EVACUATION TRANSPORT PROVISION DESIGN USING NETWORK ANALYSIS WITH GIS SUPPORT

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Resume

The research presented in paper has focused on design of the transportation evacuation during a special flood caused by an accident at a water structure using GIS-enabled network analysis. Freely available population and address point data were used to calculate the number of residents at risk. Three scenarios of time required for each evacuation activity were determined using the PERT method, and the time required for evacuation was determined using a Gantt chart. The approach proposed in the paper is suitable for obtaining relatively quick results that can be taken into account when preparing for crisis events. The results of the case study proved that the evacuation can be carried out in the necessary time, but revealed possible shortcomings of the proposed approach. These shortcomings are discussed along with possible alternative solutions and other factors influencing the evacuation planning process.

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1 Introduction

Nowadays, the increasing occurrence of crisis phenomena and disasters draws attention to the preparedness of individual government bodies, institutions, municipalities and individuals. Preparedness is generally considered to be a key aspect in the successful management of crisis events. Neglecting preparation and preparedness can lead to serious adverse consequences. That is why planning and development of crisis plans is carried out as one of the elements of preparation for crisis phenomena [1]. Crisis planning, as one of the main factors of ensuring preparedness, is also described by other authors [2-5]. Planning as a part of preparedness is also described in the Sendai Framework Terminology on Disaster Risk Reduction. Preparedness generally refers to the knowledge and capacity to respond and recover. Examples include the provision of evacuation of supplies and materials for the population [6].

The importance of preparedness in crisis management has already been addressed by Healy and Malhorta (2009). In their work, they stated that increased investment in preparedness can reduce the damage caused by a crisis event. The authors estimated that one dollar invested in preparedness can be worth $15 in the recovery phase [7]. A more recent study by Chai et al. (2021) reports that one dollar invested in mitigation and preparedness saves $6 in damage repair after a crisis event [8].

Planning for response or recovery after the occurrence of a crisis event is an effective tool to ensure the crisis management preparedness [2]. It is a strategic element for the implementation of civil protection tasks. An emergency or crisis plan should be a structured document that includes a risk analysis of the territory, prepared procedures and defined competences of individual bodies. A crisis plan should be a living document that is clear and ready whenever a crisis response is needed. The development of a crisis plan is a multidisciplinary process. This means that different professions and experts need to be brought together in the development of the crisis plan, while also ensuring that it is regularly updated. The use of information technology is recommended in the development of crisis plans, as it allows for more efficient coordination of the whole process and reduces the need for hierarchy [3].

Evacuation plans and its comprehensive provision are an important component in crisis planning and preparedness [9]. Evacuation can generally be defined as the removal of endangered populations, animals and belongings from an area [10]. According to the team of authors, evacuation can be defined as a basic means of protecting the population. It is a set of measures ensuring the relocation of people, animals, objects of cultural value, technical equipment, or machinery and material for the purpose of preserving necessary production and hazardous substances from places threatened by a crisis phenomenon to places that provide alternative accommodation and catering for the evacuated population, housing for animals and storage for belongings [11].

For the needs of effective evacuation, it is necessary to take into account in the crisis plans its transport, medical, order, supply and media provision [12-13]. The protection of residents, animals and belongings depends on the individual parts. The information of the population and the transport provision of the evacuation can be considered as a key role in this process.

The transport arrangements for evacuation consist mainly of the designation of transport proto-classes, evacuation assembly points and embarkation stations. Data plays an important role in the evacuation planning process. Data on the number of evacuees, locations of evacuation facilities and their availability for evacuees, capacities of means of transport, vulnerable populations are needed for reliable evacuation arrangements. Finally, data on evacuation routes, their length and load. Therefore, before the actual planning of the evacuation, attention should be paid to data collection and storage. A suitable solution is to implement policies, strategies and technological solutions at all levels of government and local government, as data are crucial in all the phases of crisis management as well as in decision support [12-15]. The data itself can also be applied in risk or vulnerability assessment models, where the results of the assessment can provide useful information just for decision making purposes in the evacuation route planning process [16].

Modern technologies can also be used in the actual creation of evacuation plans and their graphic parts, which are often a mandatory part [11-13, 17]. Examples of the use of modern technologies can be various sensors and weather stations that collect data in real time. These data are then fed into the risk assessment or forecasting models [18]. Geo-graphical Information Systems (GIS) are of great benefit for evacuation planning purposes. The GIS can be used in all the phases of crisis management [19]. The use of GIS in flood risk mapping with respect to the road network in Portugal, has been addressed by Rezvani et al. [17]. The authors used spatial and attribute geographic and geological data to develop a flood risk assessment model for road infrastructure. Using artificial intelligence, machine learning and GIS tools, they identified critical sections of the road network [17]. The use of GIS for decision support has been addressed by several authors. An example is also their use in the development of simulations for decision support in the planning phase [20]. Armenakis et al. have used the analytical tools of GIS programs for planning evacuation zones and evacuation routes. An example is the use of GIS in the planning and designation of evacuation facilities. By spatial analysis, it is possible to map out the location of such a facility so that it is not in the threat area of the crisis or other phenomenon under study [21]. During the September 2024 floods, there were reports of flooded evacuation centers that were not ultimately confirmed [22], or a flooded bus parking lot [23]. It is the bus transport that is often used to evacuate people.

Floods are one of the biggest threats in the world. They are also becoming more frequent due to climate change. Flash floods, caused by extreme rainfall over a short period of time, are also becoming more frequent [24]. A specific case of flash floods is the so-called special floods. An exceptional flood is caused by the failure or breakdown (breakage) of a water works. This accident or its emergency solution causes a crisis situation below the waterworks [25]. Such a flood can cause enormous damage to the property of the state and the population, and its manifestations are more dangerous than in the case of classical floods or flash floods. This is mainly due to the accumulation of large amounts of water in the reservoir, which has a higher elevation than the downstream dwellings. In the event of a breach in the water structure, the force of the flood wave would be magnified by gravity effects [26]. For the event of a special flood, the predicted reach of the flood wave and the time it takes for the wave to reach certain areas are calculated using models to ensure the safety of the population. The calculations also include water level elevations. It is this type of flood that can cause enormous damage [26-28].

