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THE APPLICATION OF GIS TOOLS IN EMERGENCY RESCUE IN SUSTAINABLE GOALS ACHIEVING

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Proper location of medical facilities is critical to planning activities for the health security of residents at the regional level. Spatial accessibility of medical services translates into the level of social security of residents and one of the key of the sustainable development. Spatial analyses of the availability of medical services can, therefore, be used to assess the distribution of the locations of stationing Emergency Medical Teams (EMT). The conclusions made will be particularly important when adjusting the strategic documentation and operation of the system, so that the changes made will have the best possible impact on improving the safety of the population. The time it takes to reach those waiting for help plays a key role here. It is a key element in ensuring the effectiveness of emergency medical services. Constantly monitored and analyzed, it can give a complete picture of the optimality of the location of facilities. Its reasonable standards determined by provincial plans year after year should be rigorously observed. However, the key to achieving the shortest possible time to reach an incident is the location and determination of optimal routes for EMT.

Keywords: Emergency, GIS, hot spots, optimization, spatial analysis, sustainability, sustainable development, sustainable transportation, transport, logistics

1. Introduction

GIS (Geographic Information System) is a tool which is used in a various application, e.g. positioning (Magiera *et al*., 2022), cartography (Banasik & Borowski, 2021), environmental monitoring (Muthoni Njeru & Imwati, 2016), forestry (Ferenčík *et al*., 2019; Kardoš *et al*., 2024) and many other fields The research paper is devoted to studying the application of GIS tools in emergency medical services (Yao *et al*., 2011). It investigated with the help of GIS tools whether the locations of Emergency Medical Service (EMS) facilities/teams optimally matched to the occurring incidents. As a result of the study, its validity will be verified. In this way, a practical example of the use of GIS to illustrate emergency medical services data, applicable, for example, in deciding on new or changing existing locations for stationing emergency medical teams, is presented. Both standard and well-known spatial analysis tools were used, such as, for example, selecting large data sets by means of attributes or locations assigned to them, or depicting phenomena in the form of map compositions that can be easily and clearly viewed, analyzed and draw the necessary conclusions. In addition to this, more advanced tools have also been used to create heat maps. With the capabilities of the ArcGIS Online platform, the functionality of virtual presentation of spatial data and ease of sharing and viewing was tested. In addition, network analysis tools were used.

One of the areas of application of GIS tools is the implementation of emergency management tasks. Emergency management services include ambulance services. Since 2013, it has been operating on a teleinformatics system capable of receiving calls, recording incidents, presenting the geographic location of the incident site, positioning medical rescue teams, and supporting the execution of tasks by medical rescue teams and the provincial medical rescue coordinator. As can be seen from the system's architecture, it is integrated with many other ICT systems and databases, including the National Geoportal of Spatial Information Infrastructure (Ładysz, 2015). The timeliness and reliability of this type of data depends on the performance of tasks in this area by Municipalities. It is their responsibility to submit the updated address database to the nationwide system (Izdebski, 2017). Sustainability in EMTs transport refers to the integration of environmentally friendly practices and technologies in the process of transporting patients during emergency medical situations. It involves adopting measures that minimize the environmental impact of the transportation activities while ensuring the efficient and timely transfer of patients to medical facilities (Jacyna-Gołda *et al*., 2017). This approach aims to reduce the carbon footprint and overall ecological consequences associated with emergency medical transport operations (Wasiak *et al*., 2017).

Optimizing the location of emergency stations is a crucial factor affecting the health security of a region's population (Gu *et al*., 2010). To gain this, it is necessary to use various management tools like community management (Otamendi-Irizar *et al*., 2022), facilities management (Opoku & Lee, 2022), sustainable transport management (Vitetta, 2022), energy efficiency management (Hafez *et al*., 2023), and time management (Dmytryshyn & Goran, 2022). Studies of the spatial availability and reachability of a given type of service involve determining whether and to what extent the supply of these services matches the demand for these services (McLaughlin & Wyszewianski, 2002). Wang (2020) draws attention to planning the location and allocation of health care resources toward maximum equality or minimum difference in access to health care (Wang, 2019). Using GIS tools, such planning is done in a partially automated efficient and optimal manner. Stępniak (2013) points out the use of a two-stage method for analysing market areas (Stępniak, 2013). As a result of the analyses, the degree of matching the distribution and size of hospital emergency departments to the variation in population distribution is obtained and allows the two sides of spatial availability - supply and demand - to be combined in a single analysis. Lindeskov (2002), on the other hand, examined the use of two methods for selecting ambulance stationing locations (Lindeskov, 2002). The first assumes minimization of average response time, and the second assumes minimization of maximum response time.

Spatial analyses should take into account factors that affect the arrival time of the ambulance at the scene of an incident, such as the availability of the Emergency Medical Service, the date and time of the call, and the type of roads on which the ambulance travels (Pniewski *et al*., 2018). Dziemba *et. al.* (2016) pay particular attention to the use of real-time incident monitoring and visualization using GIS tools (Dziemba & Senczyna, 2016). Pasha (2006) developed a prototype AMS system combining GIS, GPS (Global Positioning System) and GMS (Global System for Mobile Communications) (Pasha, 2006). It is used for ambulance routing in the road network of Hyderabad (India) city. The system searches for an incident site on the road network and locates the nearest ambulance. The interface was developed using VBA (Visual Basic for Applications) and ArcGIS. Panahi *et. al.* (2009) compared the routing results of a static method - based on time-invariant data - and a dynamic method - using real-time data (Panahi & Delavar, 2009). The results of the dynamic method turn out to be much more effective, because they take into account the current situation on the roads: traffic jams, traffic volume, etc. Pliskin *et. al.* (2004) analyzed logs of ambulance calls and dispatches. They created layers from them sorting the data by date (Peleg & Pliskin, 2004). Geographical areas were simulated in the form of polygons, so that the maximum arrival time did not exceed 8 minutes. As a result, after using the GIS model, the achievability of the designated time ceiling increased from 62 to 94%. Access to health care is a complex concept that should be analysed from several dimensions including spatial (spatial accessibility) and socio-organizational dimension (service reachability).

The purpose of this study is to examine the application of GIS tools in emergency medical services using Krakow Ambulance Service (KAS) as an example, database was collected in June 2020 (KAS, 2020). With the help of the above-mentioned tools, spatial analyses were carried out to verify whether the locations of stationing EMT are optimally selected for the prevailing conditions and occurring incidents. In addition to this, an answer will be provided as to whether the number of available EMT in each location is sufficient in relation to the number of calls. The most prominent issue addressed in the paper, however, is to examine the application of GIS tools for making decisions on the spatial structure of emergency medical services and making possible changes to meet current needs. In connection with the above, a characterization of the operation of emergency medical services in Poland was made, with particular attention to the area of operation of the KAS. The locations of the ambulance stationing site were analysed, the population in the area. Then, the locations of incidents and arrival times was traced in detail. In addition, attention was paid to the intensity of the number of calls relative to place and time, creating heat maps. The scope of the study is the time from 01.04.2019 to 31.12.2019 and the area of operation of the KAS (KAS, 2020).

2. Sustainable Development Goals

According to the approved plan “2030 Agenda for Sustainable Development” (SDGS, 2023b), to face most global challenges and transform the world for the better, United Nations member states are working to achieve the Sustainable Development Goals (SDG). In 2023, we have already passed half of the way, but still, much has not been completed and fulfilled. Moreover, stagnation or regression was discovered for specific goals and indicators (Figure 1).

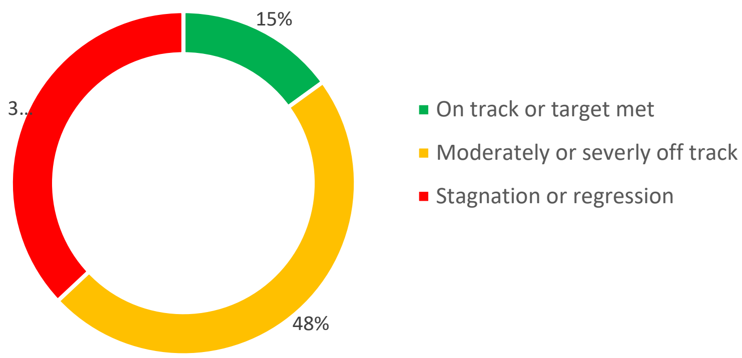

Figure 1. The Sustainable Development Goals achieved at the midpoint of 2015-2030 (UN, 2023c)

Moreover, on the World scale, only SDG 5 has no stagnation or regression part, and SDG1, SDG4, SDG6, SDG13, and SDG16 still need to be on track (UN, 2023c). Due to the Key Messages of Global Sustainable Development Report 2023 (SDGS, 2023a), the progress of 8 SDGs is deteriorating (the implementation happened to be too slow or regressing).

This argument means there is very little time left to achieve the overall aim, necessitating the urgent implementation of comprehensive measures and acceleration toward the SDGs. Many European countries have achieved a relatively high index of achieving the goals of sustainable development (Figure 2). However, their progress is still different for different goals and is yet to grow steadily across all SDGs.

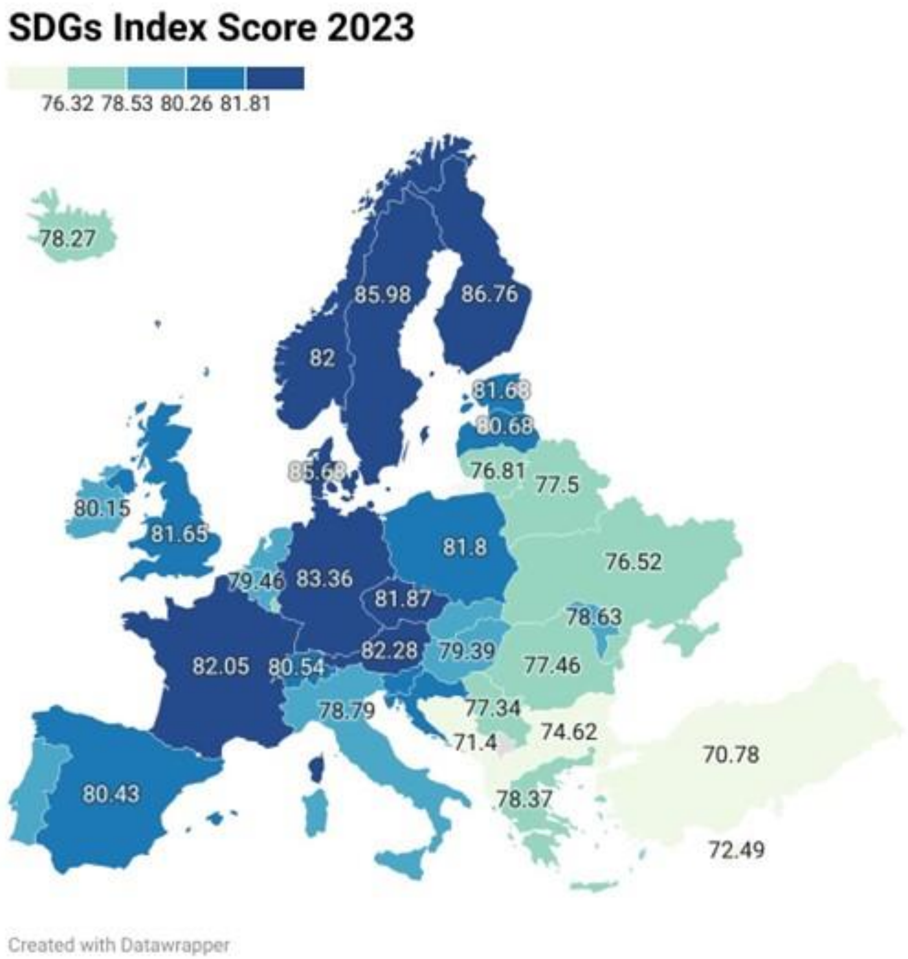

Figure 2. SDGs Index Score 2023 – Europe (dashboards.org, 2023b)

Poland has a 9/166 SDG Index Rank in 2023. However, there are also SDG targets that are getting worse (Figure 3).

