



Development Of a Three-Dimensional Indoor Geospatial Network and Address Geocoding Framework for Next-Generation Emergency Dispatch and Response-Time Optimization

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Abstract

Complex multilevel buildings create an emergency-response problem because conventional street addresses and two-dimensional maps can guide responders to a property while failing to identify the correct entrance, floor, room, vertical connector, or safe indoor route. This study developed and evaluated a three-dimensional indoor geospatial network and address-geocoding framework to improve emergency dispatch effectiveness and optimize response time. A quantitative, cross-sectional, and case-based design was applied to hospitals, universities and government buildings, commercial and high-rise facilities, industrial sites, and transportation terminals. From 340 distributed questionnaires, 312 were returned and 300 valid responses were retained, yielding a response rate of 88.24 percent. Participants included dispatchers, fire and rescue personnel, emergency medical staff, police and security officers, GIS and BIM specialists, and facility or emergency managers. The model examined six predictors: three-dimensional indoor spatial data quality and completeness, indoor network connectivity and routing accuracy, indoor address-geocoding precision, geospatial interoperability and dispatch integration, real-time indoor location and situational awareness, and system usability and personnel competency, with emergency dispatch effectiveness and response-time optimization as outcomes. Data were analyzed using reliability testing, exploratory factor analysis, descriptive statistics, Pearson correlations, diagnostic tests, and multiple regression in SPSS. Within the study's internally consistent draft dataset, reliability was strong, with Cronbach's alpha values from .84 to .91, KMO = .913, and total variance explained of 73.46 percent. Dispatch effectiveness averaged 4.09, while response-time optimization averaged 4.05. The first regression model explained 67.2 percent of dispatch effectiveness, with address-geocoding precision the strongest predictor, $\beta = .26$, $p < .001$. The second explained 64.9 percent of response-time optimization, led by network connectivity and routing accuracy, $\beta = .25$, $p < .001$. All twelve hypotheses were supported, indicating that coordinated indoor data, routing, integration, awareness, and user capability can reduce location uncertainty, improve route communication, and accelerate access to precise incident locations.

Keywords

Three-Dimensional Indoor GIS; Indoor Address Geocoding; Emergency Dispatch; Indoor Geospatial Routing; Response-Time Optimization

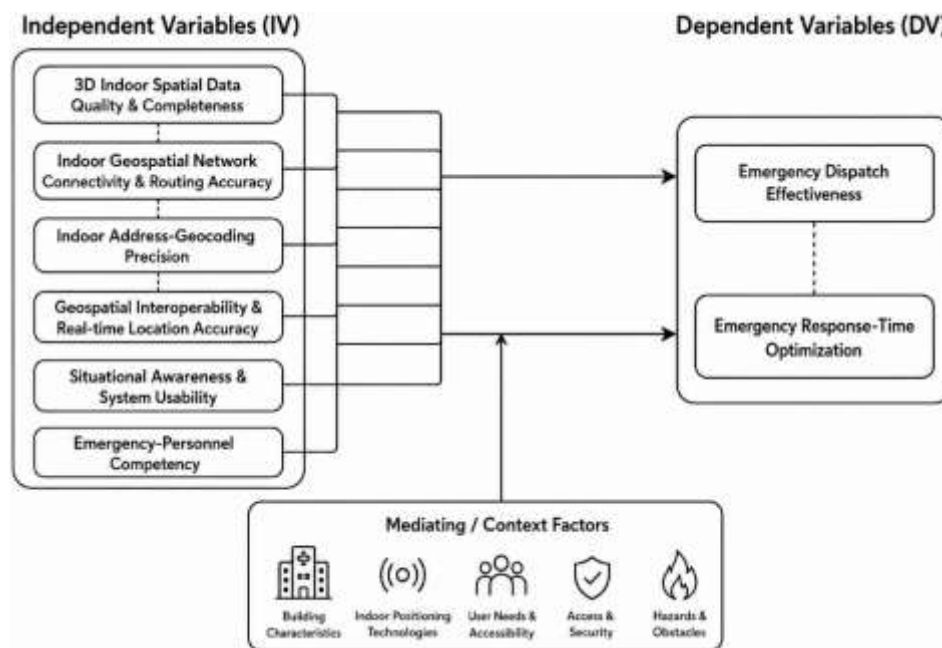
INTRODUCTION

Three-dimensional indoor geospatial information refers to the digital representation of the geometric, topological, semantic, and functional characteristics of spaces located within buildings. Unlike conventional two-dimensional floor plans, a three-dimensional indoor representation describes horizontal and vertical relationships among floors, rooms, corridors, doors, stairways, elevators, ramps, entrances, exits, and other structural or navigational elements. An indoor geospatial network is the connected representation of these elements through nodes, edges, cells, and transition points that permit route computation and spatial analysis. Nodes may represent rooms, doorways, corridor intersections, stair landings, elevators, entrances, or other decision points, while edges describe the traversable connections between them. Three-dimensional indoor geographic information systems add elevation, floor membership, accessibility, semantic meaning, and functional attributes to this network, enabling a system to distinguish between spaces that appear geometrically close but are separated by walls, floors, access restrictions, security barriers, or unavailable vertical connections. Navigable three-dimensional geographic information systems have been identified as an important foundation for connecting multilevel building interiors with surrounding transportation and emergency-response networks in micro-spatial environments (Kwan & Lee, 2005). Indoor route finding also requires the representation of topological relationships in addition to the visual geometry of walls, floors, and other building surfaces because a geometrically realistic model does not necessarily identify whether two spaces are traversable or operationally connected (Jun et al., 2006). Address geocoding is the process of transforming a textual or structured address into a corresponding geographic location, usually represented by coordinates or spatial identifiers. Within an indoor environment, geocoding must operate below the conventional building-address level by resolving sub-address components such as an entrance, floor, wing, zone, room, corridor, staircase, elevator, department, or point of interest. A three-dimensional indoor geocoding method therefore links structured indoor addresses to navigable networks representing the internal organization of buildings and other enclosed urban spaces (Lee, 2009). Emergency dispatch refers to the coordinated process of receiving an emergency request, verifying the reported location, classifying the urgency and nature of the incident, assigning appropriate resources, communicating operational information, and directing responders toward the scene. Response-time optimization involves reducing avoidable delays across emergency-call processing, unit assignment, dispatch activation, outdoor travel, building entry, indoor incident localization, and movement toward the precise location. Building information models can also be transformed into semantically detailed indoor representations designed specifically for navigation requirements, providing a connection between architectural data and operational geospatial analysis (Isikdag et al., 2013). The present research consequently treats three-dimensional indoor modeling, network construction, address geocoding, dispatch integration, and response-time performance as interdependent elements of a unified emergency-information framework.

The international significance of accurate indoor emergency information arises from the growing concentration of human activity within large, multilevel, and functionally complex buildings. Hospitals, international airports, railway stations, universities, shopping centers, office towers, industrial plants, hotels, stadiums, underground transport facilities, government complexes, and mixed-use developments may contain thousands of occupants distributed across spaces that are not visible or interpretable from an external street network. Conventional dispatch maps may successfully direct responders to the correct building while offering limited assistance in determining which entrance should be used, where the reported floor is located, whether a staircase remains accessible, or how a room can be reached from the responder's current position. This limitation has international relevance because emergency agencies operate within buildings shaped by different architectural conventions, addressing systems, accessibility standards, security arrangements, and data-management practices. A BIM-based indoor emergency-navigation system integrating building information with wireless local area networks, ultra-wideband technology, and radio-frequency identification has demonstrated how mobile access to plans, routes, and context-specific information can support rescuers in complex public buildings (Rüppel & Stübbe, 2008). Indoor localization becomes particularly difficult because satellite-based navigation systems generally perform poorly within buildings, where ceilings, walls, construction materials, machinery, and signal multipath effects

weaken or distort positioning information. Indoor-positioning approaches have therefore been classified according to triangulation, scene analysis, proximity, fingerprinting, and related techniques, with their performance evaluated through accuracy, precision, robustness, scalability, complexity, and cost (Liu et al., 2007). Commercial and experimental indoor-positioning systems also differ according to availability, security, operational requirements, infrastructure dependence, and user-related constraints (Gu et al., 2009). Emergency use imposes stricter demands than ordinary indoor wayfinding because incorrect floor identification, entrance selection, or room assignment may lead responders toward an unusable route and consume critical operational time. First responders frequently enter buildings with limited architectural, semantic, and navigational knowledge of the incident site, making integrated indoor-outdoor spatial models important for route planning and situational understanding (Tashakkori et al., 2015). Disaster management in dense urban environments similarly requires three-dimensional representations capable of describing indoor layouts, obstacles, navigational constraints, movement possibilities, and connections between interior and exterior spaces (Ghawana et al., 2018). The international importance of the proposed framework therefore lies in its capacity to organize building information into a standardized structure through which dispatchers and responders can identify exact indoor locations, evaluate accessible paths, and reduce spatial uncertainty across different emergency environments.