There are several cases of water structure breakage and subsequent disaster caused by post-flood waves in the world. An example is the disaster caused by human error and a landslide into the Vajont dam in north-eastern Italy. This disaster caused approximately 1900 casualties and completely razed villages downstream of the Piave River [29]. Another example of the consequences of a dam breach can be found in the Czech Republic. In 1916, the dam began to leak until it broke with an opening 18 meters wide. The tidal wave killed 65 people and deprived another 370 people of all their possessions [30]. Extreme rainfall in September 2024 caused the dam's embankment to break near the Polish town of Stronie Slaskie. The torrential water destroyed the entire town. The water damaged buildings, destroyed infrastructure and utilities, with damage estimated at more than 1 billion PLN [31-32]. The above examples demonstrate the severity of special floods. Therefore, it is necessary for individual towns and municipalities in their vicinity as well as crisis management authorities to be prepared for this type of event.

The aim of this paper was to propose a procedure for planning the transport provision for evacuation of people during a special flood. To achieve the objective, network analysis method with the support of geographic information system was used. The proposed solution was applied to the conditions of the city of Opava in the Czech Republic, which is threatened by the Slezska Harta and Kruzberk reservoirs. The proposed procedure enables complex planning of the transport provision for evacuation of people with the help of GIS.

2 Materials and methods

The analysis of the flood plans identified the absence of an evacuation plan in the case of a special flood in the city of Opava. Therefore, the paper's focus was on the design of the procedure for planning the transport provision for evacuation with the support of GIS and network analysis. This process consists of identification of evacuation routes, number of inhabitants at risk, available means of transport, as well as analysis of the feasibility of evacuation in terms of time.

The PERT method was used to determine the time requirements for evacuation and individual activities. This approach was chosen since the total duration of the evacuation and the duration of its individual activities cannot be determined deterministically. The PERT method is a probabilistic extension of the CPM method. Therefore, the PERT method assumes that the time of each activity is a random variable that is represented on the interval $\langle a_{ij} | b_{ij} \rangle$, where a_{ij} is the predicted shortest possible time to perform a given activity, and conversely b_{ij} is the predicted longest possible time to perform a given activity. The actual duration of an activity would be somewhere in this interval, and therefore the PERT method further assumes that the most likely duration of m_{ij} for each activity can be determined. When preparing a project for PERT processing, three time characteristics are defined for each activity:

a_{ij} - optimistic estimation
b_{ij} - pessimistic estimation
m_{ij} - modal estimation

Activity duration is a continuous random variable.

***Table 1** Results of experimental measurements for determination of the traffic restriction times - roundabout*

Type of restriction	1. measurement (sec)	2. measurement (sec)	3. measurement (sec)
RA - Krnovska	7	12	15
RA - Benzina (Krnovska)	10	18	10
RA - Nakladni	8	16	21
RA - Globus	15	17	23
RA - Obchvat	14	18	19
Sum of measurements	54	81	88
Total sum			223
Average			14.86666667
Rounding			15

RA- roundabout

***Table 2** Results of experimental measurements for determination of the traffic restriction times - traffic light intersection*

Type of restriction	1. measurement (sec)	2. measurement (sec)	3. measurement (sec)
TL - Praskova	25	50	38
TL - Bilovecka	42	70	50
TL - Tesinska Tesco	30	42	28
TL - Olbrichova	20	15	37
TL - Hradecka	23	16	34
TL - Tyrsova	15	27	26
TL - Vychodni nadrazi	56	29	67
TL - Ratiborska	40	39	54
TL - Rolnicka	59	68	44
Sum of measurements	310	356	378
Total sum			1044
Average			38.66666667
Rounding			39

TL- traffic lights

Table 3 *Activities carried out during evacuation*

No.	Activity
1.	Receipt of information on the need to evacuate
2.	Summoning the flood committee and arriving at the venue
3.	Specification of the evacuation zone
4.	Warning of the population
5.	Closure of premises and territory
6.	Request for buses
7.	Activation of the evacuee assembly point
8.	Activation and operation of evacuation centers
9.	Organization and movement of evacuees to the assembly point
10.	Movement of evacuees to evacuation centers

For all activities, three time points were determined and used to calculate the mean and standard deviation of the duration of the activity. The time data and the individual activities within the evacuation were determined based on expert estimation of firefighters from the Fire Rescue Department of the Moravoslezsky region, who operate in the Integrated Safety Centre in the city of Ostrava [33]. To determining the actual activity durations and actual delays, the following relationships were used:

$$\mu = \frac{a_{ij} + 4m_{ij} + b_{ij}}{6} \quad (1)$$

To calculate the standard deviation, the following relation 2 shall be used:

$$\sigma = \frac{b_{ij} - a_{ij}}{6} \quad (2)$$

The values of individual times for evacuation activities were averaged based on the number of expert estimates. To determine the timing of the last two activities, it was also necessary to use experimental measurements. These were used for the purpose of determining the traffic constraints and to determine the time taken to move from the furthest point adjacent to the evacuee assembly point to the assembly point.

The experimental measurements consisted of driving around the city of Opava several times on different days and at different times. Temporal data from the experimental measurements were supplemented with information obtained on the basis of consultations with the staff of the Integrated Security Centre Ostrava, to determine the temporal data on traffic restrictions in the city in connection with the occurrence of a crisis situation. Experimental runs were conducted with emphasis on routes where the traffic constraints, such as roundabouts, traffic lights and impassable bridges, are encountered. An area constraint represents an area where the traffic situation would be slowed due to evacuation and intersection control or occurring rush hour traffic. The results of the experimental measurements are included in Tables 1 and 2.

