

Evacuating Populations with Special Needs Using Analytical Hierarchy Process (AHP) Method and GIS

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Abstract

The present study is focused on the development of a methodology pertaining to the evacuation plans improvement in a scenario where infrastructures are located in residential settlements that might be threatened by fires; the aforesaid settlements are oftentimes found to be resided by vulnerable population groups, namely elderly people, handicapped people and children. The study pinpoints Evacuation Assembly Points (E.A.P.s) on the outskirts of their settlement and examines the evacuation routes accessibility and safety by way of utilizing Geographic Information Systems (GISs). What is more, our meticulously planned methodology combining quantitative analysis, as well as participatory planning, allows for improve strategies targeted on how to effectively ensure the vulnerable population groups evacuation. The study's results exhibit how vital it is to integrate technological tools in combination with each community's partaking in the process of preparing and implementing evacuation plans. The study's findings furthermore suggest the need to further research the evolution of dynamic evacuation models, which would take the ever-changing and ever-evolving needs of vulnerable population groups into account.

Keywords

GIS, Evacuation, Control Strategies, Disaster Response, Fire Safety

1. Introduction

The vast challenge to manage any occurrences of natural disasters and emergencies of any similar nature has caught the attention of multiple scientific fields, which have to complement each other, so as to develop innovative solutions and effective preparation and reaction strategies. The need for adapted solutions in

regard to evacuation procedures constitutes a reflection of the societal structures perplexity, as well as of the diversity within communities, predominantly among vulnerable population groups [1] [2]. It has been proven that the implementation of technological innovations Geographic Information Systems (GISs) in particular, and the capitalization on data from social networks improve the evacuation plans effectiveness, by way of offering more individualized approaches to crises management overall [3] [4].

Both the contemporary society's complexities and the ever-increasing challenges pertaining to natural catastrophes have created the dire need for an interdisciplinary approach, which would combine knowledge deriving from technology, social and political sciences, and psychology in the purpose of developing strategies being both effective and in the mean time sensitive to the needs of distinct population groups [5]-[8]. Developing such innovative technological tools and methodologies, e.g. evacuation simulations and danger analyses, to name but two, offer new possibilities to the understanding tackling of the challenges having relevance to natural catastrophes [9]-[11].

It is of the essence that the community partakes in the procedure of planning and realizing evacuation strategies, since its active participation therein and the reinforcement of local communities can contribute to a higher degree of the plans' durability and to render reactions to such natural catastrophes more efficient [12]-[14]. Educating and informing the public also plays a vital role in their preparing therefor, given the fact that knowing and comprehending which alarm and reaction systems they have at their disposal at any given time could be conducive to lives being saved [15]-[17].

It is imperative that more individualized and more versatile evacuation plans be developed, taking into consideration the specific needs and destinations of the vulnerable population groups, which cannot be feasible unless the diversity within such groups, e.g. the elderly, handicapped people and non-autonomous people is recognized [18]-[20]. New methodologies and technologies offer considerable possibilities for the improvement of the efficiency and accuracy of alarm and evacuation systems that are tailor-made for these groups' needs [21] [22].

This study focuses on developing a methodology to improve evacuation plans for facilities located in settlements that may be threatened by forest fires and host vulnerable social groups, such as the elderly, handicapped people, and children. It combines the Analytic Hierarchy Process (AHP) with Geographic Information Systems (GIS), highlighting the need for community involvement and the integration of specific needs. This offers a comprehensive and tailored framework for effective emergency management.

2. Methodology

2.1. Analytic Hierarchy Process and Evaluation Criteria

In the context of reinforcing measures taken to cope with forest fires, it is crucial

to efficiently prioritize evacuation. The frequency and intensity of fires render evacuation an unavoidable and unpredictable scenario, which would occur at any given time, exacting the immediate and safe transportation of the stricken people away from the dangerous zones. Amidst such critical scenaria, the determination, as well as the evaluation of the criteria that are vital to organizing an evacuation constitutes a prerequisite for protecting human lives.