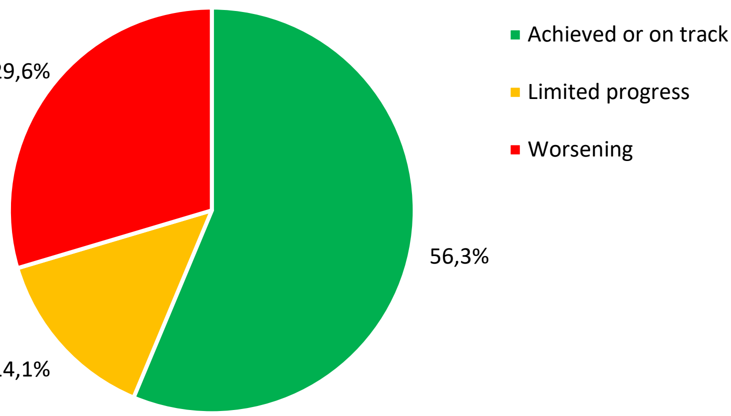

Figure 3. The Sustainable Development Goals achieved in Poland at the midpoint of 2015-2030 (dashboards.org, 2023a)

Comparing Figure 1 and Figure 3, we can see better progress in Poland than in average world indicators. Let's compare the Sustainable Development Goals in Poland with the World average and the country's group – The Organisation for Economic Co-operation and Development members' results (OECD, 2023) (Table 1).

Table 1. 2023 Current state and trends of SDG's achievement (dashboards.org, 2023c)

Sustainable Development Goals	**World**		**OECD members**		**Poland**	
	Current state	**Recent trend**	**Current state**	**Recent trend**	**Current state**	**Recent trend**
1. No poverty	🟠	→	🟡	→	🟢	↑
2. Zero hunger	🔴	→	🔴	→	🔴	→
3. Good health and well-being	🔴	↗	🟡	↗	🟠	↗
4. Quality education	🟡	→	🟢	↗	🟡	↗
5. Gender equality	🟠	↗	🟡	↗	🟡	↗
6. Clean water and sanitation	🟠	↗	🟡	↑	🟡	↑
7. Affordable and clean energy	🟠	↗	🟠	↗	🟠	↗
8. Decent work and economic growth	🟠	→	🟡	↗	🟡	↗
9. Industry, innovation and infrastructure	🟠	↗	🟢	↗	🟠	↑
10. Reduced inequalities	🟠	→	🟠	→	🟡	↑
11. Sustainable cities and communities	🔴	→	🟡	↗	🟡	→
12. Responsible consumption and production	🟡	↗	🔴	→	🟠	→
13. Climate action	🟠	→	🔴	→	🟠	→
14. Life below water	🔴	→	🟠	→	🔴	↗
15. Life on land	🔴	→	🔴	→	🟢	↗
16. Peace, justice and strong institutions	🔴	→	🟠	→	🟠	→
17. Partnerships for the goals	🟠	→	🟡	↗	🟡	↑
🟢*SDG achievement*	🟡*Challenges remain*		🟠*Significant challenges*		🔴*Major challenges*	
↑*On track*	↗*Moderately increasing*		→*Stagnating*		↓*Decreasing*	
Better than in Poland		*Needs improvement*				

Due to the data in Table 1, we can see that Poland generally has equal or better outcomes in all goals despite GDS 12 "Responsible consumption and production". Compared with OECD members' results, Poland needs improvement current state of achieving SDG 3 "Good health and well-being", SDG 4 "Quality education", SDG 9 "Industry, innovation and infrastructure", SDG 14 "Life below water". Also, additional attention requires SDG's 11 "Sustainable cities and communities". These tendencies must become an essential point of seeking universal solutions and activities to increase the chances of reaching the 2030 World target in Poland.

3. Methods

The basic idea of GIS in practice is the processing of spatial data (maps, plans, aerial and satellite images, road networks, etc.) linked to information derived from databases and having a geographical reference (address, geographical coordinates, plot or building number, postal code). Thus, a geographic information system makes it possible not only to collect, analyse and synthesize copious amounts of data and present them in the form of maps and tables, but also to model the course of processes, formulate answers to users' questions and forecast changes. The government administration body responsible for carrying out the tasks of the state medical emergency system for the whole country is the minister in charge of health, and in the province - the governor. The tasks of the voivode include planning, organizing, coordinating the system and supervising the system in the province. The number of positions of medical dispatchers in individual medical dispensaries, the method of cooperation between medical dispensaries, or the number and professional qualifications of medical dispatchers.

The emergency notification system consists of emergency notification centers, forming a unified system for handling emergency calls directed to the emergency numbers 112, 997, 998 and 999, allowing the emergency call to be forwarded to engage the appropriate rescue resources. The emergency medical system includes medical rescue teams (MROs): S-type (specialized) and P-type (basic) ambulances, Air Ambulance Service (HEMS) and hospital emergency departments (EDs).

Medical rescue teams (MROs) are units of the state medical rescue system, whose primary task is to provide medical assistance outside the hospital, to people in a state of emergency. Among them we distinguish:

- specialized teams - at least three people authorized to perform medical emergency activities, including a system doctor and a system nurse or paramedic.
- basic teams - at least two people authorized to perform medical emergency activities, including a system nurse or paramedic.
- air teams - at least three people, including at least one professional pilot, a system doctor and a system nurse or paramedic.

There are two centralized dispatch centers in Malopolska voivodeship: in Krakow and Tarnow, which are included in the nationwide ambulance dispatch system. The KAS dispatch center serves 12 counties and the city of Krakow and receive more than 1,000 calls daily, with more than 13,000 ambulance departures distributed each month. The area under the authority of the Krakow Ambulance Service is about 7,161 square kilometres, with a population of approximately 2 million people, Figure 4 shows the locations of the Medical Rescue Teams in Malopolska.

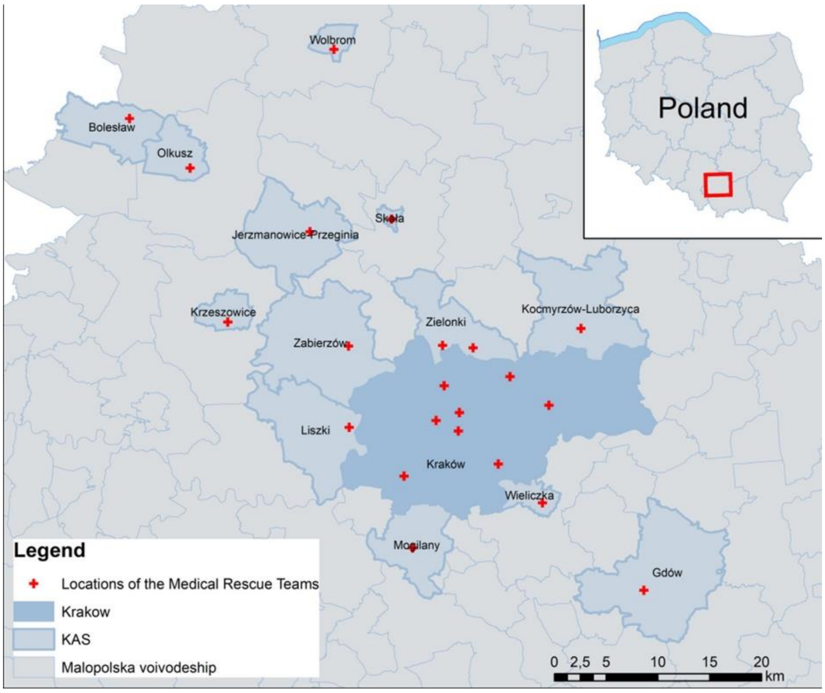

Figure 4. Map of the locations of the KAS EMSs (own elaboration based on data (geoportal, 2020; KAS, 2020))

Among the data acquired were the locations of ambulance stationing, as well as incident information. Both data sets included geographic coordinates of incident locations and addresses of EMT stationing locations. In addition, the data also includes dates and times of incidents. The dates were divided into three-time sequences: time of notification, time of team departure and time of arrival at the destination. In addition, each incident is assigned an individual incident number and EMT number. The input data set initially contained 68,494 records. The analysis began by segregating the data and removing information that distorted the results. These certainly include trips other than those that had their start at the place of stationing. It happens more than once that a team is dispatched to the place of notification, which is moving at the moment. Such situations should have been excluded from the analysis. They distort the picture of the time it takes to go to a notification, because the team in question is already fully ready and is in the process of moving by ambulance. The notification cards kept by the teams do not contain information explicitly on whether they took off from their stationing place or from the route, so it was assumed that when the difference between the time of departure and the time of notification is less than or equal to 60 seconds, the case should be considered a trip from the route. On this basis, all records meeting the above condition were excluded from the data. There were also quite a few records in the data set without recorded coordinates of the incident location. Such data were also removed, as they do not reflect the spatial situation. In the end, 58,241 records remained for analysis. The compiled and continuously updated state emergency medical services are published on the websites of public information bulletins. The texts and annexes in tabular form were obtained for the following provinces: dolnoslaskie, kujawsko-pomorskie, lubelskie, lubuskie, łódzkie, małopolskie, mazowieckie, opolskie, podkarpackie, podlaskie, pomorskie, śląskie, świętokrzyskie, warmińsko-mazurskie, wielkopolskie, zachodniopomorskie. Data on the number of EMT in each polish voivodeship do not give a complete picture of the actual availability of emergency medical services (Table 2).

