Journal of Infrastructure, Policy and Development 2024, 8(8), 5152.
https://doi.org/10.24294/jipd.v8i8.5152

Article

GIS served ambulance arrival time in the Kvemo Kartli region, Georgia

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CITATION

Elizbarashvili M, Kvirkvelia B, Chikhradze N, et al. (2024). GIS served ambulance arrival time in the Kvemo Kartli region, Georgia. Journal of Infrastructure, Policy and Development. 8(8): 5152. https://doi.org/10.24294/jipd.v8i8.5152

ARTICLE INFO

Received: 11 March 2024
Accepted: 22 April 2024
Available online: 8 August 2024

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Abstract: We aimed to estimate the arrival time of the ambulance based on a GIS in Kvemo Kartli, one of the regions of Georgia, analyze contextual factors that affect this time, and support defining the target response time standards in the region and country. For this purpose, the isochrone map of ambulance travel time intervals to patients was created based on GIS, taking into account the location of the emergency bases, settlements, the length of the roads, and data on the maximum permitted speeds of the vehicle, based on which it is estimated what percentage of the population will and will not be reached by ambulance in the different time intervals. The results show that in the underserved areas where the ambulance cannot reach the patients, within 8 minutes lives 52 percent of the population of Kvemo Kartli, which is almost 222,976 people. Thus, the 8-minute reachability area of an ambulance should be expanded, and it is also necessary to define response time standards in the Kvemo Kartli region, Georgia. These actions will enhance the quality of emergency medical services and benefit the population.

Keywords: population; maximum allowed speeds; a life-threatening call; emergency

1. Introduction

Response time is an essential aspect of the quality of the prehospital emergency medical service (EMS) (Blanchard et al., 2012).

Response time is typically measured from the moment the call is received to the arrival of EMS personnel (Lawner et al., 2016). According to the World Health Organization (WHO), an ideal emergency medical service response time is less than 8 minutes (Nogueira et al., 2016). This time differs from the actual response time. Various factors, such as roads, location of emergency medical care facilities, etc. cause the difference. The response time also depends on the category of the call, e.g., if the call is classified as life-threatening, emergency, urgent, or non-urgent.

Many countries have target response time standards for emergency care, such as arriving within a certain number of minutes for life-threatening situations. Emergency response time standards vary by country and the scales of individual countries (Aringhieri et al., 2016; Takeda et al., 2007; Vile et al., 2016).

Moreover, most European countries differentiate between emergency levels. For example: Ireland and the UK recognize five levels of emergency status, Estonia and Latvia distinguish four levels, and Belgium, Czech Republic, Germany, Hungary, Lithuania, Norway, Spain, and Turkey have three emergency levels. The Netherlands has two levels. and Croatia does not differentiate between levels of emergency (Ambulance 2015).

In 2017, the Secretary of State for Health accepted NHS England's recommendation to implement new ambulance performance standards. "The

Ambulance Response Program Review" (The Ambulance 2018) states that when a life-threatening call needs immediate intervention and resuscitation, e.g., cardiac or respiratory arrest, the average response target is 7 minutes. The 90th percentile response target is 15 minutes.

In emergencies requiring swift assessment, urgent on-site intervention, or prompt transportation—such as heart attacks, strokes, or severe burns—the target response time is 18 minutes on average (adjusted to 30 minutes for 2023/2024). The 90th percentile response target is 40 minutes (The Ambulance 2018).

If the problem is urgent and requires treatment to relieve suffering (e.g., pain control) and transport or assessment and management at the scene with referral where needed within a clinically appropriate time frame, then only the 90th percentile response target is 120 min (The Ambulance 2018).

When problems are less urgent but need assessment and possibly transport within a clinically appropriate timeframe, only the 90th percentile response target is 180 min (The Ambulance 2018).

Health organizations and governmental agencies typically establish target response time standards for emergency care to define the maximum allowable time for providers to respond and initiate care for emergency cases. The relationship between target response time standards and medical implications is significant and multifaceted (The Ambulance 2018). Georgia does not have Emergency Medical Service response time standards.

Emergency care offers immediate medical attention for life-threatening conditions like heart attacks, strokes, severe injuries, and allergic reactions. Timely action can be the determining factor in whether a person lives or dies (Elmqvist et al., 2008).

