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Modeling and Analysis of the Road Network Status in Gorgan City during an Earthquake

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Abstract: - The condition of transportation networks after an earthquake and the timing of emergency response are of paramount importance. It is necessary to consider the level of vehicle services in urban areas based on traffic networks and their constraints. The aim of this research is to provide a vulnerability analysis of the designed transportation networks in Gorgan City, which is a highly earthquake-prone city. In this study, after determining the influential criteria based on expert opinions through the collection of questionnaires that were prioritized by 20 specialists and after examining the questionnaire's reliability using Cronbach's alpha, a factor analysis was performed to identify the important factors affecting post-crisis service delivery to individuals. Additionally, a questionnaire was prepared for drivers who experienced earthquakes while driving, and their reactions to earthquakes were analyzed. In the factor analysis, factors such as access to the communication network with the performance of arterial roads grade 1, attention to bridges, compliance with distances and the protection of rivers and streams, access to the communication network with the performance of arterial roads grade 2, and others were prioritized. It was found that access and transportation networks had a significant impact on these factors.

Furthermore, since the research method is spatial and network analysis in a GIS environment, all influential factors (such as access to road networks with high penetration, road service levels in post-crisis conditions, travel time, route performance, network-related distances) in Gorgan City were analyzed using GIS network analysis. Finally, considering the recognition of various layers in the current network and access to emergency vehicle points, the status of road networks after a crisis was analyzed. In the final part of the study, to control appropriate access to various areas of Gorgan City regarding 11 emergency bases, network analysis tools and their criteria, such as travel time, road performance, distance, etc., were used to analyze the functional radius of these bases. The network analysis output showed that all stations are in desirable positions, with the difference that in some areas with a lack of service level in the city's road network, several fire stations, Red Crescent, etc., are needed for reinforcement.

Keywords: Crisis Management, Emergency Accommodation, Road Network, Network Analysis, Earthquake, Gorgan

I. INTRODUCTION

A crisis is an unforeseen event that, either naturally or by human intervention, significantly disrupts the normal daily life of people in economic, social, and environmental dimensions. Crisis management encompasses a series of continuous activities and operations, including planning, organizing, leadership, control, and coordination, aimed at preventing crises, mitigating their effects, and improving the situation after a crisis. Pre-crisis planning is one of the critical issues that city managers, particularly in the field of crisis management, are currently facing. Given that Iran is considered one of the earthquake-prone countries in the world, urban management must have a high level of capability and readiness to cope with natural disasters continuously and strive to reduce the adverse effects of urban crises.

In recent years, the establishment of crisis management support bases has been on the agenda of organizations in cities. One noteworthy aspect prior to establishing these bases is the study and assessment of the service level of emergency vehicles on the road network. In such a way that during a crisis, it can be located in a manner that maximizes the efficiency of each effective and useful base, providing shelter for individuals. Emergency response

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organizations, hospitals, and others should have the best and fastest access to crisis management bases. As mentioned, in addition to location criteria for crisis management bases (such as physical structure specifications, population density, operational function type of routes, etc.), the condition of the transportation network and response time of emergency response organizations is crucial. The service levels of vehicles from centers to various points in urban areas must be considered, taking into account the traffic networks and their constraints.

This research aims to address the challenges that arise after an earthquake. During this time, various scenarios for emergency evacuation and relocation of individuals to safe places must be considered. In addition to factors and criteria influencing the safety of emergency stations, access and transportation network analysis should be prioritized. Because demand for travel after a disaster can fundamentally change daily travel demand, and in many cases, predicting travel demand may be uncertain, while in other situations, it may be impossible due to irrational behavior of individuals. Therefore, solving this problem in the first step requires an examination of all factors affecting network analysis with a traffic-oriented approach, and subsequent steps involve sensitivity scenario modeling based on various traffic network conditions during the crisis moment, taking into account various conditions for post-crisis management.

The main goal of this research is to investigate the status of the road network in Gorgan City after a crisis (earthquake). Additionally, emergency responders must reach earthquake-affected areas and transport earthquake victims to safe locations. To carry out these movements, the road network in Gorgan must be adequately prepared. In the following sections, we will review previous research, research methodology, and its results.

Literature Review

Several studies have been conducted in the field of emergency response and evacuation planning, with a focus on transportation networks and crisis management. Schrallier and Carter (1991) investigated the location modeling of shelters and presented an algorithm for evacuation planning under flood and hurricane conditions. Satyanathatwa and Ryan (1999) developed a dynamic traffic management model for evacuating nuclear power plants.

In recent years, due to various events in Iran, such as floods and earthquakes, research on emergency response within urban networks and transportation systems has gained significant attention. Many urban and comprehensive crisis management plans have been developed to ensure the delivery of optimal services to safe locations. Today, with the expansion of cities and the development of various transportation methods, route optimization has become more complex than ever before. Researchers have continuously sought the best solutions for this problem, taking into account the characteristics of the problem and its parameters.

However, less attention has been paid to urban emergency response and evacuation within the city, including the transfer of individuals to safe locations. Furthermore, standard and established parameters for determining suitable routes for emergency response in Iran have not been defined. Given Iran's susceptibility to disasters and the presence of vulnerable areas in various Iranian cities, addressing this issue is more critical than ever.

In recent years, several studies have delved into the topic:

1. Simon Turner et al. (2015) conducted research on "How to Act in Emergency Conditions: A Review of the Use of Social Media in Transportation Route Evacuation." They explored the role of social media in route evacuation and establishing healthy communication channels during crises.

2. Jane M. Binner et al. (2016) investigated the emergency evacuation process of urban transportation routes and how to make this process more effective using social media. They highlighted the significant role of social media in emergency evacuation and crisis management, emphasizing that these platforms provide a rapidly expanding field for discussing emergency evacuation, and their article extensively addresses the serious role of media in this regard. They discussed when emergency evacuation should take place and argued that facilitating emergency evacuation through social media should consider interventions based on evacuation within the broader concepts of disaster communication and crisis management. They also addressed various scenarios for desirable evacuation behavior and formulated a Bayesian algorithm that could achieve optimal evacuation in adverse conditions.

These recent studies have shed light on the importance of efficient emergency response and evacuation planning, particularly within urban areas, and have explored the role of social media in enhancing crisis management and communication during emergency situations.

In 1396, Motakten and colleagues conducted research titled "Intelligent Spatial Model for Optimal Route Finding in Urban Transportation Network" in the field of GIS (Geographic Information Systems) using metaheuristic algorithms. Optimization algorithms, particularly multi-objective algorithms like NSGA-II (Non-dominated Sorting Genetic Algorithm II), which are capable of considering multiple conflicting parameters simultaneously in a problem, can assist in solving such issues within GIS. The objective of this research was to propose an intelligent model based on the NSGA-II algorithm within the GIS framework for discovering optimal routes in urban transportation networks. To achieve this goal, the NSGA-II algorithm was adapted to preserve the topological structure of optimal routes (continuity and absence of loops) both in generating initial routes and in the genetic operators used. To this end, two innovative genetic operators tailored to the urban transportation route optimization problem were developed. Furthermore, to enhance the model's efficiency in providing optimal routes, aside from considering route length, traffic, and route quality as objective functions, intersection crossing difficulty was also included as another objective function. To evaluate the model's capabilities, a hypothetical urban transportation network with necessary constraints was designed, and the model was assessed using it. The obtained results demonstrated the accuracy of the model's performance and its high capability in finding optimal routes with multiple conflicting objectives.

