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Research Article

A Decision Support Model for Improvement of Urban Resilience through Accessibility Analysis

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Abstract

Decision support systems provide vital benefits supplying additional information before planning in disaster management. To improve a city's resilience against disasters such organization and maintenance must be conducted during the city planning stage. In this work, an improvement suggestion mechanism is built using risk value estimation through availability of emergency centers and road network redundancy is provided. This approach investigates the study area to determine possible risk zones within the city using routing and road network analysis. Upon investigation of the necessary parameters, a risk value is calculated for each administrative division within a city. These risk values are then passed to the decision support stage in which the system can pick one or several items from a list of improvements to reduce overall riskiness of these divisions. This work combines several ideas of emergency management domain in a formula to provide a quantitative meaning to possible risk within administrative divisions. Decision support aspect can be customized further to help planners have a preliminary analysis by showing the optimal locations to place new emergency management facilities.

Keywords: Decision Support, GIS, Emergency Management, Road Networks, Modeling

Introduction

Risk analysis is a vital component of disaster management, which can reduce the effects of disasters by alleviating the negative consequences of such events (Lv et al., 2013). Many models of risk estimation have been considered for a variety of disasters such as floods (Dai et al., 2019; Rav et al., 2019; Hadimlioglu et al., 2020), earthquakes (Jena et al., 2020; Maio et al., 2018), landslides (Erener and Duzgun, 2013) and other health hazards (Barth and Tomaselli, 2016; Bucher Della Torre et al., 2016). Furthermore, the domains that risk analysis is utilized, such as health, (Barth and Tomaselli, 2016; Bucher Della Torre et al., 2016) natural hazards, (Dai et al., 2019; Jena et al., 2020; Kiureghian and Ang, 1977) and forest fires (Bonazountas et al., 2005) determine the important factors such work focus on. These models focus on certain aspects of environments, sociocultural differences, road networks, earth conditions and many other parameters that are relevant to the focus of such studies.

Investigating disasters and innovating ways to counter their effects is an important task since such occurrences may cause damage to the environment and cause casualties (Messner and Meyer, 2006). Consequently, in the light of current concerns and mortality rates of COVID-19 (Zhou et al., 2020), health emergencies can also be considered in such resilience analysis. Indeed, there are several works that primarily focus on such an approach by incorporating distance from a health center and estimating changes in mortality rates (Haddad et al., 2015; Kelly et al., 2016; Nicholl et al., 2007; Wei et al., 2008). Furthermore, Hansen et al. (2018) suggests that the survival odds of individuals who have cardiac arrests outside hospitals may be increased if they are in the vicinity of the nearest fire station. Whether a natural disaster or a health hazard, these studies point out an important fact that as urbanization continues, road networks and emergency facilities need to be considered in such events. As geographic information systems (GIS) have been utilized in emergency management scenarios (Gunes and Kovel, 2000), new analysis methods, tools and techniques can be incorporated into management of vital facilities, components and infrastructure. Using GIS for geolocation, path finding algorithms and visualization of components, emergency management and response can be coordinated.

Organizing emergency management efforts requires a thorough investigation of the environment and population (Hamalainen et al., 2000; Pathirage et al., 2012). For this purpose, there have been a plethora of work underlining several important factors such as shorter distance to emergency management facilities (Haddad et al., 2015; Nicholl et al., 2007; Hansen et al., 2018), proper arrangement of such facilities within a city (Zhang Li, 2008) and an optimized road network for urban areas (Iida, 1999). Arrangement of emergency facilities within a city must be done by the city planners through proper analysis of the area. For this, several works investigate placement of emergency assembly zones (Cinar et al., 2018), fire stations (Aktas et al., 2013), hospitals (Sahin et al., 2019) and similar facilities within a city. Furthermore, road networks have been investigated for suitability for such emergency operations (Taniguchi et al., 2012). Road network redundancy is an important factor in continuity of service as certain parts of the roads may be blocked (Jenelius, 2010). Consequently, it has been an important task to analyze road networks for emergency preparedness, evacuation planning, relief distribution and access to emergency management facilities such as hospitals (Taniguchi et al., 2012; Maya Duque et al., 2016; Lu et al., 2005). These works underline the importance of proper arrangement, organization and optimization of facilities and road networks.

As the effects of natural and man-made disasters continue and will continue to be an area worth investigating, several works underlined the importance of network redundancy for maintaining resilience and innovated methods of computation of network redundancy. The work of Lhomme et al. (2013) emphasizes the importance of network redundancy for a city's resilience and provide a methodology using Web-GIS to help improve resilience. Furthermore, Jenelius (2010) underlines the concept of redundancy importance and uses two measures of traffic flow and travel delay to help quantitative decision support systems. Similar to the work of Jenelius (2010), Xu et al. (2015) introduce two measures to characterize network redundancy and underlines that both properties can complement each other to aid planners. Moreover, several works underline the importance of availability of nearby emergency management centers and distance being a factor in mortality rate (Nicholl et al., 2007; Haddad et al., 2015; Cudnik et al., 2008). Consequently, for a proper emergency management scenario there are multiple parameters about road networks and distance which all affect emergency management scenarios. An approach, which can help making a preliminary risk analysis about a given area, may be developed by investigating these parameters and innovating an easy method to generate a relative risk estimation for a given area.