Ambulance arrival time is critically important in emergency care. Many medical conditions require prompt medical intervention. The faster an ambulance arrives, the sooner these time-sensitive treatments can be initiated, significantly improving patient outcomes. A well-functioning emergency care system is crucial for managing public health crises, such as disease outbreaks or natural disasters, and ensuring public safety during emergencies (Brendan et al., 2009).

Ambulance crews are trained to provide immediate medical care and stabilization to patients. Their early arrival allows them to monitor vital signs, administer necessary medications, and provide initial treatments to stabilize the patient's condition before they reach the hospital (Renee et al., 2010).

Ambulances are crucial in transporting patients to the most appropriate healthcare facility based on their condition. Timely arrival ensures patients reach the suitable facility on time for specialized care. The timely arrival of an ambulance can alleviate anxiety and stress for both the patient and their family members, reassuring them that assistance is on the way (Snooks et al., 2019).

Delays in ambulance arrival can lead to further complications, deterioration of the patient's condition, and increased risk of disability or death. Swift arrival minimizes these risks.

Our goal was to estimate the ambulance's arrival time based on GIS (Geographic Information Systems) in one of the regions of Georgia, analyze contextual factors that affect this time, and support defining the target response time standards in the region and country.

Understanding ambulance arrival times can provide insights into the effectiveness of the healthcare system and help in planning for future healthcare needs, such as determining the optimal locations for new healthcare facilities (Bhattarai, 2023).

GIS-estimated arrival times can be crucial in disaster response planning, allowing authorities to preposition resources and coordinate emergency response efforts more effectively. For example, GIS-estimated ambulance arrival times in the Kvemo Kartli Region, Georgia, can significantly improve emergency medical services, public health, and disaster response planning.

The research will give us a broad idea of how the ambulance arrival time changes in different areas, what contextual factors affect this time, what measures need to be taken to improve the situation and how can we define the response time standards.

2. Research method and data

The "Research method and data" section includes three sub-chapters in which the study area, data collection methods, and sources, steps of creating a Geoinformation base, as well as modeling and calculations are discussed consistently.

2.1. Study area

According to Yin (2014), case studies are particularly valuable for exploring complex phenomena in real-life contexts, providing rich and detailed insights that may be difficult to obtain through other research methods. Case study research should have practical implications for addressing real-world problems or informing policy and decision-making. In the case of ambulance arrival time in the Kvemo Kartli region, it helps us to understand contextual factors, how they affect response time, and what measures must be taken to improve the situation. Yin (2014) also stresses the importance of understanding the phenomena' context (Yin, 2014). In the case of the ambulance arrival time study in Kvemo Kartli, it is crucial to consider the unique geographical context: location, population density, roads, etc.

Georgia is situated in the Caucasus region. It shares borders with Russia to the north, Azerbaijan to the southeast, Armenia to the south, and Turkey to the southwest (**Figure 1**). In Georgia, regulations do not identify Emergency Medical Service response time standards.

The Kvemo Kartli region is a representative geographic area for the case study. Kvemo Kartli is one of the border regions of Georgia; it includes the municipalities of Bolnisi, Gardabani, Dmanisi, Tetritskaro, Marneuli, and Tsalka and the administrative center Rustavi. To the north of the Kvemo Kartli region is the country's capital, Tbilisi; to the southeast, it is bordered by the Republic of Azerbaijan, and to the south−by the Republic of Armenia (**Figure 1**).

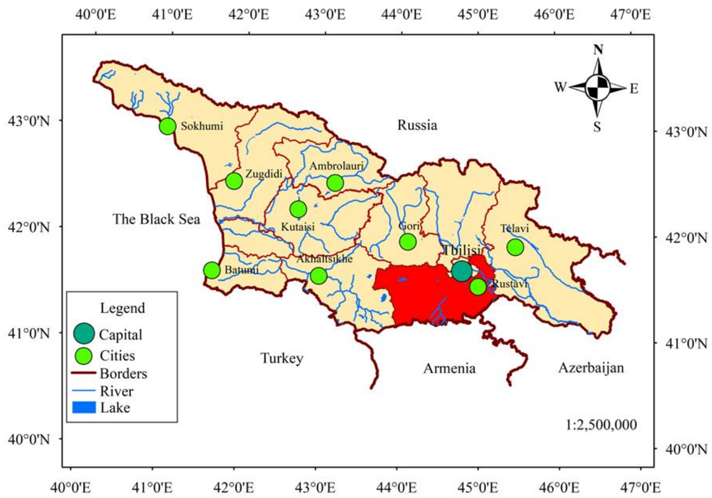

Figure 1. Georgia and the location of the Kvemo Kartli region (the Kvemo Kartli region is marked in red color).