Shari'at and Afandizadeh, in 1396, conducted research titled "Optimal Model for Emergency and Rescue Teams of Police Using ANP Method." They acknowledged the critical role of police forces as scene commanders in managing crises. Therefore, an appropriate location for deploying these forces as police bases on the country's roads would not only increase the efficiency of other responders in dealing with incidents but also reduce the consequences of road accidents nationwide. In this article, they described the current situation in the country regarding post-incident actions, crisis management, and the role of the police. They then employed location-based indicators and Analytic Network Process (ANP) methods to determine the placement of police operational bases.

In 2018, Borzou Rostami and colleagues conducted research titled "Solving Vehicle Routing Problems with Stochastic and Synchronized Travel Times." In this study, they addressed a version of the Capacitated Vehicle Routing Problem (CVRP) where travel times were considered uncertain and correlated (CVRP-SCT). Specifically, it was assumed that travel time followed a multi-variable probability distribution with known first and second moments. The primary objective of CVRP-CST was to plan vehicle routes with reliable travel times, meaning that observed travel times would not deviate significantly from their expected values. The transportation model in this research adopted an approach based on mean and variance. This led to a second-degree binary-parametric program, for which two separate algorithms were proposed based on price and time value. These algorithms were tested on a rich dataset with real-world information. Computational results showed that the algorithms developed in this research could solve vehicle routing problems for each vehicle with over 75 customers. Additionally, the obtained solutions significantly reduced time variability compared to the modified standard CVRP.

Chen and Li in 2018, in their research titled "Modeling Road Network Vulnerability for Earthquake Victims and Initial Evacuation Without Awareness," examined vulnerability in the development of transportation systems prone to catastrophic events and ensuring effective evacuation from vulnerable areas. Existing studies on road network vulnerability analysis have two significant aspects: evacuation without prior awareness and various evacuation goals and the initial behavioral response of individuals in the network. First, evacuation without prior awareness leaves limited time for proactive emergency planning. Therefore, rescue strategies in this scenario depend on real-time traffic information. Second, the goal of evacuation and the initial behavioral response of individuals in the network are to transfer immediately to the affected area after a dangerous event occurs, and the risk they face varies with the risky behavior of individuals. To address these concerns, this article provides a network-based model for assessing vulnerability during evacuation without prior awareness and applies it to a case study in Dublin, Ohio, United States. This model is suitable for evaluating network vulnerability in response to events with uncertainty and coordination and appropriate for traffic control strategies during initial unaware evacuation.

Tailor and colleagues in 2019, in their paper titled "Vulnerability and Sensitivity Analysis of Transport Networks: A Method for Identifying Critical Locations in Transport Infrastructure Systems," evaluated infrastructure and transport networks under critical conditions. Concerns from various perspectives, including development status, utilization of existing infrastructure systems, especially the permeability of transportation networks, were assessed. In this research, issues related to providing new infrastructure in public transportation, public participation in providing infrastructure, and understanding the hazards and threats to infrastructure were evaluated from both natural disaster perspectives (such as flooding, fires, or earthquakes) and human-induced factors like sabotage, war, or terrorism. Network access and permeability levels were measured based on criteria such as land use and traffic characteristics during a crisis using network analyzer tools.

Habibzadeh-Bijani and Salehi in (2021), introduced a two-objective mathematical model for the management of hazardous industrial waste, which provides systematic decisions at two levels, namely facility location and vehicle routing. They employed a simulated annealing algorithm to solve the problem in a case study in Tehran. The findings of the article confirm the effectiveness of the proposed method as it can find high-quality solutions within a reasonably short computational time. Therefore, based on the review of past studies, urban road networks are considered one of the most influential factors in crisis management in urban environments during incidents, with demand for using the existing road network reaching its maximum simultaneously with the occurrence of crises.

Determination of Effective Criteria for Network Evaluation during Crises

In urban transportation studies, travel speed, vehicle displacement between regions, and their economic, safety, time, comfort, and convenience aspects are directly related to the speed of the vehicles. When designing gateway networks, speed may be considered the most important factor. The goal in the crisis management base location problem is to increase the speed of service delivery and the transfer of individuals from different areas to these bases in the shortest possible time. Therefore, travel time can be considered one of the most important and influential factors in design. Additionally, determining the service levels of main routes and analyzing them for rapid emergency response is of great importance. The parameter of distance is directly related to the spatial dimension of the road network and can be easily calculated within a GIS environment. Considering the capabilities of Geographic Information Systems (GIS) in solving complex urban problems and the ease of spatial analysis and integration, these capabilities will be utilized. Based on a review of previous research and theoretical foundations, the criteria and sub-criteria for spatial analysis have been determined, as shown in Table 2:

Table 2 - Introduction of Information Layers and Influential Factors in Post-Crisis Services Delivery

Principles	Criteria	Sub-criteria
Efficiency	Physical tissue specifications	Proximity to worn-out texture
	Population	Population density
	Physical area specifications	Proper area
	Accessibility to communication network	Arterial roads grade 1
		Arterial roads grade 2
		Collector and distributor
		Local streets
Compatibility	Proximity to defense and emergency usages	Emergency and Red Crescent base
		Fire station
		Hospital
	Compatibility with usage	Green space and open space
		Educational
		Religious
		Sports and cultural

		Administrative and law enforcement
Safety	Observing boundaries with incompatible usages and spaces	Gas station
		Electrical substation
		Gas pump
		Pressure reducing stations
		Oil pipeline
		Gas pipeline
		Power transmission lines
	Geological specifications	Land slope
		Fault
	Torrent	River and boundaries
		Canal
	Type of surrounding vegetation cover	Agricultural
		Rangeland
		Forest

II. Study Method

A Geographic Information System (GIS) is a comprehensive system for working with computerized maps and managing spatial databases, providing a wide array of functions necessary for storing, retrieving, managing, analyzing, and displaying reference spatial data. The common capabilities of Geographic Information Systems include (Tahsin Pourghoshouni, 2012):

1. Cartography and thematic mapping.

2. Database management.

3. Interactive querying.

4. Spatial data marketing.

5. Spatial data processing.

6. Spatial data analysis.

7. Geographic logic coding.

8. Layering of different types (point, line, and polygon).

Additionally, a questionnaire was administered to a group of experts and university professors, and the results were analyzed. Another questionnaire was also distributed to drivers to analyze their behavior during earthquake emergencies. When neither the population variance nor the probability of success or failure of a variable is known, Morgan's table is used. This table provides the maximum sample size. In cases where the population variance or the error rate is not available, the well-known Morgan's table is used to estimate the sample size. This table provides a sample size for decision-making convenience with a tolerable error (0.05) and has been prepared for various situations.

Introduction of Data and Understanding of the Case Study

Study Area (Gorgan City)

Gorgan has three municipal districts: District One, District Two, and District Three. The total area of Gorgan County is 1,615.8 square kilometers, and the population of Gorgan County is 462,455 people. The population density in Gorgan County is 259 people per square kilometer. The population of Gorgan city was 28,000 in the first census in 1956. It increased to 51,000 in 1966 and to 88,000 in 1976. With the occurrence of the Islamic Revolution and the encouraging policies thereafter, as well as continued migrations, the population of this city increased from 140,000 in 1986 to 185,000 in 1996. The trend of this increase has accelerated in recent decades, reaching 390,000 in 2011.

