Information System Project of the Smart City Clinic

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Abstract. It is proposed a new approach to healthcare research, considering the dynamic interaction of all subsystems. It is created a model of a modified operation of the health care institution in a smart city, which will allow to evaluate the effectiveness of correcting the effects of various risk factors on their functioning and to offer the most favorable ways of modifying the system both from the medical point of view (reduction of the sickness rate), and financial one (efficient use of funds).

Keywords: healthcare institution, smart city, simulation model.

1 Introduction

The development of project activity in the medical field is caused by a rapid increase of information about the causes, pathogenesis, prophylaxis and treatment of various diseases. The implementation of projects that involve the development of information systems allows introducing the new methods of research of the impact on human health and modify the work of healthcare institutions in smart cities. The current level of recommendation systems based on the use of medical knowledge allows us to assess the indirect effects of risk factors on human health and to prevent the occurrence of diseases. Among the risk factors that need to be studied are social, psychological, etc. The use of referral systems increases the efficiency of their analysis.

It should be noted such works [1-4] among the existing ones on the application of referral systems in medicine. Their purpose is to effectively analyze the large amounts of medical data and make appropriate decisions. In addition, the software applications

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are developed for automation of the mentioned tasks. However, none of the papers offer a fundamentally new concept for the work of a healthcare institution, but focuses on relatively narrow, specialized aspects of the industry and does not provide changes to the structure of the institution functioning as a whole.

Existing healthcare-related models in most cases consider the process of providing medical services to patients in healthcare institutions, or logistic models of providing health services. There are models that describe the whole process of providing medical care, from calling an ambulance, delivering a patient to the hospital, determining the diagnosis of the disease, and taking appropriate medicines and drugs. The purpose of such modeling is to optimize the delivery time of the qualified medical care on which the patient's life depends. The sooner such help is provided, the greater the likelihood of the patient recovering is.

Another group of models is focused on determining the workload of medical and support staff, the means of patient delivery, and their distribution across the premises of medical institutions.

All of these models use discrete event simulation in the form of queuing systems [5-7] or a Petri net that reproduce the states of the simulated system at discrete moments with imitation of the certain event occurrence. The simulation reproduces the dynamic behavior of the system in the model as objects (e.g., patients move through units, staff, equipment) and actions (eg, registration, nursing examination, physician examination, laboratory tests, etc.) are performed. The rules controlling the movement of objects and the ways of moving depend on the features of the simulated object. Describing systems that involve human interactions requires the use of mathematics based on probability theory and statistics, which can describe the probability and discretion of events.

The reference analysis shows that there are practically no models that consider the processes of managing the national health care system based on the risk factors of the population disease with limited funding. In such cases, it is necessary to use resource models (system dynamics models) to select priorities and to normalize financial flows, taking into account the cause and effect relationships between reducing the sickness rate of population and the efficient use of funds. Therefore, the problem of optimizing and restructuring the work of healthcare institutions remains relevant and still open.

1.1 Problem Statement

Public health is the process of providing health care services, as well as dealing with all the factors (primarily non-medical ones) that affect health such as education, nutrition, the environment, etc. Today, the need for medicine arises when the disease is discovered. This is more about the doctor's professional activity and their relationship with patients.

The World Health Organization recognizes that health protection is providing with the normal physical and mental functioning of a person, both individually and in social groups. This concept includes health promotion and disease prevention activities, as well as curative and regenerative medicine in all its aspects.

According to the current legislation of Ukraine, the health protection system is the system of social and state measures aimed at ensuring the preservation and development of physiological and psychological functions, optimal working capacity and social activity of a person with the maximum biologically possible individual life expectancy.

In everyday life, the society perceives health protection as a set of measures aimed at preserving and enhancing the physical and mental health of every citizen, maintaining their active long life, providing with medical assistance in case of bad health.

Modern medicine needs to be transformed from a social-spending sphere into a social-investment one. Today, investments in a person, their physical and psychological potential are of strategic importance for the national security of the state.