The activities carried out as part of the transport support for evacuation are shown in Table 3.

The Microsoft Project (MS Project) project management tool was used to create network graphs and the links between activities. The MS Project also includes a tool that allows creation of the Gantt charts. The Gantt chart allows the creation of a timeline of individual activities. Using this diagram, it is possible to show the duration of the individual activities, their continuity, as well as the total duration of the process/project.

The time required for evacuation is also based on information about the individual evacuation routes. The evacuation route data are particularly necessary for the determination of the last two activities shown in Table 3. To determine the evacuation routes, a network analysis was used, which contains an overview of all the roads in the city of Opava. The Network analysis in a GIS environment is one of the analytical tools. It is used to model movement in networks, such as often times transportation infrastructure. This tool allows to calculate the shortest or longest route, analyzes accessibility and other parameters based on distance and time. Network analysis further uses spatial data and its attributes, such as speed limits, direction of travel or other constraints.

The network analysis for this study included the determination of parameters such as speed, direction and traffic restrictions. The ArcGIS geographic information system was used to create network analysis, to determine the evacuation routes and to determine the number of inhabitants at risk. Traffic constraints were assigned to individual roads using the network analyst tool in ArcGIS. The layer of roads in the city of Opava is shown in Figure 1.

Transport arrangements for evacuation also require information on available means of transport. In a controlled evacuation, mass means of transport are used to move the population at risk. The Ostrava Region Crisis Plan contained information on available buses. This information is included in Table 4.

Municipal transport company Opava and TQM -

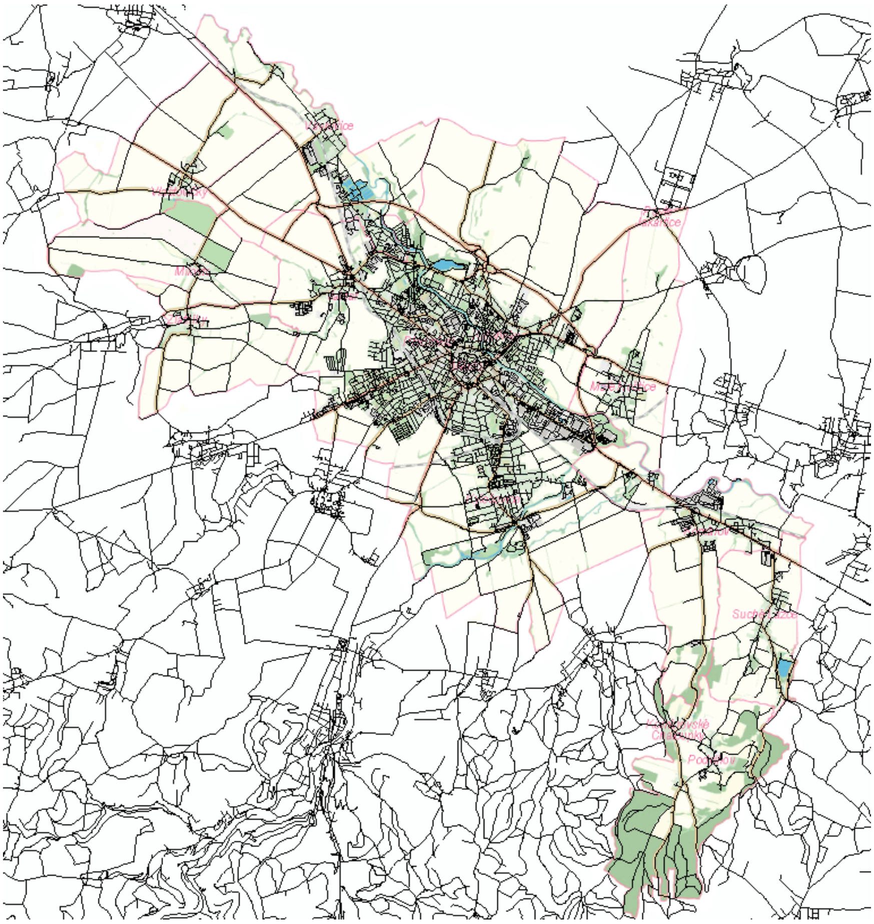

Figure 1 *Network analysis of the city of Opava*

Table 4 *Available means of public transport*

Subject	Number of buses	Max. capacity
Municipal transport company Opava	34	90
TQM - holding s.r.o.	85	90
HZS MSK	7	17

holding s.r.o. have IVECO buses, model bus Urbanway 12 m. HZS MSK would be able to provide the city of Opava with only one of its buses if necessary. However, during evacuation it is necessary to consider that the evacuees have evacuation luggage. Therefore, only 75% of the total capacity of the buses was considered in the calculations.

For planning and determining the number of inhabitants at risk it was furthermore necessary to use information on the address points of the city of Opava, information on the number of inhabitants of the city of Opava and information on the expected flooded part of the city in case of breach of water structures that threaten the city (more in section 3). The information on the number of inhabitants was obtained from the Czech Statistical Office. Information on the time, depth and extent of inundation due to a special flood was available in the crisis plan. Using the address points layer and the flood zone layer, using the Intersect function in ArcGIS, dwellings in the flood zone were identified.

The number of at-risk residents was in the crisis plan, but this information has not been updated for a long time. Therefore, the following relationship was used to calculate the population at risk:

$$Population\ at\ risk = \left(\frac{total\ number\ of\ inhabitants}{total\ number\ of\ flats}\right) * number\ of\ flats\ at\ risk \qquad (3)$$

Using the data on the total population of Opava and the total number of dwellings in Opava, the average number of inhabitants per dwelling unit is calculated. By overlaying the address points with the flood zone layer, the number of dwellings at risk is found. By multiplying these two data the approximate number of inhabitants at risk was obtained.

