. Taking in to account multifaceted interactions among variables influencing manpower supply and demand is another important attribute. Illuminating all possible connections between variables disclose the complex nature of manpower modeling[113, 114, 116, 119].

Checking what- if scenarios is another important factor which should be regarded. Sensitivity analysis allows policy makers and planners to make different evaluation of required services and consequently plan for the number of manpower required[32,113,114,116,117,120].

A system dynamic modeling approach takes in to account a complete number of dynamic variables in manpower planning and consider both quantitative and qualitative aspects. The model is useful in better policy making for manpower supply and demand by taking in to account a combination of various perspectives[32]. Ability of the model in responding what if scenarios can help planners and policy makers to decide more effectively in manpower planning[112-114, 116, 117, 119, 120].

Discussion

This paper reviews different forecasting approaches and methods for health manpower and demonstrates the issues that develop the effectiveness of health manpower forecasting. There are several conceptual approaches to forecast health manpower supply and demand [2, 8, 13-48]. Most of them are supply based approaches including manpower-population ratio which is helpful for estimating manpower requirement in a national level[13, 17, 19, 25, 26, 28, 31, 36].

Service utilization models are used to measure health manpower requirement in private sector. Similar to manpower-population ratio, demand based approach covers main regional imbalances. Both approaches also disregard the effects of manpower planning on health system outcomes[32, 39]; they also ignore the complexity and dynamic nature of health system and do not consider population health needs in manpower planning[2, 8, 14, 16-18, 21, 22, 25-27, 29, 33, 35, 45].

Needs based approach seems to be reasonable because instead of considering the current level of health manpower to be necessarily adequate; it focuses on population health needs[16,19,24,30,34,40,41,46,48.]

In health service target approach, a degree of health manpower supply is defined to respond targeted health services in a health system for a particular population. This approach is politically accepted and makes manpower planning possible in local levels[19,26,45,55,58]. There are a number of limitations regarding to above mentioned approaches. One of the main shortcomings is ignoring the health system's dynamic nature and comprehensiveness of several factors which have important effect on health manpower planning [27, 32, 33, 39, 45, 128].

The last approach is benchmarking which relies on homogenous health system indicators to determine health manpower requirement. Despite of the approach simplicity, it suffers from similar important deficits[23, 43, 44, 47, 58]. In fact none of the five approaches captures a comprehensive set of factors influencing health manpower demand and supply including economic, socio-cultural, political, technological, disease incidence, service utilization and other affecting factors. The dynamic relations among all variables cannot be shown in above approaches and making what-if scenarios to respond different situations is also impossible[27, 33, 45, 46, 49]. Our study proposes a comprehensive health manpower model which includes as many of influencing factors as possible such as demographic factors, economic, social, political and technological factors, service utilization, health needs etc with their causal effects[8,10,29,32,37,128, 131-133]. A road map for developing an effective model in manpower supply and demand forecasting is supposed to be the one that considers as many variables involving in manpower planning as possible, effective monitoring of their trend over time, their inherent uncertainty and complex interactions among them along with the ability to forecast supply and demand for a long period of time and for a large number of population[112-114, 116, 117, 119, 120].

Conclusion

Lack of adequate attention to this key process, will decrease the quality of health services patients receive and increase the burden of expenses enforced to health system [135]. There are a number of forecasting approaches and methods with their own strengths and weaknesses to forecast health manpower requirement. System dynamic modeling has the ability to consider a complete set of dynamic factors in human resource planning and regard both quantitative and qualitative dimensions. Model is also useful in stronger manpower planning for supply and demand and making reliable policies for their staffing, allocation, education and attrition objectives[113,114,120,136].

Ethicalclearance

References:

1. Bloor, K. and A. Maynard, *Planning human resources in health care: Towards an economic approach - an international comparative review*. 2003, Canadian Health Services Research Foundation: Ottawa, Ontario.
2. Hall, T.h., *Why plan human resources for health?* Hum Resour Dev, 1998. **2**: p. 77-86.
3. Léonard, C., S. Stordeur, and D. Roberfroid, *Association between physician density and health care consumption: A systematic review of the evidence.* Health Policy, 2009. **91**(2): p. 121-134.
4. Roberfroid, D., et al., *Physician workforce supply in Belgium: Current situation and challenges*. 2008, Health Care Knowledge Center: Brussels, Belgium.
5. Duckett, S., *The Australian health workforce: facts and futures.* Aust Health Rev, 2000. **23**(4): p. 60-77.
6. Zurn, P.D.P., M. Stilwell, B. Adams, O. , *Imbalance in the health workforce.* Hum Resour Health, 2004. **2**(13).
7. Kabene, S.M., et al., *The importance of human resources management in health care: a global context.* Hum Resour Health, 2006. **4**: p. 20.
8. Barer, M. and G. Stoddart, *Toward integrated medical resource policies for Canada*, in *Report to the Federal/ Provincial/Territorial Conference of Deputy Ministers of Health*. 1991, McMaster University: Ontario, Canada.
9. Committee, A.H.W.A., *Nursing Workforce Planning In Australia - A Guide To The Process And Methods Used by the Australian Health Workforce Committee*. 2004, AHWAC: Sydney.
10. Birch, S., *Health human resource planning for the new millennium: inputs in the production of health, illness, and recovery in populations.* Can J Nursing Res, 2002. **33**: p. 109-114.
11. Stokker, J.H. and H. Gillian, *The right person, in the right job, with the right skills, at the right time. A workforce planning model that goes beyond metrics.* Library Manag, 2009. **30**(8): p. 561-571.
12. Smits, M.S., V. Geurts, J. . *Improving manpower planning in health care*. in *23rd Bled e Conference 'e Trust: Implications for the Individual, Enterprises and Society*. 2010. Bled.
13. Lave, J.R., L.B. Lave, and S. Leinhardt, *Medical manpower models: need, demand and supply.* Inquiry, 1975. **12**(2): p. 97-125.
14. Anderson, G.H., K. Miller, R. Johns, M., *A comparison of three methods for estimating the requirements for medical specialists: the case of otolaryngologists.* Health Serv Res, 1997. **32**: p. 139-153.
15. Angus, D., et al., *Caring for the critically ill patient: Current and projected workforce requirements for care of the critically ill and patients with pulmonary disease: can we meet the requirements of an aging population?* . JAMA, 2000. **284**: p. 2762-2770.
16. Centre, C.L.a.B., *Canada's Physician Workforce: Occupational Human Resources Data Assessment and Trend Analysis Executive Summary*. 2000, Canadian Policy Research Networks: Ottawa, Canada.
17. Chan, B., *From perceived surplus to perceived shortage: what happened to Canada's physician workforce in the 1990's?* . 2002, Canadian Institute for Health Information: Ottawa, Ontario.
18. Dreesch, N., et al., *An approach to estimating human resource requirements to achieve the Millennium Development Goals.* Health Policy Plan 2005. **20**: p. 267-276.
19. Dussault, G.B., J. Sermeus, W. Padaiga, Z. , *Assessing future health workforce needs-Investing in Europe's health workforce of tomorrow: Scope for innovation and collaboration*. 2010, European Observatory on Health Systems and Policies: Geneva.
20. Forte, G.J., *U.S physician workforce forecasting: a tale of two states.* Cahiers de Sociologie et de Demographie Medicales, 2006. **46**(2): p. 123-148.
21. Gavel, P., *Medical workforce planning in Australia: process, methodology and technical issues.* Cah Sociol Demogr Med, 2004. **44**(1): p. 7-42.
22. Goodman, D.C., *The pediatrician workforce: current status and future prospects.* Pediatrics, 2005. **116**(1): p. 156-173.
23. Goodman, D.C., et al., *Benchmarking the US physician workforce. An alternative to needs-based or demand-based planning.* JAMA, 1996. **276**(22): p. 1811-1817.
24. Katz, A., et al., *Physician resource projection models*. 2009, Manitoba center for health policy, Department of community health sciences, Faculty of medicine, University of Manitoba: Manitoba.
25. Klarman, H.E., *Economic aspects of projecting requirements for health manpower.* J Hum Resour, 1969. **4**(3): p. 360-376.
26. Keet, M.P., et al., *Medical manpower-South African situation models for planning and recommendations.* South African Med, 1990. **78**(17).
27. Lavis, J.N. and S. Birch, *The answer is ..., now what was the question? Applying alternative approaches to estimating nurse requirements.* Can J Nurs Adm, 1997. **10**(1): p. 24-44.
28. Lee, P.P., C.A. Jackson, and D.A. Relles, *Demand-based assessment of workforce requirements for orthopedic services.* J Bone Joint Surg Am, 1998. **80**(3): p. 313-326.
29. Lomas, J., G.L. Stoddart, and M.L. Barer, *Supply projections as planning: a critical review of forecasting net physician requirements in Canada.* Soc Sci Med 1985. **20**: p. 411-424.
30. Markham, B. and S. Birch, *Back to the future: A framework for estimating health care human resource requirements.* Can J Nurs Adm, 1997. **10**(1): p. 7-23.
31. Lurie, J.D., D.C. Goodman, and J.E. Wennberg, *Benchmarking future generalist workforce.* Eff Clin Pract, 2002. **5**(2): p. 58-66.
32. Murphy, G.T. and L. O' Brien-Pallas, *How Do Health Human Resources Policies and Practices Inhibit Change? A Plan for the Future*. 2002, Commission on the future of Health Care in Canada: Canada.
33. O'Brien-Pallas, L., et al., *Health human resource planning in home care: How to approach it - That is the question.* Healthc Pap, 2000. **1**(4): p. 53-59.
34. O'Brien-Pallas, L., et al., *Health human resources: An analysis of forecasting models*. 1998, Canadian Nurses Association: Ontario, Canada.
35. Organization., W.H., *Models and Tools for Health*