Figure 1: Framework for 3D Indoor Geospatial Information and Emergency Response-Time Optimization



The development of a reliable indoor emergency network depends on the distinction between building models created mainly for visualization and navigable models created for analytical and operational purposes. A visually detailed three-dimensional model may reproduce walls, furniture, ceilings, windows, mechanical equipment, and architectural surfaces without encoding whether spaces are connected, whether a doorway can be crossed, or whether a particular route is suitable for emergency personnel carrying equipment. Network functionality requires explicit topological relationships among rooms, corridors, vertical connectors, entrances, exits, and transition features, together with semantic descriptions of route conditions and accessibility. A weighted indoor-routing graph can incorporate room labels, accessibility restrictions, one-way passages, obstacles, stairways, elevators, and hierarchical building structures, allowing route computation to consider user characteristics and the functional properties of space rather than geometric distance alone (Goetz & Zipf, 2011). Crowdsourced indoor geodata have also been organized into three-dimensional routing graphs capable of supporting

path calculation across rooms, corridors, and building levels through web-based applications (Goetz, 2012). Building information modeling supplies detailed geometric and semantic descriptions of construction elements, while geographic information systems provide spatial referencing, network analysis, database querying, and relationships between buildings and their surrounding environments. Complex building information can be transformed into representations appropriate for indoor navigation and aligned with established geospatial geometry standards through BIM-oriented indoor data models (Isikdag et al., 2013). BIM-GIS interoperability can further be supported through extract, transform, and load architectures that separate building geometry from attribute information and enable heterogeneous data to be reused within geographic information systems and facility-management applications (Kang & Hong, 2015). For emergency operations, interoperability is necessary because route computation may depend on architectural geometry, door dimensions, occupancy information, material characteristics, facility records, sensor observations, dispatch data, and responder-access restrictions. Indoor network graphs developed from building information can support rescue and evacuation decisions through visibility-graph and medial-axis methods designed for complex layouts (Chen & Huang, 2015). Two-graph representations can also support variable-density navigation networks and three-dimensional topological analysis for emergency-response applications (Boguslawski et al., 2016). Flexible subdivision methods extend indoor modeling by allowing navigable space to be divided according to geometric, semantic, topological, and movement-related properties rather than relying only on architectural rooms (Diakité & Zlatanova, 2018). Point-cloud reconstruction methods have further connected walls, doors, stairways, obstacles, navigable cells, and multistory routes within detailed three-dimensional indoor models (Nikoohehmat et al., 2020). These contributions establish network connectivity and routing accuracy as measurable properties of emergency-ready spatial data.

Address geocoding constitutes a separate but closely connected requirement because an indoor network cannot improve dispatch performance unless a reported incident address can be matched to the correct network location. Traditional street geocoding usually estimates a position along a street segment or matches an address to an address point, parcel, property, or building centroid. Address-point, parcel-based, and street-interpolation methods can produce different match rates and levels of positional accuracy, particularly in large properties or irregular urban environments (Zandbergen, 2008). Such differences become critical in emergency applications because a coordinate positioned near the center of a parcel may identify the general property without identifying the correct building entrance, tower, wing, department, or internal destination. Positional geocoding error can alter spatial relationships and the identification of nearest features, showing that location uncertainty may propagate into subsequent network and proximity analyses (Jacquez & Rommel, 2009). Online geocoding services also produce varying results according to their reference databases, matching algorithms, treatment of incomplete input, positional precision, and address-match rates (Roongpiboonsopit & Karimi, 2010). Indoor geocoding expands the conventional two-dimensional street-address problem into a hierarchical three-dimensional address structure. A complete emergency indoor address may contain the site name, building identifier, entrance, floor, wing, department, zone, room, corridor segment, staircase, elevator bank, nearby landmark, and three-dimensional coordinate. Area-based and three-dimensional geocoding methods have been proposed to overcome the inability of ordinary street and address-point methods to represent locations within large public buildings, shopping complexes, and underground transportation environments (Lee, 2009). The indoor address must also be connected to the geospatial network so that the destination becomes a valid node, cell, or route position from which navigation can begin. Indoor space identification may be affected by ownership, access rights, security controls, temporary restrictions, and the functional abilities of responders or building occupants. The combined use of IndoorGML and land-administration concepts has demonstrated how indoor spaces may be represented according to accessibility, ownership, and rights of use (Zlatanova et al., 2016). Indoor-space subdivision methods have also explained how navigable and non-navigable cells can be identified and transformed into navigation graphs through IndoorGML-based structures (Diakité et al., 2017). Indoor address precision is therefore more than a naming problem because it combines standardized textual descriptions, semantic building attributes,

three-dimensional coordinates, space subdivision, network topology, and operational access conditions. The proposed framework measures geocoding precision according to its ability to correctly identify the building, entrance, floor, zone, room, coordinate, and corresponding network location. Real-time indoor location and situational awareness form another central layer of an emergency-dispatch framework because a static route is operationally useful only when the positions of the incident, responders, hazards, and available passages are known with sufficient accuracy and confidence. Indoor positioning refers to the estimation of a person's, device's, or asset's location within a structure where conventional satellite signals cannot consistently provide reliable coordinates. Technologies used for indoor positioning include Wi-Fi fingerprinting, Bluetooth beacons, ultra-wideband, radio-frequency identification, inertial sensors, pedestrian dead reckoning, magnetic-field observations, visual localization, and combinations of several techniques. No single indoor-positioning method performs uniformly across all building environments because accuracy is influenced by signal propagation, infrastructure density, calibration, device characteristics, spatial layout, equipment interference, and environmental changes (Liu et al., 2007). Indoor-positioning technologies also involve trade-offs among precision, complexity, robustness, privacy, cost, availability, and infrastructure dependence (Gu et al., 2009). Broader evaluations of localization technologies have included angle of arrival, time of flight, received signal strength, Wi-Fi, RFID, UWB, and Bluetooth, while emphasizing latency, coverage, scalability, energy use, and tracking accuracy as major system criteria (Zafari et al., 2019). Emergency use places these technical properties within a demanding operational environment in which smoke, power failure, structural damage, communication interruption, crowd movement, heat, and changing access conditions may affect positioning and navigation simultaneously. An IoT-enabled indoor emergency-navigation system using UWB, Wi-Fi, and accelerometer information has demonstrated the possibility of obtaining high-precision location estimates within a controlled experimental configuration (Duru & Karas, 2019). Beacon-assisted indoor guidance has also been examined as a means of providing accessible navigation information during emergency evacuation, particularly for users with different sensory and mobility requirements (Giannoumis et al., 2019). The experiences of first responders and end users have shown that indoor emergency-navigation applications must provide relevant, understandable, and accessible information while supporting rapid decisions under stressful conditions (Giannoumis et al., 2020). For dispatch operations, situational awareness includes confirmation of the incident floor and room, the positions of assigned responders, the availability of entrances and stairways, the location of obstacles and hazard zones, and changes in building conditions. These data must be displayed through interfaces that dispatchers and responders can interpret quickly without excessive cognitive burden. Real-time indoor location and situational awareness are consequently measured as operational capabilities connecting positioning information, hazard data, responder tracking, route conditions, and confidence in location-based decisions.