The number of people at risk, who would need to be evacuated by mass transit, was determined using the census data. The census data on the means of transport used for commuting to work are included, as well. Further, the average family size needed to be determined. For this purpose, data on the average number of children per woman was used. The resulting number of inhabitants, who would be subject to orderly evacuation in the city of Opava, was used for the percentage, which was then applied to the number of at-risk population subject to orderly evacuation.

The above information and procedures were applied for the purpose of planning the transport provision for evacuation in the event of a special flood in the city of Opava. The main contribution is determination of the evacuation time and its comparison to the time of arrival of the flood wave in the city of Opava.

3 Results

3.1 The city of Opava and a special flood

The town of Opava is situated on the river of the same name in a fertile valley between the Low Jeseniky Mountains and the Poopava Plain. Opava currently covers an area of 90 km^2 and has a population of less than 60 000 inhabitants. The central area of the town is not divided into urban districts and is administered by the municipal authority. It consists of:

- registration part Predmesti
- registration part Katerinky
- registration part Kylesovice
- registration part Jaktar, [34].

The breakdown of the city of Opava is shown in the following Figure 2.

The town of Opava is threatened by a special flood in the event of a breach in the embankment of two water reservoirs. These are the Slezska Harta reservoir and the Kruzberk reservoir. These two reservoirs are interconnected by a cascade system. The regional crisis plan identifies the area of the Statutory City of Opava that would be at risk in the event of a special flood. This area is shown in Figure 3.

Figure 3 shows the flooded part of the town of Opava in the event of a breach of the dams of the Slezska Harta and Kruzberk reservoirs. The breakthrough wave would reach the town in 3 hours and 36 minutes. The water level in the city would reach 10.5 m [35].

3.2 Evacuation routes and traffic restrictions

The determination of evacuation routes and traffic restrictions was based on the network analysis shown in Figure 1. Traffic constraints are represented by roundabouts, traffic lights, intersections and crosswalks, evacuation slowdowns, and high-traffic sections. To determine the time constraints, the experimental measurements, shown in Table 1 and Table 2, were performed. For intersection and crossing type constraints, evacuation slowdowns, and heavy traffic, a slowdown of half was assumed. This means that if the speed limit on the road is 50 km/h, a speed of 25 km/h is assumed. These values were also consulted with experts from the Integrated Safety Centre of the Moravian-Silesian Region in Ostrava. A graphical representation of the traffic restrictions is shown in Figure 4.

Traffic constraints were incorporated into the network analysis using the Network Analyst tool in ArcGIS. Figure 4 shows what each constraint looks like in the ArcGIS software. Point constraints are represented

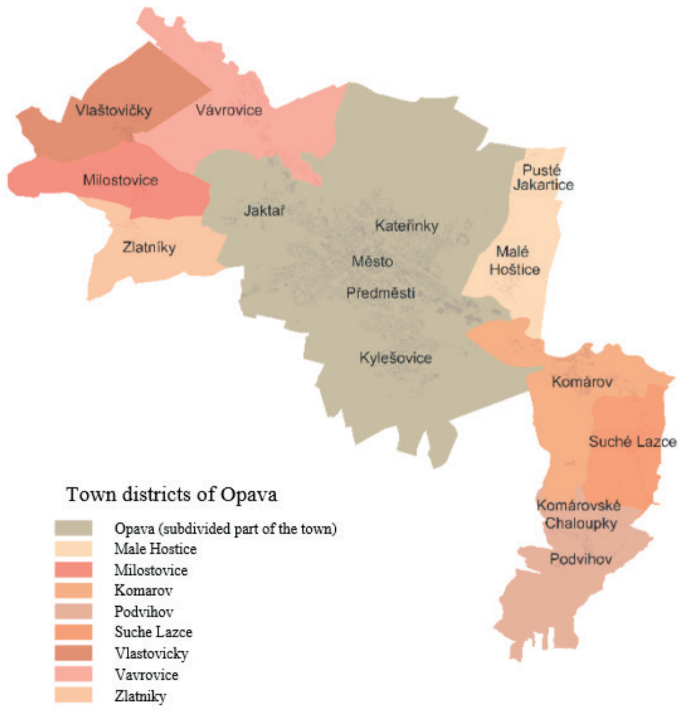

Figure 2 *Breakdown of the central part of Opava and the municipal parts of the city [34]*