The current state of healthcare facilities does not fully take into consideration the possible causes of any disease. Nowadays, it is necessary to consider the effects of factors related not to treatment but to prevention of disease (not medical factors). They include healthy lifestyle, athletic activity, a balanced diet, hygiene, abstinence, as well as social economic and psychological well-being. As shown in scientific work [8], such factors have a very high impact on the sickness rate and mortality rate due to diseases.

The **aim** of the paper is to create a model of a modified operation of the healthcare institution in a smart city, which will allow to evaluate the effectiveness of correcting the effects of various risk factors on their functioning and to offer the most favorable ways of modifying the system both from the medical point of view (reduction of the sickness rate), and financial one (efficient use of funds).

During the project development, the concept of a smart city healthcare institution is formed, which increases the level of human health and reduces the costs on treatment by preventing the emergence of the disease, influencing medical and non-medical factors. The simulation models to evaluate performance characteristics are created and investigated to compare the proposed concept with the existing system.

2 General Concept of a Healthcare Institution in a Smart City

The generalized cause-and-effect cycle of health deterioration can be described as healthy residents of a smart city under the influence of non-favorable factors acquire bad habits. Bad habits lead to the development of risk factors in a person, which in turn cause acute or chronic diseases, which lead to loss of working capacity, irreversible health deterioration or death (Fig. 1). The figure shows the special composition of the inhabitants in a smart city.

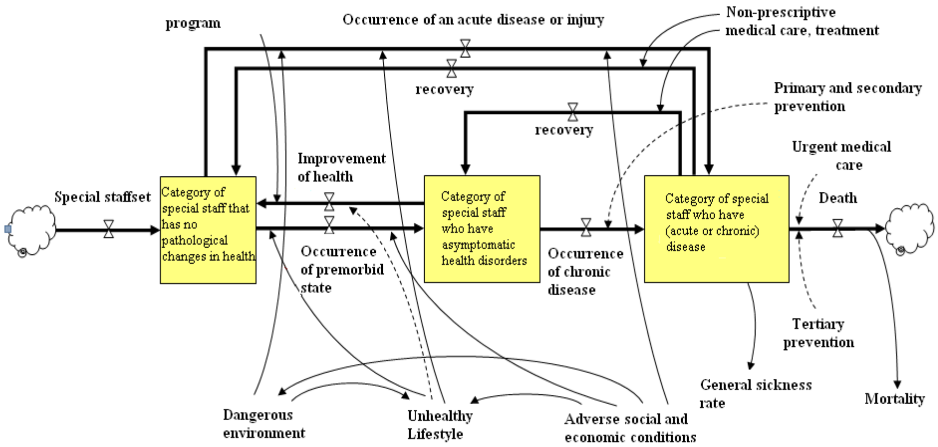

Fig. 1. Influence of various factors on human health

There is also a reverse cycle that is the process of restoring the previous state of health or not worsening the current state. For example, fight with bad habits will help some residents to give up them, thus returning to the healthy category. It means that they will significantly reduce the likelihood of acquiring risk factors. Treatment that does not allow the development of more severe forms of the disease is also possible.

Patients who have been cured of bad habits are transferred either to the category of fully healthy or to the category of people with bad habits, depending on the effectiveness of the fight. The model of a health care institution in a smart city would be incomplete if we did not consider the natural aging of the body.

The intensity of deaths usually increases with age and has the Weibull distribution. Thus, with increasing age, the sickness rate increases, the complexity of nosology raises, more money is spent on treatment and a patient. In addition, the effectiveness of treatment is reduced and the effectiveness of fighting with bad habits and promoting a healthy lifestyle is significantly decreased [8-11].

