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Spatiotemporal Analysis and Mapping of Fire Incidents Using GIS Technology

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Abstract: Spatiotemporal fire analysis and mapping can enable policymakers to develop effective fire management strategies that optimize the allocation of necessary resources. Efficient urban fire management requires a well-coordinated regional planning and response system. The primary objective of this paper is to analyze the spatiotemporal patterns of fire incidents in Austin, Texas, utilizing geospatial technologies. This research specifically addresses deficiencies in fire protection planning in Austin, along with the new challenges posed by the city's rapid expansion. The fire risk and vulnerability of buildings in Austin were assessed using Geographic Information System (GIS) technology. GIS was also employed to identify potential sites for new fire stations and to optimize the design of existing stations based on fire risk assessments. This paper focuses on developing a GIS-based fire information system for the Austin Fire Department to determine the optimal route to fire incidents. The research produced a fire incidence distribution map and examined fire occurrence patterns using spatial statistical methods, including location identification, frequency analysis, and evaluation of fire hazard vulnerability and exposure. Based on the findings, the establishment of new fire stations is recommended, particularly in areas with high fire risk. The fire information system developed to identify optimal routes could be integrated with construction and cadastral inventory data to form a more comprehensive decision support system.

Keywords: Fire Incident Mapping, Geographic Information System, Response Time Modeling, Spatiotemporal Analysis, Urban Fire Management.

1. Introduction

Economic growth and the expansion of cities and industrial areas have significantly altered the spatial dynamics of urban fires in recent years. The primary objective of fire services is to protect lives, properties, and natural resources from fire and other hazards. To meet the growing demands of communities, fire services must employ the best available resources, procedures, and training methods [1]. Fire management teams and technology experts are increasingly adopting innovative and creative approaches, leveraging new technologies to address the rising demand for fire services. Urban fires are among the most critical challenges faced by both developing and developed nations [2]. In the United States, in 2006, a fire-related fatality occurred approximately every 162 minutes, and one person was hospitalized every 32 minutes due to fire incidents. Fire is responsible for approximately 300,000 deaths worldwide each year, the majority of which occur in residential settings [3].

As urban populations continue to rise, it is increasingly essential to update, rebuild, or relocate existing fire stations and to construct additional ones to meet the growing public demand for emergency services. Fire stations are critical land uses in urban environments, playing a vital role in safeguarding residents' lives and safety. Effective outcomes can be achieved by integrating spatial data applications with Geographic Information System (GIS) technologies, as GIS is capable of analyzing large volumes of data and efficiently responding to geographical queries, which can be utilized in urban fire research. A cost-benefit analysis comparing GIS implementation with fire-related economic losses reveals that designing and operating a GIS-based system is highly economical. Globally, fire control systems have embraced GIS technology to enhance the efficiency of fire management, thereby saving lives and preventing property damage.

The spatial distribution of fire stations is a crucial factor in determining the performance of fire services. Multi-criteria decision-making is essential for optimizing the distribution of fire engines in urban and rural areas, yet reliable methods for solving these challenges remain scarce. Fire protection is a key component of public safety programs in emergencies. In relation to the development of technical means, facilities, software, and interaction, fire prevention plays a critical role in the planning and operation of fire services. GIS was first used by fire services in 1999 for wildfire management. Over the past decade, GIS has gained popularity in fire departments, contributing to improved data usage for both forest and urban fire suppression. Collaborative efforts between fire departments, housing planners, and municipal officials have resulted in the creation of multi-layer maps, which have in turn improved response times, resource allocation, and safety by monitoring hazardous materials.

Despite the proven effectiveness and usability of GIS technology, its adoption for fire prevention activities remains limited. While GIS software has enhanced fire suppression efforts, fire prevention initiatives could also benefit from GIS by better targeting high-risk zones and communities. It is crucial to ensure that fire stations are not only located in areas that allow them to serve a broad region but are also strategically positioned to minimize response times to emergency incidents.

Several significant fire events have occurred in recent years in Austin, Texas, leading to considerable property damage and loss of life. During such incidents, the public relies on the fire department for a swift response. Any delay in controlling a fire can result in irreversible property damage and fatalities. The location of new fire stations has become a major challenge in urban planning and design, due to rapid urbanization and severe traffic congestion. The evolving urban landscape significantly influences response times to emergencies, making it vital to consider these emerging concerns in spatial analyses.

Austin, Texas, is a densely populated city facing various emergency scenarios due to the influx of people. The city's population was approximately 931,830 in 2016, reflecting a 3% increase from the 2010 census [5]. The Austin Fire Department responds to over 85,000 calls annually, with nearly 70% of these being medical emergencies [4]. Other incidents include fires, hazardous conditions, and various types of rescues (e.g., cave, high-angle, rope, vehicle, and structural). These responses are managed by approximately 1,100 personnel across 45 fire stations and seven additional facilities within Austin [4]. Statistics indicate that each fire department staff member is responsible for serving approximately 848 residents. The high population-to-staff ratio places significant strain on existing resources, making the management of current events challenging. Furthermore, the occurrence of multiple simultaneous emergencies could prove catastrophic for the city, as extensive damage could occur before the team is able to respond to all incidents within the recommended response time.

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2. Literature Review

GIS plays a crucial role in assessing the service areas of existing fire stations and identifying optimal locations for new stations to minimize fire damage. Various studies have demonstrated the value of GIS in service area analysis for fire stations. For example, Balasubramani [20] recommended techniques for reducing property damage and preserving human lives by conducting a service area analysis of fire stations using GIS in Madurai City. The study primarily focused on the road dataset and the location of fire service stations. The analysis began with the creation of a network dataset, where road sections were transformed into geometric networks through a topological cleanup process. This process eliminates potential errors by adhering to predefined rules such as "must not intersect," "must not overlap," and "must be connected," thereby minimizing undershoots and overshoots. The authors then developed a network service area to evaluate the functionality of fire stations in different directions. Drive time, used as the impedance in the study, was estimated based on assumed speeds of 60 km/h for highways and 30 km/h for other roads. The overlay analysis produced travel time bands around the fire station locations, identifying critical areas where fire station services were insufficient.