The adopted approach to deal with the matter in question is based upon the Analytic Hierarchy Process, AHP (Figure 1), a methodology allowing for systematical hierarchical analysis of numerous distinct parameters affecting the decision-making to safely evacuate a disaster-stricken area. By way of scientists availing themselves of a method that allows for, smoothes the way for and expedites the systematical analysis and hierarchization of multifarious parameters affecting the decision-making process, a riskless evacuation is facilitated. Using the AHP application, two major factors to be borne in mind amidst an evacuation process were determined, namely the evacuation routes and the assembly points. Each of the aforementioned factors is further divided into four sub-criteria, allowing for a thorough and well-rounded analysis of what is required in order for an evacuation to be deemed effective.

The initial step of this process is to define the principal goal: the optimization of the assembly points demarcation so as to safely evacuate the populations in jeopardy. Following that, the hierarchy is divided into two factorial categories (escape routes and assembly points); finally, the factors are further divided into their respective sub-criteria (Escape routes and assembly points). Using the AHP application, the criteria are assessed through pairwise comparisons in order to comprehend the relative bearing of both criteria and sub-criteria, in the purposes of efficiently hierarchizing them and make informed decisions based upon a pondered and objective framework.

The AHP application in forest fires evacuation management offers a systematical method for dealing with the complexity and urgency of the problematic in question. Authorities and organizations are able to make decisions that maximize citizens' safety and welfare in crisis scenaria by way of accurately and in a regimented manner in crisis scenaria.

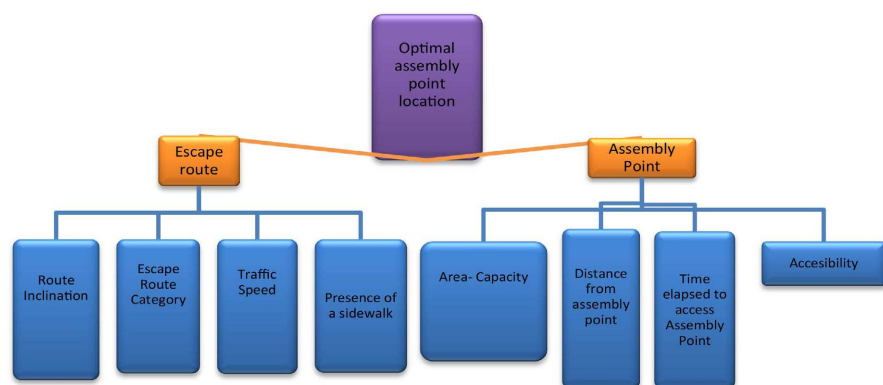


Figure 1. Flow chart (Analytic Hierarchy Process, AHP).

2.2. Escape Route

The escape route is a critical element in emergency situations, such as evacuations due to forest fires. It is vital for people in each unit to be aware of specific evacuation plans and to be informed about the routes they would have to take to reach designated assembly points, where their mass evacuation to safer locations will take place. Routes with an average gradient of more than 12% are considered particularly rutty, especially for vulnerable groups, as crossing becomes implausible, affecting energy consumption and reducing the average evacuation speed.

Another important factor is the road network of the area. A low volume of traffic increases the suitability of a route, reducing the risk of accidents. Traffic speed also plays a role, with medium and low speed routes being preferable to avoid accidents. The presence of sidewalks, separated from the road axis, also contributes significantly to pedestrian safety.

To recapitulate, the recommendable escape route is characterized by four main factors: the slope of the route, the category of route, the speed of traffic and the presence of sidewalks. Choosing the right route is a critical element for the safe and efficient evacuation of people in an emergency.

2.3. Assembly Points

The right choice of points is essential for the safe and organized movement of populations to safe locations. Public spaces such as squares, stadiums, parks and parking lots, as well as private open spaces and empty plots with low vegetation, can act as expedient gathering points.