Examination of Gorgan City's Road Network

From a structural perspective, the arterial road network within Gorgan city exhibits a more or less grid-like structure. However, in peripheral areas of the city, a circular structure can be observed. Nevertheless, even in the inner parts of the city, there is a tendency to create inner loops in some roads such as Qods and Resalat Boulevards. These loops, due to the dense urban fabric pushing the network toward a grid pattern, remain incomplete and only form isolated arcs that partially contribute to the overall grid structure. Figure 1 shows the structure of the main road network within the study area:

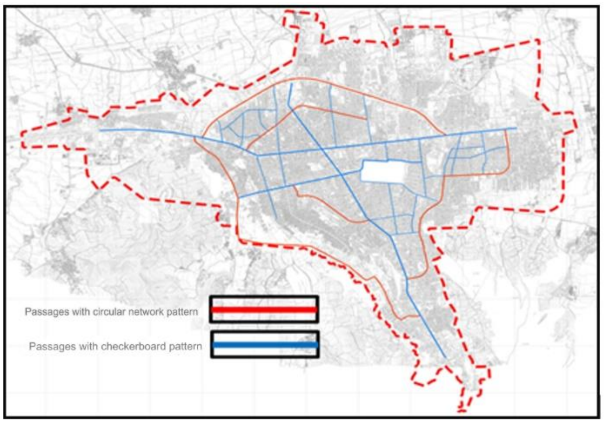


Figure 1 - Map of the main road network structure in Gorgan City (Gorgan Comprehensive Plan, 2013)

Additionally, in Figure 2, the hierarchy of main roads (up to collector and distributor levels) and some local streets can be observed:

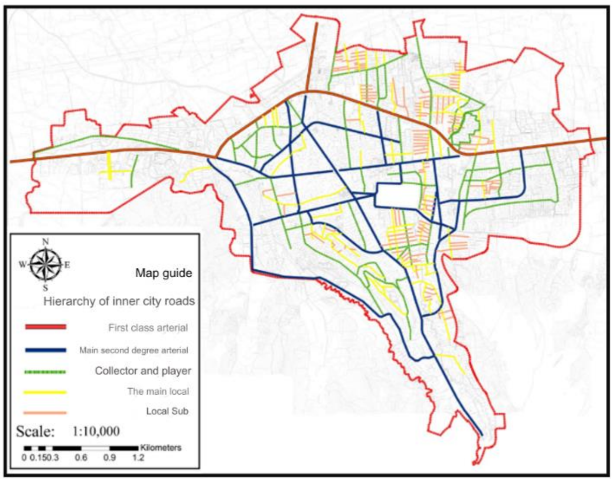


Figure 2 - Hierarchy map of inner-city roads in Gorgan

Data collection for vehicle volume counts is conducted during weekdays, from Monday to Thursday. The information in this section is derived from the Comprehensive Transportation Plan of 2017 (1396 in the Iranian calendar). As evident, vehicle counts are categorized into various types, including personal cars, taxis, vans, motorcycles, buses, minibuses, and trucks.

Traffic volume statistics for existing roadways should be collected during the peak hour and then converted into passenger car units. Therefore, considering the changes in volume observed at each intersection during each of the data collection sessions (morning, noon, and evening), the volume is ultimately reported as passenger car units.

Table 3 - Passenger Car Unit Factors for Urban Roads (Behzadi, 2011)

row	Vehicle type	Urban roads	
		two lines	four lines
1	taxi	1.3	1.1
2	Passenger car	1	1
3	Van - Nissan	1.3	1.1
4	Bike	0.3	0.7
5	Motorcycle	0.5	0.5
6	mini bus	2.5	1.5
7	Bus	4	2.5
8	Truck (Khavar)	2	1.3
9	truck	4	4
10	Trailer	7	5

After collecting traffic volume and calculating the capacity of the roadways, the ratio of volume to the capacity of the main roads during the morning and afternoon peak hours, as well as the level of service of the roadways, is calculated.

Eastbound **B12**	Arterial road grade 2	1502	0.54	**C**
Westbound **B12**	Arterial road grade 2	1882	0.78	**D**
Eastbound **B13**	Arterial road grade 2	1710	0.66	**C**
Westbound **B13**	Arterial road grade 2	1589	0.61	**C**
Northbound **B14**	Arterial road grade 2	1159	0.48	**B**
Southbound **B14**	Arterial road grade 2	1334	95	**F**
Northbound **C1**	Arterial road grade 2	896	0.41	**B**
Southbound **C1**	Arterial road grade 2	1688	0.77	**D**

Northbound **C2**	Arterial road grade 2	1618	0.7	**D**
Southbound **C2**	Arterial road grade 2	1853	0.81	**D**
Eastbound **C3**	Arterial road grade 2	1358	0.57	**C**
Westbound **C3**	Arterial road grade 2	1407	0.59	**C**
Northbound **C4**	Arterial road grade 2	1037	0.43	**B**
Southbound **C4**	Arterial road grade 2	1174	0.49	**B**
Eastbound **C5**	Arterial road grade 2	1470	0.59	**C**
Westbound **C5**	Arterial road grade 2	1506	0.6	**C**
Eastbound **C6**	Arterial road grade 2	2032	0.78	**D**
Westbound **C6**	Arterial road grade 2	1865	0.72	**D**
Northbound **C7**	Arterial road grade 2	1903	0.78	**D**
Southbound **C7**	Arterial road grade 2	1959	0.8	**D**
Northbound **C8**	Arterial road grade 2	985	0.47	**B**
Southbound **C8**	Arterial road grade 2	1411	0.67	**D**
Eastbound **C9**	Arterial road grade 2	1312	0.49	**B**
Westbound **C9**	Arterial road grade 2	884	0.34	**A**
Northbound **C10**	Collector and distributor	1058	0.48	**B**

Southbound **C10**	Collector and distributor	889	0.4	**B**
Eastbound **D1**	Arterial road grade 1	2118	0.39	**B**
Westbound **D1**	Arterial road grade 1	2814	0.52	**C**
Northbound **D2**	Arterial road grade 2	2147	0.65	**D**
Southbound **D2**	Arterial road grade 1	1934	0.59	**C**
Eastbound **D3**	Arterial road grade 1	2716	0.51	**C**
Westbound **D3**	Arterial road grade 1	2444	0.46	**B**
Northbound **D4**	Arterial road grade 2	405	0.16	**A**
Southbound **D4**	Arterial road grade 2	431	0.2	**A**

Intersection Delay Analysis

Given the numerous intersections in the road network structure of Gorgan, which is also of a circular-grid type due to its layout, it is advisable to consider the intersection delay as one of the factors for investigation. To this end, the positions of the intersections and the amount of delay imposed on each vehicle with their respective numbers are shown on the map in Figure 3:

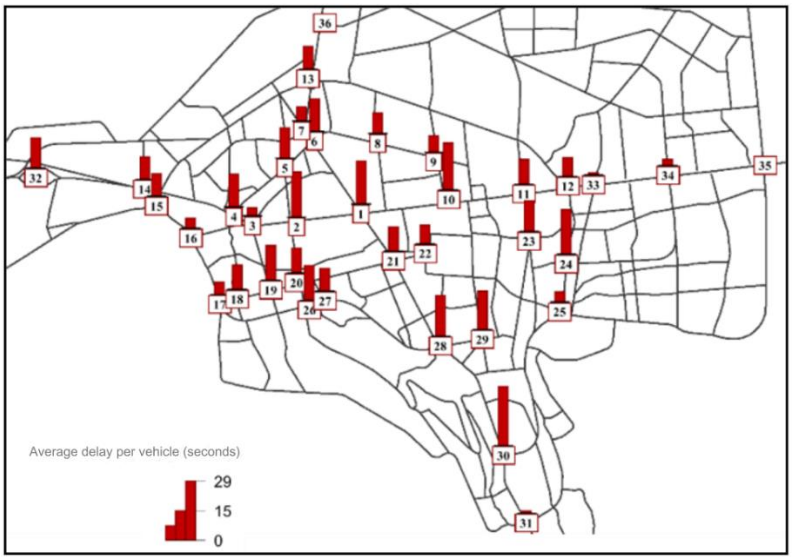


Figure 3. Intersection locations in Gorgan City and chart of average delay per vehicle at intersections.