In another study, DONG [8] combined fire risk assessment approaches with GIS tools to address fire station design issues in Lanshan District. The study involved three stages: first, the Analytical Hierarchy Process (AHP) and fuzzy comprehensive evaluation methods were used to determine fire safety levels. Next, potential fire station locations were identified by developing a "demand map of high fire risk" with a fire emergency response time of two minutes. Finally, the average route to multiple request points of fire stations was calculated, and a preliminary array of candidate fire stations was determined by selecting the shortest average route. The primary objective of AHP is to address target selection and optimize goals through a five-stage process: problem definition, establishment of a hierarchy, development of a pairwise comparison matrix, consistency testing, and projection of comparable weights for each level's components. The fuzzy comprehensive evaluation method is particularly valuable as it quantifies qualitative data, making findings more comparable and meaningful. According to DONG [8], various constraints must be considered during planning, including the shortest path (positioning the fire station as close as possible to the major fire danger point), fire emergency response time (ensuring fire crews arrive within five minutes of receiving an alarm at the farthest point of the critical region), road traffic (accounting for driving time, direction, and vehicle capacity), and emergency rescue (ensuring a reaction time of less than two minutes).

SanNwe [21] conducted a study that incorporated hotspot analysis and multi-ring buffer methods to assess the spatial distribution of fire stations. The mean center for fire station positions was established in Chanayethazan Township, revealing that areas closer to the mean center with a fire station can be adequately protected against fire hazards. Spatial modeling systems have been dynamically used for fire station placement over the past 40 years, with different models automating fire station placement using response time criteria. Response time standards are the primary criteria for fire station placement. Murray [22] developed three models for the optimal positioning of fire stations: the Maximal Covering Location Problem (MCLP), which increases the number of fire stations needed to meet demand based on funding and resource limitations; the Threshold Coverage Model (TCM), which identifies the minimum number of fire stations needed to provide the appropriate level of service at optimal locations; and the Complementary Threshold Coverage Model (CTCM), which reduces the number of fire stations required by considering the current or modeled number of stations.

Green [23] used the Flowmap software to develop a method for placing new fire stations, which shares similarities with the TCM model. The study utilized road networks to determine service reach, considering the region's terrain. GIS data layers and road networks reflect the actual conditions of urban development. When modeling response times to fire emergencies, the implementation of a road network with variable speed profiles is essential. Flow map software allows for the estimation of the distance between land parcels and the nearest firehouses. The study emphasized travel response times for fire emergencies without considering the expected response weight within each catchment area. Due to the lack of reliable historical GIS fire incident data, the authors developed a risk coverage map based on land use data and local fire inspections rather than past response data. Areas, where travel time fell within the prescribed risk category, were deemed served, while areas where travel time exceeded the required time were considered underserved. A heuristic technique was also employed to identify new fire station locations, primarily in higher-risk areas lacking adequate service. The facility location planning and accessibility-analysis approach used in the study proved to be a comprehensive alternative for assessing fire station coverage and emergency service at a strategic level.

Fire department response time is typically divided into five phases [1]: dispatch time (the time taken to answer and process an emergency call), turnout time (the period from when units accept the emergency warning to the start of their response), response time (the time from when units begin their journey to the emergency until they arrive at the scene), access time (the time taken for the crew to travel from where the vehicle stops to the crisis location), and setup time (the time required to set up equipment, attach hose lines, and prepare to extinguish the fire). Habibi [19] developed criteria for fire station location planning, emphasizing coverage area, accessibility, plot size, demographics, and city expansion directions. Regarding accessibility, fire stations should have easy and quick access to arterial or sub-arterial roads to avoid traffic obstruction and should not be situated at traffic-congested intersections. The plot size should be appropriate for current and future demands, with space reserved near stations for rescue operations that can be used as green space during normal times. Coverage area analysis should assess the extent of existing stations and their ability to respond in the region. Demographically, at least one fire station is recommended for every 50,000 people. City expansion trends should be considered when planning new fire stations.

Many researchers argue that the first step in reviewing potential fire station locations should be the creation of response time standards, typically developed after a response time analysis using GIS techniques. Efficient fire station placement is largely determined by response time, defined as the period between fire detection and the arrival of the first fire brigade at the scene. The spatial distribution and location of fire service stations are crucial for establishing response times during emergencies, which can be achieved by incorporating drive-time analysis.

Forkuo & Quaye-Ballard [24] proposed a six-stage process for optimal route analysis: data preparation, topographic map georeferencing, geo-database creation, network topology building, network dataset creation, and best route analysis. Traffic data is essential in routing analysis for two reasons: it significantly impacts travel times, and it provides routing options to avoid slower, congested roads, thereby saving time. Traffic information can be stored using live or historical traffic models. Historical traffic profiles reflect travel times for specific periods in the past, based on time intervals for each road segment. Using traffic profiles is advantageous since it is impractical to cover an entire road network with traffic recorders. It reduces computing time, minimizes database storage needs, and improves data quality. Historical traffic data can indicate peak-hour congestion, enabling emergency vehicles to avoid busy areas and reduce travel time. According to Forkuo [24], the optimal route, often referred to as the least-cost path, is the route with the lowest impedance (cost), considering factors such as distance, travel time, gradient, intersection delays, traffic volume, and parking.

Various studies have highlighted the value of GIS technologies in risk analysis. For example, Preisler [26] developed a probability-based fire risk prediction system that analyzes various fire risk factors and evaluates the effectiveness of different fire hazard indicators and climate variables. Traditional forest fire risk assessment systems have often ignored the potential for emergency response, highlighting the need for GIS, which considers fire risk, vulnerability, and response potential. Vulnerability maps can be generated daily using algorithm mapping, incorporating both dynamic and static variables. Dynamic variables include factors such as weather, while static variables include land use.

Two GIS analyses have been particularly prominent in fire hotspot identification: Getis-Ord Gi* and Kernel Density. Kernel Density estimates by smoothing discrete point data into a continuous surface. In contrast, Getis-Ord Gi* uses Gi* statistics to determine the degree of clustering within a defined distance of weighted features [27]. Getis-Ord Gi*, a spatial autocorrelation method, has recently been used to assess the level of spatial pattern aggregation, unpredictability, or heterogeneity. Spatial autocorrelation can be global or local; local spatial autocorrelation identifies cluster positions and classifications, while global spatial autocorrelation describes the overall extent of spatial autocorrelation. Gi* statistics are used to identify hotspot and coldspot clustering trends within a study area by calculating z-scores and p-values. Higher z-scores indicate hotspots, while lower scores indicate coldspots. Getis-Ord Gi* has proven to be more effective and efficient than Kernel Density in hotspot analysis.