This work applies several ideas mentioned in previous studies (Nicholl et al., 2007; Lhomme et al., 2013; Xu et al., 2015; Liu et al., 2006; Hansen et al., 2018) and models the effects of distance, existence of emergency management centers and alternative routes to compute a risk value within a study area. To accomplish such a preliminary risk evaluation, relevant layers, such as hospitals, fire stations and emergency gathering zones (EGZs) are geolocated, to perform distance calculation for each neighborhood, or administrative division, within the city. Upon evaluating the existence of these facilities within a certain radius and calculating the distances from these vital emergency management locations, a risk value is computed for each neighborhood. This specifies distance-based risk level of each administrative division, showing availability of the emergency facilities in the vicinity and the alternative routes from streets within neighborhoods to these emergency facilities. Once the risk values are generated, the decision support phase utilizes these values alongside a weighted adjacency matrix to determine possible improvements. In this stage, several suggestions, such as potential locations of new hospitals, alternative routes, and other emergency facilities are provided. This method is useful for providing distinct relevant parameters for each administrative division within a city. Local administrations can use this mechanism to analyze potential improvements within their areas. Furthermore, through this mechanism, city-level administrations can collaborate with smaller administrative divisions in a hierarchical fashion and manage a more comprehensive emergency management strategy.

System Design and Data Sources

Both computation of risk values and decision support mechanism incorporate multiple environmental parameters. These parameters are arranged according to their importance for the study area. Considering the entities used in this work, hospitals, fire stations and emergency gathering zones (EGZs) are vital entities that would affect emergency management efforts performed within the study area. These are provided to the system through certain files. Consequently, for any study area, emergency facilities and their coordinates must be provided to the system for risk computation. As the framework is built with customization in mind, researchers must provide any necessary relevant emergency facility information as the input to the processing phase of the system. Furthermore, for the application of routing and distance computation, World Street Map (Esri, 2020), a map data source which includes the road networks is incorporated.

As indicated earlier, the system is divided into three phases that perform the required operations. Initially the processing phase is utilized to load, merge, and assemble the required information for risk analysis. Next, the analysis phase acquires the processed information and utilizes routing options to compute each neighborhood's distance from emergency facilities. This phase also incorporates the availability of alternative routes to these facilities as a parameter, which is used in the risk value formula. In the context of this work, neighborhoods are considered as administrative divisions within a city. Districts, which contain multiple neighborhoods, are considered as larger subdivisions of a city. This organization can also be customized depending on the regional differences. This structure is organized to provide extra flexibility for the administration hierarchies that are involved in decision-making. Lastly, once the analysis is complete and individual risk values of each neighborhood are acquired, the decision phase is used to check the results, to make further estimations regarding the riskiness of the environment, and to provide certain suggestions to decrease the total risk value of the study area. The design of this system is shown in Figure 1.

This approach specifically benefits administrative divisions to customize their data sets and utilize a unique computation for their purposes. Such an approach is especially beneficial for decision-makers of these administrative areas. Rather than utilizing a computationally expensive process to gather information, incorporate certain empirical models and then perform the computation, an automated workflow to estimate a risk value for given administrative divisions can be useful for preliminary analysis of districts and cities. Therefore, the proposed method is not a solution to eliminate other risk estimation models; it is a model that complements them through providing a fast survey of the study area. The approach provided here helps assess overall risk values for each administrative division within a city, considering the distance of hospitals, fire stations, EGZs and availability of alternative routes from streets to these emergency management facilities.

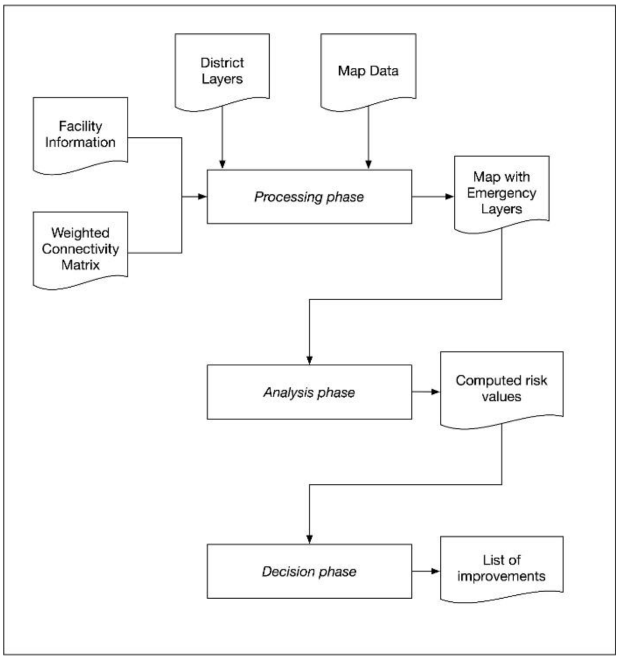

Fig. 1. Overview of the system design and the data flow.

The citywide emergency management effort, in which all the administrative divisions collaborate is not included in this study for atomicity purposes; each administrative division can perform analysis and prepare their own set of parameters for proper resilience. Through focusing on a customized set of parameters for each administrative division, a hierarchy of concerns is achieved. Upon successful assessment of risk values of each administrative division within a city, certain suggestions are generated, which can later be evaluated by the city administration for a global emergency management scenario.

Data Processing

In this phase, raw input in the form of comma-separated values (CSV) is brought into the system. Through utilization of these files, layers are formed with the needed information to make further computations regarding the environment. These files contain geographical coordinates, full address, capacity, number of vehicles, and other parameters of interest for hospitals, fire stations and EGZs. Furthermore, these three emergency centers are the definitive facility objects that the system utilizes to compute the risk values. Moreover, CSV files include weighted connectivity matrix for the administrative divisions. Once the information about the administrative divisions of the city and facilities are read, necessary structures are then created and placed in various lists in the system.