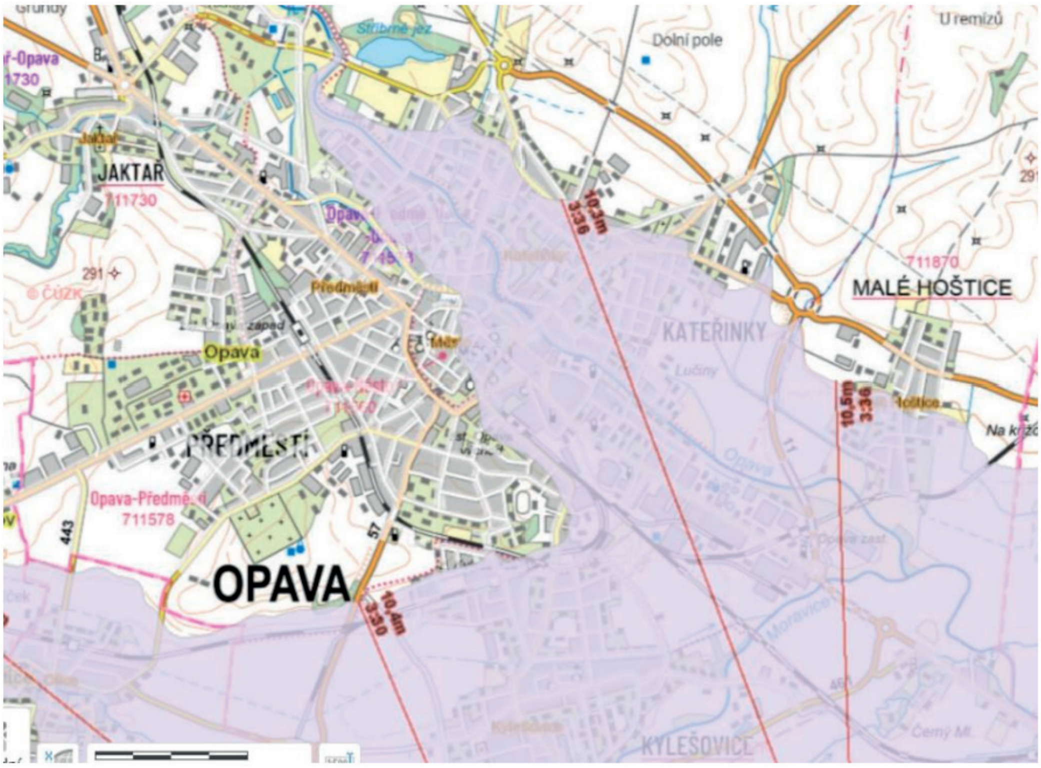

__Figure 3__ The area of Opava threatened by a special flood [35]

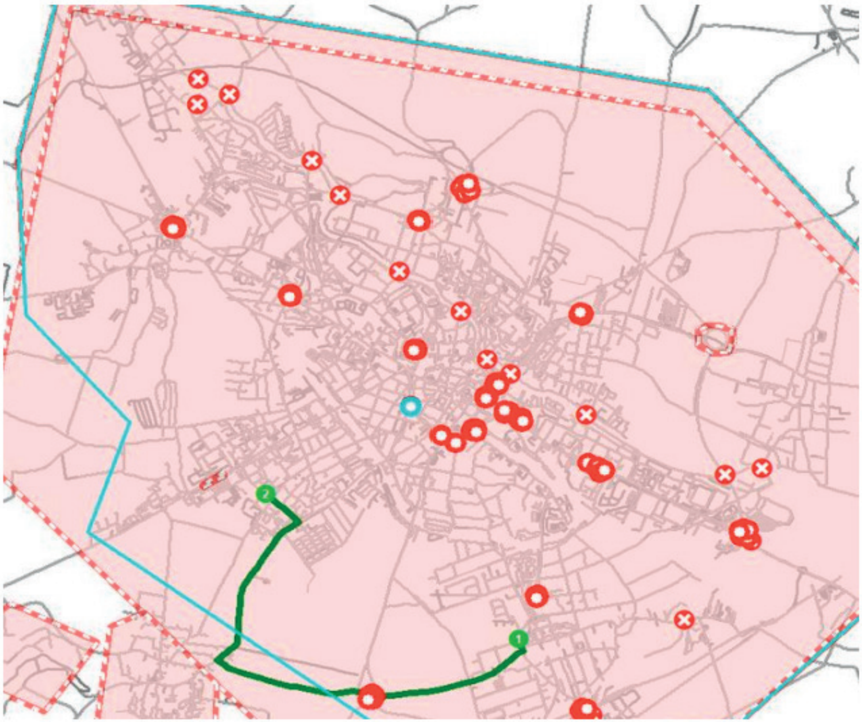

__Figure 4__ Traffic restrictions

by traffic lights, roundabouts and impassable bridges (constraints with a cross in the middle). Polygonal constraints (area-occupying constraints) are constraints associated with the slowing down of traffic due to the circumstances of the traffic situation.

To determine the evacuation routes, it was necessary to determine the beginning of the route. The start of the route is the assembly point (bus stop). The end of the route is the evacuation center (hereafter EC), which is determined in the emergency plan. ArcGIS can calculate the length of the route itself, so it was also possible to determine the time of each route. The evacuation routes were determined by ArcGIS based on the road speed parameters, the constraints that were set, and by specifying the start and end of the route. These routes are shown in Figure 5.