Hotspot analysis typically considers three categories of indices: structural (long-term), dynamic (short-term), and integrated (combining both). Structural indices change over long periods and include factors such as vegetation type, land use, population characteristics, soil, climate, elevation, and topography. Dynamic indices change gradually over time and include weather conditions and certain types of vegetation cover. Integrated indices incorporate both short-term and long-term factors, with the main challenge being how to successfully combine relevant variables to achieve consistent criteria. Mohd Said [27] used a structural index incorporating climate and forest type to determine forest fire hotspots in Brunei Darussalam. Akbulak [28] combined both short-term and long-term indices to conduct a forest fire risk analysis in Çanakkale, Turkey. Typically, the number of hotspots in each risk category is counted for index assessment. After the assessment, it is expected that most hotspots will be located in high-risk areas, while the fewest will be in low-risk regions.

3. Methodology

Several methodologies were employed in the analysis of fire risk incidence in Austin City. In this study, ArcGIS software was selected for its analytical capabilities due to several key advantages: the centralization of datasets within a unified geodatabase, the ability to simultaneously model various parameters, and the ease with which diverse dataset types can be integrated. The initial step involved the construction of a GIS database that consolidated all relevant materials for the study within a feature dataset. These layers were subsequently utilized in various analytical procedures based on the specific outputs required, as detailed below:

a. **Response Time Modeling**
   The response time model was developed using the network analysis tool, which leveraged the street layer containing various attributes, including street direction of flow, permitted speed limit per segment (in miles), the time required to traverse each segment at the specified speed, distance, and street name. The street network was constructed by interlinking the street networks, thereby enabling flow analysis. The network model's analysis of response time generated irregular polygons corresponding to the locations of fire incidents.
b. **Network Analysis**
   Network analysis is a method for analyzing, controlling, and modeling workflows associated with linear features such as road networks, rivers, and railroads. The analysis examines topological elements of connectivity, incidence, and adjacency. This method is particularly valuable for evaluating shortest path scenarios, route planning, closest facility identification, service area delineation, route allocation, location-allocation analysis, and location-based decision-making. Network analysis serves as a critical tool for modeling connectivity within networks and facilitating complex decision-making processes.
c. **Incident Trend Modeling**
   This analysis identifies the probability of fire spreading in the absence of intervention, based on mapped incidences within the study area. Hotspot analysis is employed to identify areas with high incidence rates and to extrapolate potential fire risks. Modeling these incidences is crucial for preemptive planning, ensuring adequate fire service provision, efficient event management, and optimized response times. The analytical process utilized in this study is illustrated in Figure 1.

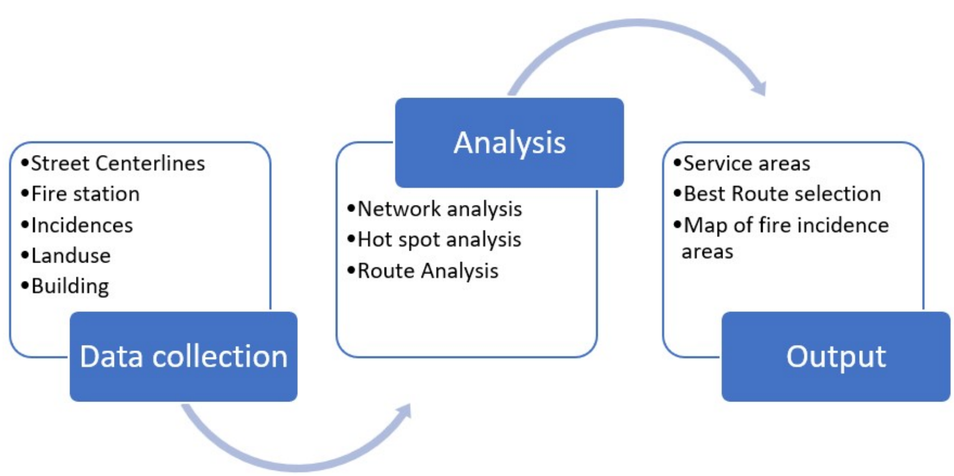

Figure 1. The Process Adopted for Fire Incidence Modeling

Data quality is paramount in spatial analysis, as the reliability of analytical outcomes is directly influenced by the integrity of the input datasets. Additionally, GIS facilitates the visualization of data through maps, necessitating that the data collected aligns accurately with the area of interest. The datasets used in this study were sourced from reputable online portals, with the majority obtained from the Austin County/City open data portal. The data, covering the period from 2017 to 2020, was selected to ensure the analysis was both relevant and current.

Table 1. Data Used [4] [6]

Data	Type	Description	Preprocessing
Street Lines	Shapefile	• Speed Limit • Distance (Length) • Time taken along the street • Name • Code	The street data was imported into a geodatabase, and a network analysis was conducted based on the travel time field.
Neighborhood	Shapefile	• Name • Area • Census Tract • Code • Population	The neighborhood data delineates the boundary of the study area. This dataset includes population attributes, facilitating the assessment of population distribution supported by the network.
Population Distribution	Shapefile	• No. of people	This dataset was joined with the neighborhood dataset through census tracts to illustrate the spatial distribution of the population.
Fire Incidences	CSV	• Type of Incidence • Response • Date of event • Year of occurrence	The data was exported from CSV and converted into point data through the plotting of X and Y coordinates.
Land Use	Raster	• Grassland • Built-up areas	This dataset delineates built-up versus undeveloped areas, aiding in the assessment of land use implications on fire risk.
Fire Station	Shapefile	• Jurisdiction • Station Location • Name • Street Access • X and Y location	This point dataset identifies the locations of fire stations and their spatial relationships to surrounding areas.

In analyzing fire risk within Austin City, several parameters were considered. According to ESRI, critical datasets essential for the analysis of fire incidences include transport nodes, service areas, natural features, critical infrastructure locations, incidences, and topographical data. It is crucial that these datasets are supported by relevant attribute data, which defines factors such as travel speed, direction, capacity, time, date, and size. In this analysis, the key datasets were downloaded, focusing on the critical attributes necessary for effective fire incidence modeling.

4. Finding and Discussion

Figure 2 illustrates the spatial distribution of fire incidences for the year 2017, categorized by type and spread within the study area. The visual representation of this data, while informative, proves challenging for extracting detailed information. Further analysis is required to enhance comprehension of spatial interactions and to support informed decision-making.

