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System dynamics modeling for general practitioner workforce forecasting in Kazakhstan

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Abstract

Background. *Primary health care has been proven to be a highly effective and efficient way to address the main causes and risks of poor health and well-being today, as well as handling the emerging challenges that will threaten health and well-being tomorrow. In our study we used the System Dynamics approach to develop a model for the population and General Practitioner workforce to include multiple inputs and their relationships in the equations for each stock and flow.*
Methods. *We built the model in the Any Logic software to cover the flow of medical workers, demographic data of the population and the prevalence of the disease over time. Three scenarios were examined for forecasting primary health care personnel resources. The base year for forecasting was 2018, and the modeling was carried out until 2030.*
Results. *All of three scenarios indicate that with the current number of graduated General Practitioners, the shortage of primary care physicians will be exacerbated. In general, the shortage can reach more than 2,000 on a population of 18.3 million (2018).*
Conclusion. *The projected shortage of doctors in the primary health care system requires special attention to human resource planning. Only one third of medical graduates in Kazakhstan go to work in the primary health care system. The government needs to develop measures to stimulate and support young medical doctors to become general practitioners.*

Introduction

World Health Organization (WHO) claims that Primary Health Care (PHC) has proven to be a highly effective and efficient way to address the main causes and risks of poor health and well-being today, as well as handling the emerging challenges that will threaten health and well-being tomorrow. It has also been shown to be a good value investment, as there is evidence that a PHC of quality reduces total healthcare costs and improves efficiency by reducing hospital admissions. With the goal of further improving the healthcare system, the Kazakhstan Government approved the document “Main directions for the development of primary healthcare in the

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Republic of Kazakhstan for 2018-2022." An important part of this program is the promotion of human resources for health through the creation of an effective methodology for healthcare workers (HCWs) planning and forecasting.

There is no perfect method for planning for medical doctors (1). None of the various methods has been applied in a pure form, although Australia (2-4), Canada (5-8), Germany (9), France (10), the Netherlands (11), and the United Kingdom (12), have a long history and valuable experience with 'need-based' planning.

In this paper we propose a model which takes into consideration the dynamic nature of the system, the feedbacks that occur naturally in it and the possible policy levers that can affect it. The model presents a systematic decision support tool for the regulators, enabling testing of the long-term effects of various policies on the health care gap. The underlying methodology is the *System Dynamics* (SD) modeling, a continuous time simulation method that models the flow of cohorts through different stages over time.

SD modeling is widely used as being a method suitable for forecasting of human resources for health (13-18). SD modeling has been applied to issues of population health since the 1970s. Topic areas have included the following: disease epidemiology including work in heart disease (19-24), substance abuse epidemiology covering heroin addiction (25), cocaine prevalence (26), and tobacco reduction policy (27), patient flows in emergency and extended care (28), healthcare capacity and delivery in such areas as population-based health maintenance organization planning (29-32), interactions between healthcare or public health capacity and disease epidemiology (14, 33, 34)

Barber et al. (16) conducted demand/need simulation for 43 medical specialists using SD model. Ansah et al. (17) used SD methodology and model to project outlook of supply need for eye care in Singapore, and the number of eye diseases and the demand for eye care services, as well as workforce requirements will rise. In Japan a forecasting model was developed to assess supply at the national level (13). In addition, time trends in number and regional distribution of physicians have been analyzed. Toyabe et al. (18) used Gini coefficient, Atkinson index, and Theil index as measures for maldistribution of physicians among the population and demonstrated that the regional maldistribution will worsen after the new postgraduate internship system starts. Thus, an analysis of regional uneven distribution is necessary not only to predict temporary trends, but also to develop health policies (13).