According to the data of the "Georgian National Statistics Service, "the population of Kvemo Kartli is 428,799 people. The Kvemo Kartli region has both industrial centers and farmlands. The main industrial cities are Rustavi and Marneuli. Kvemo Kartli is distinguished by a high population density of 64.9 people/km^2, and within Kvemo Kartli, the population density varies in a large range (**Table 1**). According to the "Ministry of Internally Displaced Persons from the Occupied Territories, Labor, Health and Social Affairs of Georgia," in Kvemo Kartli, there are nine emergency stations and 28 emergency medical service brigades, and according to the years 2021–2023, an average of 10,261 emergency medical calls per year are recorded.

Table 1. Population density in the Kvemo Kartli Region.

Municipality	Population density, people/km^2
Rustavi	1693.47
Marneuli	103.95
Gardabani	85.02
Bolnisi	75.88
Tetritskaro	19.85
Tsalka	19.21
Dmanisi	16.04

2.2. Data collection

Emergency station data were obtained from official government sources, the "Ministry of Internally Displaced Persons from the Occupied Territories of Georgia, Labor, Health, and Social Protection," and direct fieldwork, including visits to emergency stations in the Kvemo Kartli region.

The study region's cartographic base was created using orthophotos, space imagery, and cartographic maps. Road categories and the maximum permissible car travel speeds.

The total length of the roads in the Kvemo Kartli region (including the internal roads of settlements) is 3036 km. The total length of the roads of international importance is 229.2 km (Development Strategy of the Kvemo Kartli region for 2014–2021 (in Georgian)).

Information on the categories of roads in the Kvemo Kartli region Primary Road, Secondary Road, Main Artery, Tertial Road, Local Road, and the maximum speed corresponding to each of them, according to which a car can drive on the road of this category if there is no additional road sign were obtained from the Ministry of Internal Affairs of Georgia. As a result of field studies, we collected information about the position of road signs identifying the maximum allowed car travel speeds on the Kvemo Kartli roads. In particular, during field research, the coordinates of the points where the maximum permitted speed signs were located on the roads were recorded using the GPS, and this information was mapped. According to the above, we got a more detailed road division according to the respective maximum permissible speeds (**Figure 2**).

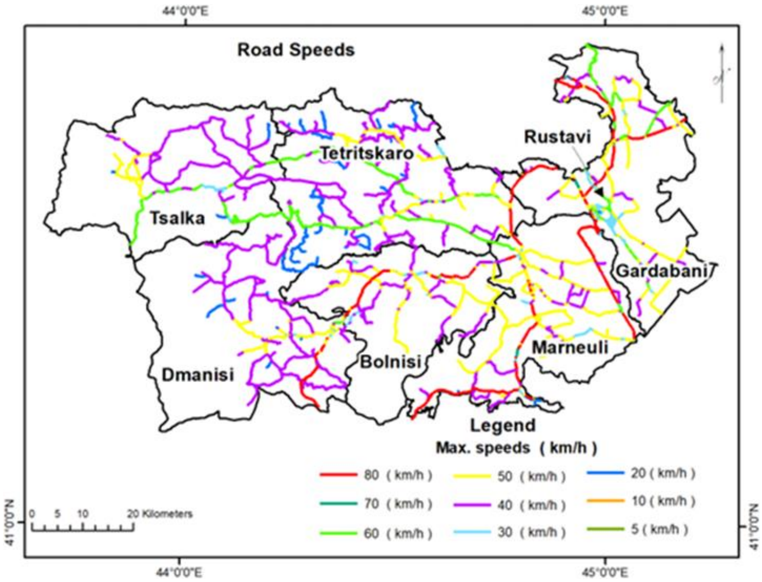

Figure 2. Permissible maximum car travel speeds on the individual section of the roads of the Kvemo Kartli region.

2.3. Methods and analysis

2.3.1. Creation of the geoinformation base

GIS is widely used to strengthen the healthcare system. GIS technology allows healthcare professionals and policymakers to analyze and visualize spatial data related to healthcare facilities, population health, disease prevalence, and other relevant factors. By mapping this information, stakeholders can identify underserved areas, plan the location of new healthcare facilities, optimize resource allocation, and improve access to healthcare services. GIS can also be used to track and respond to disease outbreaks, manage healthcare logistics, and improve emergency response systems. GIS is crucial in enhancing healthcare systems' efficiency, effectiveness, and equity (Lao et al., 2022; Tanser et al., 2006).