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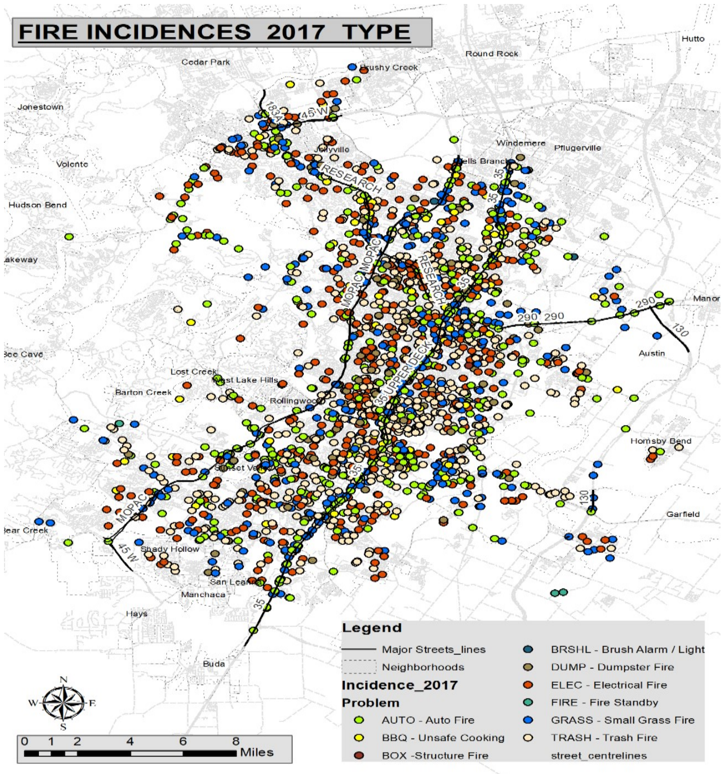

Figure 2. The Spatial Distribution of Fire Incidences for The Year 2017 Based on Type

4.1. Service Area Analysis of Fire Service Stations and Recommendations for Optimal Locations

Efficient fire service delivery hinges on rapid response times. According to the National Fire Protection Association (NFPA) Code 1710, a fire engine should ideally be positioned within 240 seconds (4 minutes) of an incident for effective intervention. Figure 3 depicts areas inadequately served by existing fire stations within the 3-5 minute response time range. These underserved areas are at a higher risk of fire damage and would benefit from the establishment of emergency facilities within their bounds.

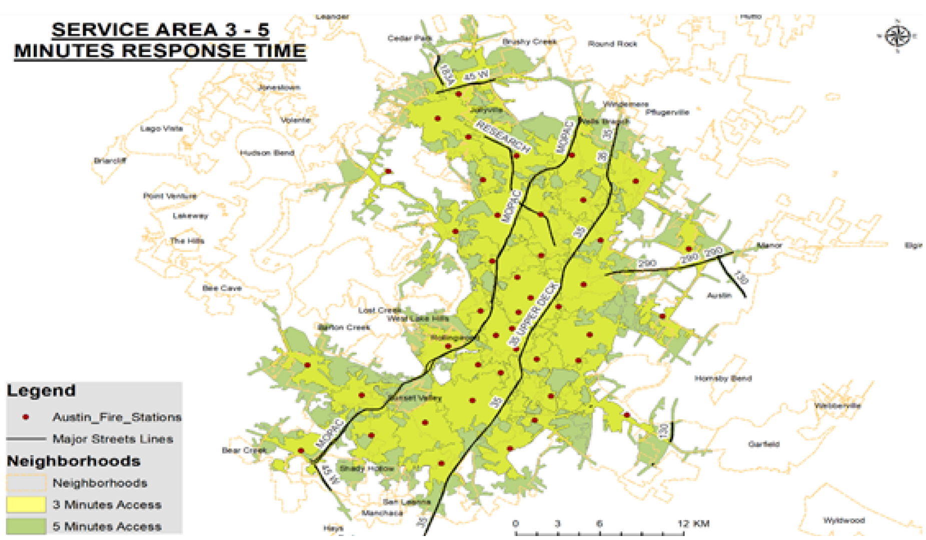

Figure 3. The Incidence Response Time, 3-5 Minutes

Other studies suggest that a response time of 3 to 5 minutes is critical for ensuring safety and minimizing property damage during fire events. In this study, a response time of three minutes was adopted as optimal, as indicated by the green and yellow regions on the map below. A network analysis was conducted to delineate the service areas of various fire stations within Austin County. While the central areas are adequately covered, peripheral regions face a shortage of fire stations. A secondary analysis extended the response time to five minutes, assessing traffic flow and speed limits for different street segments.

4.2. Development of a GIS-Based Fire Emergency Response Model

Routing is a crucial factor in fire service operations as it determines the most effective route for reaching a fire incident. In this analysis, routing was based on accessibility to the fire incident within the shortest time possible. The network analysis conducted within the study area allows for the assessment of the optimal route to reach an incident in the least amount of time, as depicted in the map below. For this test, Incident A was used to evaluate the best route from the nearest fire station to the incident location. The map in Figure 4, illustrates the selected route according to the GIS system, with the impedance value representing the shortest time required to reach the incident site.