Hospital information can include number of emergency management rooms, personnel, capacity, and similar emergency related information to accommodate better risk value computation. This scheme also allows for institutions of varying sizes to be included in the risk value computation with differing weights, which provides for a more flexible calculation. Fire stations follow the same scheme with hospitals, and they also contain geographical coordinates, number of vehicles, personnel, and similar quantifying attributes. Fire stations and hospitals are both considered as primary disaster facilities in this system.

EGZs are included in the processing phase with a different approach. These centers are gathering zones for people in an event of emergency. Depending on the environment, fallout shelters and other protective infrastructure designated by the local administrations can be included in the data set as EGZs. Although they include a capacity attribute like a hospital, the way that these areas are utilized in the computation differ as the area of influence utilized in the system is local, described by a point feature with no additional circle of influence. For example, in an event of heavy flooding, emergency rescue vehicles visiting every single house in the neighborhood might be more challenging then picking up people from EGZs. Consequently, they provide a certain amount of relief to the emergency management efforts.

Additionally, the weighted connectivity matrix of administrative divisions within the city is provided as it is required both by the analysis and the decision phases. Through this matrix, distances from one neighborhood to the other are provided for the whole district. The distance values are provided as kilometers with two digits of precision. If the neighborhoods cannot be connected directly due to another neighborhood being in the way, or no road existing between two neighborhoods, then the matrix shows that the neighborhoods are not connected. Considering the connectivity between neighborhoods, the decision phase can reason about certain decisions, such as placement of certain facilities. As location and connectivity both play important roles, these matrices must be processed and placed in vectors associated with each district.

An advantage to the initial data processing approach is that the system becomes extensible through incorporation of additional data sources. As the option to embed more facilities is left to the researcher, it can be further extended and modified for more detailed analysis. Consequently, once the geospatial data are properly structured, any customization is possible. Furthermore, during the processing phase, weights of importance can be altered using the system, further specializing the analysis. This allows the decision makers to customize the parameters according to the needs of their administrative areas. This is a major advantage, which allows the administrators to customize the geospatial parameters and environmental factors to perform a preliminary risk assessment.

These layers must be accommodated with the information relevant to the study area for visualization of the environment and computation of risk values. In many cases, placement of emergency management facilities is done according to population and the organization of neighborhoods. Thus, provision of such information helps the system focus on the administrative areas for proper risk value computation. This information in combination with the facility information mentioned earlier and a map data source providing road networks completes the processing phase.

Risk Value Computation through Accessibility Analysis

The analysis phase consists of acquisition of layer information, computation of risk values through neighborhood analysis and generating a heat map of risk values. Within the context of this work, a risk value is the quantitative value of an administrative division's resilience. This value considers distances to emergency management facilities, number of these facilities within an administrative division and road network redundancy of the study area. In this phase, neighborhoods are analyzed for emergency management risks through evaluating multiple parameters. Road network information is used by searching for alternative routes and distances to emergency management facilities such as hospitals and fire stations. Furthermore, this phase incorporates availability of EGZs within or around the neighborhoods and alternative roads in case of a failure. As indicated earlier, emergency management facilities can further be customized, yet for consistency purposes this work utilizes two default types of facilities for the analysis: hospitals and fire stations.

Number of fire stations and number of hospitals are directly related to a region being suitable for emergency management. Therefore, they are included in the risk estimation alongside EGZs, which may be helpful in maintaining rescue efforts. In the absence of hospitals and fire stations in the immediate vicinity within a neighborhood, number of EGZs can alleviate some of the inconveniences by allowing the people to gather and await rescue vehicles. This approach proves to be useful especially in cases of disasters that affect the road network. Furthermore, the distances from fire stations and hospitals are vital in risk computation. This is due to a higher mortality rate for patients who are further away from these emergency centers. As distance increases the time spent in a rescue vehicle, this may increase casualties that occur within rescue vehicles. Furthermore, distance may also cause further casualties within hospitals even if the patient survives the road as some patients may require immediate attention by a hospital (Haddad et al., 2015; Kelly et al., 2016; Nicholl et al., 2007; Wei et al., 2008). The risk value is computed through the Equation 1.

$$R_{zone} = \frac{(k_1 d_h) + (k_2 d_f)}{(1 + n_h + n_f)^2 + n_{egz} + n_{alt}}$$

Equation 1. Risk value calculation formula.

In the Equation 1, d_h refers to the distance from a hospital, while d_f refers to the distance from a fire station to a population zone. These values have coefficients k_1 and k_2 respectively to provide a measure of riskiness. Depending on the study area or the administrative choices, these coefficients may be utilized to provide a differing scheme. In this study these coefficients are used to uniformly square both distances, indicating an increase of risk for both. An increase from 10km to 30km in distance may not mean 3 times the risk, yet a relative risk quotient may be utilized to signify a dramatic increase in risk as distance increases. Therefore, the risk increases rapidly as the closest emergency management center goes further away. Nevertheless, for administrative divisions, travel distance is not the only factor that would affect the risk value. Considering that the availability of these centers also provides a benefit, n_h, n_f, n_{egz} and n_{alt} define number of hospitals, fire stations, EGZs and alternative routes to these centers.