Table 2. Population with the number of EMTs in each voivodeships in Poland (own elaboration based on data GUS)

Voivodeship	Population	EMTs	Population/EMT
Lower Silesia	2,899,986	116	25,000
Kuyavian-Pomeranian	2,074,517	93	22,307
Lubelskie	2,112,216	93	22,712
Lubuskie	1,013,031	53	19,114
Łódź	2,460,170	105	23,430
Małopolskie	3,404,863	200	17,024
Mazowieckie	5,411,446	44	122,987
Opolskie	984,345	96	10,254
Podkarpackie	2,127462	57	37,324
Podlaskie	1,179,430	93	12,682
Pomeranian	2,337,769	162	14,431
Silesian	4,524,091	49	92,328
Świętokrzyskie	1,237,369	82	15,090
Warminsko-Mazurskie	1,425,967	120	11,883
Wielkopolskie	3,495,470	90	38,839
Zachodniopomorskie	1,698,344	135	12,580

In order to visualize the collected data, administrative boundaries in the form of SHP layers imported directly into ArcMap software were necessary (Figure 5).

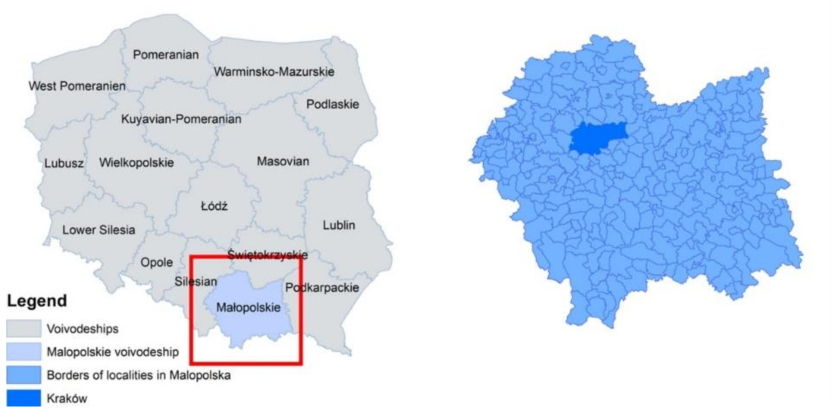

Figure 5. Acquired SHP layers source in Malopolska voivodeship (own elaboration based on (geoportal, 2020))

Both the borders of provinces and the borders of localities in Malopolska were obtained from the database provided by central office of geodesy and cartography (GUGiK) website (geoportal, 2020).

4. Results

For the purpose of performing network analyses, it became necessary to obtain data on the road network of the City of Krakow and other areas served by KES. Open Street Map is a portal that allows public viewing, adding, editing and acquiring spatial data. A great advantage of this source is the timeliness of the data at a relatively high level, as it is continuously edited by users. For planned network analyses, information on road mileage and length, as well as speed on given sections, is particularly important.

4.1. Statistical analysis

The work began with an analysis of the statistics of incidents, in the first step the number of monthly incidents over the time studied was tabulated. On average, 6,471 trips are distributed per month in the area under the Krakow Ambulance Service. The highest number of incidents was recorded in December, while the lowest in August. It can be concluded that weather and atmospheric conditions, as well as traffic volume, are a major influence, generating accidents and other traffic incidents that require the intervention of the Ambulance Service. However, the reasons for individual trips were not specified in the input data, so this is only an anecdotal hypothesis. The spread is in the range of about ±300 with respect to the average number of incidents. In most months, the number of incidents does not deviate significantly from the given value, which is shown in the graph as a trend line. The described values are shown in Figure 6.

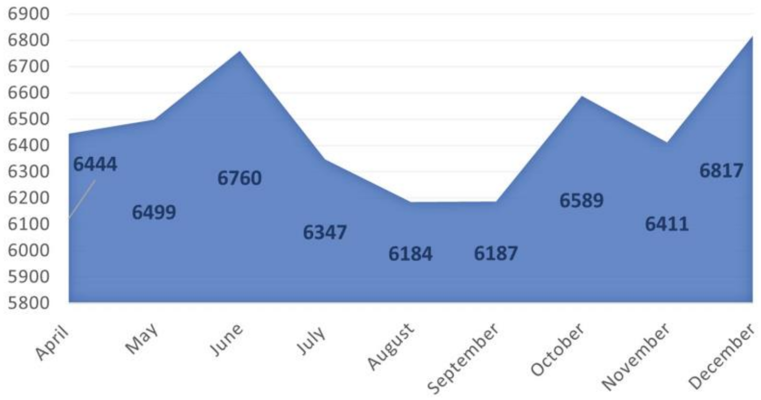

Figure 6. Number of Krakow's EMT departures in April-December 2019 (own elaboration based on data (KAS, 2020))

To get an idea of the ratio of the number of EMT trips from the City of Krakow to the rest, these results are summarized in Figure 7. The uniform trend throughout the year shows that about two-thirds of all interventions of the Krakow Ambulance Service are carried out by EMT stationed in the City of Krakow.

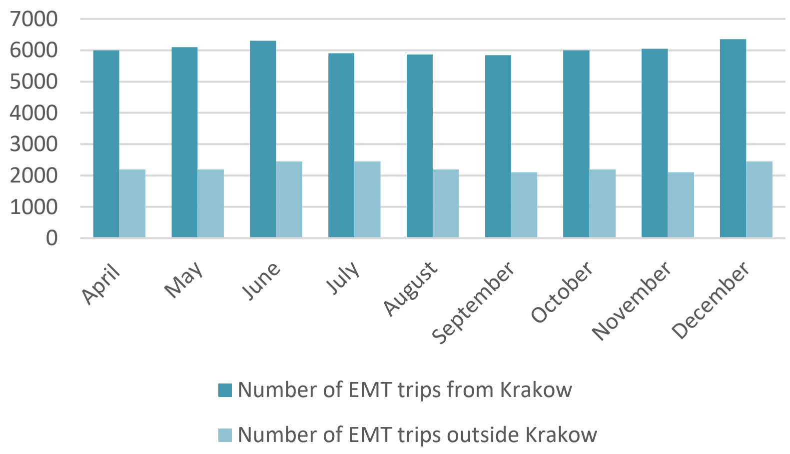

Figure 7. Distribution of Krakow's EMT departures in city and outside. (own elaboration based on data (KAS, 2020))

Classifications were then made considering where the Emergency Medical Teams in question were stationed. The number of trips throughout the year was summed up and assigned to individual address points (Figure 8). The clear leader among the number of trips is the location in Krakow at 14 Lazarza St. This is the very centre of the city, which justifies such a result. However, it is impossible not to notice that the results from the City of Krakow are extremely far from the other neighbouring towns. This is because they range from 2,000 to almost 9,500 trips per year. Therefore, in further analyses it was decided to conduct separate analyses for the City of Krakow and the other localities.

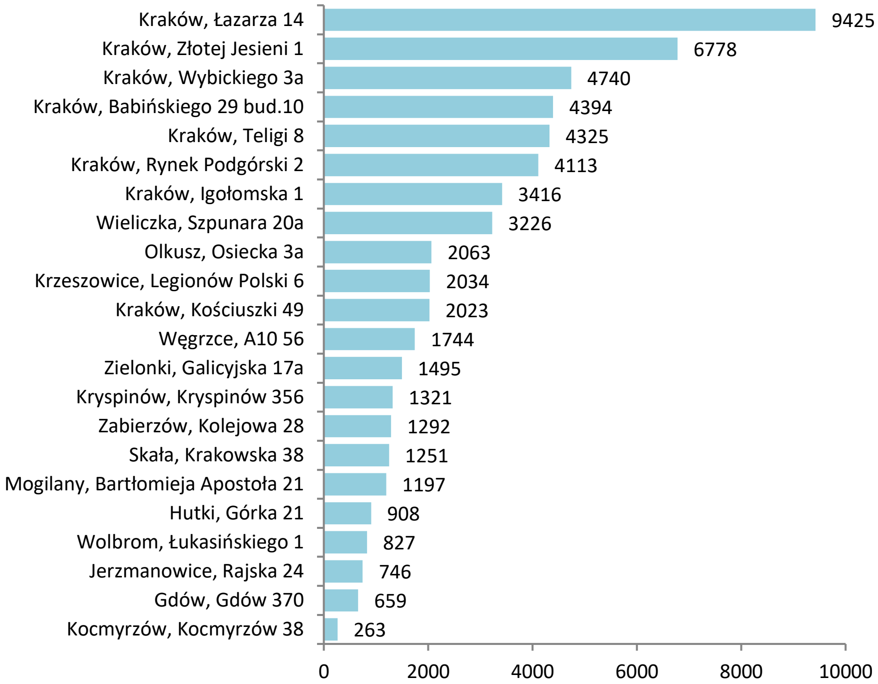

Figure 8. Number of EMT departures by stationing location in Malopolska (own elaboration based on data (KAS, 2020))

However, such a conversion rate does not fully illustrate the situation as it actually exists. Different waiting areas have different numbers of Emergency Medical Teams, which determines the number of calls handled. Therefore, a conversion of the number of calls per EMT unit was made. Teams assigned to specific waiting areas were added up and the annual number of calls was divided by the number of EMTs. In accordance with the earlier assumption, the data from the City of Krakow and the other localities were already separated here (Table 3).

Table 3. Number of yearly departures of each of Krakow's EMTs and mean number of departures per single EMS

Stationing location	EMT number	Departures number	Ratio (EMS/Departures)
Kraków, Babińskiego 29 bud.10	2	4,394	2,197
Kraków, Igołomska 1	2	3,416	1,708
Kraków, Kościuszki 49	1	2,023	2,023
Kraków, Łazarza 14	5	9,425	1,885
Kraków, Rynek Podgórski 2	2	4,113	2,057
Kraków, Teligi 8	2	4,325	2,163
Kraków, Wybickiego 3a	2	4,740	2,370
Kraków, Złotej Jesieni 1	3	6,778	2,259

In Krakow, as expected, the number of trips is almost evenly distributed among the various Emergency Medical Teams and oscillates between 1,708 and 2,370. Both the stationing location with the highest number of trips per year and the ones with the lowest have the same number of EMTs. This may suggest that their number should be increased at the "Krakow, Wybickiego 3a" location, or that the facility should be relieved by changing the dispatching of trips.

Table 4. Number of yearly departures in EMTs located in Malopolska outside Krakow with mean number of departures per single EMS (own elaboration based on data (KAS, 2020)).

Stationing location	EMT number	Departures number	Ratio (EMS/Departures)
Gdów, Gdów 370	1	659	659
Hutki, Górka 21	1	908	908
Jerzmanowice, Rajska 24	1	746	746
Kocmyrzów, Kocmyrzów 38	1	263	263
Kryspinów, Kryspinów 356	1	1,321	1,321
Krzeszowice, Legionów Polski 6	2	2,034	1,017
Mogilany, Bartłomieja Apostoła 21	1	1,197	1,197
Olkusz, Osiecka 3a	2	2,063	1,032
Skała, Krakowska 38	2	1,251	626
Węgrzce, A10 56	1	1,744	1,744
Wieliczka, Szpunara 20a	2	3,226	1,613
Wolbrom, Łukasińskiego 1	1	827	827
Zabierzów, Kolejowa 28	1	1,292	1,292
Zielonki, Galicyjska 17a	1	1,495	1,495

Analysing the situation analogously for the other localities under the Krakow Ambulance Service, a large disproportion in the number of trips for individual locations was noted (Table 4). This is a direct result of the size of the localities in question and the number of residents. For this reason, it will probably be necessary in later analyses to reclassify the study areas taking into account their demographics. Nonetheless, the location with the highest number of serviced requests - 1,744 - was singled out; these are Węgrzce 10A, where only one EMT is available. Analysing other locations similarly, in each where the number of trips per year exceeds 1,500, there are two Emergency Medical Teams available. The lowest number of trips per year was recorded in the Kocmyrzów 38 area.