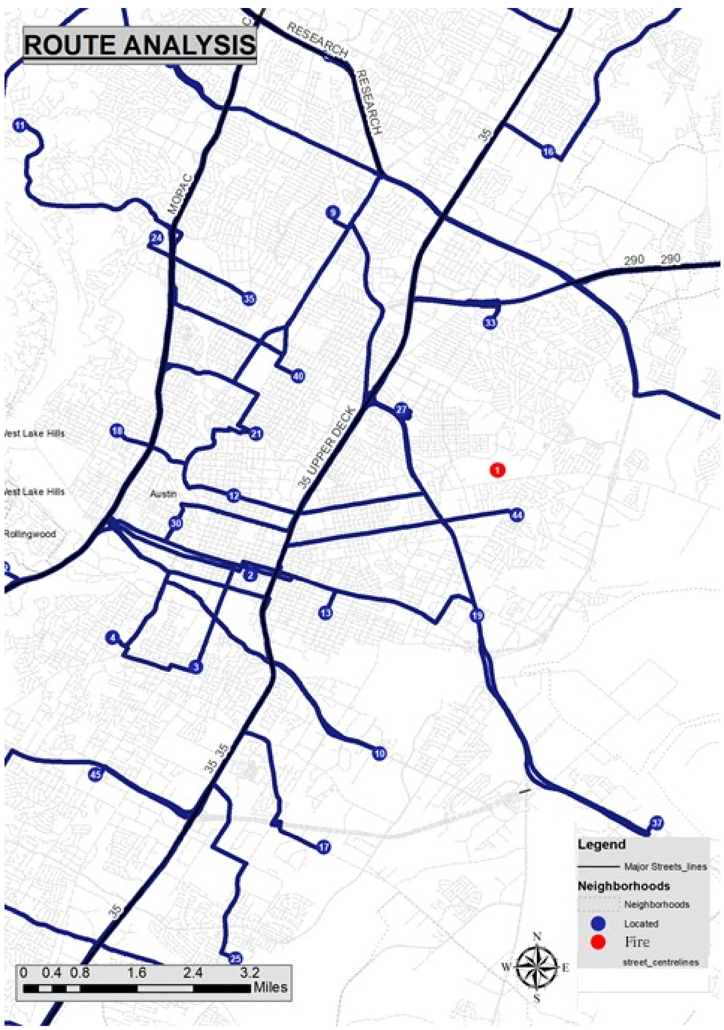

Figure 4. The Primary Nodes Connecting The Fire Station Facilities

The map portrays a hypothetical fire incident at the location marked by a red dot. If an individual at point A reports a fire emergency, the system activates to determine the optimal route to the incident site, prompting the response team to act swiftly. Blue points on the map indicate the locations of fire stations capable of responding to the fire incident at the red-marked point. This route analysis assists the response team in planning the most efficient route to the fire incident, ensuring the quickest response possible.

Furthermore, the route analysis also identifies the closest facility to an incident, suggesting the most effective route to minimize response time. For each fire incident, several factors are considered to determine the closest facility. In the hypothetical scenario described, if the fire incident is reported at the red point, the system utilizes the network dataset to identify the nearest fire station and determine the optimal route to the incident.

The fire station is then directed to respond based on its connectivity to the site. As illustrated in Figure 5, the analysis identifies the nearest fire station to the incident and maps the route to be followed to reach the facility.

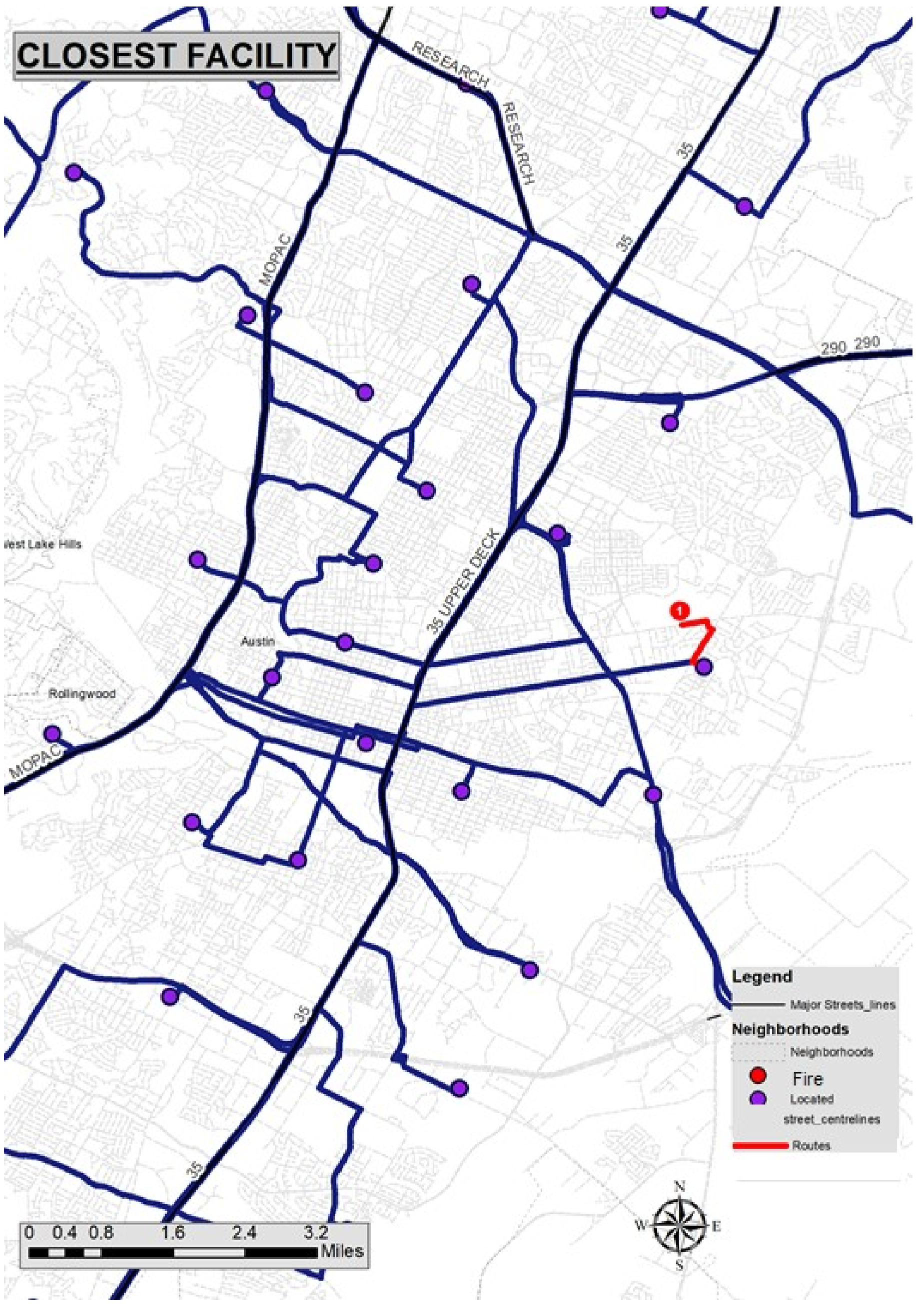

Figure 5. The Closest Fire Station to a Fire Incidence as Shown by The Green Dot

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4.3. Establishing Risk-Prone Areas in Terms of Fire Incidents Using Multi-Criteria Analysis

The study area has experienced a variety of fire incidents, including trash fires, electrical fires, auto fires, barbecue fires, and dumpster fires. Among these, trash fires are the most frequently recorded incidents. This suggests that the likelihood of fire occurrences is higher in areas with human settlements compared to those without. Given that human activities significantly contribute to the incidence of fires, a risk map was developed to highlight areas with a high probability of fire events.