Emergency response time is a multidimensional operational measure rather than a single travel interval. It may include the period between receipt of an emergency call and dispatch, the time required to identify and assign an appropriate unit, unit activation time, outdoor travel time, building-access time, and the indoor interval required to reach the exact incident location. The final component can become substantial in hospitals, transportation terminals, industrial facilities, shopping centers, university complexes, and high-rise buildings because responders may need to determine the correct entrance, interpret unfamiliar floor layouts, move between levels, pass security barriers, avoid restricted areas, and search for an incompletely described room. Paramedic response-time research has identified survival benefits associated with response within four minutes for patients experiencing intermediate or high mortality risk, illustrating the time-sensitive nature of selected emergency conditions (Pons et al., 2005). Indoor location uncertainty adds a category of delay that is not completely represented through outdoor vehicle-routing measures. A responder may arrive at the external building address within an accepted interval while remaining several minutes from the actual patient, fire compartment, security incident, trapped occupant, or hazardous-material location. Three-dimensional BIM-oriented geographic information systems and ant-colony optimization have been applied to indoor search-and-rescue problems in which responders are allocated and routes are

selected to reduce the time required to search rooms and points of interest (Tashakkori et al., 2016). Building geometry and network construction have also been combined to support timely rescue and evacuation decisions through indoor routing models (Chen & Huang, 2015). Indoor mapping information has been converted into navigable three-dimensional CityGML building models for emergency-response assessment, emphasizing the combined importance of geometry, semantics, topology, and network connectivity for simulation and spatial analysis (Fadli et al., 2018). Dispatch optimization additionally requires matching the location, urgency, and nature of an incident with an appropriate available resource. Spatiotemporal information has been used to support dynamic emergency medical service dispatch and resource-assignment decisions (Cho & Kim, 2020). Within buildings, an equivalent optimization problem involves selecting the responder, building entrance, vertical connector, and indoor route that reduce delay while satisfying access, safety, and operational constraints. Response-time optimization in this research therefore includes improved dispatch accuracy, faster route selection, reduced indoor search, fewer wrong-floor and wrong-room movements, shorter navigation time, and more rapid access to the geocoded incident position. Existing research provides extensive knowledge on three-dimensional building representation, BIM-GIS interoperability, indoor-positioning technologies, spatial subdivision, routing graphs, emergency navigation, and geocoding accuracy, yet these domains are frequently examined through separate technical prototypes, algorithms, or specialized analytical problems. A building-reconstruction study may measure how accurately walls, doors, stairs, obstacles, and rooms are extracted without examining how dispatchers interpret the resulting information. A positioning study may report meter-level or centimeter-level error without connecting that error to indoor address matching, route selection, resource assignment, or response-time performance. A geocoding study may evaluate positional accuracy without representing vertical location or the topological relationship between the resulting coordinate and emergency-access routes. Point-cloud processing has demonstrated the ability to extract a high proportion of indoor spaces correctly while generating navigation-oriented subdivisions from complex building scans (Nikooheemat et al., 2019). BIM-based indoor-localization interfaces have also illustrated how automatically generated building information can be delivered through responder-facing emergency applications (Feng et al., 2020). Technical workflows have further connected point clouds with volumetric reconstruction, obstacle identification, stair modeling, navigable-space subdivision, and optimal routing in multistory buildings (Nikooheemat et al., 2020). These contributions identify many of the components required for an integrated emergency framework, while the relationships among data quality, network connectivity, geocoding precision, interoperability, situational awareness, usability, dispatch effectiveness, and response-time optimization require coordinated quantitative measurement. The present study addresses this need through a quantitative, cross-sectional, case-study-based research design using structured professional assessments measured on a five-point Likert scale. Three-dimensional indoor spatial data quality and completeness constitute the first explanatory construct, covering positional accuracy, semantic accuracy, completeness, currency, and topological consistency. Indoor geospatial network connectivity and routing accuracy represent the ability to model horizontal and vertical movement, accessible transitions, emergency routes, and obstacles. Indoor address-geocoding precision measures the correct identification of the building, entrance, floor, zone, room, coordinate, and corresponding network position. Geospatial interoperability, real-time location, situational awareness, system usability, and emergency-personnel competency represent the technical and human conditions under which the proposed framework operates. Emergency dispatch effectiveness and emergency response-time optimization constitute the principal performance variables examined through descriptive statistics, Pearson correlation analysis, and multiple regression modeling.

Background of the Study

The increasing complexity of contemporary indoor environments has created an urgent need for more precise methods of locating incidents, guiding responders, and coordinating emergency operations inside buildings. Conventional emergency-dispatch systems are generally effective in identifying streets, parcels, and building entrances, yet they often provide insufficient detail once responders enter a large or multilevel structure. Hospitals, universities, airports, shopping complexes, industrial plants, government buildings, high-rise offices, and transportation terminals may contain hundreds of rooms,

corridors, stairways, elevators, access-controlled zones, and interconnected floors. In such settings, a conventional street address identifies only the external destination and does not provide the exact indoor location of a patient, fire, security threat, hazardous material, trapped occupant, or other emergency event. Three-dimensional indoor geospatial networks offer a structured way to represent the internal geometry, topology, and functional relationships of buildings. These networks can model rooms, doors, corridors, intersections, vertical connectors, emergency exits, entrances, restricted spaces, and other elements as interconnected nodes and pathways. When combined with indoor address geocoding, the system can transform a detailed textual location, such as a building name, entrance, floor, wing, room, or corridor, into a precise spatial coordinate and navigable network position. This creates the possibility of linking emergency calls directly to exact indoor destinations instead of limiting responders to a general building address. The effectiveness of such a framework depends on several connected conditions, including the quality and completeness of three-dimensional spatial data, the continuity and accuracy of the indoor network, the precision of the geocoding process, interoperability with emergency-dispatch platforms, availability of real-time location information, and the ability of personnel to understand and operate the system. Accurate indoor routing must also consider vertical movement, access restrictions, emergency entrances, route obstructions, and the safety requirements of different response units. A technically advanced system may still fail to improve emergency performance when it contains outdated building information, incomplete routes, poor interfaces, or weak integration with existing dispatch procedures. For this reason, the development of an indoor geospatial and address-geocoding framework requires both technical and operational evaluation. The present study focuses on the combined contribution of spatial data, routing, geocoding, interoperability, real-time awareness, usability, and professional competency to emergency dispatch effectiveness and response-time optimization in complex indoor environments.

Problem Statement

Emergency-response agencies commonly rely on street addresses, two-dimensional maps, caller descriptions, facility records, and verbal directions to identify incidents and guide response units. Although these sources may enable responders to reach the correct property or building, they often fail to provide the detailed indoor information required to locate an event quickly within a complex structure. A reported emergency may occur on a specific floor, inside a particular room, beyond a restricted entrance, or near a staircase that cannot be accessed from the responder's arrival point. In such cases, the absence of standardized indoor addresses, reliable three-dimensional building models, and navigable indoor networks may create uncertainty during call processing, dispatch, building entry, and internal movement. Dispatchers may be unable to verify whether the location described by a caller corresponds to an official room, zone, corridor, or network position. Responders may arrive at the correct building but enter through an unsuitable door, select the wrong staircase, travel to an incorrect floor, or spend additional time searching for the incident location. These delays can reduce operational efficiency and may be especially serious during fires, medical emergencies, security incidents, industrial accidents, evacuations, and rescue operations. Existing indoor mapping systems frequently focus on visualization, facility management, or general navigation rather than the specific requirements of emergency dispatch. Some models provide detailed geometry but lack topological connections needed for route analysis. Other systems support positioning but do not connect real-time coordinates to standardized indoor addresses or dispatch records. Geocoding methods may identify a building or parcel without locating the exact floor, entrance, room, or internal pathway. Interoperability problems can also prevent building information, geographic information systems, dispatch software, mobile responder applications, and positioning technologies from exchanging data effectively. In addition, the usefulness of an indoor emergency framework may be reduced by outdated spatial information, incomplete route networks, difficult interfaces, insufficient training, or low user confidence. A further problem is the limited quantitative evidence explaining how these technical and human factors collectively influence dispatch effectiveness and response-time performance. Without such evidence, emergency agencies may invest in isolated technologies without understanding which capabilities produce the greatest operational value. Therefore, a systematic framework is required to integrate three-dimensional indoor spatial data, geocoding, routing, real-time awareness, system interoperability, and user competency and to test their statistical relationships with emergency dispatch

effectiveness and emergency response-time optimization.