In large cities and agglomerations such as Krakow, the degree of traffic congestion, has an enormous impact on travel time to the destination, both for private car drivers and emergency services. Navigating the city's streets is particularly difficult during the so-called "rush hours" identified most often with commuting to or returning from work. It was conventionally assumed that in the morning these are the hours from 7:00 to 9:00 a.m., while in the afternoon from 3:00 to 6:00 p.m. To study the impact of the described phenomenon, only those whose reports fit into the assumed time were extracted from the data, while not considering the impact of other factors. Thus, 3172 events from 7:00-9:00 a.m. and 5708 from 3:00-6:00 p.m. were obtained, and they were then divided with respect to the "time" attribute assigned to them. A limit was set in the form of a statutory maximum time to reach the scene of an incident, which is 15 minutes. Then the percentage of incidents exceeding the said barrier relative to all others was calculated. The results are presented in Table 5.

Table 5. Analysis of incidents with extended arrival time at the scene during the hours with the highest traffic volume (own elaboration based on data (KAS, 2020)).

Time interval	Number of total events	Number of incidents exceeding 15 min.	Percentage of incidents exceeding 15 min.
7:00 – 9:00 am	3,172	404	13%
3:00 – 6:00 pm	5,708	1,186	21%

As can be seen from the analyses presented, much greater difficulties are encountered in the afternoon hours from 3:00 to 6:00 p.m. In their case, it can be concluded that traffic volume has a real impact on the increase in commuting time. On the other hand, in the case of the morning hours from 7:00 to 9:00, the percentage of incidents exceeding 15 minutes is so small that the reason for this phenomenon cannot be clearly established.

4.2. Spatial analysis

Spatial analyses began with previously extracted data for the City of Krakow. First of all, separate layers were selected for individual waiting places of Medical Rescue Teams. The "selection by attributes" tool of ArcMap software was used for this purpose. In this way, 8 layers were created with the names of the corresponding streets: Babińskiego, Igołomska, Kościuszko, Lazarza, Rynek Podgórski, Teligi, Wybickiego, Złota Jesień. Each layer was given an additional attribute, which is "time". It was calculated by the difference between the time of arrival at the scene and the time of notification. This is a real determinant of the efficiency of the teams' work. Its range is exceptionally large, as it varies from 1 minute to even 2 hours. There can be many reasons for this, the availability of EMTs at a given place and time, the volume of traffic on the roads, the distances to be travelled. The most crucial factor in the analyses carried out is that resulting from the right disposition for the event and the optimal location of waiting areas. To verify the most important assumptions, it would be necessary to track exactly how each case looks like and draw conclusions from what the increased time to reach the scene of an incident may be due to.

Since previous statistical analysis shows that most incidents are handled by waiting teams at Wybickiego Street, it was this that was analyzed first. The incidents throughout the year that were handled by teams stationed at Wybickiego Street are illustrated in Figure 9. As can be seen in the accompanying illustration, the locations of incidents are scattered over an exceptionally large area, which often determines the extended arrival time.

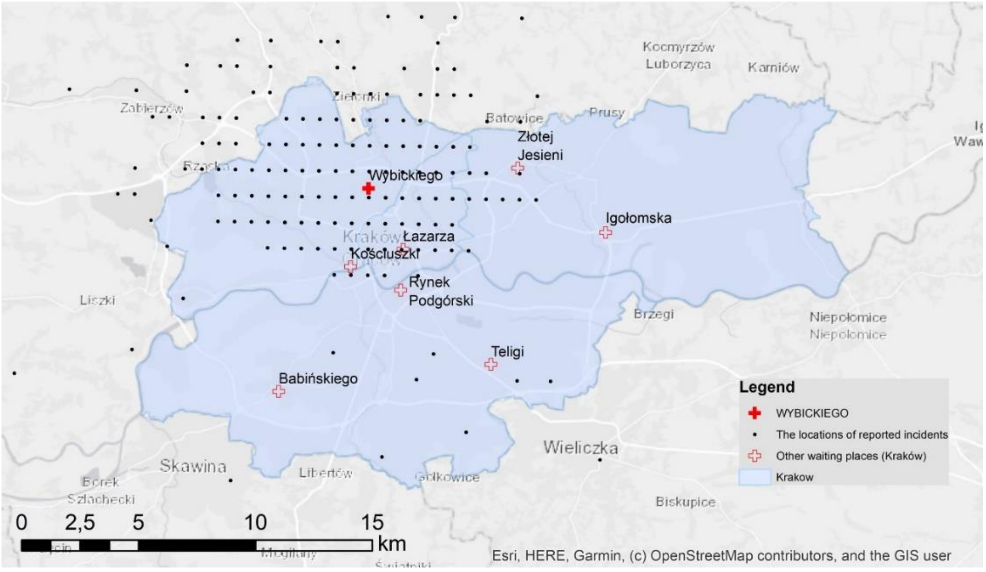

Figure 9. Departure locations for EMTs of Wybickiego in analysed period (own elaboration based on data (geoportal, 2020; KAS, 2020))

Of these, those for which the "time" attribute exceeded 30 minutes were selected to check their locations (Figure 10). Analysing the illustration created, it was noted that most of the locations are not so far away that this could cause an increase in commuting time. It is likely that current traffic conditions or the availability of the Emergency Medical Team contributed to this phenomenon. However, individual cases are very distant departure routes. It is important to consider whether the dispatcher's decision was correct and whether a closer available team would have reached the scene faster.

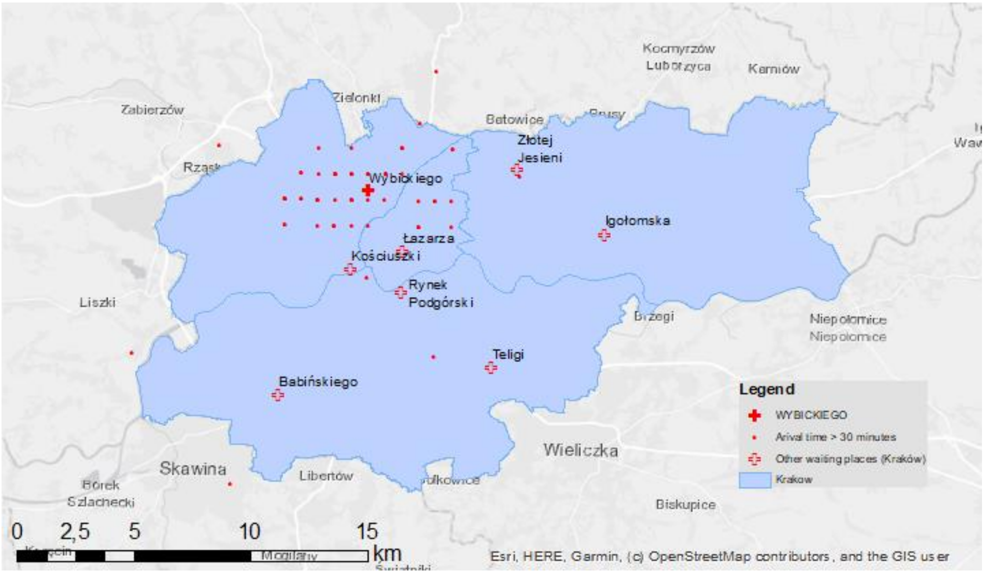

Figure 10. Locations of Wybickiego EMT departures stationed at with a time to reach the destination of the incident longer than 30 minutes (own elaboration based on data (geoportal, 2020; KAS, 2020))

In the case of emergencies that threaten people's health and lives, such a time is already a long wait for the arrival of an ambulance. It was also noted for incidents where the described attribute exceeded even 1 hour. Summarizing the analysis of cases for this waiting station, it was noted that often the time of arrival at the scene is prolonged. With such a large number of calls handled by the Wybickiego Street station, the thought arises that the number of EMTs at this location should be increased from two to three.

Special attention should also be paid to the station location with the least number of assigned calls, namely Igołomska Street (Figure 11). Based on previous analyses, it was considered that reducing the numbers of EMTs at this location in favour of another could be an appropriate solution. However, knowledge of commute times, which are crucial to the overall study, was not yet available at that stage. After selecting the events for which the "time" attribute exceeds 30 minutes by analogy, it turns out that there are almost twice as many such cases as at the Wybickiego Street location. Igołomska Street is considerably distant from the strict centre of Krakow and handles a very large number of incidents on the outskirts of the City or outside its borders. This certainly results in less traffic, but it should be remembered that the road infrastructure may be worse than that in the centre. As a result, after analysing the cases, it was deduced that the number of EMTs in this location is adequate for the volume of calls.

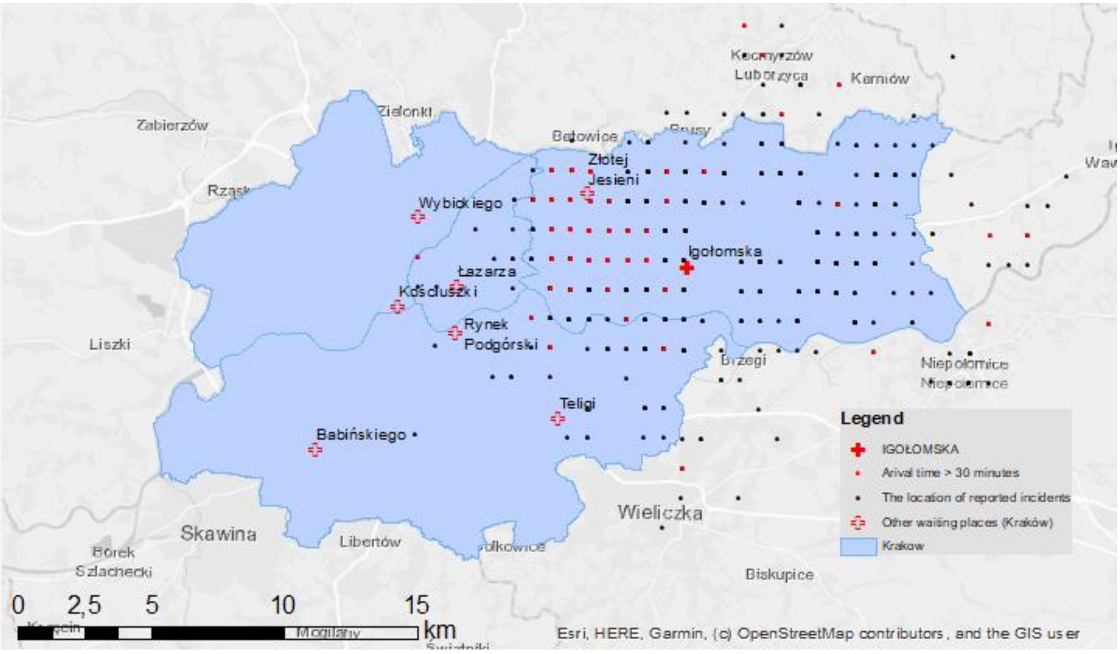

Figure 11. Locations of Igołomska EMT departures located with a time to reach the destination of the incident longer than 30 minutes (own elaboration based on data (geoportal, 2020; KAS, 2020))

Subsequent analysis focused on incidents distributed to teams stationed at Lazarus Street. This is the waiting area that has the largest number of EMTs, there are as many as Figure 8. However, on an annual basis, the number of incidents handled is the largest and up to four times greater than that of other facilities in Krakow. As can be seen from the analysis (Figure 12), the trips distributed for the teams stationed at this are in most of the area of Krakow, as well as outside its borders. However, this distance is not, interestingly enough, a determining factor in the length of the commute time, because both events in the immediate vicinity and those outside the borders of the city have a time attribute exceeding 30 minutes. Inferring from the above discussion, it is the number and intensity of calls that can largely determine the arrival time at the scene.