Spatial Dimension of Gorgan's Road Network

Figure 4 provides a general schematic and spatial dimension of the road network, encompassing all various functions from primary arterials to local streets that have been accurately designed in GIS. Additionally, precise spatial design of the movement paths for some non-grade intersections is depicted.

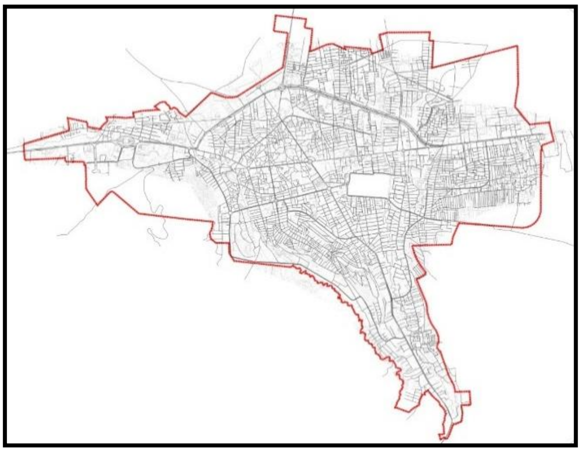


Figure 4. Spatial dimension map of transportation network along with some grade-separated intersections.

Determining the Number of Travel Lanes in the Streets

This issue is mostly significant in calculating the capacity and the volume-to-capacity ratio of the roadway, which was covered in the theoretical foundations and practical calculations in this study. In this context, Figure 5 illustrates the number of lanes in the city's road network.

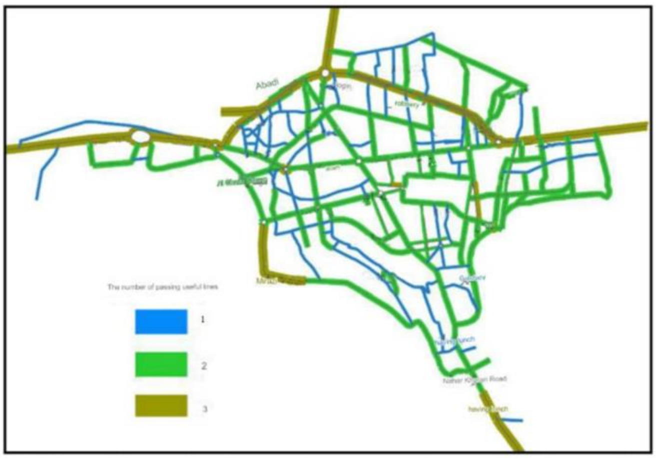


Figure 5: The Number of Useful Travel Lanes for Personal Vehicles

Sample Determination and Demographics of the Sample

In this research, the Morgan's method was utilized to determine the sample size. A total of 24 experts were selected to assess the importance of criteria through questionnaires. However, due to the unreliability of some questionnaires, some were excluded, resulting in a sample size of 20. Next, an overview of the general characteristics of the individuals who completed the criteria importance questionnaires will be presented.

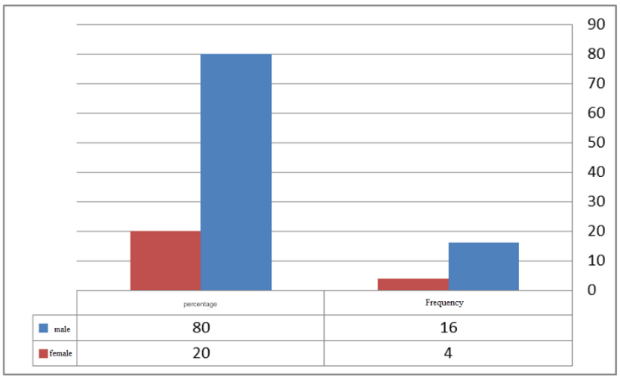


Figure 6: Frequency Distribution of Experts' Gender

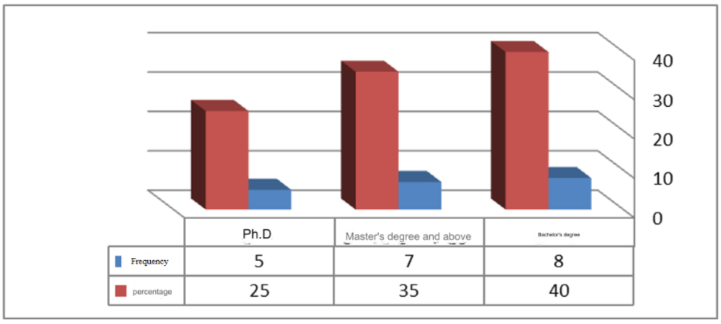


Figure 7: Frequency Distribution of Experts' Education Level

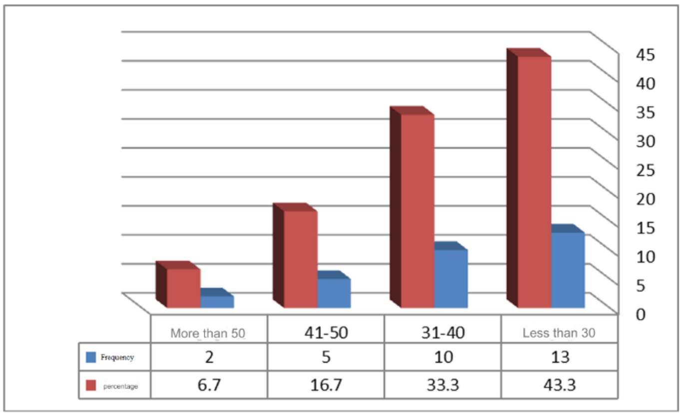


Figure 8: Frequency Distribution of Experts' Age

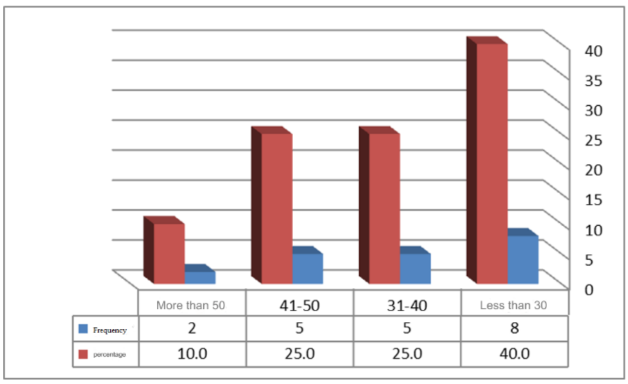


Figure 9: Frequency Distribution of Experts' Work Experience

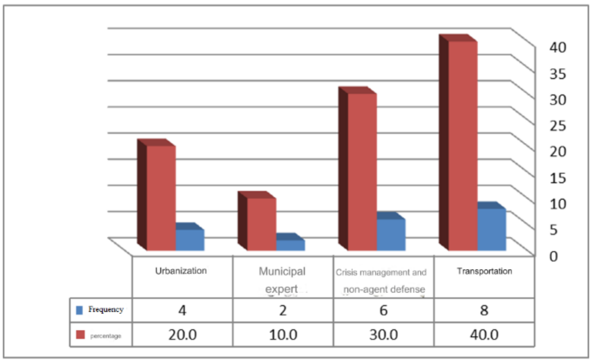


Figure 10: Frequency Distribution of Experts' Previous Experience

Assessing the Reliability of Expert Evaluations

The use of Cronbach's alpha coefficient is a method to determine the reliability of a questionnaire or test, with an emphasis on internal consistency.