The capacity of the gathering points, *i.e.* the number of people each point can accommodate, is one of the critical factors for effective evacuation. Also, the accessibility of the points, the distance from the areas under threat and the time elapsed needed to reach them are also important criteria for the selection of assembly points. Easy access for vehicles, particularly buses that will take civilians away from the fire site, is essential.

Finally, taking into account the time required to reach the assembly point, especially in scenarios involving vulnerable groups with reduced motility speed, is crucial. Accident avoidance and the safety of citizens is a priority, hence choosing the most opportune assembly points and managing them properly can be the difference between a successful and a failed evacuation.

2.4. Table of Criteria

In the table of criteria (**Table 1**) below the various criteria affecting the assessment of a route in the context of civil protection and crisis management, including route slope, route category, pavement, assembly point capacity, assembly point distance, access time, traffic speed, and accessibility of the assembly point shall be analyzed. The gradient of the route applies to both uphill and downhill gradient and is rated on a scale from one to ten, with one being the worst and

ten the best score respectively: >9% corresponds to score 1, 8.01% - 9% to score 2, 7.01% - 8.0% to score 3, and so on up to <0.5% corresponding to score 10. In addition, the speed of traffic on the road is a crucial criterion, as this can affect the safety and speed at which citizens can be transported to the assembly point. The presence of a sidewalk is also rated on a scale of one to ten, with <10% (no paved surface at all) corresponding to a score of 1 and 100% (being fully paved) to a score of 10. In terms of the capacity of the assembly points, the scale from one to ten reflects the capacity from the lowest (<100 people) to the highest (>1000 people). The distance of concentration points from the unit is also scored, with longer distances receiving a lower score. The duration of access to the assembly point is another criterion, with shorter durations being preferred. Finally, the accessibility of the assembly point, *i.e.* the road that approaches the assembly point from where civil protection vehicles will be able to collect citizens, is another crucial criterion, with the most central roads being preferred due to the accessibility of vehicles such as buses, vans, etc.

Table 1. Table of criteria.

Table of criteria								
Score	Route Inclination	Escape Route Category (to the Assembly Point)	Traffic Speed Path	Presence of pavement Path	Assembly Point Accessibility	Assembly Point Area/Capacity	Distance from Assembly Points	Route Duration to the Assembly Point
1	>9%	Motorway	>120 km/h	<10% (not at all)	Pedestrian street	<50 people	>900 m	>17 min
2	8.01% - 9%	Secondary National Road Network	90 - 120 km/h	10% - 20%	Local Municipal Roads	51 - 100 people	800 - 900 m	15 - 17 min
3	7.01% - 8.0%	Tertiary National Road Network	80 - 90 km/h	20% - 30%	Local Road Network	101 - 150 people	700 - 800 m	13 - 15 min
4	6.01% - 7.0%	Primary Provincial National Road Network	70 - 80 km/h	30% - 40%	local distributor road	151 - 200 people	600 - 700 m	11 - 13 min
5	5.01% - 6.0%	Primary Urban Network	60 - 70 km/h	40% - 50%	Secondary Provincial Road Network	201 - 250 people	500 - 600 m	9 - 11 min
6	4.01% - 5%	Secondary Provincial Road Network	50 - 60 km/h	50% - 60%	Primary Urban Network	251 - 300 people	400 - 500 m	7 - 9 min
7	3.01% - 4.0%	Street	40 - 50 km/h	60% - 70%	Primary Provincial National Road Network	301 - 400 people	300 - 400 m	5 - 7 min
8	2.01% - 3.0%	Local Road Network	30 - 40 km/h	70% - 80%	Tertiary National Road Network	401 - 500 people	200 - 300 m	3 - 5 min

Continued

9	0.51% - 2.0%	Local Municipal Roads	20 - 30 km/h	80% - 90%	Secondary National Road Network	501 - 600 people	100 - 200 m	1 - 3 min
10	<0.5%	Pedestrian street	<20 km/h	100% (all along the route)	Motorway	>601 people	<100 m	<1 min

2.5. EAPI: Evacuation Assembly Point Index

The study was based on questionnaires to evaluate criteria through the Analytic Hierarchy Process (AHP). Designed based on the principles of research methodology, the questionnaire explored criteria and sub-criteria with a hierarchical structure, allowing participants to identify priorities through pairwise comparisons. The purpose of the present application of the hierarchical method is to prioritize the criteria that contribute to a safe evacuation.