Data for events outside the Krakow are collected in the same way as for the city areas. All spatial analysis would be a repetition of analogous procedures to those already

used. Therefore, it would not bring additional insights into the use of GIS tools in emergency medical services. Due to the above arguments, it was decided that spatial analyses would not be performed for data from waiting areas located outside the city of Krakow. In addition, it should be mentioned once again that the data for these areas are much more diverse, as they include medium-sized cities such as Wieliczka and Olkusz, as well as small towns including villages. Therefore, comparing the data left with each other would give a distorted view of the situation.

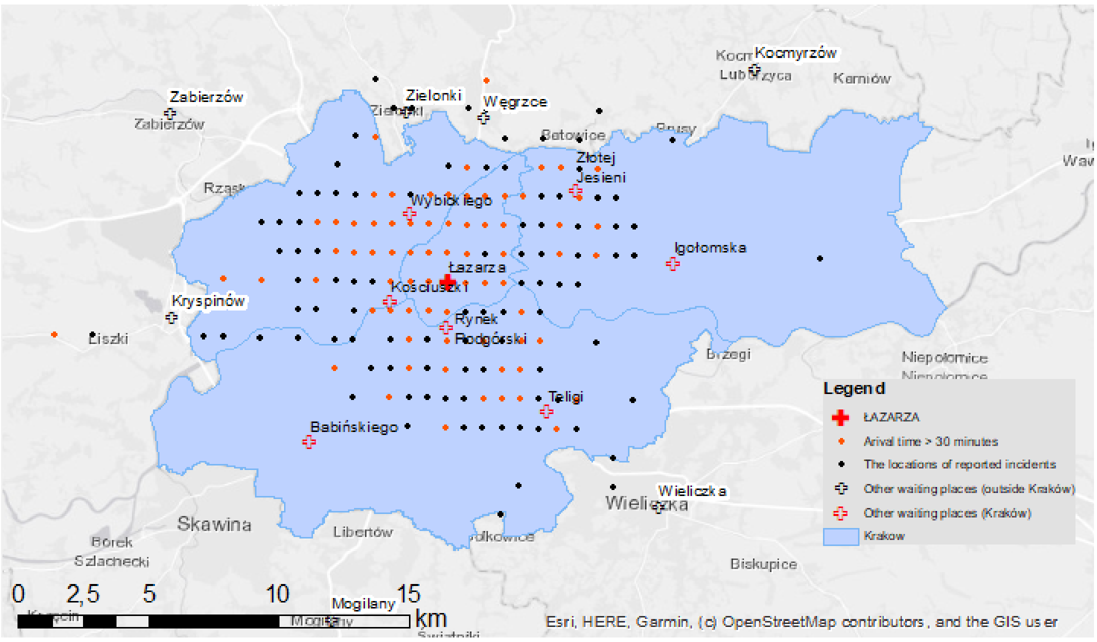

Figure 12. Locations of Łazarza EMT departures stationed at with a time to reach the destination of the incident longer than 30 minutes (own elaboration based on data (geoportal, 2020; KAS, 2020))

4.3. Heat maps

Analytical methods used in emergency management include spatial statistical tools. They are used to analyse the distribution of values associated with geographic objects and compare them with a hypothetical random spatial distribution. They can be used to answer questions such as: Where are the areas with the highest rates of ambulance incidents? What is the most optimal location for a new ambulance station? To answer the questions posed, a procedure was carried out leading to the creation of a heat map for the phenomenon under study. ArcMap software tools were used. For the analysis, the WGS 1984 mapping system was used, allowing the preservation of the most accurate distance data, which was crucial in this case. The input data are pre-selected records for EMTs stationed in Krakow which are more than 38,000. Therefore, in the first step, the so-called data aggregation was performed. Using the "Integrate" tool, the data was grouped, so that points coinciding or lying in proximity to each other were treated as the same location. Thus, events located at the same locations, whose coordinates were disturbed by inaccuracy due to GPS tools, were counted. A distance of 10 meters was used, which is a reasonable size for determining the basic inaccuracy of GPS tools.

Then, using the "Collect Events" tool, adjacent events were collected so that they formed groups with their counts. The last step is to perform HOT Spot analysis using "Hot spot Analysis tool". For the hotspot analysis, the concept of spatial relationship was used as "Fixed_Distance_Band". This resulted in consistency of the surveyed distances over the entire area. As a result, a heat map was obtained showing the events for the studied period from April to December 2019 (Attachment 2). What stands out on the completed map is the fact that both events and stationing locations are concentrated around the inner city. Both the north-western and southern parts of Krakow have an extremely high number of incidents, and there is no localized stationing for ambulance services there. They are admittedly located in close proximity outside the city limits. It should be noted, however, that the map presented does not depict incidents handled by EMTs from outside the City of Krakow. This allows us to conclude that there is a real demand for the location of waiting stations in the mentioned locations.

However, it is worth examining what the distribution in the data and the discrepancy in the frequency of events over the course of the 2019 year under study is due to. For this purpose, heat maps were made for each month separately. The variability was presented in the form of an animation (Appendix 1). The data presented was also analysed in detail using a map background. In this way, an attempt was made to find correlations between the occurrence of events and location. The trend of the data, however, does not vary enough to make such conclusions valid. Over the entire study period, it is discernible that the highest number of incidents is concentrated in the inner city. In the rest of the area, on the other hand, the variation in the number of incidents was considered random. It was also decided to check whether the highest frequency of trips from stationing locations, is in the immediate vicinity of these locations. For this purpose, heat maps were made, for each station separately. The data presented on the map is for the entire study period. Another use of heat maps is to create them for individual stationing locations. With this, it was checked whether the most frequent departure locations were in the immediate vicinity. It was observed that only in two locations - on Złotej Jesieni and Wybickiego Streets - the assumption made holds true. For the remaining stationing points, the highest frequency of departures is in the intermediate regions between stations. Based on the analysis of the above heat maps, a considerable demand was again noticed in the north-western and southern parts of Krakow, where there is no located ambulance waiting station (Figure *13*).

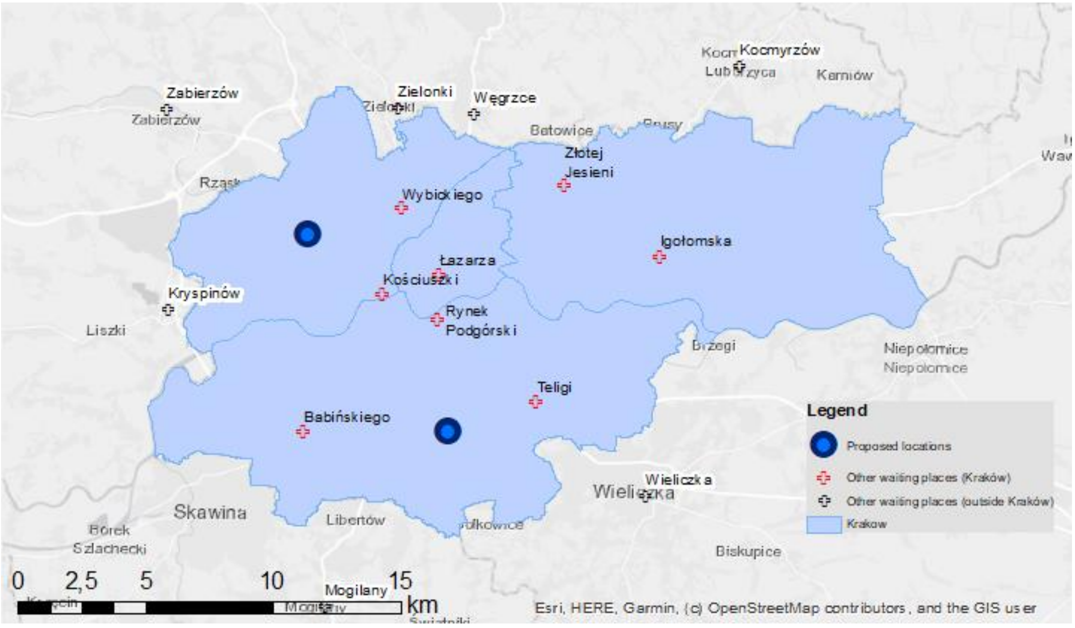

Figure 13. Locations of proposed new EMT locations (own elaboration based on data (geoportal, 2020; KAS, 2020))

When analysing the various map summaries, special attention was paid to the locations of sites with the highest frequency of incidents. It is important whether the locations of the station sites correspond to the needs of incidents. In the case of two stations: Złotej Jesieni and Rybicki, the locations of outbreaks served are in the immediate vicinity. For the others, however, the situation is different. For both the incidents handled by the Lazarus Street and Kosciuszko Street teams, the highest frequency of incidents is assigned to the strict city canter. This is related to the high volume of traffic and density of people. Both stations are in the vicinity of the canter for this reason it falls to them to handle these incidents. Analysing the maps for Igołomska and Babińskiego Streets, it was observed that the most frequent trips are to locations far away from the station locations. Both waiting areas are located on the outskirts of the City of Krakow, and therefore mainly serve places intermediate between the centre and peripheral parts of the city.