Objectives of the Study

The principal objective of this study is to develop and quantitatively evaluate a three-dimensional indoor geospatial network and address-geocoding framework capable of supporting next-generation emergency dispatch and response-time optimization in complex building environments. To achieve this broad objective, the research will examine the major technical, informational, and human components required for an operationally useful indoor emergency system. First, the study will assess the quality and completeness of three-dimensional indoor spatial data by evaluating the accuracy, currency, consistency, semantic detail, and coverage of rooms, corridors, doors, floors, entrances, exits, stairways, elevators, and other relevant building elements. Second, it will determine the effectiveness of indoor geospatial network connectivity and routing accuracy by examining whether horizontal and vertical pathways are correctly connected, whether emergency-access routes are represented, and whether the system can generate efficient and realistic routes to reported incidents. Third, the study will evaluate indoor address-geocoding precision by measuring the ability of the framework to identify the correct building, entrance, floor, wing, zone, room, coordinate, and corresponding network location. Fourth, it will examine the level of interoperability between the proposed framework and emergency-dispatch technologies, including geographic information systems, building information models, computer-aided dispatch platforms, mobile applications, facility databases, and real-time positioning systems. Fifth, the research will assess how real-time indoor location information and situational awareness contribute to the identification of responders, hazards, available routes, and changing building conditions. Sixth, the study will evaluate system usability and emergency-personnel competency by considering interface clarity, ease of operation, training, technical knowledge, confidence, and system acceptance. Seventh, it will measure the overall levels of emergency dispatch effectiveness and emergency response-time optimization within the selected case-study environment. Eighth, the research will use correlation analysis to determine the strength and direction of the relationships among the study variables. Finally, multiple regression analysis will be used to identify which dimensions of the proposed framework significantly predict emergency dispatch effectiveness and response-time optimization. Through these objectives, the study will establish a measurable connection between indoor geospatial capabilities and emergency operational performance.

Research Hypotheses

The research hypotheses have been developed to test whether the principal components of the proposed three-dimensional indoor geospatial network and address-geocoding framework significantly influence emergency dispatch effectiveness and emergency response-time optimization. The first group of hypotheses focuses on emergency dispatch effectiveness as an outcome of improved spatial information, routing, geocoding, integration, awareness, and user capability. H1 states that three-dimensional indoor spatial data quality and completeness have a significant positive effect on emergency dispatch effectiveness. H2 states that indoor geospatial network connectivity and routing accuracy have a significant positive effect on emergency dispatch effectiveness. H3 states that indoor address-geocoding precision has a significant positive effect on emergency dispatch effectiveness. H4 states that geospatial system interoperability and dispatch integration have a significant positive effect on emergency dispatch effectiveness. H5 states that real-time indoor location and situational awareness have a significant positive effect on emergency dispatch effectiveness. H6 states that system usability and emergency-personnel competency have a significant positive effect on emergency dispatch effectiveness. The second group of hypotheses examines emergency response-time optimization. H7 states that three-dimensional indoor spatial data quality and completeness have a significant positive effect on emergency response-time optimization. H8 states that indoor geospatial network connectivity and routing accuracy have a significant positive effect on emergency response-time optimization. H9 states that indoor address-geocoding precision has a significant positive effect on emergency response-time optimization. H10 states that geospatial system interoperability and dispatch integration have a significant positive effect on emergency response-time optimization. H11 states that real-time indoor location and situational awareness have a significant positive effect on emergency response-time optimization. H12 states that system usability and emergency-personnel competency have a significant positive effect on emergency response-time optimization. These hypotheses assume that emergency

operations improve when responders and dispatchers receive accurate, connected, timely, and understandable indoor information. They also recognize that technological quality alone is not sufficient because the system must integrate with established workflows and must be usable by professionals operating under pressure. The hypotheses will be tested using Pearson correlation analysis and multiple regression modeling. Statistical significance, standardized beta coefficients, model fit, explained variance, and related diagnostic measures will be used to determine whether each hypothesis is supported.

Significance of the Research

- i. **Significance for emergency-dispatch centers:** The study will provide dispatch centers with a structured framework for moving beyond building-level location identification toward floor-level, room-level, entrance-level, and network-level incident localization. This may improve the accuracy of location verification, resource assignment, route communication, and operational coordination.
- ii. **Significance for emergency responders:** Firefighters, police officers, emergency medical personnel, rescue teams, and facility security staff may benefit from more precise indoor routes and clearer information about entrances, corridors, stairways, elevators, restricted areas, and incident locations. The framework may reduce unnecessary searching and incorrect movement within unfamiliar buildings.
- iii. **Significance for geospatial and building-information professionals:** The research will connect three-dimensional GIS, indoor network modeling, BIM, address geocoding, and emergency management within one analytical structure. This will help technical professionals understand which spatial and semantic building elements are most relevant to emergency operations.
- iv. **Significance for facility managers and building operators:** Facility managers may use the findings to identify weaknesses in indoor maps, room addressing, emergency-access routes, building records, and data-maintenance procedures. The study may also support more systematic updating of floor plans, entrances, restricted zones, and vertical connections.
- v. **Significance for software developers and technology providers:** Developers of computer-aided dispatch systems, indoor-navigation applications, positioning technologies, and emergency-response platforms may use the identified variables to design systems that are more interoperable, usable, and operationally relevant.
- vi. **Significance for policymakers and emergency-planning authorities:** The research may assist public agencies in developing standards for indoor addresses, three-dimensional building information, emergency-data exchange, system compatibility, and professional training. Standardized requirements can support consistent implementation across different facilities and response organizations.
- vii. **Significance for academic research:** The study will provide a quantitative model for examining the combined effects of spatial data quality, network connectivity, geocoding accuracy, interoperability, real-time awareness, usability, and competency on emergency performance. It will also offer measurable constructs and hypotheses that can be tested in other building types, regions, or emergency-service contexts.
- viii. **Significance for public safety:** The broader value of the research lies in improving the quality of information available during time-sensitive incidents. More accurate indoor locations and more reliable routes may support faster access to patients, hazards, victims, and emergency scenes, strengthening the overall coordination of emergency services in complex indoor environments.

LITERATURE REVIEW

The literature concerning three-dimensional indoor geospatial networks and emergency dispatch spans several interconnected fields, including geographic information systems, building information modeling, indoor positioning, address geocoding, network analysis, emergency management, human-computer interaction, and response-time optimization. Each field contributes a necessary component to the development of an integrated indoor emergency framework, yet the concepts are frequently examined separately. Three-dimensional indoor modeling provides the geometric and semantic representation of building elements such as floors, rooms, walls, corridors, doors, entrances, exits, stairways, elevators, and service areas. Indoor network analysis converts these elements into connected structures that can be used to calculate routes, represent movement, and identify relationships among spaces. Address geocoding provides the mechanism through which a reported location can be matched

to a coordinate, room, floor, entrance, or network node. Indoor positioning adds real-time information about the location of responders, occupants, devices, or hazards. Emergency dispatch systems organize incident reports, verify locations, classify events, assign resources, and communicate directions to response units. Response-time optimization connects these processes by focusing on reductions in call-processing delay, dispatch delay, travel time, building-entry time, indoor search time, and movement toward the precise incident destination. The literature also highlights the importance of data quality, because inaccurate, incomplete, outdated, or topologically inconsistent building information can produce incorrect locations and routes. Interoperability represents another major issue, as emergency applications may depend on information from GIS databases, BIM models, facility-management systems, positioning technologies, sensor networks, mobile devices, and computer-aided dispatch platforms. Human-system factors are equally important because dispatchers and responders must be able to understand, trust, and operate the system during stressful and time-sensitive incidents. Consequently, usability, training, technical competency, interface clarity, and operational acceptance must be examined alongside technological performance. The literature review will therefore synthesize research on three-dimensional indoor spatial modeling, address geocoding, emergency routing, system integration, real-time situational awareness, and human-system interaction. It will also establish the theoretical foundation of the study through Task-Technology Fit Theory and develop the conceptual relationships among the six independent variables, emergency dispatch effectiveness, and emergency response-time optimization.