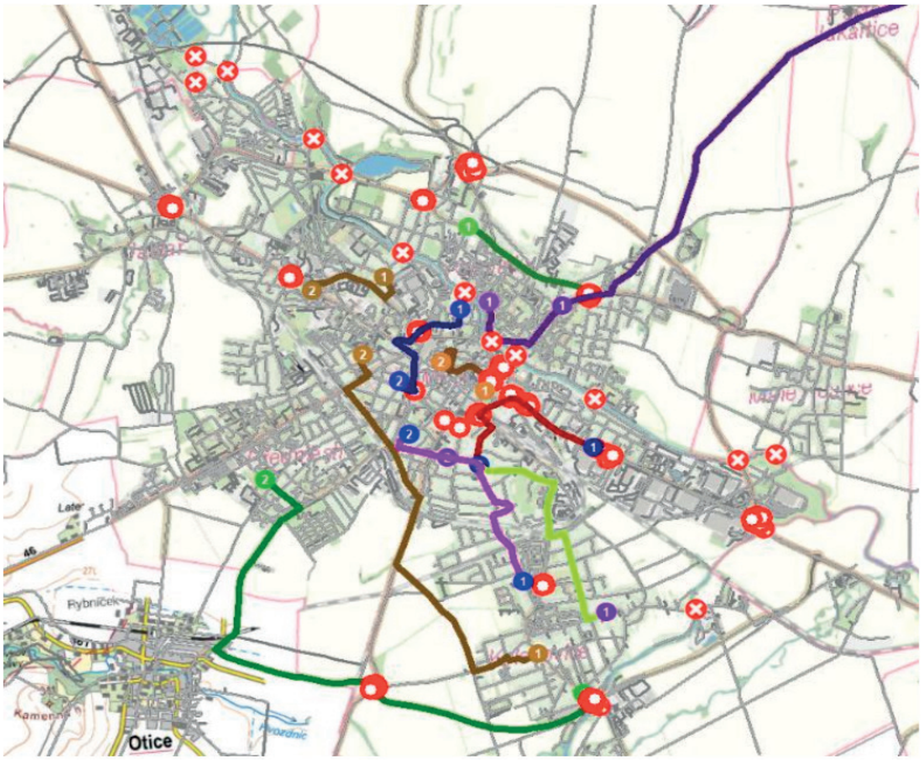

***Figure 5** Evacuation routes*

***Table 5** Description of evacuation routes*

No.	Evacuation routes for part of the town of Kylesovice:	
	Start:	End:
1	SUS stop	Evacuation centre SS zemedelska
2	Kroftova stop	Evacuation centre OA a SS logisticka
3	Bavaria stop	Evacuation centre SS honelnictva a VOS
4	Gudrichova stop	Evacuation centre OA a SS logisticka
	Evacuation routes for part of the town of Katerinky:	
	Start:	End:
5	Rolnicka stop	Evacuation centre Koberice Primary School
6	Partizanska stop	Evacuation centre Bolatice Primary School
7	Ratiborska stop	Evacuation centre Koberice Primary School
	Evacuation routes for the Predmesti:	
	Start:	End:
8	Pekarska stop	Evacuation centre Institute of Mathematics
9	Tesinska stop	Evacuation centre Bozeny Nemcova Primary School
10	Mostni stop	Evacuation centre Opava City Council
	Evacuation route for the Mesto:	
	Start:	End:
11	Praskova stop	Evacuation centre Kolarska

The individual routes have been designed in the program so that the walking distance in time per stop is no more than 30 minutes and that each route covers as large an area as possible. A total of 11 evacuation routes were created. The evacuation routes are included in Table 5.

3.3 Number of inhabitants at risk

The number of inhabitants of the city of Opava threatened by the special flood was determined using statistical data and map layers. In the first step it was necessary to overlay the layers of address points

***Table 6** Number of dwellings at risk in Opava*

Part of the city	Number of flats
Predmesti	3289
Katerinky	10140
Kylesovice	4556
Mesto	947

***Table 7** Number of inhabitants at risk of special flooding*

Part of the city	Number of inhabitants at risk
Predmesti	4638
Katerinky	14298
Kylesovice	6424
Mesto	1336
Total number of inhabitants at risk	26 696

in Opava and the flooded part of the city using the Intersect function in ArcGIS. In this way, dwellings that would be at risk in the event of a special flood were identified. The number of dwellings at risk in each part of the city is shown in Table 6.

Consequently, a procedure based on the census data was chosen. The total population of Opava was 47 985 people [36]. This figure was used to determine the average number of inhabitants per dwelling. The total number of dwellings in the city was determined in ArcGIS and is 33 930.

$$Average\ number\ of\ inhabitants\ per\ apartment = \\ = \frac{47985}{33930} = 1.41.$$

By multiplying the average number of inhabitants per dwelling in the city of Opava, the number of inhabitants at risk was obtained. The number of inhabitants at risk is shown in Table 7.

3.4 Number of inhabitants at risk subject to orderly evacuation

Today, many people in developed countries have their own means of transport. Therefore, evacuation can be divided into spontaneous evacuation, which is controlled in terms of evacuation routes and orderly provision, and controlled evacuation. Controlled evacuation is managed by the competent authorities and includes the provision of mass transport means and the activation of several evacuation facilities, such as evacuation assembly point, embarkation station, etc. [13].

The census data on population and mode of transport to work are known. From this data it is known that in Opava a total of 6328 people use their own means of transport (car) [37]. Since the cars have a larger capacity than one person, the data on the average number of children per one woman was also used. This value is 1.66 [38]. Therefore, a family of four was considered in calculations.

Number of people evacuated on their own:

$$6328 * 4 = 25312$$

Number of people subject to controlled evacuation:

$$47985 - 25312 = 22673$$

The value of 22 673 people is calculated from the total population of the city. Therefore, we will use this value as a percentage to determine the number of residents who will be subject to orderly evacuation in the at-risk parts of the city.

$$\frac{22673}{47985} = 0.47$$

Total of 47% of the population at risk of special flooding (26 696) is 12 548 people. The number of available means of public transport is available in Table 4. This means that the evacuation would take place in two waves, as the number of people to be evacuated by mass means is 12 548. However, due to evacuation baggage, it will not be possible to use the full capacity of the bus. An optimal use of 75% of the bus capacity was assumed. In that way, the evacuation would still take place in two waves, and it would also be possible to transport passengers with their evacuation luggage. This means that there would be 67 people per bus and 7 973 people could be transported in wave 1 and the remaining 4 575 people in wave 2.