Workforce Planning and Projections. 2010, Human Resources for Health Observer, World Health Organization: Geneva.
36. Petersdorf, R.G., *Health manpower: numbers, distribution, quality.* Ann Intern Med, 1975. **82**: p. 694-701.
37. Rizza, R.A., et al., *A model to determine workforce needs for endocrinologists in the United States until 2020.* J Clin Endocrinol Metab 2003. **88**(5): p. 1979-1987.
38. Roos, N.P., et al., *A population-based health information system.* Med Care, 1995. **33**(12): p. 13-20.
39. Roberfroid, D.L., Ch. Stordeur, S. , *Physician supply forecast: better than peering in a crystal ball.* Hum Resour Health, 2009. **7**(10).
40. Roos, N.P., et al., *How many physicians does Canada need to care for our aging population?* CMAJ, 1998. **158**(10): p. 1275-1284.
41. Roos, N.P., et al., *Needs based planning for generalist physicians.* Med Care, 1999. **37**(6): p. 206-228.
42. Salsberg, E., *California Physician Workforce: supply and demand through 2015*. 2004, The center for health workforce studies, University of Albany, State University of Newyork: New York.
43. Schofield, D., I. Mcrae, and R. Shrestha. *Modelling demand for medical services in Australia*. in *International Medical Workforce Conference*. 2008. Edinburgh, Scotland: the Royal Colledge of Surgeons.
44. Schofield, D., R. Shrestha, and E. Callander, *Access to general practionionar services among underserved Australians: a microsimulation study.* Hum Resour Health, 2012. **10**(1).
45. Scott, A., et al., *Alternative approaches to health workforce planning*. 2011, School of Population Health, National Health Workforce Taskforce, University of Queensland: Australia.
46. Solutions., D.C.f.H., *Better health care worker demand projections: A twenty first century approach*. 2013, Bipartisan Policy Center.
47. Weiner, J., *Forecasting the effects of health reform on US physician workforce requirement. Evidence from HMO staffing patterns.* JAMA, 1994. **272**: p. 222-230.
48. Weiner, J.P., et al., *Assessing a methodology for physician requirement forecasting: Replication of GMENAC's need-based model for the pediatric specialty.* Med Care, 1987. **25**(5): p. 426-436.
49. *The Complexities of National Health Care Workforce Planning*. 2011, Bipartisan Policy Center.
50. *PRISMA*. 2015 2015 Jan 7]; Available from: www.prisma-statement.org.
51. o' Brien-Pallas, L. and A. Baumann, *Toward evidence based policy decisions: a case study of nursing health human resources in Ontario.* Nursing Inquiry, 2000. **7**(4): p. 248-57.
52. Scheffler, R., et al., *Forecasting the global shortage of physicians: an economic and needs based approach.* Bulletin of WHO, 2008. **86**(7): p. 497-576.
53. O'Brien-Pallas, L., et al., *Integrating workforce planning, human resources and service planning*. 2001, WHO, Department of organization of health services delivery: Geneva, Switzerland.
54. Rotem, A., *Approaches to workforce planning*. 2011, Manila: Human Resources for Health Knowledge Hub.
55. Hall, T.L. and A. Mejia, *Health Manpower Planning: Principles, Methods*. 1978, World Health Organization: Geneva.
56. Dussault, G. and M.C. Franceschini, *Not enough there, too many here: understanding geographical imbalances in the distribution of the health workforce.* Human Resources for Health 2006. **4**(12).
57. *The physician workforce: Projections and research in to current issues affecting supply and demand*. 2008, US department of health and human services, Human resources and service administration.
58. Segal, L. and T. Bolton, *Issues facing the future health care workforce: the importance of demand modeling.* Aust New Zealand Health Policy, 2009. **6**: p. 12.
59. Organization, W.H., *Tools and guidelines for human resources for health*. 2008, WHO: Geneva.
60. Nyoni, J., et al., *Policies and plans for human resources for health: Guidelines for countries in the WHO African region*. 2006, Human resources for health development program, Division of health systems and services development: Brazzaville.
61. (BHRD)., U.B.o.H.R.D., *Projections of health manpower supply: a summary in the supply of health manpower: 1970 Profiles and Projections to 1990*. 1974, US Department of Health, Education, and Welfare: Washington D.C. p. 38-75.
62. Cooper, R., T. Getzen, and P. Laud, *Economic expansion is a major determinant of physician supply and utilization.* Health Serv Res, 2002. **38**: p. 675-696.
63. Cromwell, J., et al., *CRNA manpower forecasts: 1990-2010.* Med Care, 1991. **29**: p. 628-644.
64. Denton, F.T., A. Gafni, and B.G. Spencer, *The SHARP way to plan health care services: a description of the system and some illustrative applications in nursing human resource planning*. 1993, Faculty of social sciences, Mc Master University: Ontario, Canada.
65. Deane, R.T. and D.E. Yett, *Nurse market policy simulations using an econometric model.* Res Health Econ, 1979. **1**: p. 255-300.
66. Persaud, D., et al., *Determining Ontario's supply and requirements for ophthalmologists in 2000 and 2005.* Can J Ophthalmology, 1999. **34**: p. 74-81.
67. Pong, R.W., *Towards developing a flexible health workforce*, in *Towards Developing a Flexible Health Workforce Conference*. 1996: Ottawa, Ontario.
68. Ryten, E., *A Statistical Picture of the Past, Present and Future of Nursing in Canada*. 1997, Canadian Nurses Association: Ottawa, Canada.
69. Freed, G.L., T.A. Nahra, and J.F.C. Wheeler, *Predicting the pediatric workforce: Use of trend analysis.* J Pediatr, 2003. **143**: p. 570-575.
70. Bowerman, B.L. and R.T. O'Connell, *Forecasting andTime Series: An applied approach*. 1993, Belmont: Duxbury Press,.
71. Cull, W.L., et al., *Pediatricians working part-time: past, present, and future.* Pediatrics 2002. **109**: p. 1015-1020.
72. De Gooijer, J. and R.J. Hyndman, *25 years of time series forecasting.* Int J Forecasting 2006. **22**: p. 443-473.