Table 3. Cronbach's Alpha Assessment and Reliability Level of 30 Determined Criteria with 20 Expert Questionnaires

Reliability Statistics

Cronbach's Alpha	Cronbach's Alpha Based on Standardized Items	N of Items
.833	.826	30

Allocation of Variables to Factors

The table below illustrates the allocation of influential variables in assessing the factors affecting post-crisis service delivery status within the factors after rotation and 18 repetitions. Each variable is placed in a factor with a statistically significant high correlation, as indicated by the specified numbers.

Table 5. Rotated Factor Matrix - Evaluation of Factors Affecting Post-Crisis Service Delivery Status (Prioritization)

Rotated Component Matrix[a]									
	Component								
	1	2	3	4	5	6	7	8	9
Proximity of selected location to religious spaces	.921	.118					.249	.106	
Observing boundaries with incompatible power transmission lines	.840	.133			.222		.192	.156	
Observing boundaries with incompatible pressure reducing stations	.783		.291		.193		.229	.177	.123
Surrounding vegetation cover, agricultural lands	.757		.173	.341		.235	.316	.215	.150

Accessibility to communication network with local function	-.177	.931						.103	
Observing boundaries with incompatible oil pipeline		.869	.112	.180			.149		
Geological specifications, lack of fault	.141	.785	.248	.156					
Proximity of selected location to sports and cultural spaces	.264	.751	.363		.229	.215			.206
Observing boundaries with incompatible gas pipeline	.476	.586	.196		.179		.252	.117	.234
Observing boundaries with incompatible gas pump	.172	.166	.856			.174	.223		.101
Attention to canals, observing distance and boundaries			.822		.105	.152	.138	.117	.112
Surrounding vegetation cover, forest lands	.147	.164	.743	.328		.349			
Surrounding vegetation cover, forest lands	.265	.241	.720			.409	.279		.112
Observing boundaries with incompatible electrical substation		.590	.597	.108	.110	.182	.120	.222	.178
Surrounding vegetation cover, rangelands			.128	.948					.173
Proximity of selected location to administrative and law enforcement spaces			.130	.914	.195			.137	.164
Proper area of location			.357	.703		.108	.170	.457	.149
Geological specifications, lack of excessive slope	.396	.421		.556	.127	.365		.249	.174
Observing boundaries with incompatible gas station				.152	.944			.128	
Accessibility to communication network with collector and distributor function		.103			.942				
Proximity of selected location to educational spaces	.241	.321	.200			.787	.313		
Impact of proximity to worn-out texture			.183	.134	.319	.732	.362	.142	.218
Proximity of selected location to hospital	.494	.187	.277		.202	.552	.166		.194
Proximity of selected location to fire station	.225		.318	.189		.122	.796	.141	
Proximity of selected location to emergency and Red Crescent base	.294	.184	.114	.152		.362	.731	.113	
Population density	.232	.237	.199	.168	.407		.434	.364	.375
Proximity of selected location to green space and open space	.151				.247			.914	
Accessibility to communication network with arterial roads grade 2	.512	.249		.126	.213	.317	.318	.525	.185
Attention to rivers and canals, observing distance and boundaries				.419	.153	.147			.864

Accessibility to communication network with arterial roads grade 1	.588			.330	.107		.202	.144	.638
Extraction Method: Principal Component Analysis. Rotation Method: Varimax with Kaiser Normalization.									
a. Rotation converged in 18 iterations.									

As evident, considering the 9 eigenvalues, respectively the variables and factors such as: 1- Accessibility to communication network with arterial roads grade 1, 2- Attention to torrents, observing distance and boundaries from rivers and canals, 3- Accessibility to communication network with arterial roads grade 2, 4- Proximity of selected location to green space and open space, 5- Population density, 6- Proximity of selected location to emergency and Red Crescent base, 7- Proximity of selected location to fire station, 8- Proximity of selected location to hospital, 9- Impact of proximity to worn-out texture, 10- Proximity of selected location to educational spaces, 11- Accessibility to communication network with collector and distributor function, 12- Observing boundaries with incompatible usage of gas station, 13- Geological specifications, lack of excessive slope, 14- Proper area of location, 15- Proximity of selected location to administrative and law enforcement spaces have higher priority in post-disaster relief services.

Examining the questionnaire of people's and drivers' reactions after the occurrence of an earthquake in the street network

In the following tables, the general and personal characteristics of the collected questionnaires are examined based on statistical outputs from the software:

Table 5. Statistical Indices of the General and Individual Characteristics of the Collected Questionnaires

		Vehicle Ownership	Age	Gender	Occupation	Education Level	Primary Travel Purpose	Income Level	Average Traffic Calming Score
N	Valid	392	392	392	392	392	392	392	392
	Missing	0	0	0	0	0	0	0	0
Mean		1.452				3.485	3.051		3.362
Median		1.000				4.000	3.000		3.000
Mode		1.0				4.0	3.0		4.0
Std. Deviation		.4983				1.2428	1.0716		.9709
Variance		.248				1.545	1.148		.943
Sum		569.0				1366.0	1196.0		1318.0

In the table above, some of the key statistical indicators such as mean, median, mode, standard deviation, and data dispersion are displayed. These statistics pertain to the questions in the general section of the questionnaires. The most important evaluation question in modeling the flood model is the variable representing people's scores on traffic calming. The average scores have been calculated as the mean assessment, and the total score adds up to over 1300 points.

Table 6. Results obtained from questionnaire regarding different indicators

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	It has	215	54.8	54.8	54.8
	It doesn't have	177	45.2	45.2	100.0
	Total	392	100.0	100.0	
Valid	Age under 19 years	6	1.5	1.5	1.5
	Age between 19-25	78	19.9	19.9	21.4
	Age between 26-50	235	59.9	59.9	81.4

	Age between 51-70	73	18.6	18.6	100.0
	Total	392	100.0	100.0	
Valid	Male	198	50.5	50.5	50.5
	Female	194	49.5	49.5	100.0
	Total	392	100.0	100.0	
Valid	Retired	39	9.9	9.9	9.9
	Unemployed	8	2.0	2.0	12.0
	Homemaker	22	5.6	5.6	17.6
	Employed	248	63.3	63.3	88.8
	Student	44	11.2	11.2	100.0
	Other	31	7.9	7.9	25.5
	Total	392	100.0	100.0	
Valid	Below diploma	38	9.7	9.7	9.7
	Diploma	47	12.0	12.0	21.7
	Associate degree	86	21.9	21.9	43.6
	Bachelor's degree	129	32.9	32.9	76.5
	Master's degree and higher	92	23.5	23.5	100.0
	Total	392	100.0	100.0	
	Recreational trips	114	29.1	29.1	34.4
	Work-related trips	119	30.4	30.4	64.8
	Shopping trips	100	25.5	25.5	90.3
	Educational trips	38	9.7	9.7	100.0
	Other trips	21	5.4	5.4	5.4
	Total	392	100.0	100.0	
Valid	Very low income (1)	99	25.3	25.3	25.3
	Low income (2)	49	12.5	12.5	37.8
	Medium income (3)	235	59.9	59.9	97.7
	High income (4)	0	0	0	97.7
	Very high income (5)	9	2.3	2.3	100.0
	Total	392	100.0	100.0	
Valid	Very low response to road network during earthquakes (1)	26	6.6	6.6	6.6
	Low response to road network during earthquakes (2)	28	7.1	7.1	13.8
	Moderate response to road network during earthquakes (3)	149	38.0	38.0	51.8
	High response to road network during earthquakes (4)	156	39.8	39.8	91.6
	Very high response to road network during earthquakes (5)	33	8.4	8.4	100.0
	Total	392	100.0	100.0	

From the above charts, it can be concluded that the majority of respondents fall into the age range of 26-50 years old. The higher percentage in this age group is mainly due to the larger age range of 26-50 compared to the other ranges and the greater activity of this group in society. Additionally, efforts have been made to maintain relative balance between collecting questionnaires from both females and males. As evident, most individuals in the statistical population have personal cars.