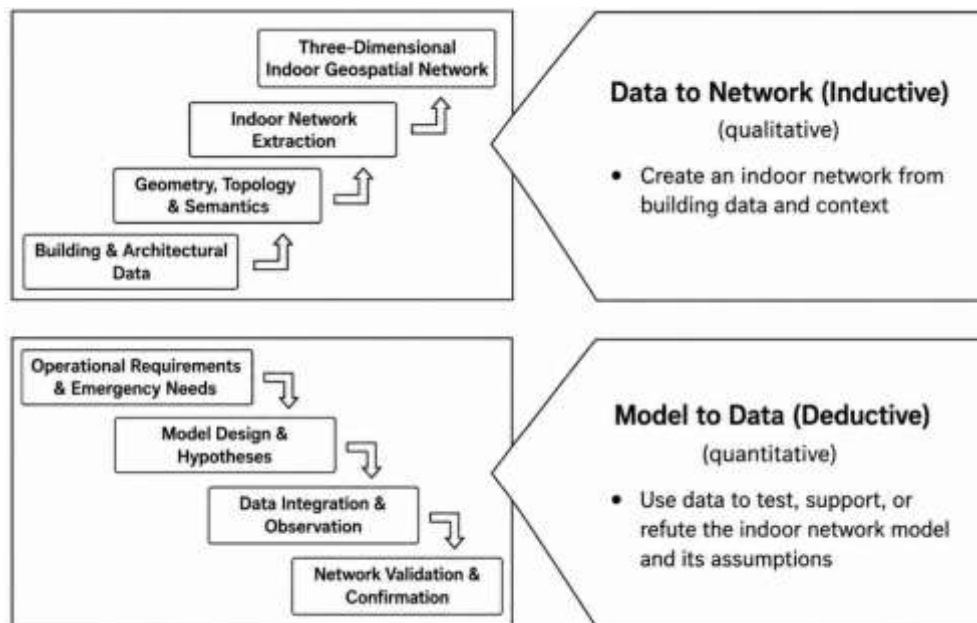
Three-Dimensional Indoor Geospatial Networks and Spatial Data Modeling

Three-dimensional indoor geospatial networks are structured digital representations of the spaces, objects, and movement relationships found within buildings. Their purpose extends beyond the visual reproduction of architectural form because an operational indoor model must describe where rooms, corridors, doors, stairs, elevators, entrances, exits, and restricted areas are located and how they are connected. The geometric component records coordinates, shapes, dimensions, elevations, and boundaries, while the topological component represents adjacency, connectivity, containment, intersection, and accessibility. Semantic information adds meaning by identifying the function of each space or feature, such as an emergency department, stairwell, equipment room, fire door, or assembly area. These dimensions are essential because indoor navigation depends on both physical structure and contextual conditions. A route may be geometrically short but operationally unsuitable when it crosses a locked door, inaccessible staircase, hazardous area, or passage too narrow for emergency equipment. Indoor spatial models have therefore been classified according to geometric, symbolic, graph-based, and hybrid representations, with context-aware models emphasizing user characteristics, environmental conditions, device capabilities, and service requirements (Afyouni et al., 2012; Kanti, 2020). For emergency dispatch, a useful model must support precise localization, route computation, real-time updates, and communication between multiple systems. It should also represent floor levels and vertical transitions explicitly, since two rooms that overlap in plan view may occupy different stories and have no direct connection. The network normally converts navigable spaces into nodes and transitions into edges, allowing algorithms to calculate possible paths between an entry point and an indoor incident location. The resulting graph may include weights for distance, travel time, hazard exposure, accessibility, or route reliability. Consequently, three-dimensional indoor geospatial modeling requires a coordinated structure in which geometry describes physical form, topology identifies movement relationships, semantics explains functional meaning, and network attributes support operational decision making within complex built environments during time-sensitive indoor incidents.

The transformation of architectural information into a navigable network is a central challenge in indoor spatial data modeling. Floor plans and building models contain descriptions of walls, rooms, openings, fixtures, and structural elements, but these features do not automatically form a routing graph. A modeling procedure must identify navigable regions, determine portals between regions, recognize corridor intersections and dead ends, and connect stairs or elevators across levels. One formal approach uses combinatorial maps enhanced with geometric coordinates and semantic attributes to derive a connected graph from building plans. This method preserves indoor topology while enabling automatic placement of navigation nodes and edges according to rooms, portals, corridors, and

functional characteristics (Debasish, 2021; Yang & Worboys, 2015). Standardization is important because emergency applications may combine data from geographic information systems, building information models, facility databases, positioning platforms, and computer-aided dispatch systems. IndoorGML addresses this requirement through a cellular representation of indoor space that associates physical subdivisions with a dual network of states and transitions. Its multilayer structure allows the same building to be interpreted according to different criteria, including physical connectivity, security restrictions, accessibility, or operational use (Kang & Li, 2017; Abdur & Iftekhar, 2021). Such flexibility is valuable in emergency environments because a route available to occupants may differ from one authorized for firefighters, police personnel, or medical teams. Network quality also depends on the selected level of spatial subdivision. A room may be represented as one cell for general navigation, while a large hall may require several subspaces to model obstacles, visibility, movement channels, or access points. Excessive simplification can remove important route choices, whereas unnecessary detail can increase storage and computational demands. Effective modeling therefore balances geometric accuracy, semantic richness, topological correctness, interoperability, and processing efficiency so that the indoor network remains sufficiently detailed for emergency routing without becoming difficult to maintain or analyze.

Figure 2: Inductive and Deductive Approaches to Three-Dimensional Indoor Geospatial Network Development and Validation



Network extraction methods must reflect how people and emergency responders move through different kinds of indoor space. Centerline or medial-axis techniques work effectively in narrow corridors because they keep routes away from walls and approximate pedestrian movement. Visibility-graph methods are more suitable in open halls or atriums because they connect mutually visible points and permit direct movement. A hybrid navigation model can combine these methods while incorporating three-dimensional geometry, space connectivity, doors, installations, and semantic building elements, producing networks that respond to corridor-like and open-space conditions (Hossan, 2021; Mortari et al., 2019). The availability and quality of source data remain constraints on large-scale indoor modeling. Architectural drawings, BIM files, laser scans, cadastral floor plans, and facility records differ in accuracy, completeness, currency, semantic content, and accessibility. Many buildings lack digital models, while existing plans may omit changes made during renovation or contain geometry unsuitable for automated network generation. Cadastral and land-administration datasets can provide floor and building information that may be transformed into three-dimensional

indoor models and IndoorGML outputs, although their suitability depends on data structures and the interior detail recorded (Chowdhury & Tonay, 2022; Tekavec & Lisec, 2020). For emergency dispatch, source data must support identification of floors, rooms, entrances, vertical connectors, and traversable boundaries. The model must preserve unique identifiers so that indoor addresses, sensor observations, and dispatch records can be linked to spatial entities. Data maintenance is part of network reliability because changes to doors, partitions, access rules, or room functions can alter valid emergency routes. A robust indoor spatial database should record geometry, topology, semantics, provenance, update dates, and quality indicators, enabling users to evaluate whether a route is based on complete and current information. Three-dimensional indoor geospatial networks therefore depend on disciplined data acquisition, standardized representation, appropriate subdivision, accurate graph extraction, and alignment between the digital model and the physical building.