73. Mahandiratta, R., *Application of queuing theory in health care.* Int J Computing Business Res, 2011. **2**(2).
74. Grytten, J., F. Carlsen, and I. Skau, *The Income Effect and Supplier Induced Demand: Evidence from Primary Physician Services in Norway.* Applied Economics, 2001. **33**(11): p. 1455-1467.
75. Iversen, T. and H. Luras, *Economic motives and professional norms: the case of general medical practice.* Econ Behav Org, 2000. **43**: p. 447-471.
76. Kernick, D. and A. Scott, *Economic approaches to doctor/nurse skill mix: problems, pitfalls, and partial solutions.* Br J Gen Pract 2002. **52**: p. 42-46.
77. Armstrong, J.S., *Selecting forecasting methods, principles of forecasting: a handbook for researchers and practitioners*. 2001, United States: Springer.
78. Crone, S., K. Nikolopoulos, and M. Hibon, *Automatic modeling and forecasting with artificial neural networks. A forecasting competition evaluation*. 2008.
79. Stavrou, E.T., C. Charalambous, and S. Spiliotis, *Human resource management and performance: A neural network analysis.* Europ J Operation Res 2007. **181**(1): p. 453-467.
80. Sharma, A. and A. Chopra, *Artificial neural networks: Applications in management.* J Business Manag 2013. **12**(5): p. 32-40.
81. Wasserman, P.D., *Neural Computing: Theory and Practice*. 1989, New York: Van Nos-trand Reinhold.
82. Ceccatto, H.A., N. H.D., and W. H., *Learning Persistent Dynamics with Neural Networks.* Neural Networks, 1998. **11**: p. 145-51.
83. Krycha, K.A. and U. Wagner, *Applications of artificial neural networks in management science: a survey.* Retailing Consumer Serv, 1999. **6**: p. 185-203.
84. Smith, K. and j. Gupta, *Neural networks in Business: techniques and applications*. Vol. 271. 2002: IDEA Group Publishing.
85. Trivedi, V., et al., *A semi-Markov model for primary health care manpower supply prediction.* Manage Sci 1987. **33**: p. 149-160.
86. Belhaj, R. and M. Tkiouat, *A Markov Model for Human Resources Supply Forecast Dividing the HR System into Subgroups.* ISSM, 2013. **6**(3): p. 211-217.
87. Chang, H.-C., et al., *Projection of the supply of and demand for board certified nephrologists for ESRD in Taiwan.* J Eval Clin Pract, 2008. **14**(2): p. 305-315.
88. Deal, C., et al., *The United Stated rheumatology workforce.* Arthritis Rheum, 2007. **56**(3): p. 722-729.
89. Joyce, C., J. McNeil, and J. Stoelwinder, *More doctors, but not enough: Australian medical workforce supply 2001-2012.* Med J Aust, 2006. **184**: p. 441-446.
90. Lipscomb, J., G. Parmigiani, and V. Hasselblad, *Combining expert judgment by hierarchical modeling: An application to physician staffing.* Management Sci 1998. **44**(2): p. 149-161.
91. Price, W.L., A. Martel, and K.A. Lewis, *A review of mathematical models in human resource planning.* Omega, 1980. **8**(6): p. 639-645.
92. Wang, J., *A review of operations research applications in workforce planning and potential modeling of military training.* 2005.