It is well known that the work of a smart city healthcare institution is funded by the city budget, so the impact of financial costs must be taken into account in the model. Non-variable costs are calculated regardless of the health condition of a citizen. They include food, housing, and other material values, as well as payment of salary. Variable costs are costs for preventive measures, early diagnosis, treatment, etc. Variable costs increase with the growth of patient amount and depend on continuous funding. So, it can be assumed that the prevention and treatment of patients stop due to the lack of funds. The created model allows us to analyze the ratio between the amount of spent money and the health of the residents.

Experiments with the model are conducted to find the answers to the following issues:

- to distinguish if there are any factors in the smart city healthcare institution that can significantly improve the general health at relatively low cost;

- to determine numerically how preventive measures and early diagnosis at a young age affect the reduction of sickness rate in the future;
- to find a combination of efforts that will maximize working capacity at the longest possible life expectancy (professional longevity);
- to discover the best ratio of the number of healthy residents to spent money;
- to determine the minimum funding required to provide a certain percentage of healthy residents from the total population in a smart city.

The simulation model is based on the principles of system dynamics and consists of funds, flows and converters [10]. The funds serve as reservoirs for the accumulation of the resident number of the city with an appropriate health status. They are filled and exhausted by flows that, by their nature of use, are divided into limited and unlimited, unidirectional and bidirectional. The flow intensity is set by a function whose coefficients are usually stored in the converters. These coefficients can be both preset constants and adjustable variables. The coefficients in the converters that can be changed in the simulation process are shown with the controller in the middle. Fig. 2 presents the interaction of fixed assets and flows of the first most common version of the smart city residents' health change model.

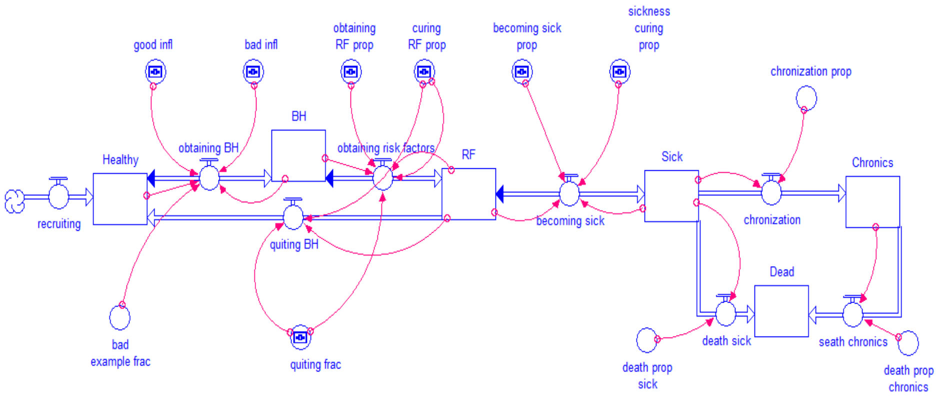

Fig. 2. A generalized model of changing public health

The model uses the following funds:

– HEALTHY – completely healthy;

– BH (Bad Habits) – with bad habits (smoking, alcoholism, drug addiction, sedentary lifestyle, unbalanced diet, lack of hygiene, etc.);

– RF (Risk Factors) – have risk factors such as health disorders that do not directly lead to disability, but without timely treatment cause more serious diseases like hypertension, obesity, diabetes, etc.;

– SICK – acute illness, temporarily disabled

– CHRONICS – chronically ill, permanent disability;

– DEAD – died due to accute illness.

Marked biflows on Fig. 2 specify:

– OBTAINING BH – acquisition or getting rid of bad habits;

– OBTAINING RF – acquiring or eliminating risk factors;
– BECOMING SICK – the development of illness or recovery.

Unidirectional flows specify:
– RECRUITING – replenishment of healthy residents in a smart city;
– QUITTING BH – getting rid of bad habits after passing a successful course of treatment;
– CHRONIZATION – acquisition of chronic diseases;
– DEATH SICK – death due to acute illness;
– DEATH CHRONIC – death due to exacerbation of a chronic illness.