To develop the map, several layers were used in the analysis they include:

1. Building: The inclusion of building data is based on the premise that areas with human activities, such as trash generation, are more likely to be at risk of fires. Buildings, therefore, are considered potential fire risk zones.
2. Population: This data helps identify areas with a higher risk of fire initiation and assesses the potential impact on both people and property. Areas with higher population densities are more likely to experience significant damage in the event of a fire.
3. Roads: Roadsides are identified as high-risk areas for automobile-related fires, particularly in the case of vehicle malfunctions or stalls.
4. Land Use Land Cover: Grassland areas are noted to be at higher risk of fire compared to other land uses. Additionally, built-up areas also exhibit a higher probability of fire incidents due to the presence of electrical connections and infrastructure.

Figure 6 illustrates the areas with varying degrees of fire risk. The red dots indicate regions with a higher propensity for fire incidents, whereas the dotted blue areas represent lower-risk zones. Orange dots further highlight high-risk areas within Austin County.

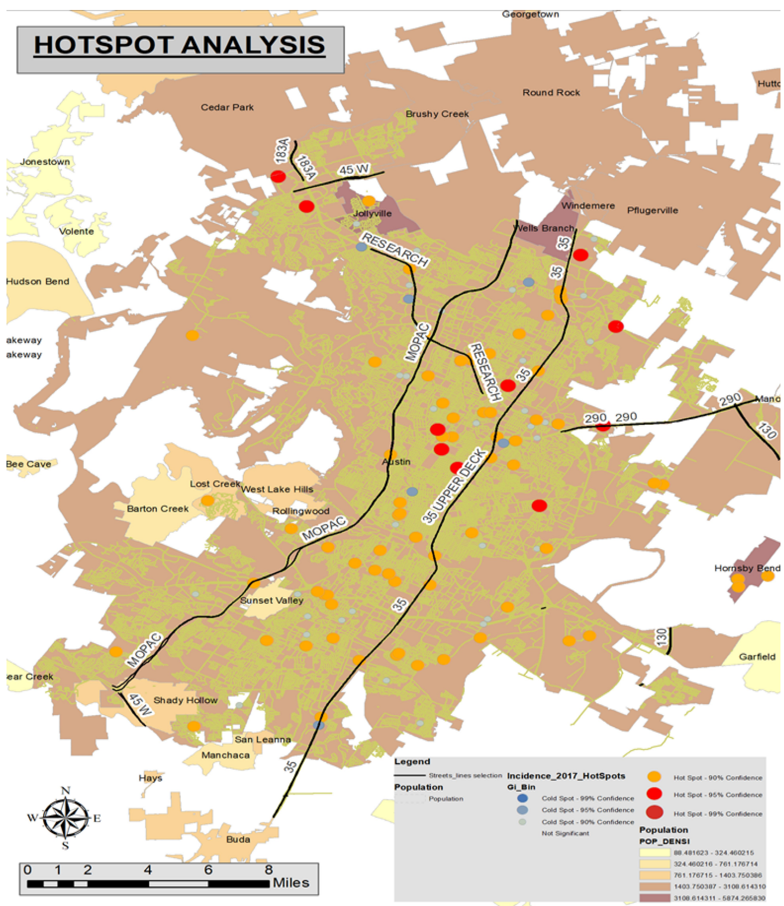

Figure 6. A Hotspot Map on Primary Infrastructure

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4.4. Development of a Hotspot Analysis of Fire incidents in Austin County for Planning Purposes

A hotspot map is designed to illustrate areas with a high concentration of events compared to what is statistically expected, thus modeling the distribution of fire incidents. This analysis highlights regions with frequent occurrences of specific incidents (hot spots) and those with fewer occurrences (cold spots), thereby providing insights into the spatial distribution of fire incidents.

The hotspot map, derived from historical fire incidence data and probability assessments, reveals that high-risk areas are generally within a 3-5 minute response time, indicating adequate coverage. The red points on the map denote areas with high fire incidence, demonstrating that these occurrences are not random but rather concentrated in specific regions. Orange dots indicate areas with a high frequency of incidents with a 90% confidence level. In contrast, blue areas represent locations where fire occurrences are random with no significant correlation between incidents.

Additionally, heat maps and density maps further illustrate the spatial distribution of fire incidents. Heat maps use color intensity to represent the magnitude of fire incidences, with higher concentrations depicted in red and decreasing intensity as one moves away from the core. This visualization helps in understanding the density and spread of fire events within Austin County.

Figure 7 displays high-risk areas concerning service response time, while Figure 8 presents a heat map showing the distribution of fire incidents across the county. The heat map visually emphasizes areas with higher fire incidence concentrations.

