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ANNOTATION
on dissertation work

for the degree of Doctor of Philosophy (PhD)
Specialty: 8D10103 – Public Health

Title: “Using Geographic Information Systems to Assess Medical-Social and Infrastructure Barriers to Emergency Medical Services”

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Relevance of the research topic. Emergency medical services (further-EMS) occupies a central place in the health care system, as it provides prompt response to conditions in which delayed intervention significantly increases the risk of death or severe complications (Knowles et al., 2020; Marshall et al., 2021; Ningwa et al., 2020; Mould-Millman & Rominski, 2015; Menbeu & Yonas, 2019). The importance of developing this area is constantly increasing against the background of an increase in the frequency of injuries of various origins, road accidents, acute disorders of the cardiovascular system and other critical conditions requiring immediate medical support (Murad, 2007; Lo et al., 2012). Cardiovascular diseases, in particular, remain the leading factor in premature mortality and permanent disability, accounting for about a third of all deaths in economically developed countries (WHO, 2025).

The experience of recent years, including the spread of the new coronavirus infection, has further demonstrated the vulnerability of health systems to sudden epidemiological threats. The COVID-19 pandemic has revealed the need to improve the organizational, infrastructural and clinical aspects of emergency medical care, which makes it possible to ensure the stability of the system and a coordinated response in the face of a sharp increase in referrals and the burden on medical institutions (Malden et al., 2022; Levy et al., 2021).

The conducted research correlates with the key directions of the WHO global strategy "Health for all in the 21st century". In particular, it contributes to the task of reducing the burden of noncommunicable diseases (target 8), as well as to the development of research and the expansion of the information and analytical base for decision-making in the health sector (target 19) (WHO,1998).

The relevance of the topic is confirmed by the strategic priorities of the National Project of the Ministry of Health of the Republic of Kazakhstan "High-quality and affordable healthcare for every citizen - Healthy nation". The study directly corresponds to the direction of "Affordable and high-quality medical care," in which one of the key guidelines is to ensure high coverage of the population with medical services. In addition, the work fits into the directions of the formation of a modern system of epidemiological forecasting and response, providing for the transition to an updated model of epidemiological surveillance and the strengthening of analytical tools, including geoinformation technologies (Government of the Republic of Kazakhstan, 2021).

An analysis of the available scientific literature shows that research on the territorial differentiation of the need for emergency medical care and the influence of geographical factors on resource planning remains limited. There are especially few studies that systematically assess the medical, social, and infrastructural barriers that create uneven access to emergency services between localities.

One of the most persistent problems of the last decade remains the response time of emergency medical teams. As the burden on emergency response services increases due to the growing number of calls, the influence of factors of transport accessibility, population density, quality of the road network and distribution of locations becomes more significant. European studies show that prompt

acceptance of a call is a critical indicator of effectiveness - within 10 seconds - since it is this parameter that determines the further chain of response and the likelihood of timely arrival of the brigade (Jensen et al., 2020).

The congestion of ambulance services poses threats to the stability of the system, increasing the risk of lengthening travel time and worsening medical outcomes (Dami & Berthoz, 2020). Therefore, the analysis of the dynamics and spatial patterns of call distribution is of fundamental importance: load fluctuations directly affect the allocation of resources, the work of dispatching services and the quality of emergency care (Ferron et al., 2021). Understanding these processes allows us to form more accurate planning models, as well as identify areas with a high risk of delays, which makes the use of geographic information systems especially relevant.

In modern conditions, methods of modeling and predicting morbidity are of key importance for epidemiology and health management, as they serve as a methodological basis for planning preventive measures and allocating resources (Murad, 2014). The use of geographic information systems (GIS) allows solving a wide range of practical tasks, such as determining the spatial location of healthcare facilities, assessing the territorial availability of medical services, analyzing structures and types of demand, as well as building models of medical service areas.

The results of this study may be useful for senior healthcare managers as an information source for making decisions on emergency medical care. In addition, we found that there is little research at the local level aimed at identifying the needs of the population in the EMS conditions of the areas, which would allow an effective response in such situations. GIS is an effective and promising tool for assessing the effectiveness, efficiency and accessibility of emergency medical care, but a deeper study of the specifics of its application is required to develop approaches to its use (Tansley et al., 2015; Al-Thani et al., 2021; Doumouras et al., 2012; Utami & Ramdani, 2022).