The participants, a total of 32, were selected because of their experience in the relevant field, ensuring the reliability of the data. The 32 respondents were experts in evacuating their facility and had been designated as security officers. The questionnaires were conducted by post or by face-to-face interview. AHP pairwise comparisons are based on experts' judgements, which may be subjective and influenced by personal preferences. The survey was conducted with closed-ended questions and a 5-point rating scale, producing 416 comparisons that contributed to understanding the importance of the criteria. Closed-ended questions are represented by rating scales and would be used for pairwise comparisons, where participants assign numerical values to the relative preference of each subcriterion. The number of participants is considered sufficient to ensure reliable results, as it achieves a satisfactory level of representativeness and accuracy in the experts' estimates. The result was the development of a model for the classification and prioritization of concentration points, enhancing the research approach with specific data.

The sum of the highest in significance criteria on the hierarchical scale can be calculated by multiplying the significance levels of the lowest ones in the hierarchy. Thus, the Evacuation Assembly Point Index (EAPI) can be determined as a function of the following formula:

$$\text{Assembly Point Index (EAPI)} = 0.141*(IC) + 0.148*(RC) + 0.127*(TS) + 0.088*(SP) + 0.163*(AC) + 0.097*(APAC) + 0.108*(DCAP) + 0.128*(RDAP)$$

where IC is inclination, RC is Road Category, TS is Traffic speed, SP Sidewalk Presence, AC is Accessibility, APAC is Assembly Points Area and Capacity, DCAP is distance to be covered from assembly points and RDAP is routes' duration to the Assembly Points.

3. Results

3.1. Area of Study

Based on the Assembly Point criterion analyzed above, there are eight possible

gathering sites selected for evaluation. Three vacant plots were selected, a public parking area, the area of the Association of Olive Growers, a square, the facility parking and the Vamos stadium. The uses of the premises were found by an on-site autopsy.

The study area (**Figure 2**) chosen is the settlement of Vamos. The settlement belongs to the Prefecture of Chania and more specifically to the Municipality of Apokoronas, which is a historical seat. It is located 25 km. away from the city of Chania and 35 km. from the Rethymnon city center. Vamos is located at an altitude of 300 meters above sea level and is a semi-mountainous village. The settlement is surrounded by wild and cultivated nature dominated by local bushy and wooded vegetation. The permanent population of the Municipal Community of Vamos, according to the latest census conducted in the country in 2021, amounts to 698 citizens.

