iJDASE International Journal of Data Analytics and Smart Education

iJDASE | ISSN: 2736-979X | Vol. 1 No. 1 (2025)
https://doi.org/10.64817/83vqnm16

PAPER

GIS Network Analysis Tools and Emergency and Disaster Response: Industrial Use Case

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ABSTRACT

This paper explores the trend and use of GIS Network analysis tools in the Emergency and Disaster (EDR) market, as well as in the emergency response service (ERS) industry. The use of GIS Network analysis tools in the EDR and ERS market over the years has increased the market competitiveness and has given room for increased efficiency and profit sharing for both public and private enterprises in the industry. The paper also explores the new ArcGIS pro Network Analyst tools and its underlying operating techniques. Proactive and reactive network analysis tools, including route analysis, service area, and location-allocation analysis tools, were explored, and case studies were reviewed on their use in relation to the EDR and ERS industry.

KEYWORDS

Emergency Response Service, Emergency and Disaster Market, GIS Network Analysis, ArcGIS Network Analyst, GIS, ERS preparedness

1 INTRODUCTION

From concepts to development, Geographic information system (GIS) technologies have witnessed a great revolution, transitioning to Geospatial Information systems and technologies, having footprints in every discipline

E. O. Makinde, T. J. Salami, A. O. Kanmijeje. (2025). GIS Network Analysis Tools and Emergency and Disaster Response: Industrial Use Case. *International Journal of Data Analytics and Smart Education (iJDASE),* 1(1) pp. 122-135 https://doi.org/10.64817/83vqnm16

Article submitted: 12.03.2025 Revision uploaded: 07.07.2025 Final Acceptance: 11.07.2025

and profession in the world, revolutionizing every field of study and paving ways for new discoveries and fields of endeavors. [1-7].

GIS analysis tools have been used in investigating and exploring datasets from diverse sources and industries with a view of enhancing and improving existing systems, as well as for making informed and progressive business and human-centered decisions [2]. With a goal for human safety and extended life preservation in the face of harsh and uncontrolled natural and human-induced disasters, GIS analysis tools have found leverage in enhancing and improving the emergency and disaster response (EDR) market and emergency response service (ERS) delivery using existing datasets. The use of Network datasets like transportation and route networks in ERS delivery and industry, and GIS network analysis has increased the industry competitiveness and profitability, and has given room for advancement and development of new fields of study. This paper examines the application of GIS network analysis tools, including Route Analysis, Proximity Analysis, and Service Area Analysis, in the EDR market and ERS industry, with a focus on proactive and reactive emergency response service delivery and planning.

2 GIS AND EMERGENCY AND DISASTER MARKET

The Emergency and Disaster Response (EDR) Market describes an industry focus on mitigating and managing unanticipated incidents [8], as at the start of 2024, the industry was estimated to be worth $166.73 billion [9] with projected growth of 6.58% during the forecast 2024-2029 period [8]. Technological advancements and increased frequency of climate-related disasters, as well as geopolitical insecurities, have made the market a gold mine of late, and the role of GIS analysis tools seems indispensable for response time management, coordination enhancement, and resource optimization [10]. The ongoing global climate crisis has seen the need for effective risk assessment and planning, improved emergency response service delivery and situational awareness, and efficient damage assessment and recovery, all of which are vital for any enterprise, be it public or private, to be able to have a good share in the EDR global market [11, 12].

2.1 The EDR Infrastructure Segmentation and GIS Network Analyst

Challenges in the EDR market are huge, according to market research by Modor Intelligence (2024) [8]: budget constraints, financial constraints, limited resources, inadequate infrastructure are a few. An effective and efficient EDR enterprise depends primarily on robust technological infrastructure using advances in technology – Internet-of-Things(IoTs),

Artificial Intelligence (AI), Drones, and Machine Learning, etc. This infrastructure, in turn, is supposed to be GIS-compatible to enhance service delivery. The use of Satellite imagery, GPS trackers, digital resource maps, and so on allows for the deployment of GIS network analysis tools to improve service quality in the EDR market. Most developing countries are yet to meet up with essential EDR infrastructures like stable power supply, efficient telecommunication sector, and effective financial system, thereby giving room for GIS entrepreneurs to explore ways to use available technologies for the enhancement of service quality [13, 14].