To compute the distance to emergency management centers, alternative routes from neighborhoods to the emergency management centers are extracted using the map data. Upon extraction of these alternative routes, an average distance value is computed for each neighborhood. Furthermore, shortest paths from each neighborhood to the emergency facilities are computed through the customized A* algorithm (Hart et al., 1968) implemented for the system. This algorithm is also used for computing distances between newly constructed facilities and neighborhoods in the decision phase. Considering the distance being an important factor in potential mortality rate, hospitals and fire stations are considered as most effective in a 5km radius. Beyond this value, the zones are considered as having no nearby facility. This in turn increases the potential risk of the environment. Indeed, considering a populated urban environment, a hospital being 10km away may cause inconveniences due to travel time, as others living nearby to the hospital may need servicing as well.

Aside from the distance, which is an important component of the computation, number of the entities also play a vital role. According to the specification, number of hospitals and fire stations provide greater support for emergency management than number of EGZs and alternative routes. As an example, a community with two alternative routes to the hospital, which is 20km away, can be considered. An increase of number of routes would provide vehicles additional access to the community if one route gets blocked. This would alleviate the negative circumstances that a disaster may cause in the region. However, as the emergency management center is the only one within 20km, it may take a while until the neighborhood receives some help from the only hospital in the area. If an additional hospital is placed closer to the neighborhood, additional vehicles could be included in the scenario, which potentially could bring help faster to the area.

Emergency gathering zones would not directly increase the speed of service, yet they may provide a safe location for the people to wait for emergency vehicles and personnel. These zones could possibly help with first aid efforts and therefore, they are included in the computation as well. Placement of these EGZs is planned and evaluated by city planners and consequently, it is expected that the EGZs can help the surrounding communities by providing adequate capacity.

Finally, the number of alternative routes is incorporated in two ways. First, in computation of distances to emergency management centers, distances of each alternative route from streets to these facilities are calculated, and their averages are taken to estimate average distances from each street to the emergency management centers. By calculating the averages of the distances from each street to emergency management facilities, an overall accessibility value is acquired to be used in risk value computation for each administrative division, or a neighborhood. Furthermore, the number of alternative routes is used similarly to number of EGZs, which is considered a minor risk alleviation in each area. In choice of alternative routes, major higher capacity roads are considered as streets may not affect the overall scenario considering larger study areas. An example, which shows the utility of alternative routes, is provided in Figure 2.

Fig. 2. Application of Alternative Routes in Risk Value Estimation. Satellite Imagery from Google, CNES / Airbus, Landsat / Copernicus, Maxar Technologies, Map data (2021).

Upon consideration of all parameters, a risk value for every neighborhood within the district is computed. These values are then classified utilizing Jenks natural breaks classification method (Jenks, 1967) for proper categorization, which will then be used for coloring the map. Among the choices of data classification, natural breaks classification is effective in maximizing the differences between groups of values. On the other hand, while manual or defined intervals would precisely group the risk values, it would require additional effort for each new study area for refinement. Consequently, it is practical to choose natural breaks algorithm for representing significant differences on maps. Using a diverging color scheme, lowest risk zones are indicated as darker green while highest risk zones are shown as red. Coloring phase is parametric and therefore, number of classes can be altered depending on the study area, which in turn changes the variety of colors on the map. Number of classes may affect how the feeling of riskiness is delivered and therefore, different number of classes may need to be generated and then evaluated for suitability.

Decision Support through Risk Value Optimization

The final phase of the system utilizes the decision-making engine to generate solutions that would alleviate the issues considered in the previous phase. According to the design of the risk formula, a high-risk value is the result of high distance values to emergency centers, lack of these centers in the vicinity, and unavailability of alternative routes. As higher risk values correspond to a potentially higher damage and mortality rates, the system tries to balance the risk values throughout the district by trying to reduce the risk values by utilizing the list of improvements it can apply to the study area. As these improvements are categorized according to the cost and importance, some of these tests can be skipped if they are not applicable for the study area. Through customizing the weights of importance of the suggestion items, it is possible to rearrange, ignore or enforce certain types of suggestions. Figure 3 shows the overview of this phase.