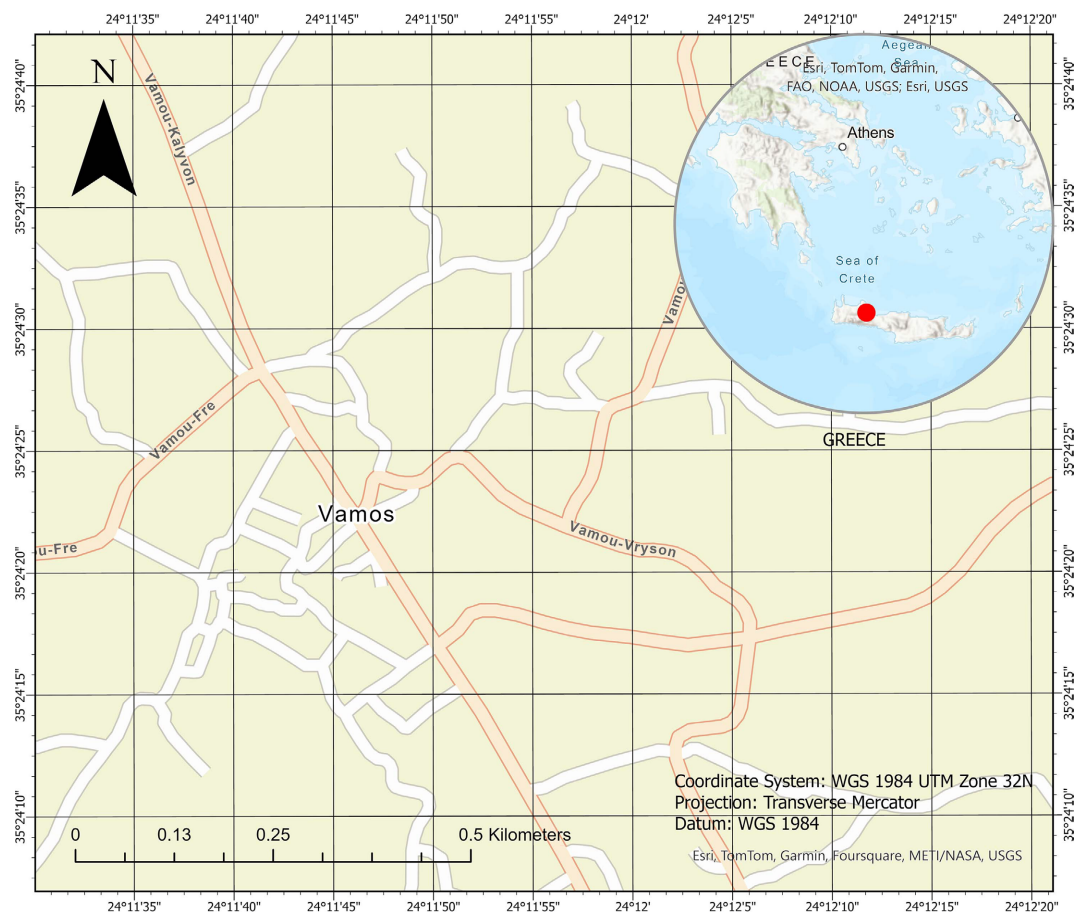


Figure 2. Map of study area.

First, a virtual evacuation scenario is examined in the settlement of Vamos, where a possible forest fire approaching the residential fabric was studied. The unit of the school located in the settlement was selected and a plan for its evacuation at possible assembly points will be examined.

Based on the Assembly Point criterion analyzed above, there are eight possible

gathering sites selected for evaluation. Three vacant plots were selected, a public parking area, the area of the Association of Olive Growers, a square, the facility parking and the Vamos stadium. The uses of the premises were found by an on-site autopsy. Finally, Network Analyst's Closest Facility analysis tool in ArcGIS Pro was used to find escape routes. This tool has the ability to locate the nearest route from a set of installations. At the same time, it has the ability to apply restrictions such as the direction of movement in the network, the means of movement (walking, road), the application of time restrictions, the application of barriers on the road network, etc.

3.2. Scoring Escape Routes

The table below (**Table 2**) presents the final results of the method for all escape routes of Vamos School and the score map (**Figure 3**). More specifically, all routes recorded an index greater than 3.33, but at the same time less than 6.66 indicating a moderate level. The route from Vamos School to the Public Parking Area has recorded the highest score with an index of 5.42/10 and is depicted in green on Map. On the contrary, the route with the worst index is the Vamos School, Association of Olive Growers with an index of 3.90/10 and a red gradation. The remaining assembly points range in EAPI index values from 4.13/10 to 4.66/10 marked in orange on the map below. According to the above data, the route Vamos School, Public Parking has the largest Evacuation Assembly Point Index and is considered the optimal.

Table 2. Assembly points ranking.