4.4. Network analysis

Network analysis tools were used to test the effectiveness in reaching a destination within specified time norms. With the help of data obtained from Open Street Map, an SHP layer representing roads in Lesser Poland was acquired. Since the area of detailed research was limited to Krakow, only those containing within the city limits were selected. The key attribute needed for the analyses turned out to be the speed and length of the relevant road sections. The former was extracted directly from the data in the form of "maxspeed" values, while the lengths of the sections were generated automatically by ArcMap software, during the creation of the network data set. This made it possible to obtain the most crucial factor under study, namely the time required to drive the relevant route elements. Although ambulances, as emergency vehicles, are not subject to speed limits, acceptable standards were not increased. The area studied is a city, with heavy traffic, which makes the movement of such vehicles much more difficult. With the data thus crafted in advance, a network analysis procedure was carried out. The service of so-called allocation or otherwise "service area" was used. Its task is to determine places or roads distant from a given point by a given distance or travel time. As a result, polygons defining a given time were obtained. As mentioned earlier, the maximum travel time to a site cannot exceed 15 minutes in a city of more than 10,000 people. Therefore, the thresholds set for the created polygons are 5, 10 and 15 minutes, respectively. To present the results, one of the ambulance station locations - at 2 Podgórski Market Street - was chosen (Figure 14). Presenting all of them on one map composition would be unreadable, while creating separate ones for each of them is analogous repetition of the same steps.

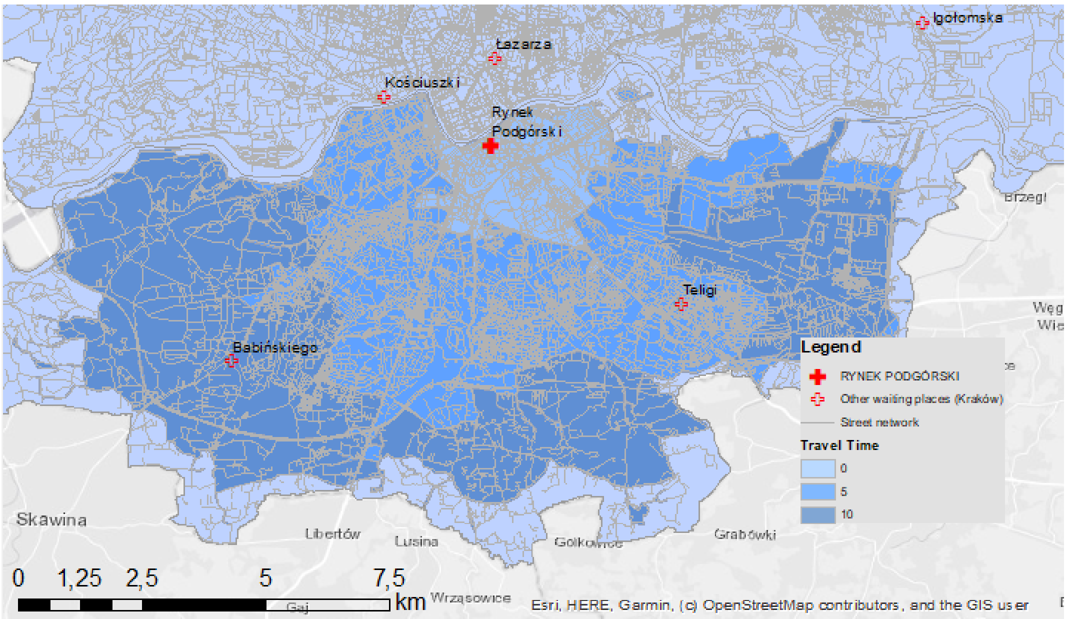

Figure 14. Polygons representing arrival times obtained from network analyses (own elaboration based on data (geoportal, 2020; KAS, 2020))

In the next step, it was decided to compare the theoretical travel times to the present locations obtained from network analyses, with practical ones obtained directly from data on ambulance departures from the waiting area under study. For this purpose, the data was extracted as a punch layer, so that only trips starting from the Podgórze Market remained. They were then divided into 4 groups so that:

- The travel time to the scene did not exceed 5 minutes (Figure 15),
- The travel time to the scene did not exceed 10 minutes (Figure 16),
- The time to reach the scene of the incident did not exceed 15 minutes (Figure 17),
- The time to reach the scene of the incident was more than 15 minutes (Figure 18).

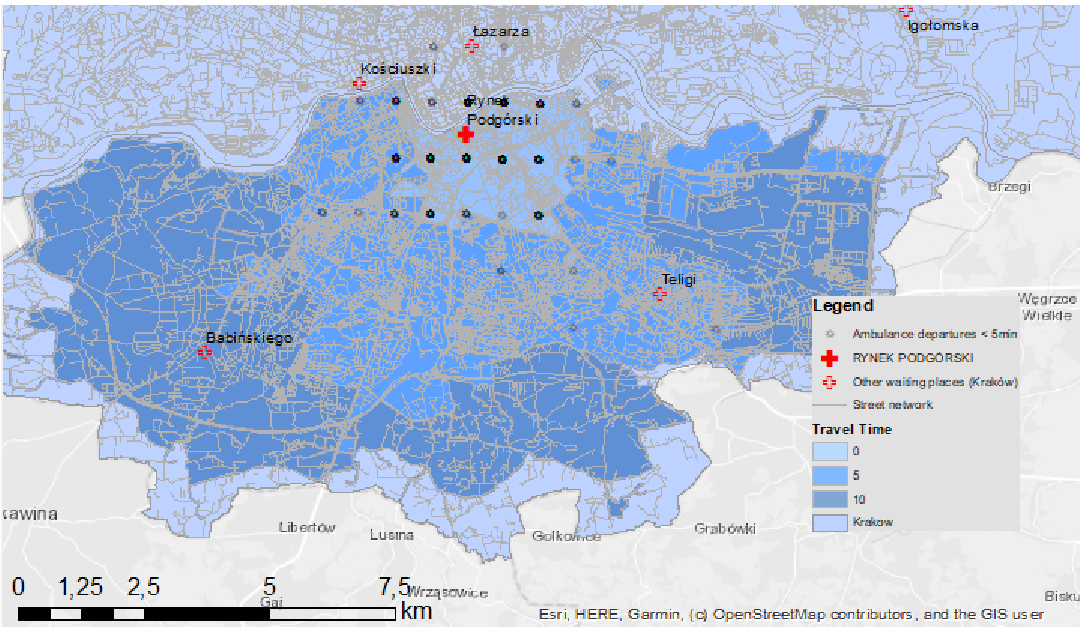

Figure 15. Comparison of real ambulance travel distance in 5 minutes with the theoretical one obtained from network analyses (own elaboration based on data (geoportal, 2020; KAS, 2020))

In the first case considered, it was noted that despite the impediments of traffic congestion, ambulances often arrive further in the assumed time than assumed from theoretical values.

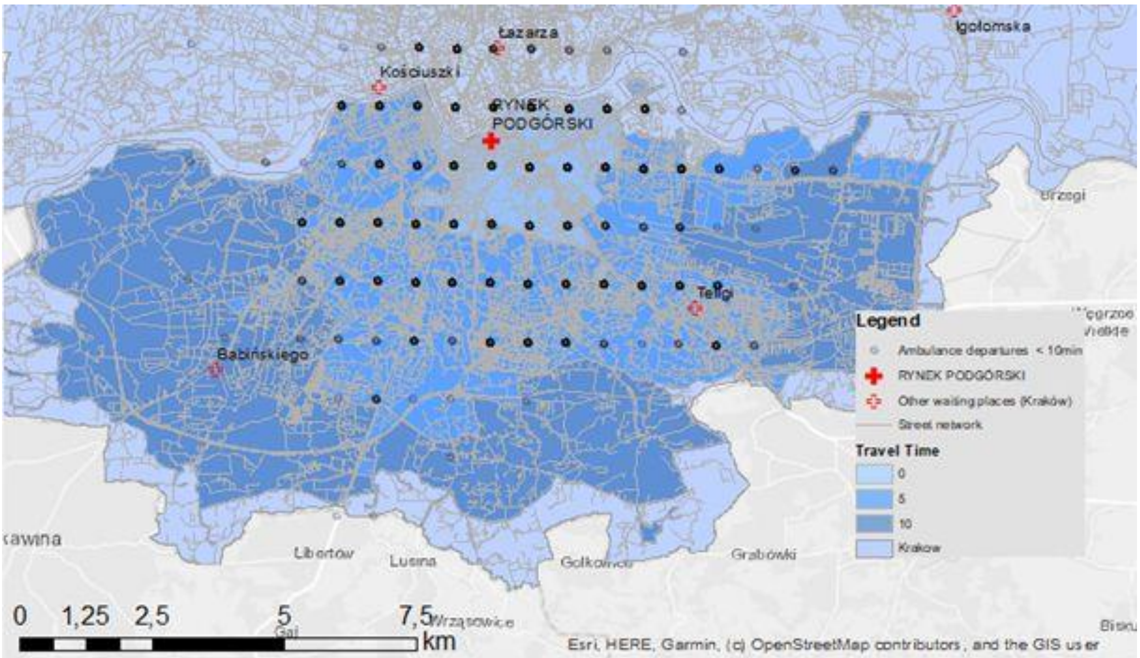

Figure 16. Comparison of real ambulance travel distance in 10 minutes with the theoretical one obtained from network analyses (own elaboration based on data (geoportal, 2020; KAS, 2020))

On the other hand, in the second situation considered, where the assumed arrival time is 10 minutes, most trips are contained within a specific training ground. Few of them are able to reach farther areas in such a time. Unfortunately, cases were also observed where the real time exceeded the theoretical time and despite the short distance, it took longer than expected to arrive.

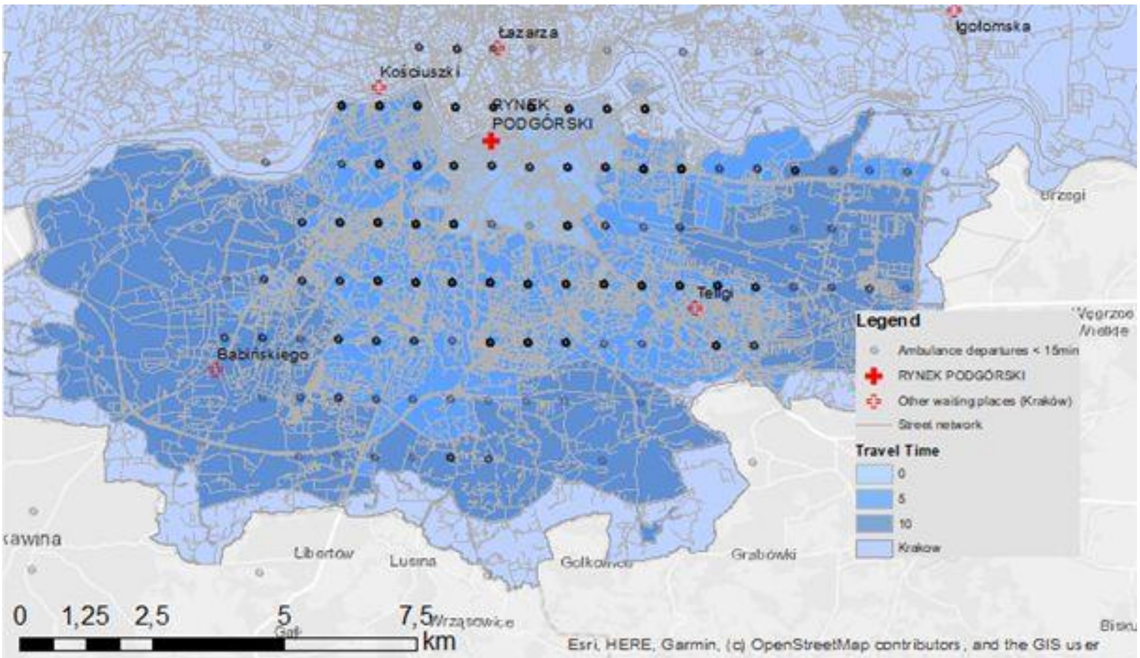

Figure 17. Comparison of real ambulance travel distance in 15 minutes with the theoretical one obtained from network analyses (own elaboration based on data (geoportal, 2020; KAS, 2020))

Another case is the assumed arrival time of no more than 15 minutes. It was observed that it was the trips to closer routes that took this length of time. However, there have also been incidents where ambulances have arrived farther than the assumed time.