The geoinformation base is built through a combination of desk and field works, involving the representation of points, lines, and polygons. Using the WGS_84 projection and UTM 38-N coordinate system ensures standardized spatial referencing and supports accurate spatial analysis in the Kvemo Kartli region.

- A 1:10,000 scale cartographic base was compiled and processed for the study. The base was created by digitizing orthophotos, space imagery, and cartographic maps from 2000 to 2017 using ArcGIS 10.8.1. program.
- Emergency stations are represented as point objects on the 1:10,000 scale map.
- Settlements are represented as polygonal layers at a 1:10,000 scale. Due to scale limitations, each settlement is depicted as a single polygon. The attribute table includes information such as the settlement's name in Georgian and English, municipality, area, and perimeter. Given the scale of 1:10,000, the representation of settlements does not include individual buildings.
- Recognizing that the study's data are mainly reflected in the road layer, a separate road layer was created at a larger scale of 1:1000 (**Figure 3**). This scale allows for a more detailed spatial distribution of values calculated on the roads.

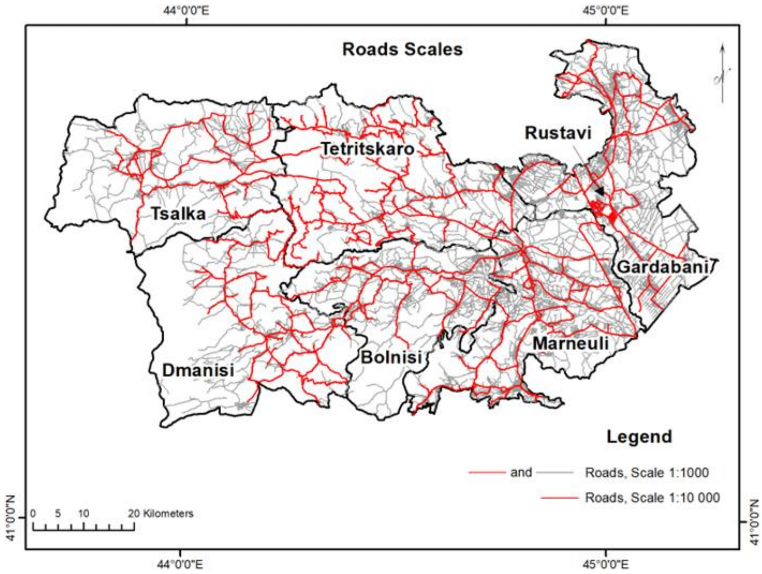

Figure 3. The different scales road network of the Kvemo Kartli region.

- Roads are represented as linear objects on the 1:10,000 scale map. Due to scale limitations, they cannot be considered polygonal objects. Attribute tables for road data include information such as maximum permitted speed, international road names, and the length of specific road sections.

2.3.2. Modeling and calculations

The Arc GIS 10.8.1 geoinformation platform was used to process information and data obtained during fieldwork and desk work, calculate travel times, generate an isochrone map, and analyze the isochrone map to identify served and underserved areas. Isochrone maps are a valuable tool as they show the areas that can be reached within a certain travel time (Dovey, 2017; Śleszyński et al., 2023).

The car travel time along the road was calculated using the maximum permissible car travel speed and the length of the individual section of the road. Moreover, all the roads depicted in red and gray colors in **Figure 3** are used for calculations. Based on the calculated travel times, isochrone lines were generated and areas that are reachable within specific time intervals (8, 15, 30, 45 minutes, and 1 hour) from the origin emergency base were delineated (**Figure 4**). Emergency bases were chosen as the starting points, and the travel times were calculated based on the assumption of a fixed travel speed between two places (assuming a constant maximum speed) along the road. The maximum permissible car travel speeds according to road signs in each segment along the road between two places were used for calculations.

Therefore, the main elements used to calculate the travel time intervals of ambulances are roads (linear object), settlements (polygonal object), and emergency bases (point object).

The isochrone map showing the ambulance travel time to the settlement (**Figure 4**) was used to calculate the population within different travel-time intervals (**Figure 5**).