2.2 The EDR Market Research Trend

Recent EDR market research shows that in meeting up with inadequate infrastructures, social media is been used to improve the quality of service delivery, especially in emergency response to natural disasters both at national and regional levels [10, 15]. The impact of quality of service delivery in EDR has been shown to affect economic growth and vital sectors in a national economy including food security, especially during climate-induced and intense natural disasters going by recent global events; the England flooding of January 2024 where hundreds of homes were submerged, the flooding in the city of Orenburg Russia and Northern Kazakhstan 2024, and the Nigeria flood of 2024 where over 21 Local governments in 10 states and the FCT were underwater as of July 5 2024 [16-19]. Also worth mentioning, is the Los Angeles Wildfire disaster of 2025, where more than 12,000 homes were razed to the ground, with a loss of over $275 billion dollars in damages, the use of social media played a vital role in alerting responders and saves lives through fast and effective deployment of safety gadgets and rescuers [20]. As a GIS entrepreneur, the use of GIS network analysis tools combined with social media-generated data could enhance the quality of service delivery in the EDR market alongside improved social media image.

With respect to the Emergence Response Service (ERS) industry, there is a greater shift towards quality and effectiveness of service delivery than focus on the nature of preparedness for a disaster relief response and the nature of the disaster in view. [21, 22]. One of the vital GIS datasets for ERS is the existing transportation network, which plays an indispensable role in making enterprise in ERS effective, efficient, and as well competitive in the industry. [21]. The use of advancements in geospatial technology, improvement in societal connectivity, and development in the ERS industry play a vital role in the ever-expansion of the industry and increase in the market share compared with the EDR market. [8, 21, 22].

2.3 GIS Network Analysis Tool and EDR/ERS

GIS network analysis tools, including service area coverage, location allocation, and optimal path analysis, have been used in selected research studies for optimal service delivery in EDR [3, 11, 23, 24]. As a GIS-entrepreneur, GIS network analyst tools are vital for survival in the EDR market. The Chinese government made use of a GIS network-based model and dynamic network analysis in assessing the evolution of the COVID-19 epidemic response system over time, providing baseline information for GIS-entrepreneurs in EDR [25]. GIS network analyst tools are data-driven tools and effective in the cyclical dynamic of resilience and learning from disasters, and the transformative dynamic of learning through disasters due to the wealth of historical data [26].

3 NETWORK ANALYSIS

While the term "Network" is used by different professionals and researchers to mean different things based on context, a Network refers to a series of connecting nodes and edges with directions to GIS discipline [7, 27-29]. Hevey [29] defines a Network as a graphical relationship depicting connectivity among nodes and edges. Furthermore, the use of nodes and edges describes spatial datasets in their basic mathematical representations, where point location data describes nodes, line or linear data describes the edges, and the aggregation of nodes and edges is used in describing polygonal or areal data[7, 30]. Network Analysis, on the other hand, describes spatial operations that could be performed on a network based on its characteristic inheritance, with a view to extracting complex spatial information and relationships [29]. The ESRI ArcGIS software Network Analyst tool has gained popularity among GIS researchers and professionals in applying different network analysis techniques on geographical datasets [11, 31, 32]. While Nagne and Gawali [33] grouped network analysis techniques into 3 (Connectivity, Circuitry, and Accessibility), Church and Murray [2] classified network analysis techniques into 4, including query, proximity, centrality, and service zone analysis. Advancements in Network analysis and applications have generated new classification groupings and subgroupings. This is evident in the new Network Analyst Toolbox, which aligns more with road transportation systems application areas [34].

The latest Network Analyst Toolbox for ArcGIS Pro 3.4 is equipped with capabilities to provide the following analysis according to ESRI [34];

a) Route Analysis (optimal path)
b) Proximity Analysis (Closest Facility/Vehicle)

c) Service Area Analysis (Trade Zone Area)
d) Location-allocation Analysis
e) Origin Destination Cost Matrix
f) Vehicle routing Problem Analysis
g) Last-Mile Delivery Analysis

Of all these, the network analysis technique in reactive Emergency Service Response (ESR) is Route Analysis, while proactive ESR mainly uses Service Area and Location-allocation analysis [2, 3, 7, 23, 33-35]. The Proximity analysis is mainly used in the planning and decision-making process. [36] while the last three analyses (Origin Destination Cost Matrix, Vehicle routing Problem, and Last-Maile Delivery) mainly concern traffic and transportation systems [11, 37-39]. Before any of the techniques can be applied, a Network dataset is needed, which is defined as a model that is an abstraction of a transportation network with topology and connectivity. [40](see Figure 1). The focus of this paper will be on the ESR-related analysis.