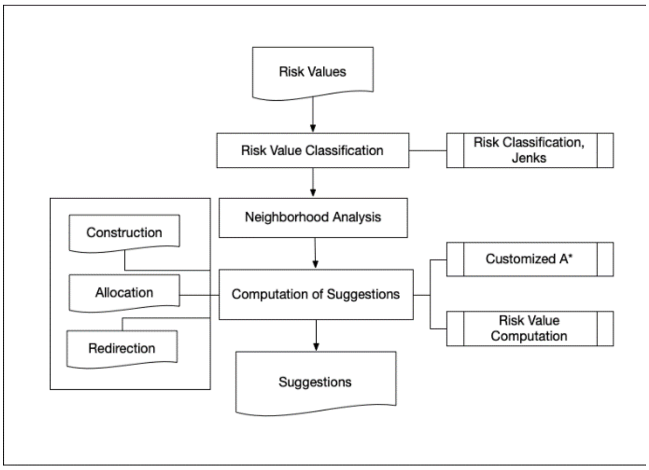

Fig. 3. Overview of the decision-support phase

Minimizing the cost can further be guided through provision of certain restrictions to the system. Population plays an important role as the system considers a hospital or a fire station per number of people, which can be customized further to match regional emergency preferences. This prevents the system giving a decision of a new hospital or a fire station construction in smaller areas. Population is also useful to allocate new EGZs as the system needs to know about the population of the area to decide on their locations and capacities. Like the layers that the system can initially receive in the data processing stage, this portion can also be customized to involve additional decisions that are relevant to the study area. Each neighborhood, or administrative division, within the district is considered according to its connectivity with the other neighborhoods. For this purpose, a weighted connectivity matrix is supplied for the purpose of performing spatial analysis on the study area. The weighted connectivity matrix focuses on the cost in terms of distance and thus, it is directly used in route selection stage. To perform route selection, each neighborhood is associated with its connected neighborhoods as nodes. These nodes are considered destinations and are used in computation of paths to emergency facilities. Once the data is structured in a tree format, a customized A* algorithm, which focuses on finding shortest distances to certain emergency management facilities is performed. As the risk value is acquired in the previous stage, this phase can reason about the environment in general and pinpoint risky neighborhoods and their connected neighborhoods to consider improvements. With the connectivity matrices in use, the locations are marked considering their levels of importance. This process also incorporates population as previously underlined and therefore, it is a distinct step than merely assigning risk values. Once the marking process is complete and neighborhoods are marked according to their general riskiness, the system proceeds to the next step to pick one or several improvements among the list of applicable measures. To reduce the riskiness of neighborhoods there are several categories of decisions that the system can make. These categories are provided as modular to be further customized if required. This customization can place additional constraints on local administrations if the city-level administration does not approve certain types of improvements. Furthermore, if there are restrictions regarding cost, categories can be omitted from decision-making phase, making the decisions more cost-efficient

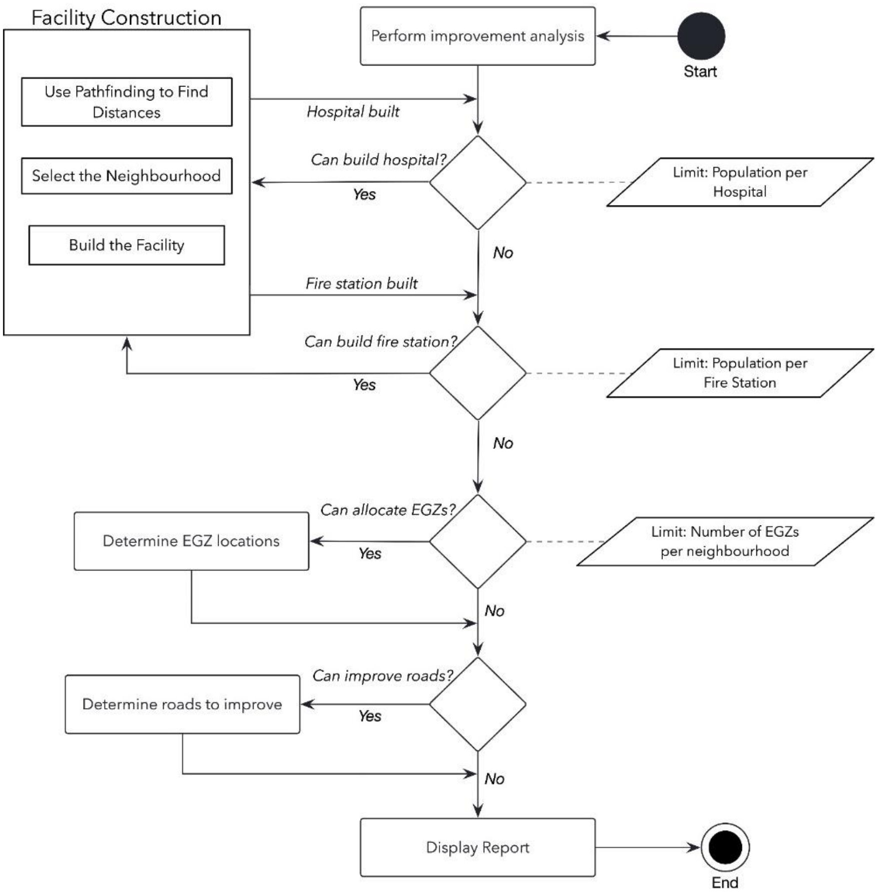

Fig. 4. Overview of the decision-support phase

for the administration. The default implementation contains 'construction', 'allocation' and 'redirection' as broad categories of actions the system can perform. The flow diagram of performing improvements in the environment is visualized in Figure 4. Initially, this phase analyses if a new hospital or a fire station is required for the area. To go through this analysis, it requires some values provided manually, such as how many hospitals and fire stations should be used per certain population. This value determines the leniency this phase considers when it is giving construction decisions. Upon evaluating construction options, it proceeds with EGZs to allocate. Finally, it evaluates road redundancy per neighborhood to estimate if improvements are required.

Construction category includes construction of hospitals, fire stations and any necessary emergency management facilities that the system recognizes from data processing stage. As the weights of importance are already embedded in the processing phase, decision-making engine has means to quantify each of their importance for the study area. EGZs and other 'areas' can be allocated by the system to provide relief in events of emergency. This option provides a minor alleviation to the underlying issues, yet it can be utilized for neighborhoods that have no such zones. Lastly, redirection computes routing options a particular neighborhood has and decides if addition of alternative routes can help maintain emergency management efforts. To compute this, it checks if a minor number of routes can possibly reduce the risk level of the neighborhood to a lower category. If so, it determines that route improvements can be performed. As each one of these options contain a cost, which can be modified by the researcher to match the actual localized costs, the system tries to lower the risk while keeping the costs at a minimum. This step performs a series of computations using the risk value calculation formula and repeatedly trying to place emergency management facilities to appropriate locations. After each operation, it compares the previously computed overall risk value of the study area with the new one. Once an optimal level of risk is achieved, which is to reduce the risk values below a certain value depending on the computed values, the operation stops and a report containing decisions is displayed.