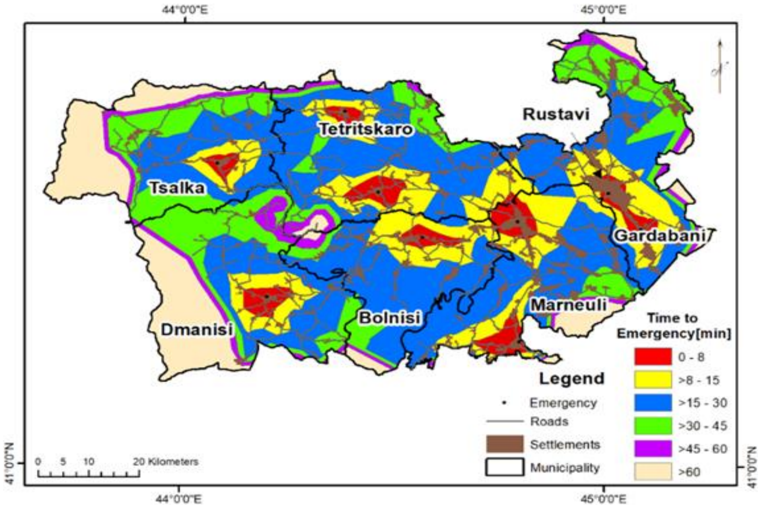

Figure 4. An isochrone map showing the ambulance travel time from the nearest ambulance base to the patient.

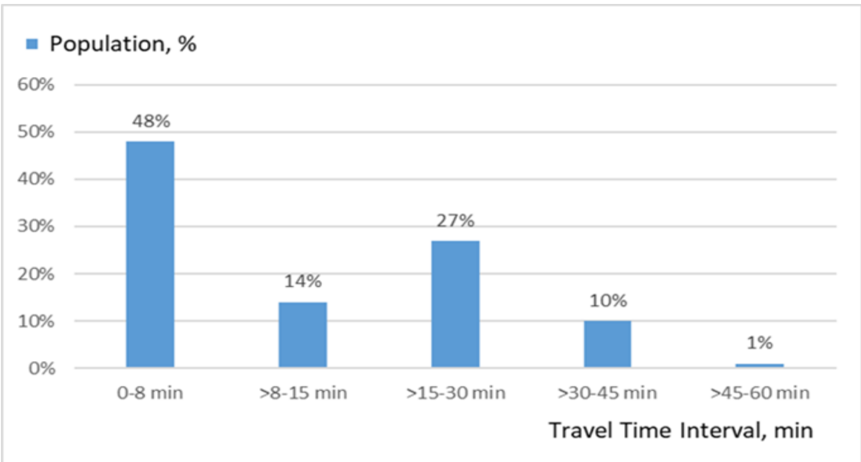

Figure 5. Percentage distribution of the population of Kvemo Kartli in terms of reaching and not reaching an ambulance in different travel-time intervals.

3. Results

3.1. The isochrone map

The isochrone map presented in **Figure 4** shows the spatial distribution of (red, yellow, blue, green, purple, and light brown) areas, which correspond to the following car travel time intervals: 0–8 min, >8–15 min, >15–30 min, >30–45 min, >45–60 min, >60 min.

Figure 4 shows that an ambulance will reach people living in the red area within 8 minutes, in the yellow area it will take 8 to 15 minutes, in the blue area it will take 15 to 30 minutes, in the green area 30 to 45 minutes, and in the purple area it will take 45 to 60 minutes. The brown area is located on the border of the municipalities of Tsalka, Tetritskaro, Bolnisi, and Dmanisi, and also in the remote parts of the region, where there are no settlements. Thus, within 60 minutes, an ambulance can reach almost any settlement in the Kvemo Kartli region.

3.2. Population within the different travel time intervals

Figure 5 presents the distribution of the population according to time intervals.

Such distribution of population is determined by the location of the ambulance base and the region's population density change. Population density varies widely between municipalities (**Table 1**) and within the municipality itself; the population is unevenly settled. There are nine ambulance bases in the Kvemo Kartli region; ambulance bases are located in the centers of municipalities and also in large settlements, where the population density is the highest, and the distance from the ambulance bases decreases. That is why the largest percentage of the population is included in the 8-minute interval, and the percentage composition of the population decreases in the following time intervals. An exception is the 15–30-minute interval, i.e. blue color on the isochrone map (**Figure 4**), which covers a large area, i.e. covers the main territory of the Kvemo Kartli region, and accordingly, 27% of the population of Kvemo Kartli is settled here.