Basu and Gupta (35) employed the SD model for analyzing the need for doctors in a Canadian province. They predicted the number of General Practitioners (GPs), medical specialists and surgical specialists. To estimate future demand, data on population dynamics were used. The resulting gap between demand and supply was analyzed, and various ways to reduce it were discussed (for example, increasing admission to medical schools for future family doctor candidates, reducing emigration, postponing retirement, etc.). In a study conducted by the Canadian Nursing Association in 2009 (36), the same SD methodology was applied to nurses. Vanderbi et al. (37) developed a SD model reflecting the demand for labor in a particular specialty at the national level, and demonstrated its capabilities in planning the number of heart surgeons in Canada. Lyons and Duggan (38) presented a model of sustainable health development based on SD and tested it on the empirical data of the Irish Health Service. The model shows the ability of healthcare to meet the demand for services in general and for selected age categories. The model is the basis for making management decisions that affect the sustainability of the healthcare system.

Kunc and Kazakov (39) showed the full range of the strategic planning process in healthcare. The authors monitored the status of patients with chronic heart disease and its impact on the cost of the entire healthcare system (eg, hospitals, patients, government) using SD. After an initial assessment of factors affecting the healthcare system, a quantitative SD model was developed that focused on the ways in which chronic cardiac patients follow in terms of drug behavior: diagnosis, initial prescription, treatment switching behavior, and treatment sustainability. The significance of SD modeling for the healthcare system has been also shown by Cave et al. (40), who described a number of case studies in this area. These case studies included workforce planning, as well as public access to care and public health policies in England.

In our study we used the SD approach to develop a model for the population and GPs workforce to include multiple inputs and their relationships in the equations for each stock and flow. Thus, it was possible to predict the gap between needs and supply of GPs in the future. Any intervention attempt could also be verified by changing the variables followed by modeling.

Methods

Since the human resources for healthcare market is a dynamic system, consisting of several influencing factors, we built the SD model in the Any Logic software to cover the flow of medical workers, demographic data of the population and the prevalence of the disease over time. The base year for forecasting was 2018, and the modeling was carried out until 2030. The model is able to recognize the procedures that allow to improve the system or solve its problems. The model consists of two main components: sub-models of supply and of demand. The sub-model of the supply consists of stock, inflow and outflow. The stock characterizes the current situation, the inflow includes new GPs (graduates and recruitment), and outflow includes retirements, emigration and attrition. The demand sub-model estimates the number of GPs required to meet the public health needs. To this end, the conceptual framework of the model was based on three main elements: population size, health needs and the level of use of services that are relevant to the specialty of GPs.

The current situation for each predicted year is calculated as the sum of the inflow and outflow, as shown below

$$Stock(t) = \int_{t_0}^{t} [Inflow(s) - Outflow(s)]ds + Stock(t_0)$$

Where inflow and outflow are indicated by values Inflow (s) and Outflow (s) at any given time (s) in range from the initial (t_0) to present time (t).

Data for the model were collected from various sources, which are presented in Table 1.

To assess the various flows, we used data for the last four years, provided to us by the Department of Science and Human Resources of the Ministry of Health. According to the Department, there is approximately 1% of PHC workers every year who leave their occupation due to retirement. Emigration is approximately 0.1% of the total number of PHC physicians, attrition for other reasons (getting higher specializations, migration within the country, transfer from one medical facility to another, military service, transfer to another field of activity, maternity leave, illness and death) averaged 15%, recruitment (without new graduates) about 10%. All these values were used in our model.

In 2018 in PHC there were 10,314 doctors. On average one doctor worked 1.02 FTE (Full Time Equivalent). With these numbers, the total available supply in FTE for 2018 can be calculated as 10,520 FTE. According to the Ministry of Health in 2018

Table 1 - Data source

Element	Value (calculated by relevant government body)	Source
New graduates per year (all medical universities in Kazakhstan)	900	Department of Science and Human Resources of the Ministry of Health
Recruitment	10%	Department of Science and Human Resources of the Ministry of Health
Exits from the health workforce due to retirement	1%	Department of Science and Human Resources of the Ministry of Health
Exits from the health workforce due to another reason	15%	Department of Science and Human Resources of the Ministry of Health
Average population per 1 FTE GP	1,678	Republican Center for Health Development
Birth rate in 2018	21.64 per 1,000 people	Statistics Committee of Kazakhstan
Death rate in 2018	7.15 per 1,000 people	Statistics Committee of Kazakhstan
Immigration rate in 2018	0.86 per 1,000 people	Statistics Committee of Kazakhstan
Emigration rate in 2018	2.09 per 1,000 people	Statistics Committee of Kazakhstan
Average visit per person in 2018	2.5	Republican Center for Health Development
Average patient visit per GP in 2018	4,689	Republican Center for Health Development

the deficits between healthcare demand and available supply was 3%. Based on the total available supply in 2018 of 10,520 FTE and the gap of 3%, the required GPs are estimated at 10,836 FTE. Accordingly, one FTE accounts for 1,678 members of the population.