3.5 Evacuation timeline

Determining the timing of evacuation is important to determine whether it can be completed before the flood wave reaches Opava. The exact timing of the evacuation cannot be determined because it is affected by many factors that are not precisely

Table 8 *Evacuation times 1-8*

Activity	a_{ij} (min)	b_{ij} (min)	m_{ij} (min)	2σ (min)	Final time (min)
1	5	15	10	4	14
2	30	120	75	30	102
3	3	10	5	4	10
4	15	45	30	10	40
5	30	75	55	16	74
6	15	25	20	4	24
7	5	10	8	2	10
8	60	90	75	10	89

Table 9 *Times of evacuation actions 9-10 for individual evacuation routes 1-11*

Route	Activity	a_{ij} (min)	b_{ij} (min)	m_{ij} (min)	2σ (min)	Final time (min)
1	9	18	24	19	2	22
	10	11	17	15	2	17
2	9	12	17	15	2	17
	10	15	22	18	2	21
3	9	15	29	23	6	29
	10	9	15	13	2	15
4	9	18	25	20	4	25
	10	8	14	12	2	14
5	9	15	21	18	2	20
	10	19	27	24	2	26
6	9	14	17	15	2	18
	10	25	34	30	4	34
7	9	21	25	22	2	25
	10	16	22	19	2	21
8	9	16	19	17	2	20
	10	6	11	9	2	11
9	9	18	26	22	4	26
	10	5	13	9	4	13
10	9	15	23	18	2	21
	10	3	6	4	2	6
11	9	15	25	16	4	22
	10	3	7	5	2	7

determined. The approximate evacuation time can be determined using the PERT method, which assumes that the individual activities are continuous random variables.

Table 3 lists the different evacuation activities. For the first 8 activities, the individual times according to the PERT method were determined based on expert evaluation. The actual times and standard deviations were calculated according to Equation (1) and (2). The individual times, standard deviations and resulting times plus standard deviation for activities 1-8 are shown in Table 8.

ArcGIS was used to determine the times of the last two evacuation activities along with experimental measurements. These times represent the time required to travel from the farthest part of the evacuation zone to the assembly point (staging area) and the times required to transport evacuees to the evacuation centres. A network analysis of traffic constraints was also used. The time data are calculated for the single-individual evacuation routes, which are shown in Table 5. The times are available in Table 9.

The data thus prepared was then entered into the MS Project, which was used to create a timeline and calculate the total evacuation time. Evacuation times 1-8 and evacuation times 9-10 for evacuation route 6 were entered into the Gantt chart. Route 6 was selected since it takes the longest time to perform activities 9-10 for this route. If the evacuation of people along this route can be completed before the arrival of the flood wave, the entire evacuation can be completed.

The results from the timeline for Route 6 indicated that the evacuation would take 3 hours and 28 minutes. From the evacuation timeline, calculated from the mean values of Route 6, it is clear that the evacuation can be managed before the flood wave reaches Opava. Since according to the county's crisis plan, the flood wave will be in Opava in 3 hours and 36 minutes from the time of the dam break. This means that even if the evacuation will take place in two waves, it will be possible to complete it in this time. The time margin is 1 hour. As fewer people will be evacuated in Wave 2, buses on the two routes with the longest travel distances (5 and 6) can be afforded to be omitted. In this case, the schedule for Route 6 even with the second wave of evacuations would take 3 hours and 38 minutes, but this exceeds the arrival time of the wave.

If the evacuation is a critical scenario and all the activities preceding the transfer of people to the EC are delayed, it would be difficult to achieve evacuation in the specified manner. In such a case, there would be six routes to which buses could not return and take the rest of the people. This means that only five routes can be used to transport the rest of the evacuees. In this case it would be appropriate to set the capacity of the buses at 80%. This would result in 72 people per bus. In the first wave 8 568 persons would be transported and in the second wave the remaining 3 980 persons would be transported. In the case of the second wave of EC transfers, the capacity of the buses would already be at its maximum; if it were limited, it would not be possible to transport everyone. As a part of the evacuation solution, the Fire and Rescue Service requested that the possibility of only seating on the buses be considered, which would mean that all the buses would have to run 4 times, which, as the previous results show, is not feasible.

4 Discussion

Addressing the issue of evacuation planning in the event of an emergency flood caused by reservoir failure, the current flood plan was found to be inadequate and outdated. It was therefore necessary to propose how to update it and how to align it with the regional crisis plan. There are several possible procedures, methods and tools to address this issue and its sub-steps. The approach chosen by the authors of this paper uses mathematical and statistical tools supported by applications and GIS. These are relatively simplified solutions, but they do not diminish the suitability and meaningful value of the individual outputs. The above approach to the problem addressed is relatively unpretentious in the process of data collection, processing and analysis. Therefore, it is suitable for cases where the required data is not available, or their collection would be time and cost-consuming. As the evacuation of a population is a complex process, influenced by several factors, it is not possible to accurately determine the timing, the number of evacuees and the means of transport required. However, the above results show the following:

If the conditions as set out in this paper are met, the evacuation would be completed before the arrival of the flood wave.

The basic prerequisite for this scenario is to use the capacity of the available means of transport. If only seating capacity were used, the evacuation could not be carried out to the extent required.

The following are some possibilities to achieve results that would be closer to reality. First, the duration of the evacuation routes, here fixed values of the restrictions of the junctions and roundabouts are chosen, from a statistical point of view it would be more appropriate to choose the crossing intervals, but the GIS system does not allow this.

Another limitation of this study is the experimental data. Using these data, traffic constraints were determined. For each traffic constraint, three measurements were taken at different times and days. These data were then summarized and consulted with experts from the Integrated Security Centre Ostrava. The input data was therefore based on expert estimates. The experimental data served as a guide. To increase the accuracy of the reported evacuation planning procedure, it would therefore be advisable to take into account several variables when measuring the time constraints. At the same time, more measurements would be necessary. Important factors that can limit the traffic situation are weather conditions and the times when the monitored road sections are most congested [39-40]. Based on the analysis of the results, several directions for future research can be identified to address the current limitations. First, it would be beneficial to provide a more detailed explanation of how experimental data are collected, with a particular focus on varying conditions under which evacuation may take place - such as peak traffic periods or adverse weather. These factors can significantly influence the capacity of transport infrastructure and the overall evacuation time. Furthermore, greater attention should be paid to the analysis of alternative routes and potential disruptions to evacuation paths, such as traffic accidents, temporary road closures, or failures at key network nodes. Incorporating such scenarios would contribute to a more realistic risk assessment and enhance the practical applicability of the proposed model in the real-world emergency situations.