Vamos School Routes	Scoring	Rank
Vamos School—Public Parking Area	5.42/10	Highest
Vamos School—Association of Olive Growers	3.90/10	Lowest
Vamos School—Square	4.45/10	Moderate
Vamos School—Vamos stadium	4.66/10	Moderate
Vamos School—Plot 1	4.52/10	Moderate
Vamos School—Plot 2	4.13/10	Moderate
Vamos School—Plot 3	4.49/10	Moderate
Vamos School—Settlement's public parking area	4.43/10	Moderate

It is noteworthy that among the eight criteria set, only the route gradient (5.8/10) and the accessibility (5.6/10) have on average scored greater than 5.5/10 (**Table 3**). On the contrary, the presence of a sidewalk is one of the most significant disadvantages on these routes with an average score of 2.4/10. Its highest score is 4/10 with a sidewalk presence rate of 34.93%. Among the Assembly Points, on Plot 2 and in the Olive Growers Association there are the least sidewalk presence rates, with rates of merely 5.21% and 6.58% respectively. The lowest route slope from Vamos School with a percentage of 3.8% is recorded in

the Public Parking. In addition hereto, the highest evacuation time is recorded in the Public Parking with 9.83 minutes. On the contrary, the worst evacuation

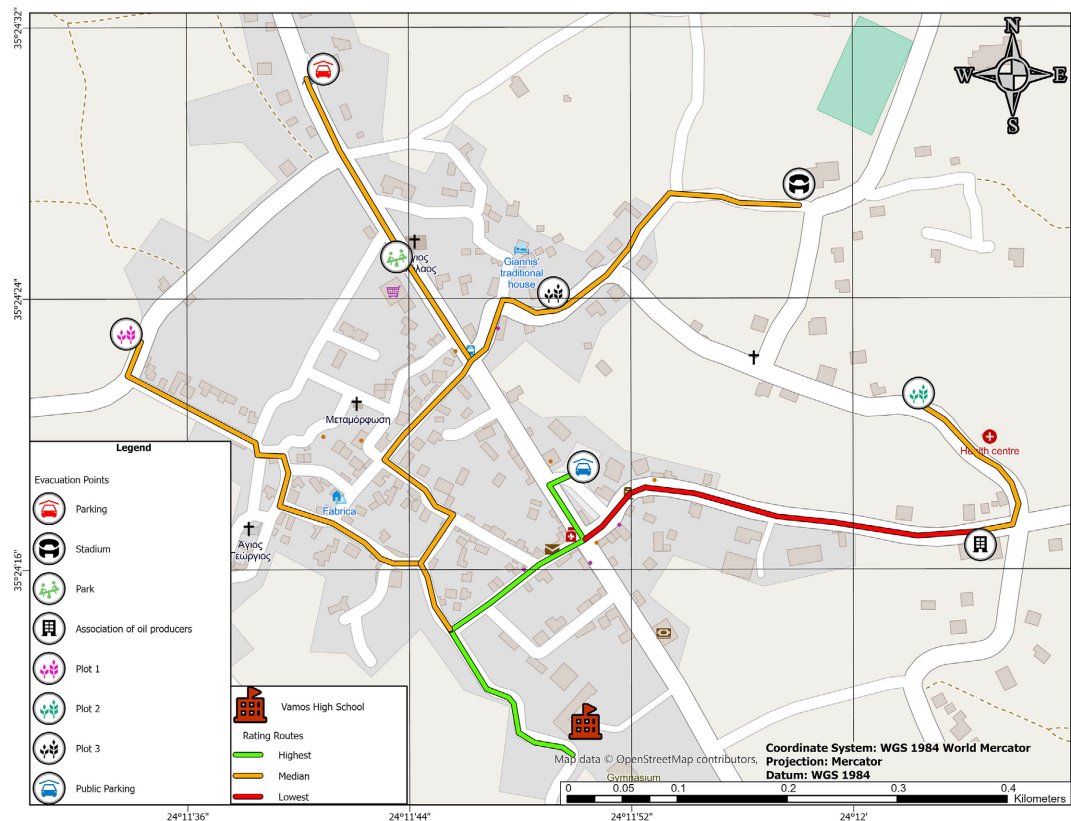


Figure 3. Escape routes.

times identified, with a slight difference between them, are the Vamos Stadium with 21.14 minutes and Plot 2 with 21.24 minutes.