Results

To test the capabilities of the methodology, a study area is selected. The study area selected for this work is Urla district of the city of Izmir, Turkey. Urla is in the western part of Izmir where a peninsula with the same name is formed, and it has a population of 67,339 by 2019 according to Turkish Statistical Institute (2020). Considering the urban population, although the town, also called by the district name, can be considered populated, residential areas are scattered and thus, a large area must be covered for any emergency management operations handled in the district. This makes the location particularly interesting for this work as emergency operations in such an area would be challenging. As it is known that rural areas may prove to be detrimental in terms of road network redundancy, districts with such scattered urbanization should be analyzed to estimate possible accessibility issues. Focusing on the nature of how the population is spread across the district and landscape affecting the major roads and servicing lines, it is important to detect any inconveniences the district may face in an event of emergency.

As this work incorporates information regarding road networks, World Street Map, which is curated from multiple data sources such as U.S. Geological Survey (USGS), U.S. Environmental Protection Agency (EPA) and Esri, is utilized as the base map. This base map contains necessary information such as highways, major and minor roads, and railways to be utilized for risk value estimation. Although more can be incorporated, it is beyond the scope of this study.

Furthermore, to accommodate the need of emergency management facilities for calculations, fire stations, hospitals and emergency gathering zones (EGZ) are defined on the map. For EGZs, capacity and type of zone is also embedded into the data for use if required. These layers are resourced from several governmental institutions, such as Izmir Fire Department (2020a,b), Republic of Turkey Ministry of Health (2020) as raw textual information, converted into appropriate GIS layers and then incorporated into Esri's ArcGIS Online for visualization purposes. For this work, the study area is divided into 51 neighborhoods to be investigated further.

Figure 5 shows the resulting map once the raw data is processed. From visualization, it becomes clear that in Urla there is a single hospital, a single fire station and multiple EGZs. Considering the population of Urla, which is approximately 70,000, additional stations can possibly be helpful in risky scenarios, considering the population distribution and landscape. Furthermore, number of EGZs would alleviate some of the inconveniences by providing safe gathering zones for the people, who can be helped via helicopters, boats, and buses. Initial analysis shows that the capacities of these EGZs are sufficient for handling such operations considering the population. Some parts of the district remain quite unreachable, due to long distances from the hospital and the fire station. Such remote locations contain fewer major roads than areas closer to the district center.

As discussed earlier, roads were analyzed and utilized in computation both for evaluating the road network availability and calculating the distance between important centers and the neighborhood in question. Weighted connectivity matrices, which are structured in the processing phase as multidimensional arrays are used for this purpose. Using A* algorithm, shortest paths from each neighborhood to the closest emergency facilities are calculated. Once these paths are computed, as the neighborhood information already contains number of roads, hospitals in vicinity and the other required information, there is no further need for the matrices until the decision phase.

Once the road networks are evaluated and parameters that are needed for risk value computation is acquired, the system proceeds to the next stage. After the risk values are computed, the neighborhood map is visualized using ArcGIS Online with the utility of World Street Map and the layers, such as fire stations and hospitals generated for Urla. The risk values are classified into 6 classes using Jenks natural breaks classification method and the neighborhoods are colored utilizing a diverging color scheme from dark spring green to red. The ranges used for visualization are also provided by the system within the output. Figure 6 shows a portion of the system output produced in the analysis phase and the colored risk map of Urla, Izmir. The output can be set up to print the risk value of any neighborhood of choice. For convenience, in Figure 6, the risk value output of every 10th neighborhood in the study area is provided.