The most important driver of health workforce inflows comes from the domestic education system. The training period for GPs is 7 years: future doctors of 5 years are studying undergraduate degrees in General medicine and then 2 years of internship. According to the Departments of Employment of Medical Universities, about 30% of those entering the specialty "General Medicine", after completing the internship, work in PHC. From 2015 to 2018, the government reduced the number of grants allocated to medical specialties, including the specialty "General Medicine". In subsequent years, from 2019 to 2021, the government plans to leave their number unchanged at 2,700. So we accepted that in 2019-2030 each year 900 new GP graduates would enter the labor market.

The population from the year 2019 to 2030 under this approach was simulated using the model formula

$$P_t = P\left(1 + \frac{Gr}{1000}\right)^t$$

where

Gr – population growth rate (birth rate - death rate + immigration rate – emigration rate)

P - present population

P_t - population at the time *t*

The simple aggregate population model shows births, deaths and net migration as the three determinants of population change. Births are a function of average birth rate and the population, whereas deaths are a function

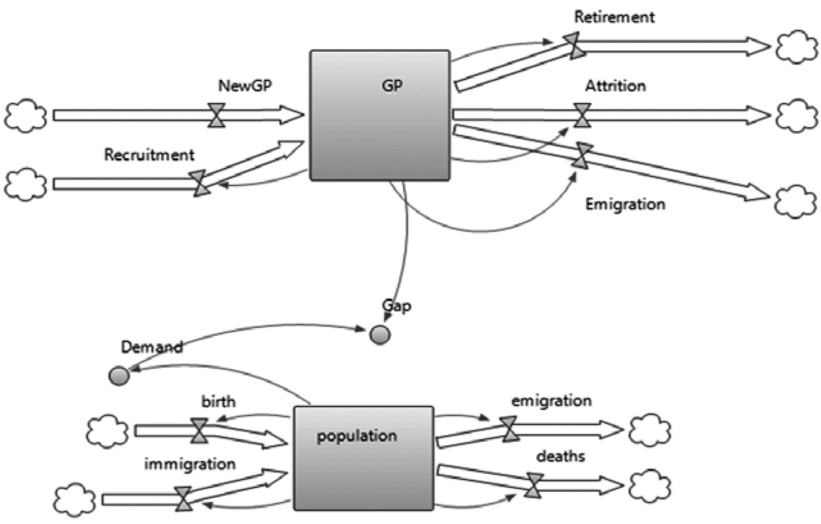


Figure 1 - Demand and available supply SD model

of the population and life expectancy at birth. Migrations are a function of immigration and emigration rates (Figure 1).

Results

Baseline projection: Workforce-to-Population Model

In the baseline we project the demand for HCWs assuming that the same level of service (defined as headcount density per population) is provided for an increasing population. Two inputs – total population and average population per workforce – are used to forecast workforce requirements under this approach. Using available data, average population per GP was estimated and assumed to remain constant from the year 2018 (it is estimated as 1,678). Total GPs required for each year is then calculated by dividing the total population by the average population per GP.

The total gap is derived from expansion demand and available supply. SD model is illustrated in Figure 1.

Due to low wages and staff shortages, many doctors take on additional workload (without increasing the number of hours) and receive additional payment due to vacant rates. The Ministry of Health estimates the shortage of personnel at 3%, i.e. in 2018, corresponding to 522 doctors.

SD modeling shows that in subsequent years, according to the baseline scenario, the need for GPs will increase as a result of population growth (Figure 2).