By the same token, the fact that the Public Parking Area is located near the main road of the settlement establishes that it has the highest accessibility rating. As a final point, the results allow us to see the weaknesses of the optimal route with the aim of proposing measures to further improve it, the construction of a sidewalk along its entire length, measures to reduce local traffic speed and increase capacity through the acquisition of adjacent land if possible, among others.

Table 3. Criteria rating.

Vamos School		
Criteria	Assembly Points Total Rating	Mean Rating
Route Inclination	46	5.8
Assembly Points Accessibility	45	5.6
Escape Route Category (to the Assembly Point)	43	5.4
Traffic Speed	42	5.3

Continued

Assembly Point's Area/Capacity	36	4.5
Distance from the Assembly Point	28	3.5
Presence of a sidewalk	19	2.4
Time it takes to reach the Assembly Point	18	2.3

4. Discussion

This research has contributed to the development of an improved framework for emergency evacuation planning, applicable to facilities of vulnerable social groups located in settlements that may be threatened by forest fire. The importance of developing such a framework is undeniable, given the increasing frequency and intensity of natural disasters worldwide. The integration of Geographic Information Systems (GIS) and Hierarchical Process Analysis (AHP) offers an innovative approach that combines technological capabilities with analytical methodologies to improve the efficiency and safety of evacuation plans.

The implementation of GIS and AHP has allowed accurate assessment and prioritization of the various parameters affecting evacuation planning. This methodological approach facilitated the development of evacuation strategies tailored to the specific needs and conditions of each facility, enhancing the safety and efficiency of the evacuation process.

Its significant contributions notwithstanding, the present research is not without limitations. The dependence on data that may not always be up-to date or complete constitutes a significant matter of contention, to say nothing of the need for continuous updating of the system with new data and parameters. Moreover, the application of the methodology to different geographical and socio-economic conditions may require adjustments to effectively respond to individual needs.

For the future, the integration of these technologies could contribute to the development of more dynamic and flexible evacuation systems, which can adapt in real time to changes in the environment or risk conditions. The development of such security standards can be exploited by the operations centers of civil protection teams through an automated process of an algorithm, so that the above calculations are made in real time. Through continuous improvement and innovation, we can strive to achieve an environment, where crises management and evacuation procedures are as efficient and safe as possible for all.

5. Conclusions

The findings of this research offer several notable contributions to the field of emergency management. First, it facilitates a systematic and data-driven approach to evacuation planning, ensuring that decisions are based on objective assessments rather than subjective judgments. To paraphrase this, each strategy developed takes into account the diversity of risks and needs of affected populations, offering a more comprehensive framework for dealing with situations in

settlements that may be threatened by forest fire.

Second, it takes into account the unique characteristics and requirements of a facility with a vulnerable population, recognizing the distinct challenges associated with the evacuation of these individuals. Focusing on such special groups ensures that the most vulnerable can receive the attention and protection they need in emergencies, reducing the risk of loss of life and enhancing the community's capacity to respond effectively.

Based on the findings of our study and in agreement with the existing literature, it becomes clear that the integration of advanced technologies such as GIS and the use of multi-criteria decision making methods can significantly improve the effectiveness of evacuation procedures [1] [2]. Moreover, continuous collaboration between authorities and researchers is essential for the development of dynamic and adaptive crisis management systems.

In a nutshell, this research highlights the importance of applying modern technological tools and methodologies to decision-making for emergency management, enhancing the effectiveness, safety and flexibility of evacuation and response plans.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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