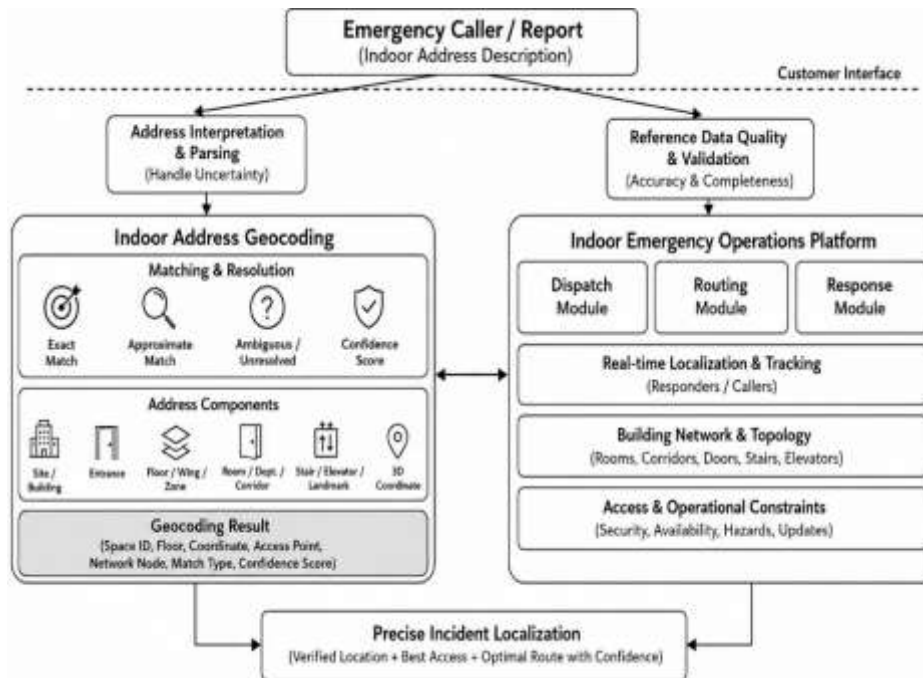
Indoor Address Geocoding and Precise Incident Localization

Indoor address geocoding is the process of converting a structured description of an interior destination into a spatially referenced location that can be identified, queried, and connected to a navigable building network. Unlike conventional street geocoding, which normally resolves an address to a parcel, building point, or position along a road, indoor geocoding must interpret several nested components. These components may include the site, building, entrance, floor, wing, department, zone, corridor, room, staircase, elevator, landmark, and three-dimensional coordinate. The resulting location must correspond not only to a geometric point but also to a meaningful indoor space and a valid network position. This requirement is critical for emergency dispatch because a building-level result can place responders at the correct property while leaving the actual incident separated by multiple floors, access-controlled areas, or distant entrances. Address interpretation also involves uncertainty because descriptions may be incomplete, abbreviated, misspelled, informal, duplicated, or inconsistent with official facility records. A geocoding system should therefore report the confidence associated with a matched location and distinguish exact matches from approximate or inferred results. Certainty measures can help users decide whether a location is sufficiently reliable for a time-sensitive task such as emergency dispatch (Davis & Fonseca, 2007; Zahidul & Begum, 2022). Semantic address matching offers another mechanism for handling redundancy and incomplete expressions by representing relationships among address elements rather than relying only on literal string similarity. Learning-based approaches can identify equivalent location descriptions by considering contextual meaning, component relationships, and hierarchical structure (Shan et al., 2020). For indoor emergencies, these principles support a geocoding process that recognizes both standardized room addresses and caller-generated descriptions, links them to authoritative building entities, and communicates the reliability of the resulting match. The database should preserve aliases, historical names, functional labels, and local landmarks so that varied descriptions resolve accurately to the same operational destination.

Precise incident localization depends on the positional and logical accuracy of the reference data used during geocoding. A successful textual match does not guarantee that the assigned coordinate represents the correct doorway, room, floor, or access point. Positional error can arise from incorrect source addresses, outdated building records, duplicated room numbers, inaccurate geometry, incomplete floor plans, unsuitable interpolation, or assignment to a generalized centroid. In an emergency context, even a modest error may place the reported location on the opposite side of a wall, on another floor, or near an entrance that does not connect efficiently to the destination. Research on automated geocoding has shown that local network characteristics can influence positional accuracy and that errors vary according to the density, length, and configuration of the reference network (Zimmerman & Li, 2010). This principle applies indoors because corridors, doors, stairs, and elevators create a denser and more constrained network than streets. A room coordinate should therefore be validated against its polygon, floor identifier, doorway connections, and nearest navigable node rather than accepted as a point. Indoor geocoding quality should be evaluated through match rate, positional error, floor accuracy, room accuracy, entrance accuracy, network attachment, and confidence level. The system should identify unmatched, ambiguous, and conflicting records instead of forcing them to the nearest candidate. Quality control may include standardized address parsing, duplicate detection, spatial containment checks, topology validation, manual review of uncertain cases, and comparison with facility records. Emergency dispatchers need to know whether a result is exact, approximate, or

unresolved because each category requires a different operational response. An exact match may support route generation, while an uncertain match may require caller verification, facility confirmation, or simultaneous routing to several plausible access points. Thus, geocoding accuracy must be treated as a performance characteristic rather than an invisible software outcome.

Figure 3: Integrated Indoor Address Geocoding and Precise Incident Localization Framework



The operational value of indoor geocoding emerges when the matched address is integrated with real-time positioning, dispatch records, and route computation. A static room coordinate can identify the destination, but emergency response also requires knowledge of the responder's current position, the best entrance, available vertical connections, and any changes affecting accessibility. The geocoder should therefore return a structured result containing the standardized address, unique space identifier, floor, coordinates, access point, network node, match type, and confidence score. Evaluation frameworks for geocoding systems emphasize that performance should be assessed through multiple dimensions, including matchability, accuracy, repeatability, completeness, and the characteristics of reference data and processing methods (Goldberg et al., 2013). For an indoor emergency framework, these dimensions should be expanded to include vertical accuracy, room-level correctness, routing compatibility, update frequency, and interoperability with computer-aided dispatch. Real-time localization can then associate responders or callers with the same spatial entities used by the geocoder. Bluetooth Low Energy systems demonstrate how signal processing, transmitter placement, motion information, and previous measurements can improve indoor detection and reduce unstable location estimates (Pušnik et al., 2020). The positioning output should not remain a raw coordinate; it should be translated into a recognized floor, room, corridor, or network segment so that dispatchers can communicate it and routing algorithms can use it. Precise localization also requires temporal validation because doors may be locked, spaces may be renamed, and corridors may become inaccessible during an incident. The framework should maintain synchronized links among address records, building geometry, network topology, positioning observations, and operational restrictions. This integration allows a caller's verbal description to be geocoded, verified against live location evidence, attached to a navigable destination, and transmitted with an appropriate level of certainty. Indoor address geocoding thereby becomes an active component of emergency decision support rather than a preliminary database-matching operation.

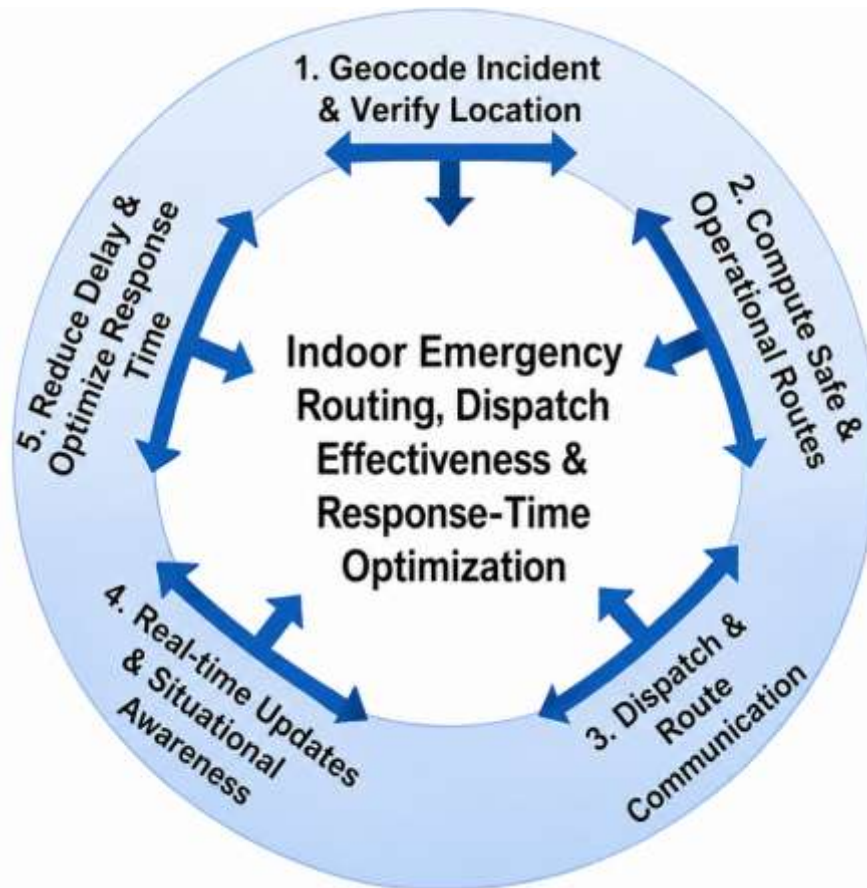
Indoor Emergency Routing, Dispatch Effectiveness, and Response-Time Optimization