Examination of Indicators Regarding People's Responses after an Earthquake in the Network

Based on the conducted surveys, people's responses in the system within the city of Gorgan have been evaluated, as described in Tables 7 and 8.

Table 7. Evaluation of the most important preferences of people during an earthquake in the study area.

People's preferences during an earthquake				
Challenges	Establishment in the surrounding environment of the house building	Going to public shelters in any location	Going to multipurpose crisis management sites and parks	staying at home
Percentage	38.8%	35.8%	19.6%	12.3%

Table 8. Assessment of Access to Needs After an Earthquake or Access to Safe Points in the Study Area

Access to Needs					
Challenges	Use of Local Streets	Main Streets within Urban Areas	Using collector and distributor streets	Transit Corridors and Belts	Other Issues
Percentage	18.5%	26.4%	23.5%	19.3%	12.3%

As mentioned, the design of the questions was based on variables that were confirmed to be important in the reactions of individuals after an earthquake in previous research. Additionally, other factors that emerged from initial exploration, field observations, and the opinions of experts and professors were integrated into the questions. The questions are divided into two sections, which are explained as follows. The table below illustrates the prioritization of qualitative responses, ranging from very low to very good:

Table 9. Rating of Factors Affecting Traffic Calming on Main Roads in the Studied Area, City of Gorgan

Variable/Statistical Indicator:	**Mean**	**Median**	**Mode**	**Std. Deviation**	**Variance**	**Sum**
1. Level of Service on Main Streets within the City	3.658	4.00	4.00	1.13	1.27	1434.0
2. Level of Service on Throughways and Beltways	3.508	4.00	5.00	1.30	1.69	1375.0
3. Level of Service on Local Streets	3.439	3.00	3.00	1.13	1.28	1348.0
4. Access to Key Transportation Services (e.g., gas stations, secure	3.406	3.00	5.00	1.33	1.78	1335.0

parking facilities within city limits, etc.)						

Examining Indicators Regarding Drivers' Responses after an Earthquake in the Network

In this article, the specific response of drivers during earthquakes was examined through the following questionnaire, aiming to assess traffic and investigate the traffic situation on city roads during an earthquake. The results are presented below. Given the research topic, its population, and the broad population size, the sample size for drivers was calculated using the following formula:

$$n = \frac{NZ^2P(1-P)}{Nd^2 + Z^2P(1-P)}$$

Where:

- N represents the population size.

- n represents the sample size.

- Z is the critical value corresponding to the desired confidence level (1.96 for a 95% confidence level).

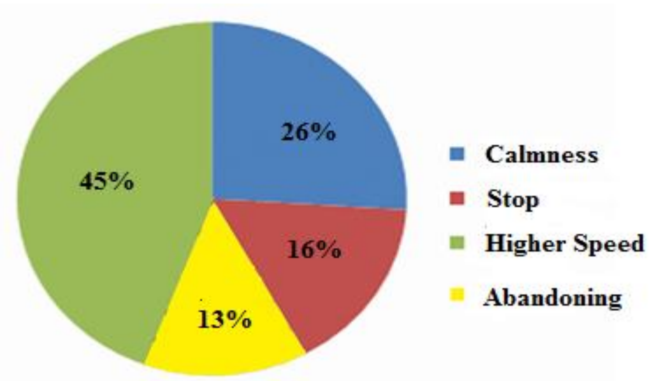
- P is the estimated proportion from previous studies (0.5).

- d is the acceptable margin of error (0.05).

Based on this equation, the sample size for drivers was calculated to be 100 people.

Driver Questionnaire	
Age:	**Gender:**
Do you continue driving calmly on your route during an earthquake?	
Do you drive at a higher speed on your route during an earthquake?	
Do you stop while driving when an earthquake occurs and then resume your route after the earthquake?	
Do you abandon your vehicle during an earthquake while driving?	
Have you ever encountered conditions while driving that led to an earthquake accident during your journey?	

Drivers' questionnaire form



Cronbach's Alpha (Questionnaire Reliability)

Cronbach's alpha coefficient is used to assess the reliability of a questionnaire or test with an emphasis on internal consistency. In this method, the components or sections of the questionnaire are employed to measure the reliability coefficient of the test.

Table 10. Evaluation of Cronbach's Alpha and the Reliability Level of 8 Variables Determined in the Response of Individuals After an Earthquake in the Road Network of Gorgan.

Reliability Statistics

N of Items	Cronbach's Alpha Based on Standardized Items	Cronbach's Alpha
8	.881	.882

Additionally, in Table 11, Cronbach's Alpha has been examined for each of the 13 influential factors in the response of individuals after an earthquake in the road network of Gorgan:

Table 11. Cronbach's Alpha for Each of the 13 Influential Factors in the Response of Individuals after an Earthquake in the Road Network of Gorgan when Removed

Item-Total Statistics

	Scale Mean if Item Deleted	Scale Variance if Item Deleted	Corrected Item-Total Correlation	Squared Multiple Correlation	Cronbach's Alpha if Item Deleted
Service Level of Main Streets Inside the City Limits	38.477	96.956	.713	.753	.865
Service Level of Thoroughfares and Beltways	38.783	95.234	.708	.766	.865
Service Level of Local Streets	39.153	100.800	.583	.699	.872
Access to Transportation Services (e.g., Gas Stations, Secure Parking, and Open Areas Within City Limits)	39.069	102.182	.565	.646	.873
Individual Preferences During Earthquakes	38.727	99.089	.597	.804	.871
Access to Needs After an Earthquake or Access to Safe Locations	38.709	101.971	.534	.804	.875
Status of Response and Service in the Gorgan Road Network During Earthquakes	38.867	97.282	.703	.651	.866

Examination of Land Uses Affected in Evaluating Factors and Conditions Affecting the Provision of Services to Individuals during Crises

Emergency and Red Crescent Bases

Emergency and Red Crescent bases, as rescue and risk prevention centers, can be considered in assessing the factors affecting the provision of services to individuals after a crisis.

Location of Fire Stations and Municipal Services

Among land uses and urban service spaces, the optimal deployment of fire stations is of significant importance due to the increasing attention to safety services and measures for disaster management in cities. Timely service delivery to fire stations depends, above all, on their coverage and accessibility, allowing them to reach the incident site as quickly as possible without encountering environmental obstacles and urban constraints, while minimizing negative impacts on residents' lives.