The model uses the following adjustable converters:
– GOOD INFL – aggregate positive influences aimed at giving up bad habits (include an extremely wide range of influences from promoting healthy lifestyles to improving living conditions, reducing stress, providing psychologist services, creating sports facilities and making healthy eating available, etc.);
– BAD INFL – aggregated negative influences that lead to bad habits and stress, overwork, poor social conditions, etc.;
– QUITING FRAQ – percentage of people who abandon bad habits, which is proportional to the spent time by psychologists to fight with bad habits.

Converters specified by constants are:
– BAD EXAMPLE FRAC – the bad example factor (the more people have bad habits, the more likely other people will get them);
– OBTAINING RF PROP – the likelihood of the development of risk factors as a result of the influence of bad habits;
– CURING RF PROP – the likelihood of successful treatment of risk factors, which depends primarily on early diagnosis;
– BECOMING SICK PROP – the likelihood of severe (acute) illness due to risk factors;
– SICKNESS CURING PROP – the probability of successful treatment of the disease;
– CHRONIZATION PROP – the probability of chronic disease;
– DEATH SICK PROP – the likelihood of death due to illness;
– DEATH CRON PROP – the likelihood of death due to an acute illness.

The extended model takes into account the aging processes, which are simulated by the sequential transition of people by age groups up to 20, up to 30, up to 40, and up to 50 years [12, 13]. The mentioned age groups are represented in the model by the respective funds. In the model, the categories as healthy people, with bad habits and others are divided into separate sectors.

The coefficients that change the intensities of the model flows in the converters are given as an array of coefficients where the indices of these arrays determine the age groups. In order to close the cause and effect cycle, it is introduced a dependency on financing. The closed circuit looks like the more healthy residents of a smart city are, the better it develops, but the cost of maintaining health increases in turn.

The main goal is to find the ratio of costs for preventive measures and treatment, which will provide the desired percentage of healthy residents in a smart city at a minimum cost.

The complete model with corresponding blocks is presented in Fig. 3.

The model reproduces the processes of financing the healthcare institution in a smart city with the use of a budget block (BUDGET), which has a certain balance of funds at the beginning of the simulation. Once a year, the budget of the healthcare institutions is replenished with revenues from the State budget (BUDGETING flow). Every month, the budget of the city is funded (UPKEEP) by the operation of a smart city healthcare institution. To determine management actions in the medical service based on the above models, it is necessary to conduct a series of experiments under given scenarios to determine the best management decisions[14-20].

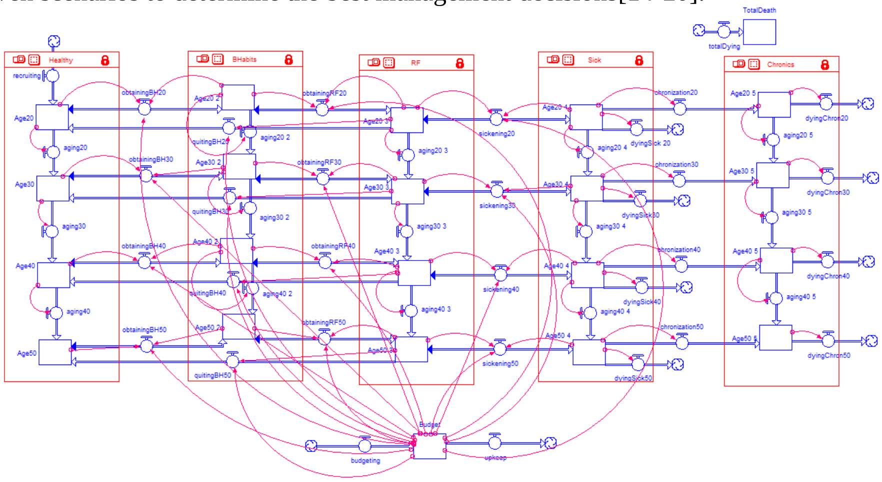

Fig. 3. A model that determines the level of the population health based on funding

3 Analysis of Experiment Results

It is necessary to consider three scenarios that identify disease prevention, improvement of the social and psychological well-being of people in healthcare institutions of a smart city and social and economic activities that contribute to giving up bad habits. To investigate the impact of each group of factors, it will be conducted the following experiments:

- equal distribution of efforts between factors (standard budget);
- refusal from influence on social and psychological factors in favor of disease prevention with a standard budget;
- effort division with a 40% increase in budget that is close to the best one.