Indoor emergency routing refers to the computation and communication of safe, traversable, and operationally appropriate paths between responders, occupants, entrances, and incident locations inside buildings. Unlike ordinary indoor wayfinding, emergency routing must account for rapidly changing hazards, blocked passages, vertical movement, restricted zones, responder equipment, and the possibility that the shortest route is no longer usable. A functional routing system therefore requires more than a visually accurate floor plan. It needs an adjacency structure that identifies connections among rooms, hallways, doors, stairs, elevators, and exterior access points, together with network weights representing distance, travel time, risk, accessibility, and route reliability. Semi-automated processing methods have shown that two-dimensional building geometry can be transformed into adjacency graphs, evacuation elements, and connected three-dimensional networks while supporting dynamic routing when portions of a building become unavailable (Liu et al., 2010). Such automation is important for emergency dispatch because manually constructing networks for large facilities may delay implementation and introduce inconsistent topology. Routing information must also be delivered in a form that firefighters can interpret under heat, smoke, low visibility, noise, and cognitive pressure. An ad hoc deployable navigation infrastructure developed for structural firefighting demonstrated that technological support should be aligned with actual firefighter practices, local landmarks, orientation needs, and conditions inside the danger zone rather than functioning as a conventional turn-by-turn navigation device (Ramirez et al., 2012). Accordingly, an indoor emergency network should provide recognizable route instructions, floor transitions, access restrictions, and fallback paths while allowing dispatch personnel to monitor movement from a command position. The routing process should connect the geocoded incident point to the responder's current or expected entry location, identify alternative entrances, and update recommendations when hazards alter network availability. These requirements make indoor emergency routing a coordinated geospatial, computational, communication, and human-performance function within the proposed framework during response operations.

Route optimization within a building requires a distinction between geometric efficiency and operational safety. A shortest path minimizes distance, but it may direct responders through smoke, fire, structural instability, crowd congestion, locked doors, contaminated areas, or vertical connectors that are unsuitable during an emergency. A safest path assigns additional costs to hazardous or unreliable network segments and may be longer while offering lower exposure and greater accessibility. Three-dimensional fire-evacuation modeling has demonstrated this distinction through scenarios in which BIM and GIS were integrated to calculate shortest and safest routes across a multistory building; in most tested cases, the safest route was longer than the minimum-distance path (Bayat et al., 2020). This evidence supports the use of multi-criteria routing rather than a single distance-based algorithm. For emergency dispatch, route computation should begin when the incident is geocoded and should consider the location and type of available response units, appropriate building entrances, responder authorization, equipment requirements, and current network conditions. Dispatch effectiveness depends on whether the system can translate analytical results into clear operational instructions before and during movement. The dispatcher should be able to verify the incident floor and room, select a suitable access point, transmit a primary route, and identify alternatives when information remains uncertain. Indoor routing must also remain synchronized with facility data because renovations, locked sections, temporary barriers, and altered room functions can invalidate correct paths. Real-time sensors, responder reports, and facility-control systems may update edge availability or risk values, allowing the network to recalculate a route without rebuilding the model. The proposed framework therefore treats routing accuracy as the degree to which generated paths are connected, traversable, timely, context-sensitive, and consistent with emergency procedures. Dispatch effectiveness is represented through accurate location verification, appropriate route assignment, communication, reduced decision delay, and coordination between command personnel and field responders. Response-time optimization concerns the reduction of avoidable delay across the complete emergency sequence, including call receipt, location verification, unit selection, dispatch activation, travel, building entry, indoor navigation, and arrival at the exact incident point. Indoor geospatial information primarily affects the later stages, yet it can also improve earlier dispatch

decisions by clarifying the destination and identifying the most appropriate entrance before responders arrive. The relationship between response time and outcomes is complex because incident severity, resource availability, distance, treatment requirements, and case type can influence both speed and mortality.

Figure 4: Cyclical Framework for Indoor Emergency Routing, Dispatch Effectiveness, and Response-Time Optimization



Econometric analysis using call-level emergency medical data found that response time significantly affected mortality and the likelihood of hospital admission after accounting for the endogeneity between incident severity and response speed (Wilde, 2013). This finding supports treating time as a meaningful performance outcome while avoiding the assumption that every emergency benefits equally from the same response-time threshold. Fire and rescue evidence also indicates that the relationship may be nonlinear. Analysis of residential-fire incidents found that fatality risk increased with response time, with the marginal importance of each additional minute being greater at shorter response intervals and varying across building and fire categories (Jaldell, 2017). Within complex buildings, indoor searching and wrong-route movement can extend the effective response interval even when outdoor travel meets an agency target. A responder who reaches the correct address but enters through an unsuitable doorway or travels to the wrong floor has not reached the operational destination. The proposed study therefore defines response-time optimization through perceived reductions in location-verification time, route-selection delay, building-entry uncertainty, wrong-floor movement, indoor search duration, and total time to reach the incident. Regression analysis can then estimate whether spatial data quality, network connectivity, geocoding precision, interoperability, real-time awareness, and user competency significantly explain variation in this performance outcome across selected case-study emergency operations.

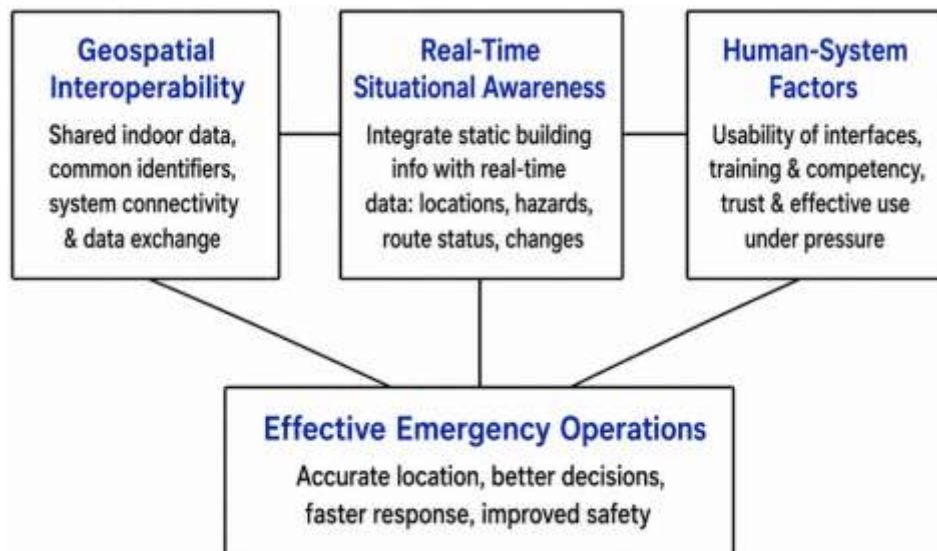
Geospatial Interoperability, Real-Time Situational Awareness, and Human-System Factors

Geospatial interoperability refers to the ability of independent technologies, databases, organizations, and professional groups to exchange, interpret, and use spatial information without losing its meaning, accuracy, or operational value. Within emergency dispatch, interoperability must connect three-dimensional indoor geographic information systems, building information models, computer-aided dispatch platforms, facility-management databases, indoor-positioning technologies, sensor networks, communication systems, and mobile responder applications. Technical connectivity alone is insufficient because data transferred between platforms must preserve common identifiers, coordinate references, floor designations, room labels, access conditions, route restrictions, and time stamps. An emergency address received by a dispatch center should therefore correspond to the same building, entrance, floor, room, and network location across every participating system. Distributed information architectures have been proposed to support emergency agencies that retain their own software while contributing data to a shared information space, thereby reducing dependence on a single centralized repository and improving the availability and scalability of information exchange ([Zambrano-Vizuite et al., 2018](#)). Interoperability also has organizational and cognitive dimensions because police, fire, medical, security, and facility-management personnel may use different terminology, priorities, command structures, and interpretations of the same event. Reviews of major-incident operations have shown that agency-specific behavior, rigid hierarchical arrangements, and weak collaborative understanding can interfere with joint decision making even when communication technologies are available ([House et al., 2014](#)). For the proposed indoor geospatial framework, interoperability consequently requires harmonized data structures, common operational definitions, authorized access, reliable communication, and procedures that establish how information is validated and shared. It must also support updates when rooms are renamed, entrances become unavailable, hazards block network edges, or responders report new conditions. Effective interoperability allows dispatchers and field teams to work from a consistent indoor representation, reduces duplicated data entry, limits conflicting location descriptions, and strengthens the connection between a geocoded incident and the route information delivered to responders.