It is predicted that the number of GPs will also increase over the years due to the annual graduation of 900 GPs. This will allow to some extent the replenishment of the personnel resource, but will not be able to fully cover the needs. The shortage of personnel will decrease in 2019-2025, and then will again begin to grow to 463 doctors in 2030.

Scenario 1: Service Target-Based Model

Target-based approaches set targets for specific health care services, based on health worker supply or health services demand. In Kazakhstan, the GP is entrusted with the duty of serving the 2000 population without division into age categories. However, every healthcare facility has the right to adjust that ratio annually. So, in 2018, one FTE doctor is accounted for 1,678 subjects on average. The

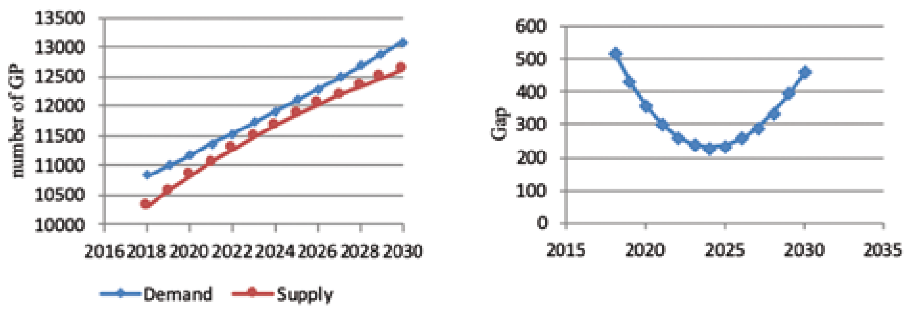


Figure 2 - The prediction for the demand, the supply of GPs and the gap between them (base scenario)

government plans to reduce this standard down to 1,500 subjects per one FTE doctor by 2023 (2020). A specific schedule for this decline is not specified in governmental documents, and therefore we suggested a gradual decrease to 1,600 people in 2019-2022 and to 1,500 - in 2023 and subsequent years. These changes will increase GPs needs. The predicted values obtained using our model are shown in Table 2.

With this same course, there will be an even greater gap between the needs and possibilities in the labor market, the deficit will be approximately 800-900 doctors per year until 2022. In the following 2023–2030, the situation will worsen and the shortage of GPs will approach two thousand, reaching 2,016 doctors in 2030 (Figure 3).

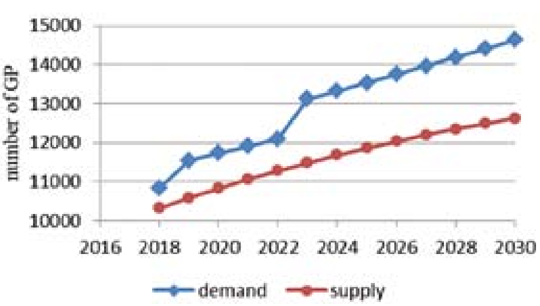


Figure 3 - The prediction for the demand and supply of GPs (target-based approach)

Scenario 2: Needs based Model

Needs-based approaches estimate future health workforce needs based on the projected health service needs (both met and unmet). The development of PHC in Kazakhstan aims to make PHC a point of entry into the health system and a place to provide the bulk of medical services. Under this approach, three input variables - total disease prevalence, average visits per person per year and average patient visits per GP per year - were used to estimate workforce requirements (Figure 4).

Average patient visits per GP per year and average visits per person with disease per year were assumed to remain unchanged over the simulation period (Table 1).