The conducted research allows us to form proposals focused on practical healthcare, primarily on improving the work of the ambulance service in conditions of dense urban development, population growth and mobility. The use of GIS helps identify key medical, social and infrastructural barriers affecting the availability of emergency care, as well as substantiate monitoring and management decision-making mechanisms, including the activities of primary health care units. This makes it possible to analyze ambulance call protocols, determine routes and time of arrival of the team, as well as analyze data on the condition of patients and the use of resources of medical institutions within the emergency care system. Such studies make it possible to identify and analyze features in the provision of emergency medical care, determine the effectiveness of measures taken and develop recommendations for optimizing the operation of the emergency care system.

Purpose of the study.

Scientific substantiation and development of a model of emergency medical care, taking into account medical, social and infrastructural barriers

through the use of geoinformation systems

Objectives of the study:

1. To conduct a comprehensive comparative analysis of international standards for the use of geoinformation technologies in healthcare.

2. Identification of barriers to emergency medical care and their classification.

3. Analysis and modeling of identified barriers to emergency medical care using geoinformation technology.

4. Development and implementation of a recommendation model for emergency medical care, taking into account the identified barriers using geographic information systems.

The materials of the study were:

- databases of the automated management system 'Komek 103', which has been used at the ambulance station since the end of 2019, and automated information systems 'ADIS for 2018-2023';

- data from authoritative databases on scientific research (Web of Science, Scopus);

- GIS-technologies.

Research Methods.

Information-analytical, modelling, bibliometric, bibliographic, statistical methods.

Object of study.

Medico-social and infrastructural barriers to emergency medical care.

Scientific novelty of the research results:

1. For the first time, a spatial analysis of the territorial accessibility of emergency medical care in different districts of Astana city was conducted, which allowed to identify the influence of geographical, demographic and infrastructural factors on the quality of emergency care. This approach provided a deeper understanding of the relationships between the location of medical institutions, transport network and response time of emergency services.

2. For the first time the significant features of COVID-19 pandemic impact on emergency medical care in the Republic of Kazakhstan were studied and identified. The analysis showed changes in the load on emergency services, redistribution of resources, as well as revealed new requirements for efficiency and medical personnel in conditions of increased risk of infection.

3. Models for optimal distribution and routing of emergency medical care based on GIS technologies are developed and proposed. The key components of the model include the analysis of spatial and temporal availability, forecasting the population's needs in emergency care, dynamic resource allocation and route optimisation. The new model makes it possible to automate the decision-making process and significantly improve the efficiency of the organisation of emergency medical care.

Subject of the study.

Emergency medical calls associated with coronary heart disease cases

(I20-I25), COVID-19, GIS technology.

Research results and practical significance:

1. A model of emergency medical care using GIS technology has been developed to improve the effectiveness, efficiency and accessibility of emergency medical care based on scientific principles and data analysis.

2. Maps of territorial accessibility of emergency medical care for the population of Astana city have been developed.

3. The needs for emergency medical care before and after the COVID-19 pandemic have been identified.

Basis for conducting the study.

SCP on PCV 'City Emergency Medical Aid Station' of the Akimat of Astana city.

Main points to be defended:

1. Based on the conducted geospatial analysis and modeling of territorial accessibility, it has been established that in certain areas of the city - including Baikonursky, Saraishyk and Yesilsky - a significant proportion of calls exceeding the standard 10-minute arrival time of the brigade is recorded. The results obtained indicate the presence of critical territorial and infrastructural gaps in the provision of prompt emergency medical care, which indicates the need to optimize logistics and regulate the allocation of resources of the ambulance service.

2. The results of modeling the spatial concentration of calls related to coronary heart disease and COVID-19 infection have shown their concentration in the central and most densely populated areas of the city, which leads to an increased burden on emergency medical services. The level of accessibility to EMS and medical organizations within 3, 5 and 10 minutes shows satisfactory coverage, however, a significant number of calls remain outside these areas, which poses a risk to patients with acute conditions.