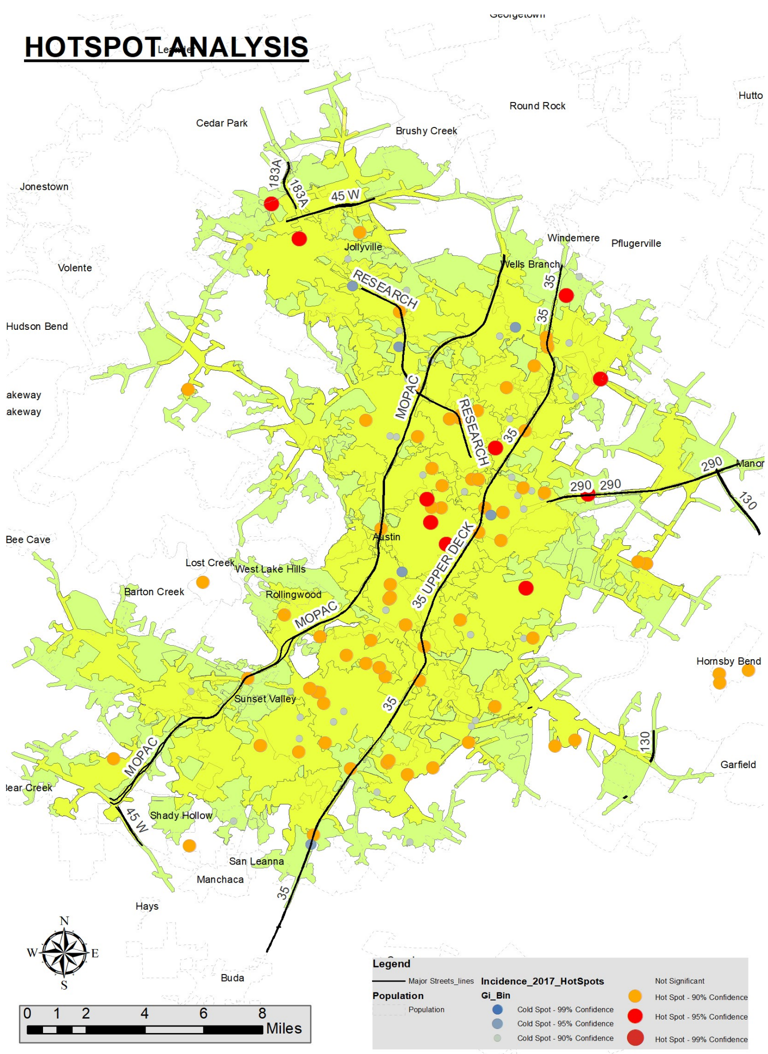

Figure 7. High-Risk Areas with Regard to Service Response Time

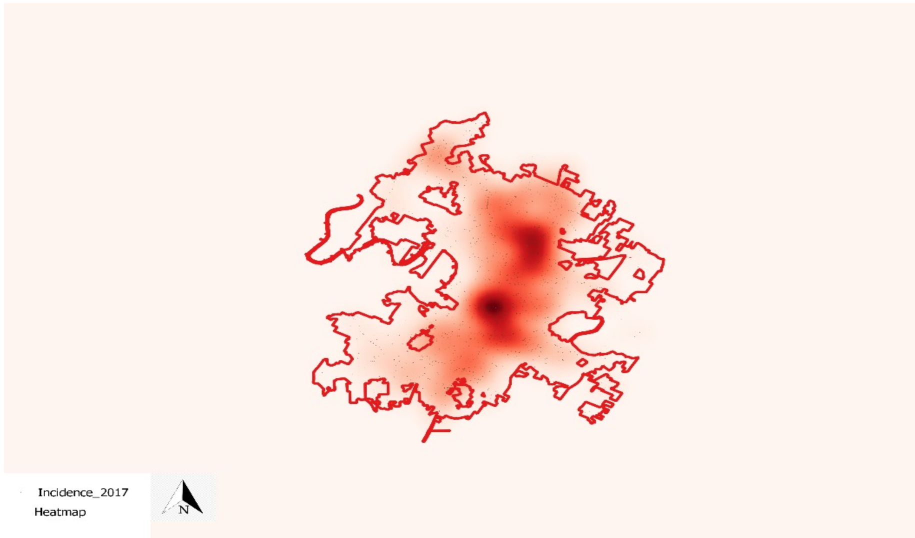

Figure 8. A Heat Map Showing the Incidence Distribution in Austin County

Figure 9 illustrates the density of fire incidents from 2017 to 2018, providing a detailed view of fire event occurrences as recorded by the county.

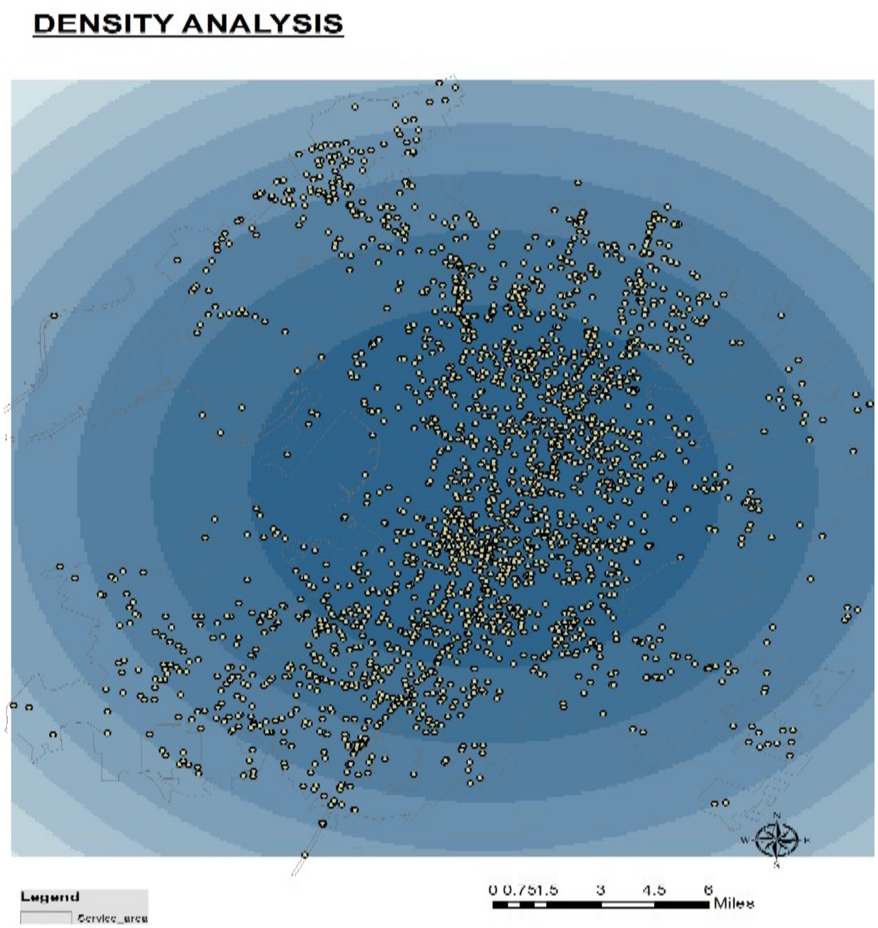

Figure 9. Density Map Showing The Concentration of Fire Incidences

4.5. Policy Recommendations for Fire Control and Management

There is a need to identify areas that are underserved by the existing fire stations and enhance policies to improve the efficiency of the fire response team. As previously established, the most suitable response time should be within three (3) minutes. This standard should be enacted as a policy to ensure that areas not meeting this threshold are addressed. Potential sites for developing additional fire response units are indicated in Figure 10.