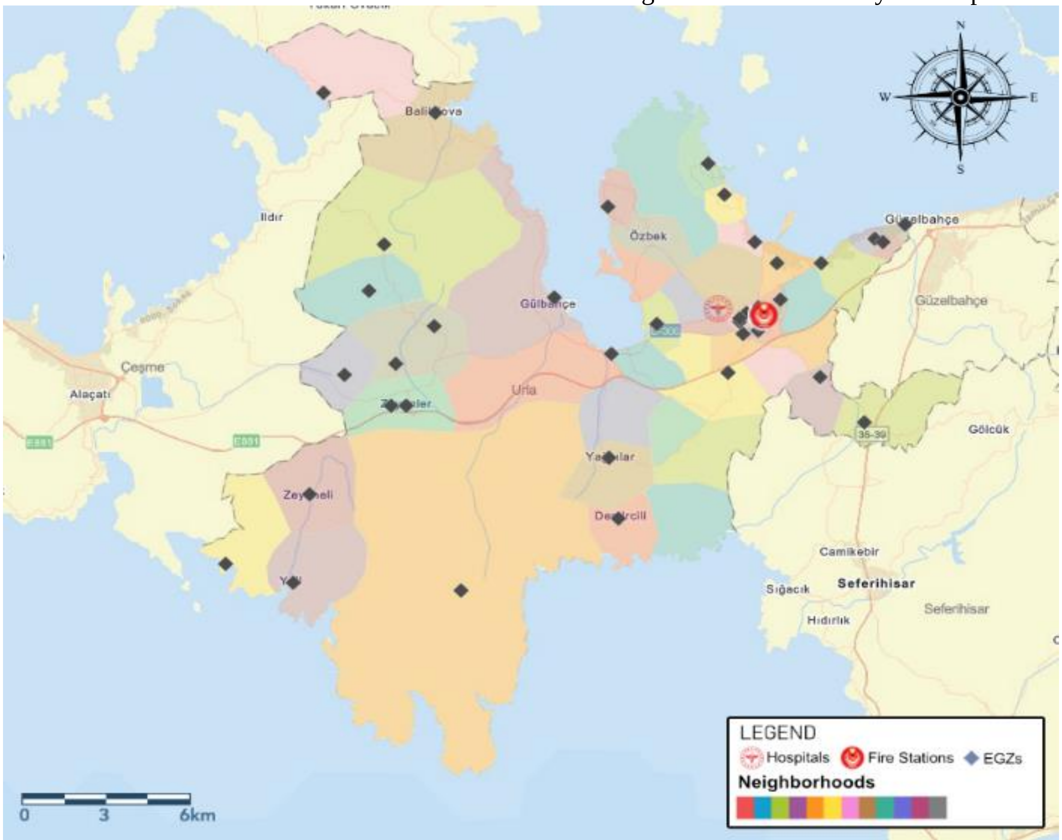

Fig. 5. Map of Urla, Izmir showing hospitals, fire stations and EGZs.

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Risk value of the neighborhood 0 is: 0.78
Risk value of the neighborhood 10 is: 134.27
Risk value of the neighborhood 20 is: 227.62
Risk value of the neighborhood 30 is: 215.85
Risk value of the neighborhood 40 is: 20.88
Risk value of the neighborhood 50 is: 1.16
Total risk of the environment is: 12248.90

The following classes must be used for risk visualization:
0.34 - 93.16
93.16 - 606.57
606.57 - 742.29
742.29 - 1294.15
1294.15 - 1777.22
1777.22
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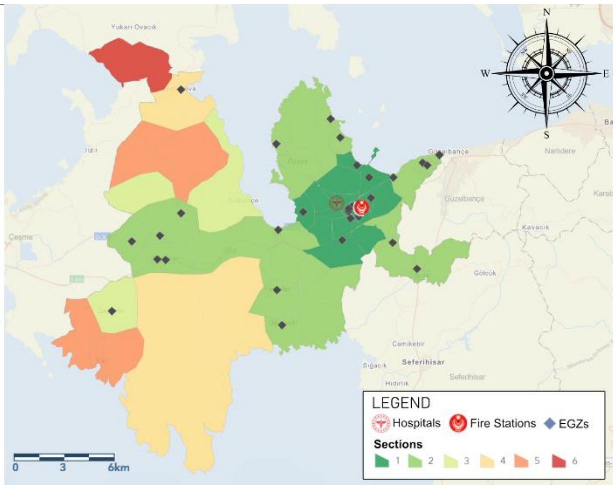
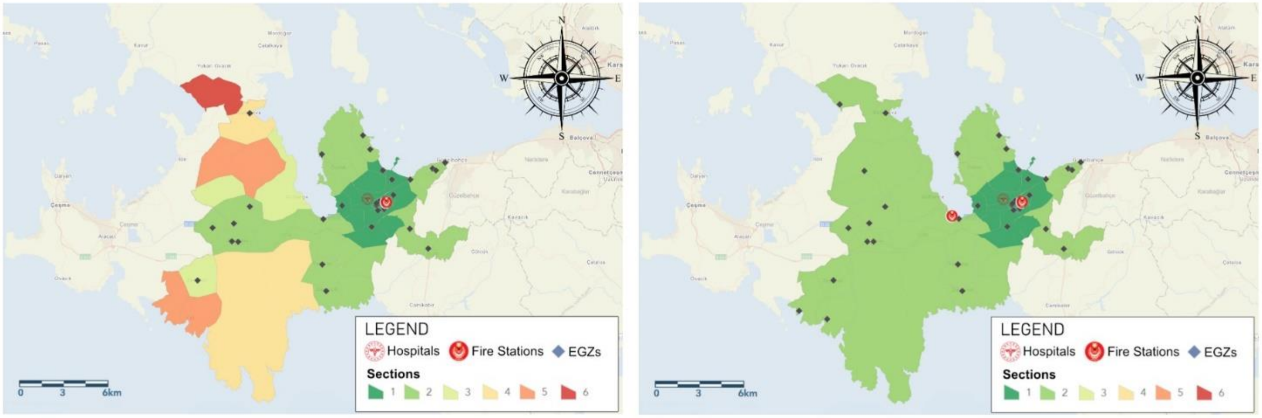


Fig. 6. Part of the output and the map of Urla, Izmir colored with risk values.