3. Districts of Astana such as Baikonur, Saraishyk and Almaty are characterized by a high frequency of calls and insufficient access to emergency medical care within 10 minutes. In these circumstances, there is a need to reassess the existing resource allocation schemes and adjust the spatial location of emergency medical facilities in order to reduce travel time and ensure sustainable availability of medical services.

4. During the COVID-19 pandemic, there was a significant increase in the number of emergency requests: an increase of about 150% at the initial stage and 7,6% during peak loads. The increased intensity of calls led to additional pressure on the infrastructure of the emergency service and identified the territorial zones with the highest concentration of calls. These "hot spots" necessitate the strengthening of human and technical resources in the most vulnerable areas to ensure the sustained responsiveness of medical care in times of crisis.

5. The developed model of emergency medical care organization based on the use of geographic information data has demonstrated high efficiency in identifying areas with insufficient availability of medical services. The results

obtained confirm the importance of spatial analysis as a tool for sound planning, optimizing resource allocation and increasing responsiveness in conditions of increasing burden on the healthcare system.

Approbation and implementation of the research results.

The main provisions of the thesis were reported at international conferences in RK:

- Assessment of barriers to emergency medical care using geographic information systems // International Scientific and Practical Conference of Students and Young Scientists 'Medical Science and Education: Youth and Striving - 2019' (Nur-Sultan, 1-2 October 2019);

- Demand for the use of geoinformation technologies in emergency medical care // 'Science and Public Health' (Semey, 25 September 2020) ;

- Dynamics of emergency calls during the COVID-19 pandemic in Nur-Sultan // scientific and practical conference of students and young scientists 'Insurance Medicine. Science. Education' (Nur-Sultan, 21-22 December 2020).

Certificate of state registration of rights to the object of copyright No. 26453 dated 24 May 2022, IP No. 26453 'Use of geoinformation systems to assess medical, social and infrastructural barriers to emergency medical care' (work of science), (Annex A of dissertation).

Certificate of state registration of rights to the object of copyright No. 51129 dated 06 November 2024, IP No. 51129 'Trends of emergency medical aid calls before and after COVID-19 in Kazakhstan' (work of science), (Annex A of dissertation).

Act of implementation of the results in practice of the State Enterprise on PCV 'Emergency Medical Aid Station' UZ Shymkent (Annex B of dissertation).

Act of implementation of the results of research work of SE on PCV 'Regional station of emergency ambulance' of Aktobe region (Annex B of dissertation).

Act of implementation of the results of research work of State Enterprise on the Municipal Emergency Medical Station of the Akimat of Astana (Appendix B of dissertation).

Publications on the subject of the thesis. On the subject of the dissertation published 9 publications, including 4 in publications recommended by the Committee for Control in the field of education and science of the Ministry of Science and Higher Education of the Republic of Kazakhstan, 3 speeches and publication in collections and materials of international scientific and practical conferences in Kazakhstan; 2 articles published in the Open Access Macedonian Journal of Medical Sciences (SJR 0.288 in 2020, percentile on Citescore - 48%) and 'Georgian medical news' (SJR 0.139 in 2023, percentile on Citescore - 38%).

Scope and structure of the thesis. The thesis consists of a table of contents, a list of notations and abbreviations, an introduction, a literature review, materials and methods of research, 4 sections of the results of own research, a discussion of the results obtained and a list of literature sources used. The total volume of the thesis is 109 sheets of computer text (excluding applications). The list of used sources contains 134 sources. The thesis is illustrated with 41 figures

and 18 tables.

Personal contribution of the doctoral student. The dissertation of Chayakova A.M. is a completed independent work performed at a high scientific and methodological level. The author personally developed a model for assessing medical, social and infrastructural barriers to emergency medical care using geoinformation technology. The author directly participated in the collection and analysis of initial data, approbation of the research results, preparation of publications on the completed work, presentations at international conferences, preparation and receipt of author's certificates.