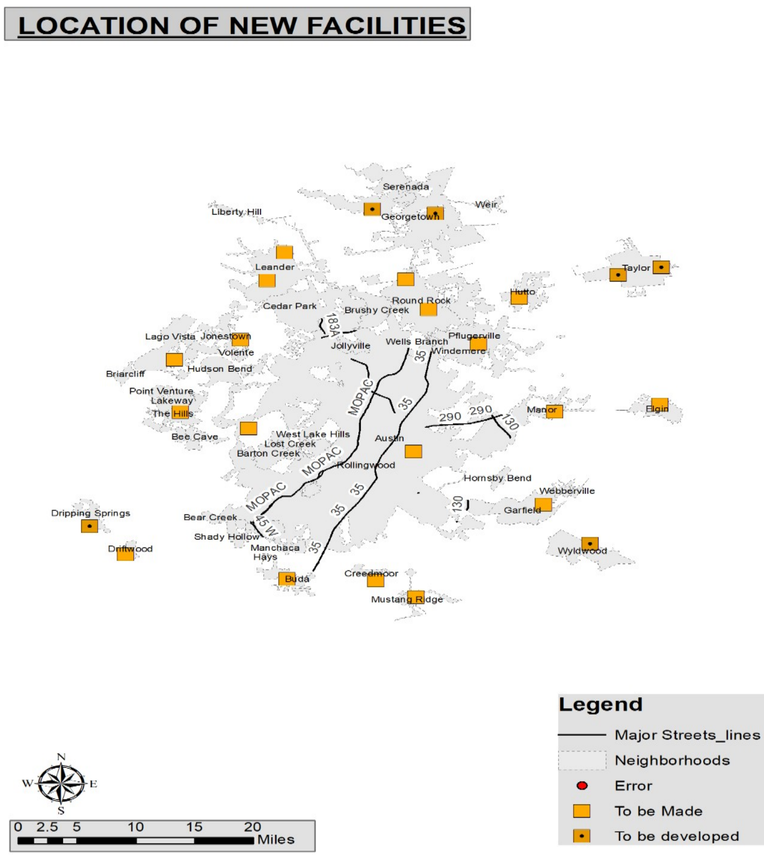

Figure 10. The Suitable Locations for New Facilities

Based on the analysis, 78.27% of the area is adequately served within a five-minute response time, while only 22.83% of the area remains uncovered. Most of the central part of the study area is well-served, while the regions that are more distant have vegetation land use with dispersed settlements. Since these areas are not closely connected, an alternative firefighting approach can be considered by reallocating some fire stations to the northern part of the area, which is significantly underserved with no fire station currently located. The five-minute response time is deemed the most suitable for a fire emergency, as the risk and damage are manageable based on several studies and previous response times by firefighters. The map below shows the output of the location-allocation tool and identifies the best locations for new fire stations. Given that the northern part is underserved, the location-allocation tool was used to identify suitable areas for placing new fire stations. The location-allocation analysis, considering existing fire stations and underserved areas, highlighted these regions as needing new facilities.

Overall, the adoption of technology, along with analysis, modeling, and result display, cannot be achieved without hardware components. Therefore, the department should invest in advanced and functional computers to enhance data collection, analysis, and overall efficiency. Such investments will enable the department to use highly efficient gadgets that speed up response times and allow the team to manage incidents more effectively. Efficient machines will also support smart analysis and provide timely advice on the best response strategies. Additionally, examining how mobile technology can improve response through real-time mapping, photography, and data gathering during reported incidents is crucial for enhancing the fire department's effectiveness.

5. Conclusion

Since the scope of the study is to assess the role of GIS in spatial-temporal mapping of fire incidents for decision-making purposes, several emerging trends from the analysis need to be addressed to alleviate fire risk. First, it is essential to establish fire stations in the underserved areas marked in red. These areas should be prioritized as they are at a higher risk of damage in the event of a fire. Second, areas highlighted in green could benefit from additional fire stations to reduce response times to 3 minutes, thus improving efficiency in the fire service. Third, emergency calls should be linked to a database that notifies the nearest fire facility as quickly as possible. This can be achieved using an integrated database that allows the caller to send an ID alert to the fire team, enabling the nearest team to respond immediately with minimal delays.

The analysis conducted for Austin County can be applied in various ways to improve the response to fire incidents within the study area:

1. Developing a Strategic Fire Plan:
   The study will identify potential hotspots for fire incidents, enabling preemptive planning for fire emergencies. The plan involves mapping high-risk areas and valuable resources, allowing the fire department to strategically position fire centers near these high-risk areas to reduce response times. Additionally, the fire department can organize and plan for fire prevention activities and place suppression resources close to the population. A strategic budget could also be developed to address potential demands, including equipment purchases, hydrant locations, and planning for multiple simultaneous fires to ensure swift responses.
2. Improving Response Efficiency:
   Effective fire incident response requires comprehensive information. The analysis will aid in developing network analyses of neighborhoods, linking data on fire station locations, response times, and high-risk areas. Synthesizing this data will assist in decision-making regarding the best routes to use during a fire. Improving efficiency involves creating a database with necessary data for modeling fire incidents, which will support planning for future incidents. GIS plays a critical role in enhancing response times and optimizing response routes.
3. Developing Mitigation Procedures:
   The model can be used to devise strategies for mitigating fire incidents, such as clearing vegetation, establishing fire buffer zones, and placing fire hydrants and extinguishers. Decisions based on collected data are often more informed and effective in managing fire events.
4. Formulating Better Policies:
   The data collected from fire incident analyses can reveal patterns and scenarios that enhance policy-making processes. By modeling incidents, the data flow can illustrate how fires spread, assess their impacts, and quantify changes needed for rebuilding and mitigating future impacts.
5. Rebuilding Cities:
   The analysis will guide the process of rebuilding areas after fire incidents. GIS data, including aerial imagery and land use analysis, can depict the extent of damage and advise on redevelopment strategies. GIS applications are crucial for zoning, improving safety, and enhancing emergency preparedness.

To further improve the system's functionality for future applicability, consider integrating advanced technologies such as machine learning, geospatial analysis, and artificial intelligence. These technologies can enhance data analysis and management. Additionally, incorporating automation to identify fire incidents and automatically map the best route in real-time—based on satellite data, traffic routes, and proximity—can significantly reduce damage.

Future developments should also focus on improving the quality of data gathered for analysis. Databases should be updated and merged with historical data to enhance analysis quality. GIS is instrumental in centralizing both spatial and non-spatial data. However, webGIS applications with simplified user interfaces could make the system more accessible, even to users with limited GIS knowledge. Identifying key datasets and integrating them effectively will improve analysis quality. Approaches such as incident trend analysis, event modeling, and response time modeling can be further developed using GIS and high-quality data.

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