To forecast the epidemiological situation until 2030, we used data from previous years and found a high correlation ($r = 0.95$) between the population size and total disease prevalence - the total number of individuals in a population who have a disease or health condition at a specific period of time (the overall incidence). The total disease prevalence for each forecasted year was calculated (see Table 3) using the obtained regression equation:

$$\text{total disease prevalence} = 1.22769 \times \text{population}$$

The statistical significance of the equation is estimated in Table 4. As it can be seen from these data, the correlation coefficient is 0.95. According to the Fisher criterion, the model

Table 2 - Target-Based Model simulation results

	Population	Stan-dard	De-mand	Attri-tion	Recruit-ment	Emigra-tion	Retire	New gps	Supply	Gap
2019	18,469,981	1,600	11,544	1,587	1,058	11	106	900	10,577	967
2020	18,762,507	1,600	11,727	1,624	1,082	11	108	900	10,825	902
2021	19,059,666	1,600	11,912	1,659	1,106	11	111	900	11,057	855
2022	19,361,532	1,600	12,101	1,691	1,128	11	113	900	11,277	824
2023	19,668,179	1,700	13,112	1,722	1,148	11	115	900	11,483	1629
2024	19,979,682	1,700	13,320	1,751	1,168	12	117	900	11,677	1,644
2025	20,296,119	1,700	13,531	1,779	1,186	12	119	900	11,859	1,672
2026	20,617,568	1,700	13,745	1,805	1,203	12	120	900	12,030	1,715
2027	20,944,108	1,700	13,963	1,829	1,219	12	122	900	12,192	1,771
2028	21,275,819	1,700	14,184	1,852	1,234	12	123	900	12,344	1,840
2029	21,612,784	1,700	14,409	1,873	1,249	12	125	900	12,487	1,922
2030	21,955,086	1,700	14,637	1.893	1,262	13	126	900	12,621	2,016

is statistically significant ($p < 0.00000$), and the determination coefficient $R^2 = .90599670$ shows that the model is in good agreement with the observed data.

Intercept is statistically insignificant and we did ignore it in the equation.

Regression coefficient is 1.22769 and statistically significant ($p = 0.00000$)

Since the needs-based approach assumes that all people with care needs seek care, the total disease prevalence was multiplied by the average visits per person with the disease per year to obtain the projected demand for PHC services. This was then divided by the average patient visits per GP per year to predict the number of GPs required.

Table 3 - Population count and total disease prevalence. Observed and predicted values

Year	Observed population	Observed total disease prevalence	Year	Predicted population	Predicted total disease prevalence
2003	14,866,837	14,571,088	2018	18,157,337	22,291,581
2004	14,951,200	14,956,810	2019	18,469,980	22,675,410
2005	15,074,767	15,171,726	2020	18,762,506	23,034,542
2006	15,219,291	15,638,230	2021	19,059,666	23,399,362
2007	15,396,878	16,058,298	2022	19,361,532	23,769,959
2008	15,571,506	16,337,360	2023	19,668,178	24,146,427
2009	15,982,370	16,860,225	2024	19,979,682	24,528,856
2010	16,203,274	17,155,620	2025	20,296,119	24,917,343
2011	16,440,470	17,186,522	2026	20,617,567	25,311,982
2012	16,673,933	17,402,761	2027	20,944,107	25,712,871
2013	16,910,246	17,485,870	2028	21,275,819	26,120,110
2014	17,160,855	17,347,489	2029	21,612,784	26,533,799
2015	17,415,715	17,355,270	2030	21,955,086	26,954,040
2016	17,669,896	18,700,902			
2017	17,918,214	19,329,964			

Table 4 - Regression Summary for Dependent Variable: prevalence (Spreadsheet1)

	Beta	Std. Err. - of Beta	B	Std. Err. - of B	t (13)	p-level
Intercept			-3155272	1783496	-1.76915	0.100308
population	0.951839	0.085035	1.22769	0	11.19344	0.000000