Results:

EMS is a key element of the healthcare system that ensures timely response to acute life-threatening conditions, including coronary heart disease and acute respiratory infections such as COVID-19 (WHO, 2025; Malden et al., 2022; Ferron et al., 2021). Accelerated urbanization, the increasing burden on ambulance services and the changing pattern of morbidity, especially in the context of a pandemic, increase the requirements for the effectiveness of the organization of EMF and the territorial accessibility of medical care for the population of large cities. Against this background, the use of GIS is considered as one of the most promising areas for analyzing spatial patterns of applying for EMF, identifying medical, social and infrastructural barriers, and developing models for optimizing the work of the service (Ahasan et al., 2020; Ozdenerol, 2024; Thrall, 1999; Centres for Disease Control and Prevention, 2024).

The Republic of Kazakhstan, like many countries, faces a high prevalence of cardiovascular diseases and a significant contribution of coronary heart disease to the overall mortality of the population (Academy of Preventive Medicine of the Republic of Kazakhstan, 2024; Shaltynov et al., 2022; Ministry of Health of the Republic of Kazakhstan, 2017). An additional challenge to the healthcare system was the COVID-19 pandemic, which led to a sharp increase in the number of calls for infectious symptoms, a change in the structure of calls, a reallocation of resources, and temporary restrictions on planned and emergency care for other life-threatening conditions. In a large megalopolis such as Astana, these trends are particularly acute: differences in population density and age structure, uneven placement of medical organizations and EMS substations form a complex set of medical, social and infrastructural barriers that are difficult to take into account in the management system without special analysis tools (Ahasan et al., 2020; Thrall, 1999; McLafferty, 2003; Rocha et al., 2017; Khakh & Fast, 2019; Davenhall & Kinabrew, 2012).

In this regard, the dissertation research was devoted to the scientific substantiation and development of a model for providing emergency medical care to the population of Astana based on identified medical, social and infrastructural barriers using geoinformation systems.

To achieve this goal, tasks have been consistently solved, including the analysis of international standards and experience in the use of GIS in healthcare, a retrospective epidemiological analysis of applications for EMF, the identification

and classification of medical, social and infrastructural barriers, spatial modeling of CHD and COVID-19 challenges, as well as the development of a recommendation model for the organization of EMS using the tools of ArcGIS Pro and network analysis. This ensures a logical continuity between theoretical assumptions, empirical observations, and practical solutions for the healthcare system.

A retrospective analysis of requests to the EMS station in Astana for the period 2020-2024 made it possible to characterize the volume and structure of the load on the service in dynamics. The total load on the EMS service was high: 2,469,283 calls (100%) were registered during the analyzed period, and the number of calls for coronary heart disease accounted for 1.4% of the total number of calls (a total of 33,716 calls for coronary heart disease were recorded).

It was found that the time indicators of work (the time from the moment of treatment to the departure of the team, the time of arrival, the duration of stay at the address and the time of delivery to the hospital) tend to increase.

- The average arrival time of the brigade increased from 15.05 minutes (2020) to 16.56 minutes (1st half of 2024), an increase of +1.51 minutes.

- The total call-to-hospital time ranged from 50 minutes 49 seconds (2020) to 57 minutes 44 seconds (2023) and 1 hour 00 minutes 55 seconds (1 month 2024), reflecting the lengthening of the pre-hospital stage.

An analysis of the daily and weekly dynamics of calls showed a steady increase in the number of calls at the beginning of the week and during daytime hours (the heavy call load falls on Mondays, the peak is during the daytime (10:00-11:00), the least calls at night (00:00-06:00)).

A study of the demographic characteristics of patients who sought EMS for coronary artery disease revealed patterns consistent with global epidemiological data. During the period 2020-2024, middle-aged and elderly people prevailed among patients with coronary heart disease, while the proportion of men was slightly higher, but gender differences were offset over time by an increase in the proportion of women in older age groups (men accounted for 54-55%, women — 45-46%). The average age of patients with coronary heart disease remained consistently high, reflecting the accumulation of risk factors and the duration of the disease (men 62.6–63.5 years, women 65.1–66.5 years).

Pronounced seasonal fluctuations were noted: the greatest load on EMS, as a rule, occurs in the winter months, especially December and January, while high values are also observed in some autumn and summer months..