According to the results of the experiments given in Table 1 and Table 2, with a balanced distribution of efforts, the health care institution in a smart city is unstable because of a lack of funds (too much of the budget goes to meet social needs and, as a consequence, there is not enough money for anything else). The number of inhabitants under such a strategy is unstable and insufficient. In the case of excluding social and psychological factors, the numbers and costs are stabilized, but the level of health of the city residents is unsatisfactory, due to the excessively high sickness rate and chronic diseases.

Table 1. Budget for the end of period and recurring costs

Bad Infl	**Good Infl**	**Buiting Infl**	5 years		10 years		15 years		20 years		25 years		40 years	
			upk	budg	upk	budg	upk	budg	upk	budg	upk	budg	upk	budg
0.5	0.5	0.5	5,5	8	3,45	8	3,5	7,8	3,5	7,8	3,5	7,8	3,5	7,8
1	0.6	0.5	10	7	11	6	11	8	10	6	12	4	11	6
0.8	0.9	0.9	22	13	23	13	22	13	23	13	22	13	23	13

Table 2. The number of health groups and the total number

	BadInfl	GoodInfl	Quiting	5 years	10 years	15years	20years	25years	40years
SumHealthy	0.5	0.5	0.5	250	400	300	300	300	300
SumBH	0.5	0.5	0.5	200	350	250	250	250	250
SumRF	0.5	0.5	0.5	50	100	100	100	100	100
SumSick	0.5	0.5	0.5	25	50	50	50	50	50
SumChron	0.5	0.5	0.5	125	150	130	130	130	130
SumHealthy	1	0.6	0.5	350	350	350	350	350	350
SumBH	1	0.6	0.5	300	300	300	300	300	300
SumRF	1	0.6	0.5	75	75	75	75	75	75
SumSick	1	0.6	0.5	50	50	50	50	50	50
SumChron	1	0.6	0.5	100	100	100	100	100	100
SumHealthy	0.8	0.9	0.9	600	600	600	600	600	600
SumBH	0.8	0.9	0.9	350	350	350	350	350	350
SumRF	0.8	0.9	0.9	75	75	75	75	75	75
SumSick	0.8	0.9	0.9	50	50	50	50	50	50
SumChron	0.8	0.9	0.9	80	80	80	80	80	80

In the case of an increase in the budget, we can see that such actions make it possible to use the funds more efficiently, the number of inhabitants is increasing or stable, the sickness rate is significantly reduced, and the number of chronic diseases is also significantly decreased.

Conclusions

Research on healthcare institutions in a smart city shows that funding is needed to be increased by 30-40% to effectively implement various programs aimed at preventing diseases to improve the health of urban residents. The unexpected results are the low efficiency of dramatic improvement of social conditions, without a large number of profile and preventive measures. This is due to the very high cost of such actions. Working with the city's residents and implementing profile programs contributes to improving the health of the city's residents. However, complete neglect of social factors can also lead to negative changes.

Thus, it can be concluded that the means of improving living standards and reducing social pressure should be distinguished in view of the normal financing of preventive measures. This strategy will improve the health condition of residents in a smart city twice and increase its level by 40-50%.

In further studies it is advisable to take into account the environmental health of the population and the impact of negative environmental factors related to the reduction of noise and pollution of air, water, soil, as well as social well-being. This requires the development of preventive measures aimed at preventing the occurrence of diseases by eliminating the causes and conditions of their occurrence and development, as well as to increase the resistance of the organism to the effects of adverse environmental, productive and domestic environmental factors.

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