93. Grant, E.W. and F.N. Hendon, *An application of linear programming in hospital resource allocation.* J Health Care Market 1987. **7**: p. 69-72.
94. Kwak, N.K. and C. Lee, *Linear goal programming model for human resource allocation in health care organization.* J Med Sys 1997. **21**(3): p. 129-140.
95. Larson, R.C. and A.R. Odoni, *Introduction to queuing theory and its applications*, in *Urban Operations Research: Massachusetts Institute of Technology*. 1999.
96. Green, L., *Queuing analysis in health care: Reducing delay in health care delivery*. 2006, New York: Springer.
97. Gupta, I., J. Zoreda, and N. Kramer, *Hospital manpower planning by use of queuing theory.* Health Serv Res, 2000. **6**(1): p. 76-82.
98. Bretthauer, K.M. and M.J. Cote, *A model for planning resource requirements in health care organizations.* Decision Sciences, 1998. **29**(1): p. 243-270.
99. Singh, V., *Use of Queuing Models in Health Care. University of Arkansas for Medical Sciences*. 2006.
100. Fomundam, S. and J.W. Herrmann, *A survey of queuing theory applications in health care*. 2007, The institute for systems research technical reports, University of Maryland: Maryland.
101. Gokkaya, H. and A. Sahiner, *An application of constrained nonlinear programming to the physical problem.* Acta Universitatis Apulensis, (Special Issue).
102. Baker, J.R., E.R. Clayton, and B.W. Taylor, *A nonlinear multi criteria programming approach for determining country emergency medical service ambulance allocations.* J Operat Res Soc, 1989. **40**(5): p. 423-432.
103. Luenberger, D.G. and Y. Yinyu, *Linear and nonlinear programming*. 3rd ed. International series in operations research and management science. 2008: Springer.
104. Mordecai, A., *Nonlinear programming analysis and methods*. 2003: Courier Dover Publications.
105. Law, A.M. and W.D. Kelton, *Simulation modeling and analysis*. Second ed. 2000, NewYork: Mc Graw Hill.
106. **Hall, T.**, *WHO simulation models for intermediate-term health workforce planning*, in *Toolkit for planning, training and management*. 2000.
107. Colwill, J.M., J.M. Cultice, and R.L. Kruse, *Will generalist physician supply meet demands of an increasing and aging population?* Health Aff 2008. **27**: p. 232-241.
108. Grover, A., et al., *Shortage of cardiothoracic surgeons is likely by 2020.* Chardiac Surgery, 2009. **120**: p. 488-494.
109. Song, F. and T. Rathwell, *Stochastic simulation and sensitivity analysis: Estimating future demand for health resources in China.* World Health Stat Q, 1994. **47**: p. 149-156.
110. Harrington, H.J. and K. Tumay, *Simulation modeling methods*. 1999, New York: Mc Graw Hill.
111. Banks, J., et al., *Discrete-Event System Simulation*. Fifth ed. Upper Saddle River. 2010: Pearson Education.
112. Forrester, J.W., *Industrial dynamics*
1961: Cambridge MA: MIT Press.
113. Mutingi, M., *System dynamics of manpower planning strategies under various demand scenarios.* Manag Sci Letters, 2012. **2**: p. 2689-2698.
114. Brailsford, S.C. *System dynamics: what's in it for health*