The COVID-19 pandemic has had a significant impact on the structure and dynamics of EMS referrals. 135 911 calls related to COVID-19 were analyzed; during peak periods, the average daily number of EMF calls was about 1,500-1,600 calls per day, and the maximum average daily level for the entire study period reached 2,195 calls per day. During the peak of the incidence (summer 2020), the share of calls related to symptoms characteristic of COVID-19 and confirmed diagnoses of a new coronavirus infection reached a significant part of

the total number of calls (during the peak, the average arrival time of the brigade increased to 18.13 minutes (compared with 15.26 minutes in the pre-pandemic period). The revealed changes emphasize the need for the EMS service to be ready for sudden load surges, reorientation of routing and reallocation of resources in the context of epidemics and other crisis situations.

Based on the analysis of time, demographic and organizational indicators, a classification of barriers to emergency medical care was proposed, including two large groups: medical, social and infrastructural. Medical and social barriers reflect the characteristics of the patient population (age, gender, population density), behavioral aspects of appeal, as well as organizational factors that affect the delay in treatment and decision-making about the call. Infrastructure barriers characterize the spatial distribution of EMS substations and hospitals, the density and configuration of the road network, transport accessibility, and the presence of remote and hard-to-reach areas.

The use of geoinformation systems (ArcGIS Pro 3.1.0) and spatial analysis methods (nuclear density, hotspot analysis, network analysis of accessibility zones) made it possible to move from a purely statistical description to visualization and modeling of territorial differences in EMS accessibility. In the course of the work, a unified geospatial database was created, including the results of geocoding 48 515 calls, of which 38,333 (79.1%) were for COVID-19 and 10,182 (20.9%) for coronary heart disease. The constructed maps of density and "hot spots" showed the concentration of calls in the central and northeastern districts of the city, especially in the old part of Astana, while "cold" areas with low call density formed in the western and peripheral zones.

Modeling accessibility zones with thresholds of 3, 5, and 10 minutes for EMS substations and inpatient healthcare organizations made it possible to quantify territorial disparities in access to emergency care. It is shown that, despite the fact that most of the urban area is formally covered by a 10-minute accessibility zone, there is a small but significant proportion of calls that go beyond the regulated intervals. The highest concentration of calls outside the 10-minute zone was detected in the Baikonur district, Saraishyk district, and parts of Almaty, Saryarkinsky, and Yesilsky districts. Similar risk zones have been identified for calls related to COVID-19 and coronary heart disease, which indicates the systemic nature of infrastructure constraints.

At the final stage of the study, based on network analysis, a recommendation model of the EMS organization was developed and tested, including optimization of the location of new substations and medical organizations. Priority locations have been identified for additional EMS facilities (Lesnaya Polyana – Kosshy, Talgat Nigmatullin and Polet Streets, Bakanas and Zhanaturmys Streets) and healthcare organizations (No. 229 Street, Bypass Road and Dzhunusov Street, 201st Street and Ulytau Street). The simulation showed that adding new facilities can significantly reduce the average transportation time: the time from the EMS substation to call addresses decreased by 6 percentage points, and the time from addresses to hospitals decreased by 4.5 percentage

points. To assess the effect of the proposed model for addresses with an initial arrival time of "more than 30 minutes", the average transportation time was calculated for various scenarios (EMS and HO, priorities 1-3, types of COVID-19 and coronary artery disease calls). According to the data, the creation of new substations for emergency medical care reduces travel time by an average of 6.2–12.3 minutes (10-20 p.p.), and for routes to healthcare organizations — by 2-6 p.p. (1.5–4.4 min.).

Thus, as a result of the conducted research, the purpose of the dissertation work has been achieved, all the tasks set have been solved. A model for the organization of emergency medical care for the population of Astana has been scientifically substantiated and developed, based on the integration of geoinformation technologies, a retrospective analysis of emergency medical care data and a structured classification of medical, social and infrastructural barriers. The results obtained allowed:

• to show the importance of GIS as a tool for assessing and visualizing the availability of EMF in a large metropolis;

• Identify key time, demographic, and organizational barriers affecting referral and response time;

• identify high-load territorial clusters and areas with an increased risk of non-compliance with regulated time standards;

• To offer sound recommendations on the reallocation of resources, the placement of new substations and the optimization of patient delivery routes.

The practical significance of the research results is confirmed by the possibility of their direct use by healthcare managers, Astana city authorities, heads of ambulance services and organizations of inpatient and outpatient care. The developed density maps, accessibility zones, and recommendations for the placement of new facilities can serve as a tool for planning and modernizing infrastructure, reducing critical response times, and increasing the resilience of the EMS system to crisis loads, including repeated epidemics and other emergencies.