Hospital and Medical Center Locations

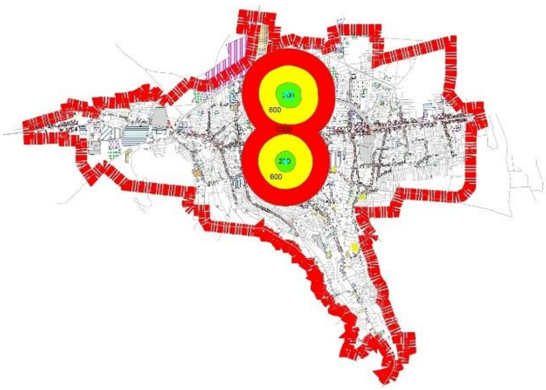
Based on conducted assessments, predicting the provision of healthcare services and the positioning of hospitals in post-crisis services can reduce or minimize mortality, illnesses, and physical and psychological disabilities resulting from natural disasters and unexpected incidents. Therefore, it is necessary to analyze the road network service level in a way that strategically positions it relative to hospitals and healthcare centers, ensuring preparedness for systematic response to potential crises.

Administrative and Law Enforcement Facilities

Administrative and law enforcement land uses, as support spaces during crises and afterward, can be highly significant. For example, uses such as city administration, law enforcement headquarters, governorates, etc., fall into these categories.

Hazardous Facilities and Their Regulations

In post-crisis service provision, certain land uses like power and gas substations, water reservoirs, etc., are highly impactful and need to be strategically positioned within a standard distance (approximately 200 meters) as recommended by the Provincial Crisis Management Department.



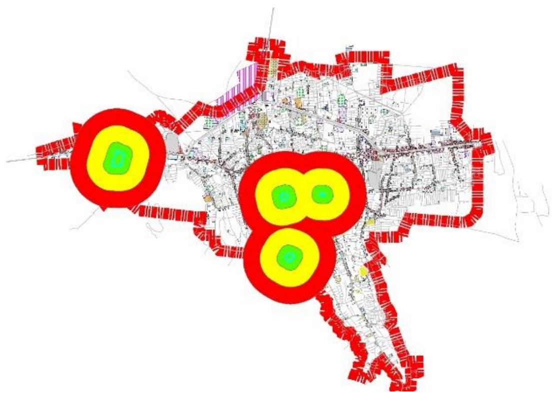


Figure A. Red Crescent and important emergency services

Figure B. Municipal and fire station services

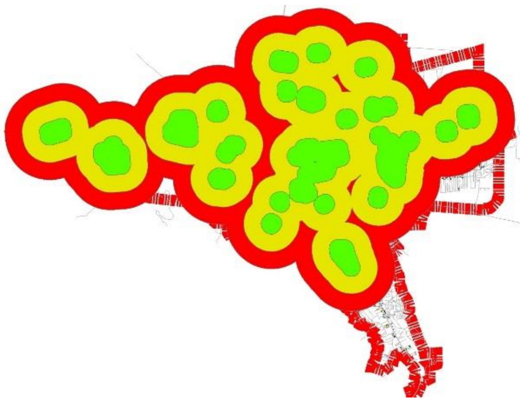


Figure D. Administrative and law enforcement

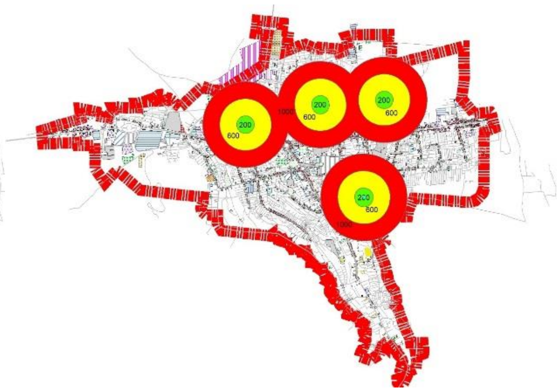


Figure E. Hazardous facilities

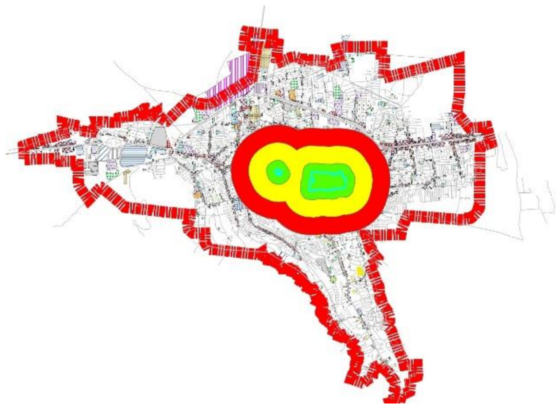


Figure C. Medical services

Figure 11. Suitable service coverage of bases and centers

Assessment of the Network Status and Post-Earthquake Services in Gorgan City

Pre-crisis planning is a crucial issue today for urban managers, especially in the field of crisis management. Given that Iran is among earthquake-prone countries, urban management must possess high capabilities and resilience to deal with natural disasters. Continuous efforts are required to reduce the adverse effects of urban crises, and post-crisis services have become part of the agenda of urban prevention and crisis management organizations in recent years.

One significant aspect to consider before analyzing the road network service level and proper accessibility to various land uses and functions is the assessment of service provision post-crisis. In the previous phase, factors influencing post-crisis services, such as highly accessible roadways, compatible and incompatible land uses, and certain regulations like river boundaries and fuel stations, were statistically analyzed and displayed using GIS. Now, before delving into the analysis of the transportation network, which is one of the most critical topics in this research, we will assess the level of road network service, taking into account the decline in permeability and access after the crisis. This will allow us to measure the interactions among these factors simultaneously.

The map below illustrates the impact on service delivery in the road network after crises in Gorgan city during natural and non-natural disasters, based on network criteria, in relation to emergency bases (Red Crescent, fire stations, and emergency services).

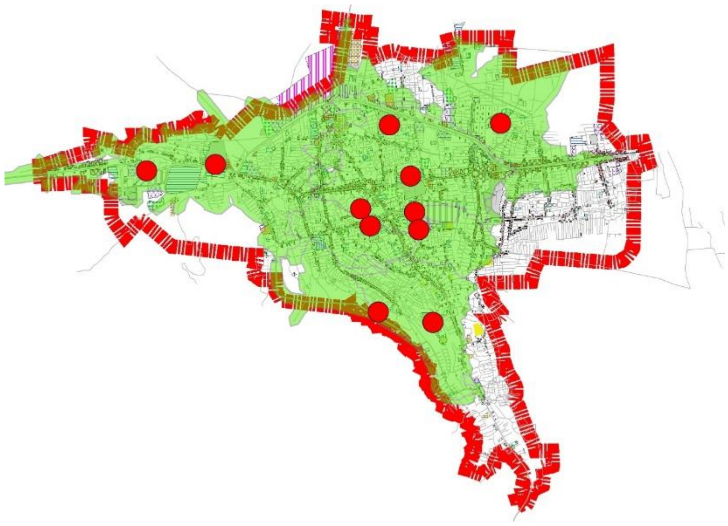


Figure 12. Map of Areas Affected by Service Delivery in the Road Network after a Crisis in Gorgan City

Creating Transportation Dataset

Considering the theoretical foundations discussed in Chapter 2, such as Geocoding, routing, topology, etc., in order to perform the analysis, we must first construct the network and simulate the connections of movement routes and their directions realistically within the GIS environment.