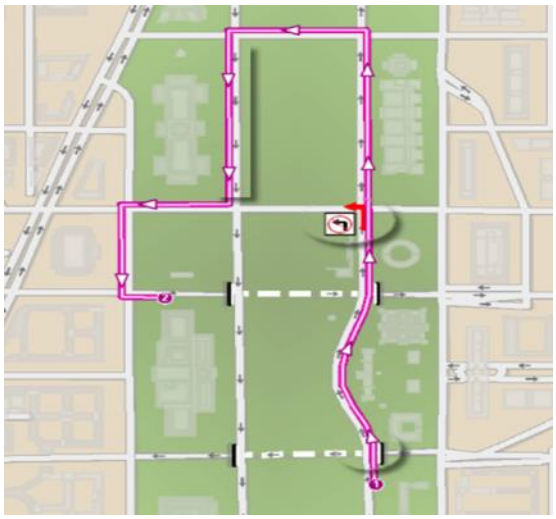

Fig. 1: A sample Network Dataset [39]

3.1 Route Analysis (Network Analysis for Optimal Path)

In network analysis, route optimization is one of the challenges in the enhancement and improvement of transportation systems and networks [41-43]. The route optimization describes the movement of an entity from one end to the other using a route with the least resistance, either in terms of time, number of stops, days of the week or based on selected movement constraints. The ArcGIS route solver, which is the analysis engine, can be used to determine the optimal path based on either travel time, traffic consideration, or the number of destinations. [44]. Theoretical documentations on operational, mathematical, and programming

techniques in route optimization can be reviewed in [4, 7, 44-46]. Popularized models and relevant case studies in the use of route optimization are published in [43, 47].

3.2 Service Area Analysis (Trade Zone Area)

A network service area, interchangeably used as a Trade, Proximal, Viewshed, or Catchment area, is a location-specific entity as highlighted by Church and Murray [2]. The creation of a service area describes a geographical region or areal coverage within which an entity can be attached. The ArcGIS Network analyst tool uses Dirichlet polygons for delineating area coverages and can be created via analog, proximal, or gravity models [2, 7]. Coverage of an EDR/ERS enterprise, the effectiveness of an EDR/ERS within a geographical location based on travel time, movement constraints, cost, or other forms of constraints can be easily be analyzed using service area analysis. As an example, a proactive ERS enterprise interested in servicing and maintenance of fire extinguishers would need to estimate its service area for maximum market share and profit-making. Also, reactive EDR/ERS public service delivery, like a Fire station, would need to estimate its effective service area coverage in terms of time and other known factors in order to be efficient in its service delivery. The ArcGIS Service Area analysis solver gives room for the creation of service areas based on the use of a single factor or a combination of factors. This makes the tool viable for any EDR/ERS enterprise with the required network datasets.

3.3 Location-allocation Analysis

Location-allocation is a vital network analysis tool for any profit-oriented organization or efficiency-oriented public enterprise [48]. It is one of the most used GIS analysis tools since it cuts across several industries, including education, retailing, resource allocation and management, as well as ERS [1, 12, 48-52]. The tool uses points and line features to determine the optimal entity (facility) for selected demand points. The modeling technique may require more data for solving different types of Location problems, such as barriers, travel mode and direction, and cost attributes. According to ESRI [53] Location-allocation problem types include minimize weighted impedance (P-Median), maximize coverage, maximize coverage and minimize facilities, maximize attendance, maximize market share, target market share, and maximize capacitated coverage. Of these problem types, P-median, maximize coverage, and maximize capacitated coverage are best suited for the ERS industry based on recent studies [8, 13, 14, 52].

4 CASE STUDIES

Several researchers have investigated the use of different Network analysis tools in the ERS industry, Ahmed, Ibrahim [35] investigate the use of route analysis and proximity analysis for proactive emergency response service for health care providers using the existing route network of Greater Cairo, Egypt. Habibi and Panjaitan [54] utilizes a modified form of location-allocation network analysis tool in solving optimal location of blood bank facilities as a reactive measure in health-related ERS. Mohammed and Ukai [51] applied AHP (analytic hierarchy process) alongside location-allocation analysis in determining optimal siting of university campuses within Egypt. These are just exciting recent researches in ERS.