R = .95183859 R^2 = .90599670 Adjusted R^2 = .89876567 F(1.13)=125.29 p<0.00000

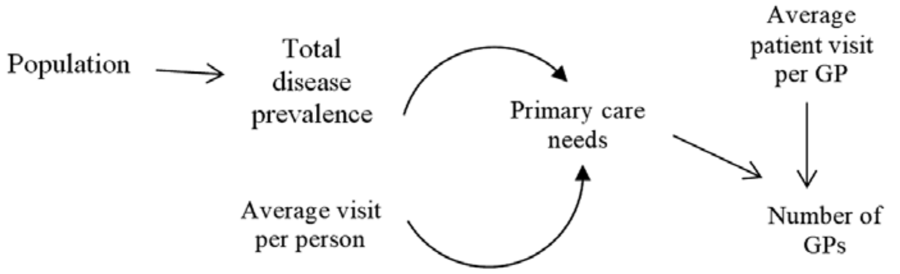
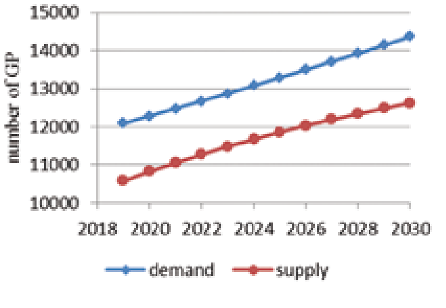


Figure 4 - Needs based approach model

According to our forecasts, from 2019 to 2030, the average population growth rate in Kazakhstan will be 1.6%, which will accordingly lead to an increase in demand for medical services. Under the needs based approach, already in 2019 the deficit would be 1,512 GPs, and the request from 2018 to 2030 would increase by 33%. As in the previous scenario, the staff deficit will be partially covered by university graduates, but from 2025 it will begin to grow and reach 1,749 GPs in 2030 (Figure 5).

Discussion

Most forecasting models test different scenarios to ascertain different future situations. Typically, this involves the presence of a baseline scenario and one or more alternative scenarios (41). These scenarios are typically based on certain assumptions and estimate the likely effects of one or more factors (for example, changing the national training capacity for specialties, or assessing the consequences of reforms on



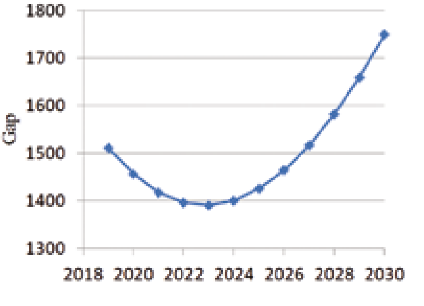


Figure 5 - The prediction under the needs based approach

government expenditure and tax increases) on the future healthcare workforce.

Currently, Kazakhstan is upgrading PHC in the healthcare system. In the future, the major element in PHC should be a kind of GP who has the knowledge and skills to organize care for the most common diseases across all age groups, supported by a team consisting of qualified secondary medical and social workers and other professionals needed to meet the needs of the assigned population. Today in Kazakhstan there are 15 medical universities or universities with medical schools. Most students study for free on the basis of state grants. After completing the internship, they have the right to independently decide to go to work in PHC or to continue their studies to obtain a specialization. The state is implementing various support measures for doctors, especially in rural areas: however, despite this, there is currently a shortage of them.

In this study, we examined three scenarios for forecasting PHC personnel resources until 2030. All of them indicate that with the current number of graduated GPs, the shortage of PHC physicians will be exacerbated (Table 5).

Even in the basic scenario, based on the simple growth of population of the Republic, the annual production of 900 GP is clearly not enough to cover the GPs deficit. Starting in 2025, the deficit will increase and reach its peak in 2030 (590 GPs).

The situation will become even more complicated if the Target-based scenario is implemented. Reducing the ratio (down to 1 GP per 1,500 population) will require increasing the output of doctors for primary care. Otherwise, the deficit can reach up to more than two thousand.

According to the third scenario, rise of the population in the Republic will lead to increased demands for medical services. This factor should also be taken into account when drawing up governmental health development programs. According to our model data, a change in the epidemiological situation (growth of *total disease prevalence*) will require additional resources of labor.

To date, the only source of human resources for health is the flow from medical schools. A reform of higher medical education is being prepared in Kazakhstan. Instead of the formula 5 + 2 (bachelor's degree plus internship), a six-year study at the university will be offered and then a residency aimed at practical activities. Now the heads of the Healthcare Ministry and the medical universities are considering steps to prevent the negative consequences of the transition from one system to another. All of these available data can and should be used to develop policy used internally by the profession. Such data would help to set an advocacy agenda to encourage state and local policies to obtain an improved access to GP services.