care simulation modelers. in *Simulation Conference*. 2008. UK: University of Southampton.
115. Richmond, R., *Systems thinking: critical thinking skills for the 1990s and beyond.* System Dynamics Review, 1993. **9**(2): p. 113-33.
116. Aburawi, I. and K. Hafeez, *Managing dynamics of human resource and knowledge management in organizations through system dynamics modeling.* Int J Sci Tech Automatic Control Eng, 2009. **3**(2): p. 1108-1125.
117. Park, S., et al., *A dynamic manpower forecasting model for the information security industry.* Indust Manag Data Systems, 2008. **108**(3): p. 368-384.
118. Barber, P. and V.B. Gonzales-Lopez, *Forecasting the need for medical specialists in Spain: Application of a system dynamics model* Hum Resour Health, 2010. **8**: p. 24.
119. Morecroft, J. and S. Robinson. *Comparing Discrete-Event Simulation and System Dynamics: Modeling a Fishery*. in *Operational Research Society Simulation*. 2006. Birmingham, UK.
120. Brailsford, S.C. and N.A. Hilton. *A comparison of discrete event simulation and system dynamics for modeling healthcare systems*. in *ORAHS* 2001. Glasgow, Scotland.
121. Kelly, R.A., et al., *Selecting among six modeling approaches for integrated enviromental assessment and management*. 2000, The Australian national university Australia.
122. Organization., W.H., *Workload indicators of staffing need (WISN): a manual for implementation*. 1998, WHO: Geneva.
123. Shipp, J.P., *Guidelines for developing and using workload indicators of staffing need*. 1998, World Health Organization: Geneva.
124. Belayet, H. and S.A. Alam, *Likely Benefit of Workload Indicators of Staffing Need.* Hum Resour Health 1999. **3**(2).
125. Kolehmaninen - Aitken, R.L. and P. Shipp, *Indicators of Staffing need: assessing health staffing and equity in Papua New Guinea.* Heath policy Plan, 1990. **5**(2): p. 167-176.
126. Namaganda, G., *Determining staffing levels and mix of UCMB affiliated hospitals.* Health Policy Dev 2004. **2**(3): p. 236-241.
127. Ozcan, S. and P. Hornby, *Determining Hospital Workforce requirements: A case study.* HRDJ 1999. **3**(3).
128. Joyce, C.M., J. Mc Neil, and J.U. Stoelwinder, *Time for a new approach to medical workforce planning.* MJA 2004. **180**: p. 343-346.
129. Ono, T., G. Lafortune, and M. Schoenstein, *Health Workforce Planning in OECD Countries: A Review of 26 Projection Models from 18 Countries*, in *OECD Health Working Papers*. 2013.
130. Birch, S., et al., *Health human resources planning and the production of health: Development of an analytical framework for needs-based health human resources planning*. 2007, McMaster University: Ontario.
131. Curson, J. *Physician workforce planning: what have we learned? Lessons for planning medical school capacity and IMG policies*. in *7th International Medical Workforce Conference*. 2003. UK: Oxford.
132. Dill, J. and E. Salsberg, *The Complexities of Physician Supply and Demand: Projections through 2025*. 2008, Association of American Medical Colleges, Center for Workforce Studies.
133. Duboi, C.A. and M. McKee, *Cross-national comparisons of human resources for health - what can we learn?* Health Econ Policy Law, 2006: p. 59-78.
134. Greenberg, L. and J.M. Cultice, *Forecasting the need for physicians in the United States: the Health Resources and Services Administration's physician requirements model.* Health Serv Res 1997. **31**: p. 723-737.
135. Karppinen, J., et al., *Modic changes and interleukin 1 gene locus polymorphisms in occupational cohort of middle-aged men.* Eur Spine J, 2009. **18**(12): p. 1963-70.
136. Rafiei, S., et al., *Approaches in Health Human Resource Forecasting: A Roadmap for Improvement.* Electronic Physician, 2016. **8**(9): p. 2911-2917.