In reference to the ERS proactive and reactive network analysis, a special case study was performed within the University of Lagos main campus, Akoka, Lagos, Nigeria. This study develops a GIS-based fire emergency response system for the University of Lagos (UNILAG) Halls of residence. The study utilizes the vector data of the fire service center, the hall of residences, the route networks, and the locations of Fire service hydrants. Emergency response service delivery scenarios were simulated. GIS network analysis tools employed include optimal routes, service area coverage, and proximity analysis tools to determine best routes for speedy service delivery, service coverage of the existing fire service, and the best location for proposed fire service centers. The system enables the UNILAG fire service to identify optimal routes for swift intervention (See Figure 2). GIS network analysis maps the coverage areas of the existing fire station and hydrants (See Figure 3). The study also proposes suitable locations for an Emergency Response Center (ERC) and a new fire station, enhancing university-wide emergency response coordination and resource allocation (See Figure 4). The methodology utilizes route analysis, service area analysis and location-allocation analysis on existing rod network data within the campus. The findings propose new sites for the ERC and fire station, addressing coverage gaps and improving campus fire safety. The system enhances emergency response capabilities, minimizes response times, and optimizes resource distribution during fire incidents. This research significantly improves fire safety measures in UNILAG's Halls of residences, promoting a safer campus environment and protecting the university community.

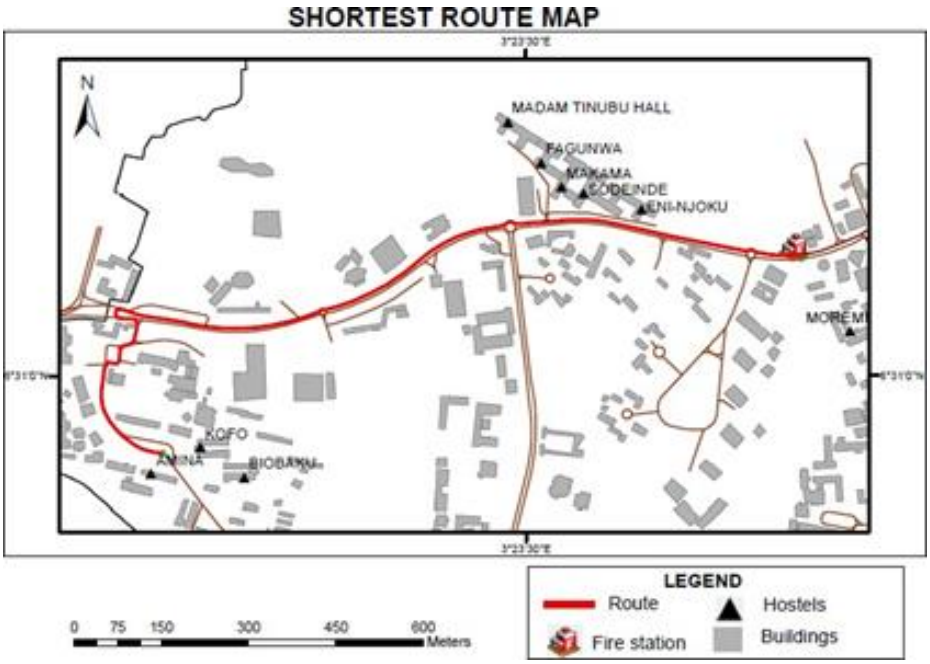

Fig 2: A Map showing the shortest distance from the Fire Station to one of the halls of residences.