Another limitation of that approach is that it does not consider the evacuation of health and social facilities. Health and social facilities are considered vulnerable elements as they house people with certain limitations that may prevent them from moving. There are different procedures on how to deal with such facilities in the event of a flood. These may need to move patients by available ambulances or, in the event of a flood, to move patients to higher floors. Evacuation procedures follow the evacuation plans of specific facilities. The most vulnerable patients should be moved by ambulances to other hospitals or relevant facilities. Those who are mobile are either moved themselves or discharged [41]. There are several approaches that address the issue of evacuation from healthcare facilities [42-44]. The neglect of planning for transport provision and patient transport is described by Yazdani et al. as one of the most ignored components of hospital evacuation planning [43]. However, evacuation planning for healthcare and social service facilities is a topic that lends itself to separate research, which highlights the complexity of the issue at hand.

Along with hospitals, schools and dormitories are another category to consider when planning a city evacuation. Especially if it is a larger city where colleges or universities are located. The projected population may be considerably higher in this case.

In the case of the city of Opava and its threat of a special flood, it is also possible to consider the transfer of evacuees on foot. In this case, only people who are medically fit can be counted on. The expected flood wave resulting from the accident at the Slezska Harta and Kruzberk reservoirs would not flood the entire town and its expected arrival in the town is more than three and a half hours. As the evacuation centres are located within the non-flooded part of the city, it is possible to consider the use of evacuees' transfer on foot. Such a method of evacuation has been addressed, for example, by Parajuli et al. [45]. However, it would be difficult to determine the number of residents who would move to the evacuation centres on foot. It can be assumed that at least the people who are closest to the evacuation centres from their homes would use this method of evacuation. This would reduce the number of people who need to be transported by public transport, which would be used as a priority for the evacuation of school facilities, health facilities, etc.

The determination of the number of people to be spontaneously evacuated and the number of persons subject to orderly evacuation shall be determined based on an estimate. In this case, an alternative solution could be a questionnaire survey. However, the questionnaire would have to be chosen to be accessible to all residents of Opava, which is time-consuming, and its implementation would have to involve all residents of Opava, which is very difficult to implement. Another alternative way is to use available census data. Specifically, this is data on the degree of mobilisation. The degree of mobilisation indicates the number of cars in each area per 1 000 inhabitants. If one focuses on individual parts of the city, the numbers of inhabitants who evacuate themselves and those who are evacuated by the competent authorities are obtained. However, this approach is also heavily influenced by estimation.

Planning the transport arrangements for evacuation is a challenging logistical process. Therefore, the above procedure could be extended in the future by considering the solution of transportation problems by linear programming. In area evacuation, transport problems are used to optimize the transport of people from boarding stations to evacuation centres. In particular, the number of people transported, distances, and possibly unit cost per person are considered in this process [46].

At the same time, it must be considered that the behaviour of residents during an evacuation has a significant impact. Examples of problems related to human behaviour during an evacuation may be inexperience, ignorance, the need to return for belongings, etc. The knowledge and skills of the management staff also play an important role [47]. However, these factors are difficult to consider in the case of area evacuation planning. The solution may be to take these factors into account in the timing of individual activities.

The proposed procedure for planning the transport support for evacuation is a relatively simple approach, however, it provides sufficient information to crisis managers with decision-making authority. This information is particularly useful in preparedness and allows crisis management authorities to react to the current situation and availability of resources. More detailed planning would first require the introduction of a data collection system. More precise information on the number and movement of the population in one-individual parts of the city and hours would allow more accurate data to be established on the number of inhabitants at risk. Given the specific example of the city of Opava, it would also be advisable to consider moving evacuees on foot who have evacuation centres close to their homes.

5 Conclusions

The aim of this research was to propose a traffic evacuation using the network analysis in GIS. The transport provision for evacuation was divided into several activities. First, it was necessary to determine the evacuation routes. For this purpose, it was post-necessary to add traffic-related constraints to the network analysis and to determine the start and end of the route. The start of the route was determined so that the maximum walking distance to the site would be 30 minutes and that as much of the area as possible would be covered. The end of the route (evacuation center) was determined from the County's emergency plan. Using ArcGIS software, 11 evacuation routes were designed. In addition, it was necessary to determine the number of residents located in the area at risk of a special flood. For this purpose, it was necessary to use the address points layer using ArcGIS software and overlay it with the flood wave layer to determine the number of homes at risk.

This data was then multiplied by a factor reflecting the number of inhabitants per house to obtain the number of inhabitants at risk from the special flood.

The number of people at risk from the special flood had to be divided into two groups. The first group was subject to spontaneous evacuation and the second group to controlled evacuation. The number of people subject to controlled evacuation was 12 548. Total of 119 buses with a capacity of 90 seats could be used to transport these people. According to the capacity of the autobuses, considering space for evacuation luggage, there were 2 evacuation waves. In wave 1, 7 973 people could be transported with 75% of the bus capacity and in wave 2, the remaining 4 575 people could be transported.

For verifying the correctness of the proposed solution, the evacuation time course was determined. The times and deviations of individual evacuation activities were determined using the PERT method. A network analysis of the individual activities, their time course and continuity were created using MS Project. The Network analyses were created for all 11 routes in two scenarios. The first scenario was the most likely scenario, and the second scenario was a pessimistic scenario in which all the activities would be delayed. Based on the results of the most likely scenario, the evacuation could be completed in time, even if buses on Routes 5 and 6 were unused. The time margin in this case is 1 hour. In the pessimistic scenario, the evacuation can be managed with 80% occupancy of the buses. The time margin in this case is 2 minutes. However, this would have to delay all activities.

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Conflicts of interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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