Figure 6 shows the percentage of the Kvemo Kartli population that can be reached and not reached by ambulance within the 8-, 15-, 30-, and 45-minute travel time intervals starting from the nearest ambulance base.

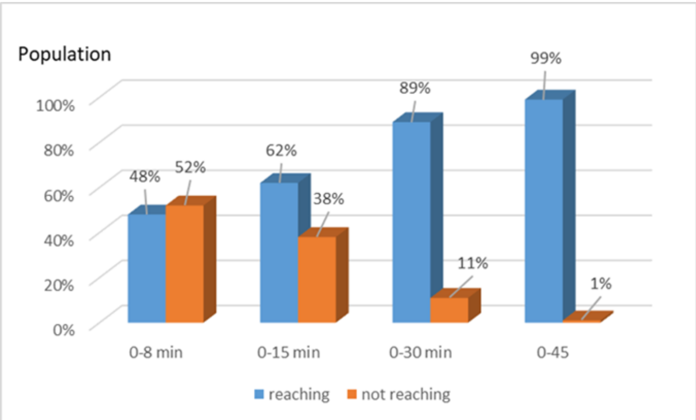

Figure 6. Percentage distribution of the population of Kvemo Kartli in terms of reaching and not reaching an ambulance in different travel-time intervals.

Thus, 48% of the population of Kvemo Kartli lives in an area where an ambulance can reach within 8 minutes; therefore, 52% of the population is outside this 8-minute reachability area. 62% of the population of Kvemo Kartli lives in the area where the ambulance can reach within 15 minutes, while 38% live outside this 15-minute reachability area; 89% live in an area where an ambulance will arrive within 30 minutes; accordingly, 11% of the population remains outside this area; 99% live in an area where an ambulance can reach within 45 minutes, and 1% live outside this area.

4. Discussion

4.1. Response time for life-threatening situations

From the point of view of emergency medical service, the situation in Kvemo Kartli is complex, since here more than half of the population (52%) lives in an area where an ambulance cannot reach within 8 minutes, and almost a third (38%) lives in an area where an ambulance cannot reach within 15 minutes. According to the World Health Organization (WHO), an ambulance should reach the patient in less than 8 minutes (Nogueira et al., 2016), and according to the "Ambulance Response Program Review" (The Ambulance 2018), life-threatening situation, an ambulance is necessary to reach the patient in 7 minutes. Response time is closely tied to the medical consequences of various conditions. For example, asthma attacks require immediate intervention to prevent life-threatening complications like respiratory failure. Anaphylaxis also requires quick access to medical care, including the administration of epinephrine, to counteract severe allergic reactions.

According to the American Heart Association, brain death and permanent death begin within 4–6 minutes after cardiac arrest occurs. Cardiac arrest has the potential to be reversed if promptly treated with an electric shock and advanced life support (ALS) intervention to restore a normal heartbeat. Studies supporting this standard indicate that a victim's chances of survival decrease by 7%–10% with each minute that passes without defibrillation and advanced life support intervention. Successful resuscitation attempts are rare after 10 minutes (Sade, 2011). Although resuscitation efforts are less likely to succeed after 10 minutes, some individuals can still be successfully resuscitated even after longer periods, especially with advanced techniques and technologies (Sade, 2011).

Thus, we can see that it is especially important for the ambulance to reach the patient on time during life-threatening emergencies, since in this case every minute is crucial for saving the patient's life. In different countries, response time standards have been introduced, and ambulance arrival times are regularly monitored. For example, in most European countries, the response time for life-threatening situations is 15 minutes or less, except for the Czech Republic, which is 20 minutes, in Ireland for life-threatening situations, the response time is 8 minutes; in Latvia, the arrival time is set between 8-10 minutes (Ambulance 2015).

The average arrival time for emergency medical services in Brazil is 14 min, and in the U.S. is about eight minutes. Nonetheless, in rural areas, this duration extended to 14 minutes, with approximately 10 percent of patients waiting nearly 30 minutes (Howard et al., 2017; Marcos et al., 2023).

According to recent research in Asian countries, the average response time is 7.2 min, in European countries 11.1 min, in North American countries 9 min, in Oceania countries 8 min, and in African countries 19.5 min (Cabral et al., 2018).

Thus, the research results highlight that, in Kvemo Kartli the 8-minute reachability area of an ambulance should be expanded, which is possible by moving the ambulance posts or creating new ones; the roads are paved.