Analysis of Service Radius and Network Status Analysis after a Crisis in Gorgan City (Considering Proposed Locations

In the figure below, the service radius for 11 initial proposals in Gorgan City is examined at different times. As evident, areas in the western and southern regions of Gorgan City face challenges in service delivery due to deficiencies in the network's road conditions, particularly in the southern region where urban density is significantly high. Therefore, certain recommendations will be made to improve the road network's service level.

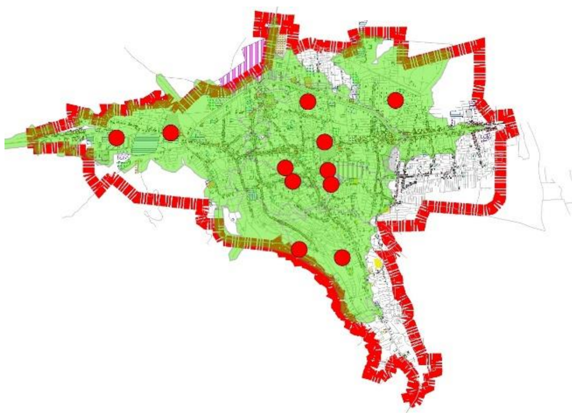


Figure 13. Network Analysis of Gorgan City for Access to 11 Initial Proposed Bases within 5 Minutes

As shown in the above map, almost all areas of the city, except for a portion in the west, south, and a specific area in the southern end of the city, have appropriate access within 5 minutes to the proposed initial bases. As mentioned earlier, these spaces can also serve public purposes such as parks, green spaces, sports activities, etc., even in non-crisis situations, providing services to various neighborhoods and districts of Gorgan City.

Additionally, to access the bases in the northern part, another station is proposed, mostly located near the beltway of Golshahr Street and Valiasr Boulevard (arterial road grade 2), while considering the riverbank's boundaries and other criteria. Ultimately, in this study, based on the factors affecting the network analysis of road conditions, 16 proposed points are suggested to establish these emergency-transportation bases in Gorgan City. The final map, which shows their locations and the time it takes to reach them, is as follows:

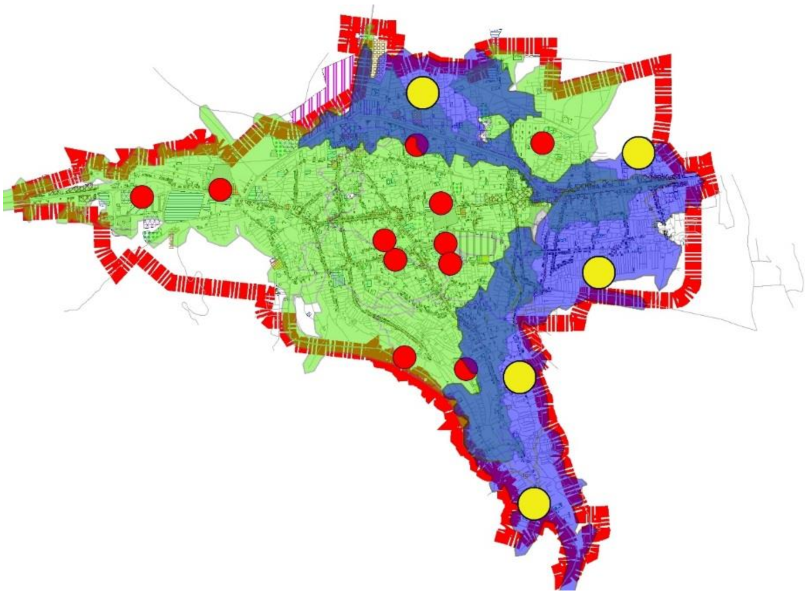


Figure 14. Network Analysis of Gorgan City for Access to 16 Final Proposed Bases within 5 Minutes

III. CONCLUSION

The location of public shelters and emergency-transportation bases should be determined based on suitable distances for quick access, urban structures, urban facilities, and other considerations. Coordination with regional organizations such as the regional water and power organization, telecommunications, Gas Company, sewage organization, and municipal authorities is essential. Ensuring the distance of the shelter location from pressurized fuel tanks and reservoirs, sewage, water wells, high-pressure cables, chemical storage facilities, and wells is mandatory. This distance is determined based on the potential risks associated with these factors.

The shelter's location must be coordinated with entry and exit routes to prevent blocking evacuees from adjacent damaged buildings and to ensure they are placed as close as possible to high-capacity and high-penetration routes. Based on the findings of this research, the following results and findings are presented:

1. Gorgan city, due to its location on the banks of several rivers, the surrounding topography, high population density, and an aging urban fabric covering over half of the city center, requires spaces with suitable access and comprehensive coverage.

2. Considering the hypothetical assumption above and the presence of suitable and penetrable accesses at the city level, proper management during crises enables the capacity to implement emergency and sheltering plans under the proper analysis of Gorgan city's road network.

As evident from the factor analysis results for 30 considered criteria, variables and factors such as:

1. Access to the communication network with the performance of grade 1 arterial roads.

2. Attention to drainage channels.

3. Distance and separation from rivers and streams.

4. Access to the communication network with the performance of grade 2 arterial roads.

5. Adjacency of the selected location with green and open spaces.

6. Population density.

7. Adjacency of the selected location with emergency and Red Crescent centers.

8. Adjacency of the selected location with fire stations.

9. Adjacency of the selected location with hospitals.

10. Impact of proximity to an aging urban fabric.

11. Adjacency of the selected location with educational spaces.

12. Access to the communication network with the performance of collectors and distributors.

13. Observing the separation distance from incompatible land uses such as gas stations.

14. Geological characteristics of the land (slope not exceeding the limit).

15. Adequate land area.

These factors prioritize transportation network services significantly, in terms of network functionality, permissible speed, distance, and travel times within the 5-minute timeframe. Due to inadequate coverage in some parts of the city, 5 additional bases have been proposed. After network analysis using GIS-T and Service Area tools, these 16 proposed points were analyzed for their network performance criteria, permissible speed, distance, and travel times within a 5-minute timeframe.

Finally, after identifying the criteria and spatial factors within the GIS system and spatial analysis of some areas, the analysis of the post-earthquake road network status in Gorgan city, along with 11 proposed points, was presented. After network analysis using GIS-T and Service Area tools, it was found that due to inadequate coverage in some parts of the city, 5 additional bases were recommended. In summary, these spaces are mainly located in green and open areas, sports fields, close to hospitals and emergency support spaces, at a suitable distance from riverbeds and hazard-creating facilities, and most importantly, in proximity to high-capacity and high-penetration routes, ensuring that people and resources have appropriate access to them during times of crisis. Additionally, considering the results of the questionnaire completed by drivers, where 45% of drivers continue to their destinations at higher speeds, there is a need to organize training courses on earthquake driving and how to deal with this crisis and promote this culture so that we do not face traffic difficulties and road closures in such conditions.

In accordance with municipal laws, municipal authorities are responsible for urban affairs and manage various services for citizens under normal conditions. These services include but are not limited to safety services, educational services, cultural services, urban development, urban transportation, waste management, and waste disposal. Based on the National Disaster and Relief Plan, more than 23 national task forces with responsibilities for various organizations and agencies have been anticipated. According to this resolution, the responsibilities of the Fire and Hazardous Materials Safety and Relief Team and the Debris Clearance Team (street and public space cleanup) and burial have been assigned to the municipal authorities. Therefore, municipal authorities are considered one of the most important organizations responsible for urban crisis management. It should be noted that the law on the organization of the National Crisis Management Agency and its executive regulations have also addressed this issue.

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