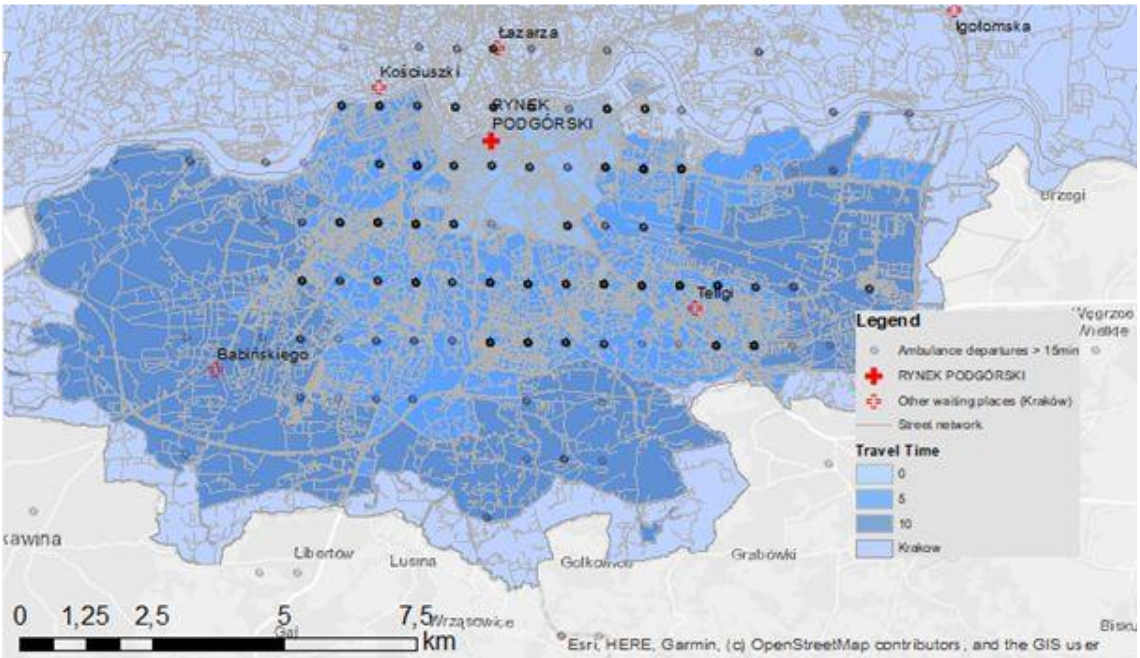

Figure 18. Comparison of real ambulance travel distance exceeding 15 minutes with the theoretical one obtained from network analyses (own elaboration based on data (geoportal, 2020; KAS, 2020))

The last case is situations that exceed the maximum allowable travel time to the scene of an incident, which is 15 minutes. The reasons that make up its extension are many, they can be traffic congestion, road repairs, weather conditions, or other random events.

4.5. Medical emergency impact

Achieving each sustainable development goal cannot be held entirely in isolation. Moreover, according to the definition of the UN, sustainability is "meeting the needs of the present without compromising the ability of future generations to meet their own needs." This statement means that if the development improves one object but at the same time deteriorates another, it is not sustainable (UN, 2023b). Therefore, reforms and innovations related to achieving the SDGs should be comprehensive and involve various subjects and spheres of activity simultaneously.

The recent global pandemic of the coronavirus, as well as the beginning of military conflicts in several countries (Ukraine, Niger, Israel) contributes to increased attention to the achievement of SDG 4 "Good health and well-being."

In Poland, colossal attention is paid to achieving the Sustainable Development Goals. The state regularly monitors the implementation of the SDGs; in 2023, a new voluntary national review was held. The Ministry of Economic Development and Technology is the lead government unit for implementing the 2030 Agenda at the national level in Poland. However, this unit joins affairs with other ministries according to the task. The primary ministry in the implementation of SDG 4 is the Ministry of Health. Coordinating Ministries are the Ministry of Climate and Environment, the Ministry of Family and Social Policy, the Ministry of Sport and Tourism, and others when needed (National Report 2023, 2023).

One of the critical factors for the success of health care lies in the timely, highly qualified, and relevant provision of first aid. The life, health, and further working capacity of the patients depend on the time they take the necessary medicine and perform medical procedures.

Improving medical services primarily affects the achievement of SDG 4; however, all goals are interrelated and influence each other's achievement. Therefore, specific actions or inaction in one field impact the result in another - only the degree of this impact can be different.

To study the relationship between progress in the provision of emergency medical care and various components of Sustainable Development Goals, we rank the degree of impact according to 4 categories:

(1) Strong direct impact.
(2) Slight direct impact.
(3) Strong indirect impact.
(4) Slight indirect impact.

In addition, it will also be essential to determine the direction of the relationship:

(1) Back – if medical emergency service affects SDG.
(2) Forward – if SDG impacts medical emergency service.
(3) Two-way connection – if medical emergency service impacts SDG and SDG impacts medical emergency service.

During the research, we start with sustainable practices (those that cannot worsen the situation). However, such an analysis will be one-sided, only considering the possibility of improvement by the studied objects. Therefore, we will also consider reducing or avoiding potentially harmful trends or phenomena in achieving the SDGs. The data in Appendix 2 is based on the SGDs' targets and indicators list and collected in 22 blocks, which are given in Figure 19.

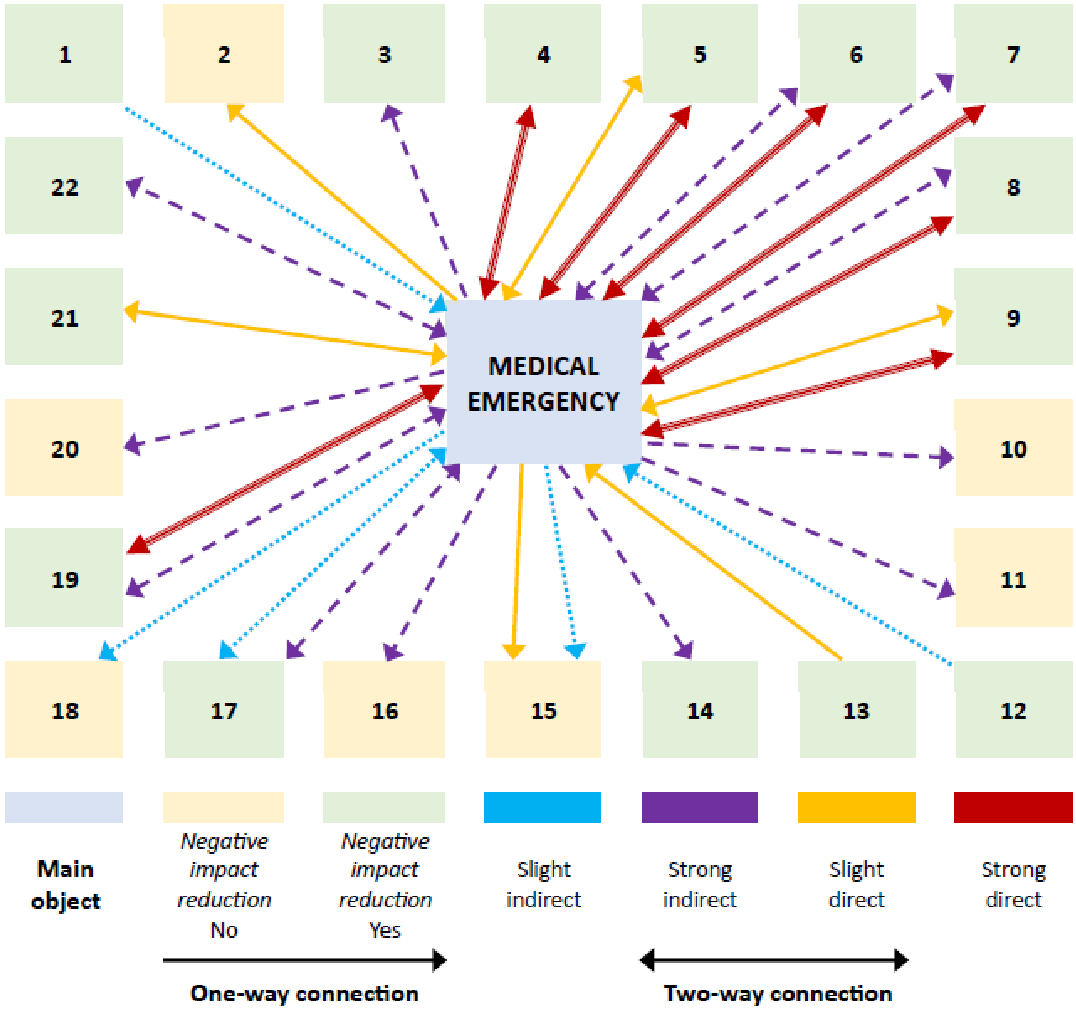

Figure 19. Medical emergency direct and indirect impacts on SDG and vice versa (UN, 2023a)

The application of GIS technologies allows to build an effective system of locating ambulance stations, hospitals and to determine the travel routes of the ambulance for the maximum coverage of the entire population of Krakow with high-quality and timely medical services. In this context, the crucial element will be the speed of arrival of an ambulance to the patient or to the hospital. The primary consequence of increasing the speed of this task is preserving human life and health, increasing the chances of successful recovery and maintaining a sufficient quality of life after. However, the speed of the ambulances also has other, not so obvious effects:

(1) If the emergency car runs on fossil fuel, then saving travel time and distance saves exhaustive resources.
(2) When running on fossil fuel, such a car emits harmful substances into the atmosphere, which contributes to environmental pollution and increases the greenhouse effect.
(3) The passage of an ambulance creates noise - both because of the movement of the car itself and in connection with the siren activation. Therefore, reducing the travel time minimizes the noise level in the city.
(4) Other modes of transport must prioritize movement to an ambulance. The longer the ambulance goes, the greater the chances of traffic jams, changes in the plans of other drivers, delays, and nervous tension during traffic.
(5) If the ambulance cannot get to the destination for a long time, it can lower the effectiveness of measures to save the patient's life and health since the ambulance does not replace the completeness of the medical facility. During a long journey, it may need more equipment, highly specialized medics, sufficient medical supplies, or room for medical interventions. Accordingly, the inability to provide adequate assistance to the patient in time can contribute to the development of hopelessness, apathy, and depressive states among medical personnel.
(6) In the case of an infectious disease, rapid isolation and transportation of the patient to a medical institution lowers the probability of infection of medical personnel, other people and the spread of the virus.
(7) The ability to quickly and competently provide first aid to patients increases the attractiveness of medical education and employment in the first medical aid system.
(8) Well-laid routes and a shorter distance to the target reduce the likelihood of a traffic accident involving an ambulance with all the possible negative consequences of such an event.