Created an isochrone map (**Figure 4**) effectively illustrates the areas within Kvemo Kartli that remain beyond 8 minutes of travel time (yellow, blue, green, purple, light brown), that can be considered as underserved areas where the ambulance cannot reach the patients in the appropriate recommended time when it is a life-threatening call, it is this area that needs to be reduced and the area of red color needs to be expanded.

4.2. Some solutions

According to the information of the "Ministry of Internally Displaced Persons from the Occupied Territories, Labor, Health and Social Affairs of Georgia" and the "Emergency Situations Coordination and Urgent Assistance Center of Georgia," in recent years, the infrastructure of medical institutions has been gradually updated in Georgia. In the summer of 2023, 23 new, high-speed, Euro-standard ambulances and ambulance motorcycles were purchased, equipped with modern medical equipment, and designed for movement on complex terrain and in cities with traffic jams. These cars and motorcycles will be distributed in different regions of the country. To improve the emergency medical service and respond effectively to emergency cases, the renewal of the motor car park will continue continuously. It is essential to carry out such updates in Kvemo Kartli.

4.3. Pros and cons of the using isochrone mapping

Using (Guagliardo et al., 2004; Lao et al., 2022; Lovett et al., 2002; Tanser et al., 2006; Yin, 2014) an isochrone map for studying ambulance travel times has several pros and cons: Isochrone maps provide a clear and intuitive visualization of ambulance travel times, helping quickly understand areas reachable within specific timeframes. They aid in decision-making for emergency service planning, resource allocation, and infrastructure development by highlighting areas with limited access to timely care (Fitrinitia et al., 2019).

The accuracy of isochrone maps depends on the quality and accuracy of underlying data, such as road network information and ambulance travel speed. The strength of our research lies in the fact that we used the 1:1000 scale read network to calculate travel time, and even each tiny section of the road network of the study region was assigned the maximum permissible traffic speed in this section. Thus, we calculated travel times by considering these speeds and modeling the movement of vehicles along the road network. The strong point of our study is also that we used the maximum permissible speeds; the maximum permissible speed is the most realistic expression of the speed of the ambulance, because usually when an ambulance goes to a call, it goes at the maximum possible speed that is possible on this or that section of the road. There is a good agreement between the maximum permissible and maximum possible speeds since the maximum permissible speeds indicated on road signs are identified by considering road surface conditions, terrain, steep bends, ascent or descent, or other real-world difficulties that may affect real-time travel.

The isochrone map is valuable for studying ambulance travel time. However, it should be used alongside other data and analysis methods to understand service coverage and accessibility comprehensively. Estimating ambulance travel time to a patient involves several factors and can be approached differently depending on the available data and resources. One of the critical aspects is analyzing historical ambulance response data, which can provide insights into average travel times for different locations and times of day. We do not have such data for Georgia and Kvemo Kartli. Therefore, it is essential to monitor the response time and collect data in the future. For example, this can happen by equipping ambulances with GPS devices, allowing real-time location and speed tracking. Combining multiple methods, such as GIS analysis with real-time GPS tracking, can provide a more accurate travel time estimation.

5. Conclusion

The results show that in the underserved areas, where the ambulance cannot reach the patients within 8 minutes, 52% of the population of Kvemo Kartli, which is almost 222,976 people, live there. Thus, the 8-minute reachability area of an ambulance should be expanded, and it is also necessary to define response time standards in the Kvemo Kartli region, Georgia. This will increase the quality of prehospital emergency medical services and benefit the population.

The presented study is a pilot study of only one region, and it is necessary to create a geographic information system for all of Georgia. This system will allow us to assess the ambulance’s arrival time throughout the country, determine the emergency response time standards, and identify critical areas where intervention and improvement of the situation are needed.

Given the importance of the topic, it is necessary to stimulate the development of other studies that try to understand the factors related to response time, which will allow a scientifically proven understanding of what can be done to reduce it.

Author contributions: Conceptualization, ME and BK; methodology, ME; software, TK; validation, BK, ME and TK; formal analysis, EE; investigation, EE; resources, TK; data curation, NC; writing—original draft preparation, ME; writing—review and editing, NC; visualization, TK; supervision, BK; project administration, ME. All authors have read and agreed to the published version of the manuscript.

Funding: This work was supported by the Shota Rustaveli National Science Foundation of Georgia (SRNSFG) under Grant No. FR-19-14993.

Conflict of interest: The authors declare no conflict of interest.

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