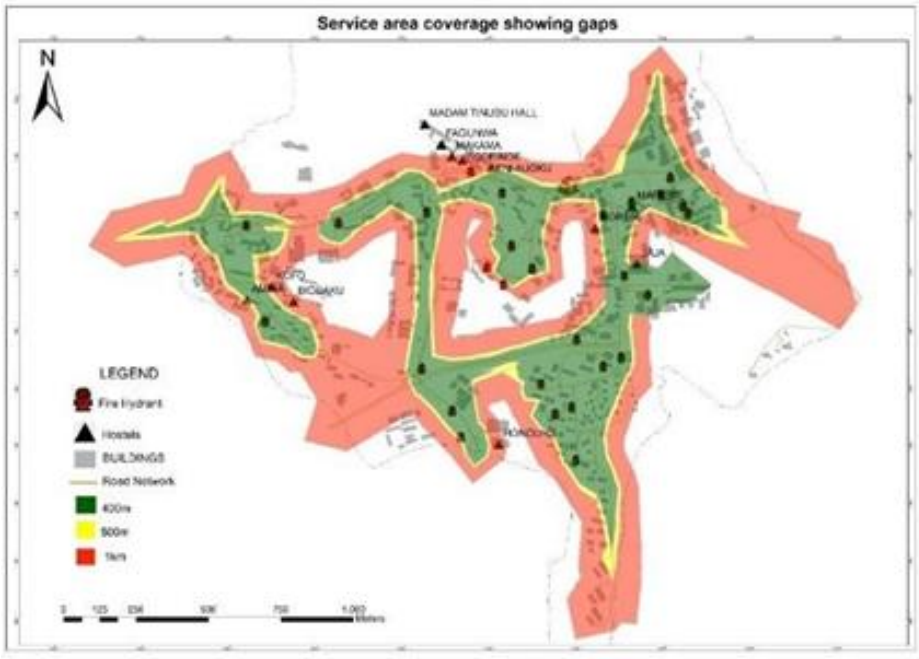

Fig 3: A Map showing Service Area Coverage.

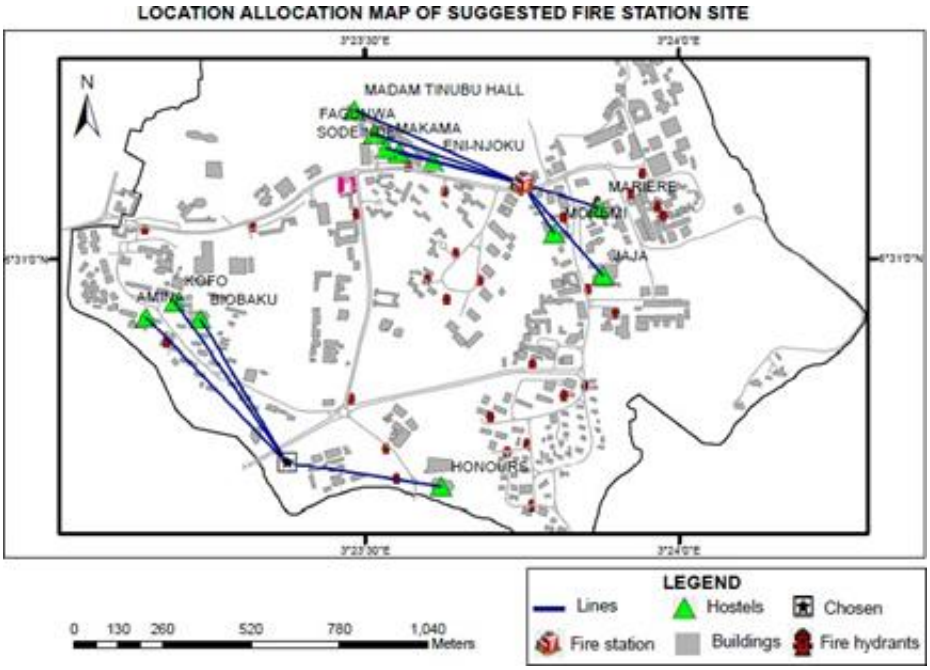

Fig 4: A Map showing Facility location-allocation

5 CONCLUSION

The Emergency Response Service (ERS) market is a large industry cutting across multiple other industries and providing urgent needed services in order to save lives and properties. A good transportation network, on the other hand, is a vital dataset for a well-functioning and suitable city. For an effective and productive entrepreneur or enterprise, network analysis tools provide a means of enhancing service delivery using the existing transportation network. The effectiveness and efficiency of the use of GIS route network analysis tools have been proven using a case study where fire emergency scenarios were simulated and GIS route network analysis tools were used with satisfactory results.

6 ACKNOWLEDGMENT

The authors acknowledge the staff of the Preventive Unit of the Medical Centre, University of Lagos, for providing the waste bin evacuation records.

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