The methods and applications of SD and system feedback modeling for policy analysis can assist in designing better policies for the supply of GPs that take into account the complexity of social and ecological environments and a plurality of perspectives. The main objective of our model was to simulate the consequences of different

Table 5 - Gap between needs and supply of GPs

Year	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
Baseline	430	356	302	261	238	231	236	257	290	335	393	463
Target-based	967	902	855	824	1,629	1,644	1,672	1,715	1,771	1,840	1,922	2,016
Needs based	1,512	1,457	1,418	1,397	1,391	1,401	1,426	1,465	1,517	1,582	1,660	1,749

policies aimed at improving the capacity of the Kazakhstan healthcare system. Medical universities require a certain amount of time to train specialists. From the point of view of the model, these are time delays that affect the behavior of the entire system. From his point of view, the planner has to choose a certain time before the effects of his policies start to be effective. Our model was designed to be used by the planner to simulate the effect of potential changes in their choices. Although the model is a useful planning tool, it has limitations in simulating the effects of regulatory changes on the healthcare sector. The model is as realistic as all the given input parameters are realistic. The problem of obtaining objective data on the healthcare workforce is the greatest limitation in our workforce planning model implementations. Fortunately, the model and the software by which it is implemented allow the modification of these parameters - number of new graduates, number of residencies, retirement rate, emigration, etc.- allowing the planner to see what would happen if the parameters under planning control were changed, whether one at a time or in combination. The planner would use the parameters as tools in human resource policy and to regulate the supply.

Conclusion

The Covid-19 pandemic has revealed a number of health problems in many countries around the world, including a common lack of doctors in PHC. This problem is also relevant for Kazakhstan. The situation is aggravated by the fact that, until recently, the approaches to healthcare workforce forecasting and planning used in the Republic were ineffective. Human resources planning has historically not been a priority of health policy implemented by local health officials. In this regard we are taking steps to introduce various models for forecasting human resources for health. Obviously, in the post-crisis period, healthcare organizers will be faced with new tasks to ensure human resources, especially in PHC. At present only a third of medical graduates in Kazakhstan decide to work in the PHC system. The government needs to develop measures to stimulate and support young medical doctors to become GPs. We do not know yet what steps the state will take to solve workforce problems that emerged during the pandemic. However, we are confident that the results of our research can be the basis for the formation health workforce policy.

Riassunto

Prevedere il numero di medici di medicina generale necessari in Kazakhstan utilizzando la modellizzazione secondo "system dynamics"

Premessa. L'assistenza sanitaria primaria ha dimostrato di essere un modo altamente efficace ed efficiente per identificare i prevalenti rischi di salute di una popolazione, per affrontare oggi le principali malattie, nonchè per gestire le sfide emergenti che minacceranno la salute e il benessere di domani. Nel nostro studio abbiamo utilizzato l'approccio "System Dynamics" per sviluppare un modello previsionale del numero di medici di medicina generale necessari in rapporto con la popolazione, che permetta l'inserimento di più variabili e tenga conto delle relazioni tra loro nelle più diverse situazioni.

Metodi. Abbiamo creato il modello nel *software* "Any Logic" per comprendere il flusso degli operatori medici, i dati demografici della popolazione e la prevalenza delle malattie nel tempo. Sono stati esaminati tre scenari per la previsione delle risorse di personale di assistenza sanitaria primaria. L'anno base per le previsioni era il 2018 e la modellizzazione è stata prolungata a tutto il 2030.

Risultati. Tutti e tre gli scenari indicano che con l'attuale numero di medici che vengono laureati, la carenza di medici di medicina generale si aggraverà nel tempo. In linea generale, la carenza potrà raggiungere oltre 2.000 medici su una popolazione di 18,3 milioni (2018).

Conclusioni. Solo un terzo dei laureati in medicina in Kazakistan sceglie di divenire medico di medicina generale. Il governo deve sviluppare misure per stimolare e supportare un numero adeguato di giovani medici a scegliere preferibilmente quella carriera.

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