Relevant transport infrastructure high-quality road surface, cleared of snow or other precipitation, decreases the time of the medical emergency journey and the probability of traffic jams. The maximally equidistant distance to ambulance stations and medical facilities improves equality for all people without discrimination.

5. Discussion

To draw objective conclusions summarizing the entire course of the study, it is necessary to trace the most important insights from each stage. The work began with meticulous preparation of the data. Analysis of their structure and elimination of outliers ensured the exclusion of so-called information noise. The most important feature of the data, allowing effective analysis, is its uniformity in terms of structure. In the case of spatial data, this is constituted by attributes, both geometric and descriptive. Before embarking on key research using spatial information system tools, the data was analysed from a statistical perspective. Illustrating numerical values in the form of graphs and tables allows for convenient and clear analysis. Over the entire study period, i.e., from April to December 2019, there were no sharp increases in the number of trips in each month. This allows us to conclude that the season has a negligible impact on the number of incidents. It is likely that over the course of the year the causes of incidents requiring ambulance intervention change, but nevertheless their number remains stable. The study area is the territory governed by the Krakow Ambulance Service. Based on the data obtained, it is clear that throughout the year about 60% of the incidents are handled by Medical Rescue Teams stationed in Krakow. The number of incidents attributed to each ambulance stationing location was juxtaposed. On this basis, it was decided to divide the conducted analysis by location. The City of Krakow was separated from the other localities, due to the significant discrepancy in the data. Treating them uniformly would have distorted the results obtained. As a result, two locations in the City of Krakow were singled out, for which the number of handled incidents per number of teams reached minimum and maximum values. It was decided to study their situation in detail in later spatial analyses. The remaining localities showed exceptionally large disproportions. This is due to their size, population, as well as the existing infrastructure and road network. Therefore, it was decided to focus only on cases from the City of Krakow in the spatial analyses.

It was also decided to study the impact of road obstructions during peak traffic hours on the time it takes emergency services to reach incidents. Two ranges were adopted for this purpose, from 7:00 a.m. to 9:00 a.m. and from 3:00 p.m. to 6:00 p.m. The result was the conclusion that during the morning hours the impact is negligible. In the afternoon, on the other hand, the percentage of incidents with exceeded maximum arrival time is already significant enough to be considered a real cause of increased arrival time at the scene.

According to legal assumptions, the maximum arrival time at the scene of an incident for cities with more than 10,000 residents should not exceed 15 minutes. Reviewing the data, it was clear that the reality differs significantly from the theoretical assumptions. Therefore, in the first of the analyses, a time of 30 minutes was assumed as the threshold. By presenting the locations of the incidents in the form of map compositions, it was observed that distance does not always contribute to increased travel time. In the case of the stationing point at Wybickiego Street, the greatest impact was due to the high volume of calls handled falling on only two Emergency Medical Teams. Looking next at the location with the smallest ratio converting the number of calls to the number of EMTs (Igołomska Street), the final conclusion was that reducing the number of stationed ambulances would not be an adequate move for the situation. Due to the dispersion of handled incidents over a large area, the problem of exceeding the acceptable time standard is also a major concern. This demonstrates the belief that the locations of waiting areas are optimally suited to the prevailing conditions and incidents occurring. However, the number of available Medical Rescue Teams is insufficient, which is also confirmed by the case of the most numerous waiting point on Lazarus Street.

Thanks to the use of heat mapping methodology, the areas with the highest intensity of incidents were illustrated in an obvious way. Undoubtedly, this is the area surrounding the inner city. This is juxtaposed with the locations of ambulance waiting areas. Therefore, these places are served by ambulances from the city centre or from neighbouring towns. This significantly increases the travel time. It would be appropriate, therefore, to think about whether locating new stationing points there would not bring the desired results.

The next test of the efficiency of the services in a given time is the network analysis carried out. It was decided to confront real data on arrival times with theoretical values, created on the basis of information about the road network of the City of Krakow. It was observed that a significant part of the teams arrives at the incident in the time allowed by road infrastructure conditions. This is about 49% of all trips in the surveyed location. This is not a fully satisfactory result. It would therefore be necessary to introduce a system for investigating the reasons for the increase in response times to calls. If this is solely the result of unfavourable road conditions and traffic volume, it will be extremely difficult to make improvements. However, it may turn out that the problem is too few available Emergency Medical Teams in a given location. This would confirm earlier suggestions about the need to increase the number of available ambulances.

6. Conclusions

Summarizing the research conducted and the discussion of the results, the thesis of the optimal location of existing waiting areas for Emergency Medical Rescue Teams in the City of Krakow was confirmed. However, a suggestion was made to locate two new stations in areas where such demand has been demonstrated. Currently, this area is served by neighbouring waiting points or ambulances commuting from outside the City of Krakow. We are talking about the north-western and southern parts of the city. This is a proposal based solely on spatial analysis. However, further studies and a series of demanding procedures would be needed to make a final decision on such a measure, allowing for the creation of additional waiting points in Krakow. This is a serious and long-term undertaking, so other solutions have been tried to help improve the operation of already existing stations. One of them is to answer the question of whether the number of dispatchable Emergency Medical Teams is sufficient in relation to the number of incidents handled. During the analysis, it was clearly shown that the time to reach an incident is often much longer than acceptable, which significantly reduces the efficiency of the services. Therefore, it was proposed to introduce monitoring of the reasons for increased arrival times. An additional field could be introduced to the form filled out by emergency medical services during each trip, which would signal the reason for the exceeded time standard. Optionally, these could be problems with road infrastructure, traffic congestion or the volume of calls per waiting point. In the event that a significant percentage will be too many calls per the number of available ambulances, an adequate solution would be to increase the number of working teams at specific locations. This is a much less complicated measure than the creation of new waiting areas, as it does not require such a large financial outlay and complicated procedures related to meeting spatial and infrastructure requirements.

The most principal issue addressed in the study was to examine the use of GIS tools in emergency medical services. A number of analyses and activities were carried out on the basis of data obtained from the Krakow Ambulance Service, using a wide range of ArcGIS software tools and the ArcGIS Online platform. The creation of various map compositions, heat maps, animations and virtual presentations enabled efficient and clear presentation of the data. As a result, it allowed conclusions to be drawn and objective assessments to be made. Geo-information products created with GIS tools allow easy exchange of observation results between the GIS specialists creating them and decision-makers responsible for the operation of Emergency Medical Services. The collected results prove the indispensable use of GIS tools by the bodies responsible for modifying and improving the structure of the Emergency Medical Service. Increasing the effectiveness of the medical service functioning, in turn, will make it possible to approach the achievement of SDGs' targets and indicators directly or indirectly.

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Appendix 1

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Appendix 2

Table 6. Connections between SDGs' targets and medical emergency

№	Target	Impact				Con-nection	Negative impact reduction
		Strong direct	Slight direct	Strong indirect	Slight indirect		
1.	1.4, 11.1, 17.1, 17.3	-	-	-	Emergency help is available to everyone	Back	Yes
2.	1.5, 6.1, 6.3, 6.4, 10.7, 11.6, 12.4, 13.1, 16.1,	-	Better state - less burden on the ambulance	-	-	Forward	No
3.	1.a, 4.7, 8.2, 12.2	-	-	Better state – better care, modern ambulances, with less noise and emissions.	-	Forward	Yes
4.	3.1, 3.2, 3.6	Faster medical emergency - more chances to save life and health	-	-	-	Two-way	Yes
5.	3.3, 14.1,	Faster medical emergency – less diseases	The sooner an infected patient is hospitalized, the less likely infects others	-	-	Two-way	Yes
6.	3.4, 3.5, 11.7	Faster medical emergency - more chances to save life and health	-	More efficient medical emergency – better comfort and mental health of the staff	-	Two-way	Yes
7.	3.8, 3.b, 17.14, 17.18	More efficient medical emergency - more chances to save life and health	-	Emergency help is available to everyone	-	Two-way	Yes
8.	3.9, 9.5, 9.b, 9.c	Faster medical emergency - more chances to save life and health	-	Better state – better care, modern ambulances, with less noise and emissions.	-	Two-way	Yes
9.	3.c, 3.d,	Better development and capacity of medicine – more efficient help	More efficient medical emergency – better comfort and mental health of the staff	-	-	Two-way	Yes
10.	4.4	-	-	Higher professionalism of staff – better work	-	Forward	No
11.	4.6, 16.10	-	-	Better education, understanding of one's rights and actions	-	Forward	No

№	Target	Impact				Con-nection	Negative impact reduction
		Strong direct	Slight direct	Strong indirect	Slight indirect		
12.	5.1, 5.b	-	-	-	Possibility to get medical help and protect the health	Back	Yes
13	7.1, 7.3, 8.4, 12.c, 13.2	-	Better state – less noise, footprint emissions	-	-	Back	Yes
14.	8.8	-	-	Increased safety in the ambulance – less risk of accidents	-	Forward	Yes
15.	9.1, 11.a	-	Transport junctions, the possibility of access from the suburbs, the distance from remote areas to medical care	-	Emergency help is available to everyone	Forward	No
16.	10.1	-	-	Financial interest in working in the ambulance obtaining a medical education	-	Forward	No
17.	11.2, 17.7	-	-	Better state - less burden on the ambulance	Emergency help is available to everyone	Two-way	Yes
18.	11.3	-	-	-	Protection of the rights of medical workers and patients by a developed civil society	Forward	No
19.	11.5	Increased safety in the ambulance – less risk of accidents	-	Better state - less burden on the ambulance	-	Two-way	Yes
20.	12.6	-	-	Increased interest authorities in better efficiency of medical services, quality of roads and infrastructure facilities	-	Forward	No
21.	12.7, 16.8, 17.16	-	Possibility of sharing experience	-	-	Two-way	Yes
22.	12.8, 15.1, 15.3, 16.7	-	-	Sustainable development will contribute to better public health	-	Two-way	Yes