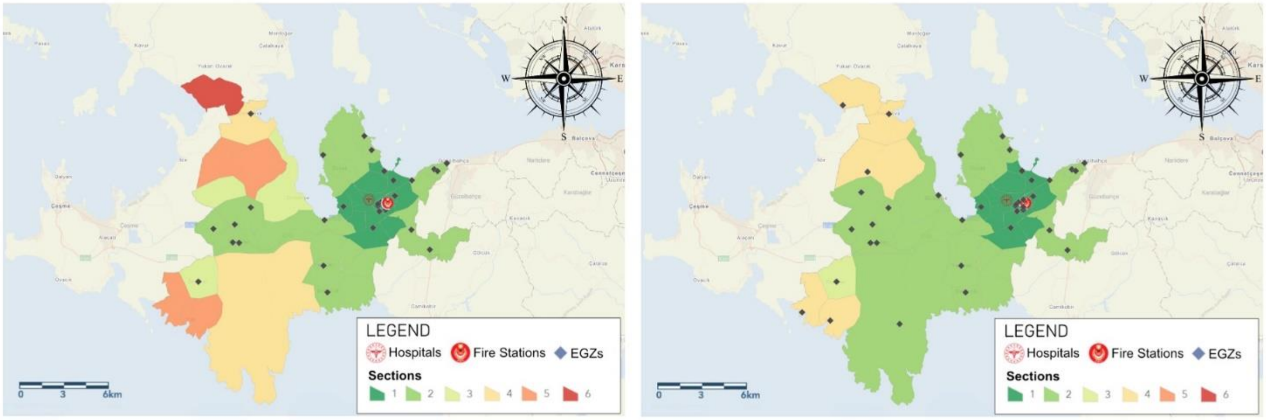
According to the results shown in the previous phase, the neighborhoods that are far away from the district center have the highest risk values. Distance is not the only problem in the study area; the landscape and as a result, lack of major roads contribute to a higher risk value. The effect of EGZs and a proper road network can be seen towards the north of the district. As it can be seen, an administrative division, further away from the district center can be considered lower in risk value due to the availability of EGZs. It can be inferred that availability of an EGZ would help collect victims of the disaster, which would alleviate the issues that could occur in the rescue efforts. At this point, the decision phase applies several steps to perform further analysis and estimation of improvements. Firstly, this phase checks the population of districts and according to restrictions provided by the researcher, such as people served per hospital, it determines if such improvements are worthwhile. In Urla, per the default values provided in this test, it is considered one hospital per 70000 people and one fire station per 35000 people should be allocated. After hospital and fire station evaluation, EGZs and alternative routes are also evaluated.

Once these tests are performed, the decision phase indicated that construction of a hospital is not required yet a fire station can be built at neighborhood 30 and several EGZs can be allocated at neighborhood 22, 24, 25 and 32. Furthermore, the system offered to improve routes from neighborhood 25 as it had less than average road network redundancy compared to others in the district. With these suggestions implemented, the environment is visualized similar to the risk map previously generated in the analysis phase. Figure 7 shows the comparison of the original and the new risk maps. There is an overall improvement in the study area as the sum of neighborhood risk values of the initial map is 12248.90, while it is reduced to 5912.49.



(a) (b)

Figure 7. Visualization of the risk values (a) with the initial data and (b) once decisions are applied



(a) (b)

Figure 8. Visualization of the risk values (a) with the initial data and (b) with EGZs allocated

As the decision phase can be guided by the researchers' restrictions, another scenario is provided to experiment with this phase further. In this scenario, the assumption is that the construction of a new fire station is too costly for the district. Furthermore, route improvements cannot be proceeded with as the budget is insufficient. The only way to improve the neighborhood is to allocate EGZs if needed. Once these restrictions are provided as the rules to guide the decision-making process, the phase automatically ignores construction and route improvement options and focuses on EGZs. The resulting map, side by side with the original risk map is provided in Figure 8. It is worthwhile to note that the phase is not allocating EGZs everywhere, but it focuses on where it can have a positive effect in the environment. It suggests construction of EGZs in neighborhoods 22, 23, 24, 25, 31, 32 and 33, bringing the total risk value of the environment from 12248.90 to 9619.82.

Considering these results shown in Figures 7 and 8, the suggestions offered by the system are optimal. Decision support mechanism worked properly by offering to build a minimum number of facilities, helping reduce the costs while minimizing the risk. Such an automated mechanism is important for preliminary analysis of a given study area. One potential improvement to EGZ decisions is to incorporate the population per block basis as the placement of EGZ within a neighborhood is currently random, as it can be seen on the map. Nevertheless, this is used as a symbolic placement in this work as the population information per block of the study area is not publicly available.

Discussion and Conclusion

The methodology explained in this work provides a method to estimate the risk values of administrative divisions within a district for emergency management tasks by analyzing availability of emergency management centers and alternative routes to these centers. Upon evaluation of the study area, risk values are generated. Classification using Jenks natural breaks provides appropriate classes for visualization purposes. Upon computation of the risk values, the decision phase considers the neighborhood connectivity and repeatedly applies risk value calculation and path-finding algorithm to estimate best available improvements applicable for the study area.

Providing additional geospatial data can possibly increase the accuracy of suggestions. However, providing a customizable and flexible decision support mechanism, incorporating only the base parameters of the study area, is useful for guided decision-making. With such a tool, combined with data sources that automate organization of the data, any urban area can be investigated for riskiness. As more data sources are becoming publicly available including governmental and crowdsourced data sets, such modular implementations can be used as plugins to other tools to enhance their usability. This work also turns several statistical data regarding change of mortality rates with distance into practice by adding this idea into risk value computation. Therefore, an automated approach such as the one presented in this work is useful for analysis of the administrative divisions. With supplication of additional external data from other regions, states or cities, the analysis can be enriched to provide further insight regarding the study area.

The analysis in this work considers the facilities within a district yet it does not account for a citywide emergency management effort in which various districts cooperate. Such a large-scale scenario should be tested before making certain conclusion about disaster resilience of a city, as larger districts may be able to help smaller districts using available resources they have. Consequently, future work will incorporate all the facilities, including military for a large-scale disaster management scenario. Upon data availability, parameters such as population density, congestion, and other relevant information such as local work hours and emergency routes can be utilized. Using an appropriate data exchange format can possibly link districts and cities, which can allow authorities to collaborate in emergency management. Furthermore, it is important to incorporate population as a parameter to estimate risk values. Although the risk value mentioned in this paper refers to serviceability of a region, with the addition of accurate population data set, it can be converted to an impact value estimating how much damage and possible casualties a disaster may cause. Utilizing such a data set would prevent large forests and mountains with no population to be considered as risky due to lack of emergency management facilities and a proper road network.

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