This study makes a significant contribution to the development of the concept of spatially oriented management of emergency medical care in the Republic of Kazakhstan and can serve as a methodological basis for similar studies and projects in other major cities of the country.

Based on the conducted research, the following **conclusions** were drawn:

1. An analysis of international standards and GIS application experience has established that international standards form a unified environment for the exchange of cartographic and clinical data, increasing the compatibility, quality and effectiveness of GIS solutions. The application of standards ensures the accuracy of spatial data, simplifies the integration of various platforms, and facilitates compliance with regulatory requirements for personal data protection, which is especially important for scalable emergency medical systems. The results of the study confirm that GIS is applicable for organizing and making

managerial decisions in emergency medical care.

2. The identification of barriers to emergency medical care and their classification show that the number of requests for emergency medical care has been increasing in Astana in recent years. Middle-aged and elderly people are predominantly represented among those who seek emergency medical care; among patients with coronary heart disease, the male sex prevails; among patients with COVID-19, the distribution between the male and female sexes is uniform; emergency medical care is more often sought during the daytime, the number of calls is greater during the cold season. When analyzing the pre-hospital stage of providing care to patients with coronary heart disease and COVID-19 in Astana, a set of time and organizational restrictions was identified due to the peculiarities of the territorial location of the service and the logistics of the departure of teams, exceeding the regulatory arrival threshold by 6.12 minutes, which indicates the presence of systemic barriers affecting the responsiveness.

3. Analysis and modeling of the identified barriers to emergency medical care using geoinformation technology showed that 1.74% of calls are beyond the 10-minute availability of emergency medical care; "hot spots" are localized in the districts of Baikonur, Saraishyk and Yesil. A pronounced positive correlation was found between population density and the frequency of referrals for coronary heart disease ($r > 0.7$). The COVID-19 pandemic has led to a 60% increase in the number of emergency medical care requests, indicating an increased burden on the healthcare system.

4. The development and implementation of a recommendation model for emergency medical care, taking into account the identified barriers using geoinformation systems, showed that the addition of 5 new substations for emergency medical care and 5 healthcare organizations (priority - Lesnaya Polyana-Kosshy, T. Nigmatullina str., Polet; ul. No. 229, Dzhunusova Bypass Road) reduces the average response time from the moment of the call to the arrival of the team at the patient's address from 16.12 minutes to 15.05 minutes (by 6.66 percentage points), and the transportation time from the patient's address to the medical organization from 56.49 to 53.19 minutes (by 4.51 percentage points).

Practical recommendations:

1 The results and conclusions obtained are applicable to healthcare managers, healthcare management authorities in Astana, EMS services, health insurance, primary health care services, dispatch centers, as well as to departments of urban infrastructure and GIS. The recommendations are intended for planning medical care, increasing responsiveness, optimizing patient routing (especially with coronary heart disease), and preparing for crisis loads (pandemics).

1. Use GIS for continuous monitoring and analysis of ambulance calls in order to efficiently allocate teams and resources. Regularly update availability zone models to improve planning and minimize arrival time at the call location.

2. Based on the analysis of call density and arrival time, it is recommended to review the current location of emergency departments in Astana. Additional

units should be created or existing ones reorganized in areas with increased workload, such as Baikonur and Saraishyk and Almaty districts, in order to reduce response time and increase the responsiveness of assistance. Based on the analysis of the call density by time of year and day, it is recommended to develop a forecasting and warning system. Such a system will make it possible to predict in advance the peak load on the EMS services, especially during the winter months and on Mondays, which requires the training of additional teams and resources.

3. During crises such as the COVID-19 pandemic, provide temporary mobile emergency centers in areas with high call density (for example, Baikonur and Almaty districts) in order to reduce the burden on inpatient hospitals and speed up hospitalization.

4. In order to reduce critical response times, medical infrastructure should be strengthened in peripheral areas, especially in high-risk areas such as the Esil district. Using the results of modeling accessibility zones to the lake, it is necessary to optimize the routes of delivery of patients, especially with coronary heart disease.