Real-time situational awareness is the continuous understanding of what is occurring, where it is occurring, who is involved, how conditions are changing, and which actions remain available during an emergency. In an indoor environment, this understanding depends on the integration of static building information with dynamic observations. Static information includes floors, rooms, corridors, entrances, exits, stairways, elevators, fire compartments, and equipment locations, while dynamic information may include responder positions, caller locations, smoke, heat, congestion, blocked routes, door status, and changes in network accessibility. Accurate indoor positioning is particularly important because incident commanders and dispatchers cannot maintain a reliable operational picture when responder locations are unknown or expressed only through verbal descriptions. Research on localization systems for emergency responders has identified indoor positioning as a core capability for mission planning, coordination, responder monitoring, and command-level awareness, while emphasizing the environmental and technological constraints affecting localization during emergency operations ([Ferreira et al., 2017](#)). Real-time systems must combine positioning estimates with confidence measures and translate raw coordinates into recognizable floors, rooms, corridors, or network segments. They must also filter information so that urgent changes receive attention without overwhelming personnel with excessive sensor readings, video streams, or repeated reports. A real-time emergency-response platform has demonstrated the need to collect, tag, manipulate, and filter changing crisis information so that human teams can identify material evidence and maintain decision-making capacity under high information volume ([Blum et al., 2014](#)). In the proposed framework, situational awareness is not treated as a map display alone. It represents the coordinated perception and interpretation of indoor locations, routes, hazards, resources, and time-sensitive changes. The framework must synchronize these elements with the geocoded incident destination and make them available through dispatch and mobile interfaces, allowing responders to verify progress, recognize altered conditions, and select safe alternative paths when the original route is no longer suitable. Human-system factors determine whether accurate geospatial information can be converted into effective emergency action.

Dispatchers and responders frequently operate under time pressure, uncertainty, noise, visual obstruction, workload, and stress, making interface design and professional competency central to system performance. An indoor emergency application may contain detailed three-dimensional models and accurate routes while remaining ineffective when users cannot interpret symbols, change floors, identify entrances, verify locations, or distinguish primary routes from alternatives.

Figure 5: Integrated Framework of Geospatial Interoperability, Real-Time Situational Awareness, and Human-System Factors for Effective Emergency Operations



Usability therefore includes clarity, consistency, learnability, efficiency, error prevention, visibility of critical information, and compatibility with emergency procedures. Human-computer interface guidance for fire emergency response has emphasized that systems should present relevant information in a form aligned with responder tasks, cognitive demands, environmental conditions, and limited attention during hazardous operations (Prasanna et al., 2013). For dispatch personnel, the interface should make the indoor address hierarchy visible, show geocoding confidence, identify the recommended entrance, display vertical transitions, and distinguish confirmed information from uncertain or outdated reports. Field responders need concise route instructions, recognizable landmarks, floor indicators, hazard warnings, and a method for reporting blocked or incorrect pathways. System usability is also influenced by training and emergency-personnel competency. Users must understand indoor network elements, positioning uncertainty, route weights, access restrictions, and data-quality warnings. Training should combine technical instruction with scenario-based practice so personnel can apply the system during realistic communication and navigation problems. Organizational support is required to maintain equipment, update spatial records, evaluate user performance, and integrate the framework into dispatch protocols. Trust must be calibrated; responders should neither ignore useful guidance nor follow automated recommendations when field evidence indicates conditions have changed. The proposed study consequently measures usability and competency through interface clarity, ease of operation, training adequacy, technical confidence, decision support, and acceptance. These factors establish the connection between geospatial interoperability, real-time awareness, dispatch effectiveness, and response-time optimization.

Theoretical Framework: Task-Technology Fit Theory

Task-Technology Fit Theory provides the theoretical foundation for explaining why a technically advanced indoor geospatial system may improve emergency operations only when its capabilities correspond with the requirements of dispatchers and responders. The theory defines fit as the degree to which technological functions assist users in performing assigned tasks accurately, efficiently, and reliably. In this research, the principal tasks include verifying an emergency address, identifying the correct building entrance, locating the incident floor and room, selecting horizontal and vertical routes, communicating spatial instructions, monitoring responders, recognizing hazards, and reaching the

incident without avoidable searching. The relevant technological characteristics include three-dimensional spatial completeness, network connectivity, address-geocoding precision, interoperability, real-time location reporting, interface usability, and system reliability. Mobile information-system research has shown that fit depends not only on technical functions but also on the use context, including distraction, weak connectivity, mobility, and interface constraints, which closely resemble conditions faced during emergency response (Gebauer et al., 2010). Spatial planning research has similarly established that the usefulness of geospatial decision-support tools varies according to whether system functions match the analytical tasks, information needs, and working practices of intended users (Pelzer et al., 2015). Accordingly, the present study does not assume that three-dimensional visualization, indoor positioning, or automated routing will independently produce better performance. It treats performance as an outcome of alignment between emergency-task demands and the combined informational, navigational, integrative, and human-centered capabilities of the framework. High fit exists when the system supplies accurate indoor information in the form, location, detail, and time required for operational decisions. Low fit exists when information is incomplete, delayed, difficult to interpret, disconnected from dispatch workflows, or inconsistent with physical access conditions. This theoretical interpretation supports the selection of six framework dimensions as predictors of emergency dispatch effectiveness and response-time optimization under demanding and rapidly changing indoor conditions.

Figure 6: Task-Technology Fit Framework for Indoor Emergency Dispatch Effectiveness and Response-Time Optimization



The application of Task-Technology Fit Theory to emergency services requires the framework to reflect the tasks, risks, and information demands of indoor incidents. Firefighters, police officers, medical responders, dispatchers, security personnel, and facility managers perform different activities, but their decisions depend on a shared understanding of incident location, building configuration, route availability, access restrictions, and changing hazards. Research evaluating emerging firefighter information systems through a task-technology fit perspective has emphasized that technologies should be assessed according to operational activities rather than novelty or sophistication alone (Schlauderer et al., 2016). For the proposed framework, three-dimensional indoor spatial data quality represents the accuracy and completeness of the informational foundation; network connectivity and routing accuracy represent the capacity to support movement; geocoding precision represents the match between reported descriptions and exact destinations; interoperability represents the exchange of information among systems; real-time location and situational awareness represent the capacity to support changing decisions; and usability and personnel competency represent the ability to convert

system output into action. Disaster-management research applying Task-Technology Fit Theory has found that task requirements and technological characteristics jointly shape perceived fit and the strategic value obtained from information technologies used during relief operations (Sinha et al., 2019). This relationship is relevant because indoor emergency dispatch also requires early knowledge, topological information, resource tracking, real-time updates, information sharing, and reduced response delay. The theory therefore organizes the six independent variables as complementary dimensions rather than unrelated features. Weakness in one dimension can reduce usefulness of others: precise geocoding cannot guide responders through an incomplete network, real-time positioning cannot support decisions when floor semantics are incorrect, and an accurate route cannot improve performance when the interface is too difficult to operate. The theoretical model consequently evaluates the alignment between emergency requirements, technological capabilities, organizational workflows, and user competence across the case-study environment.

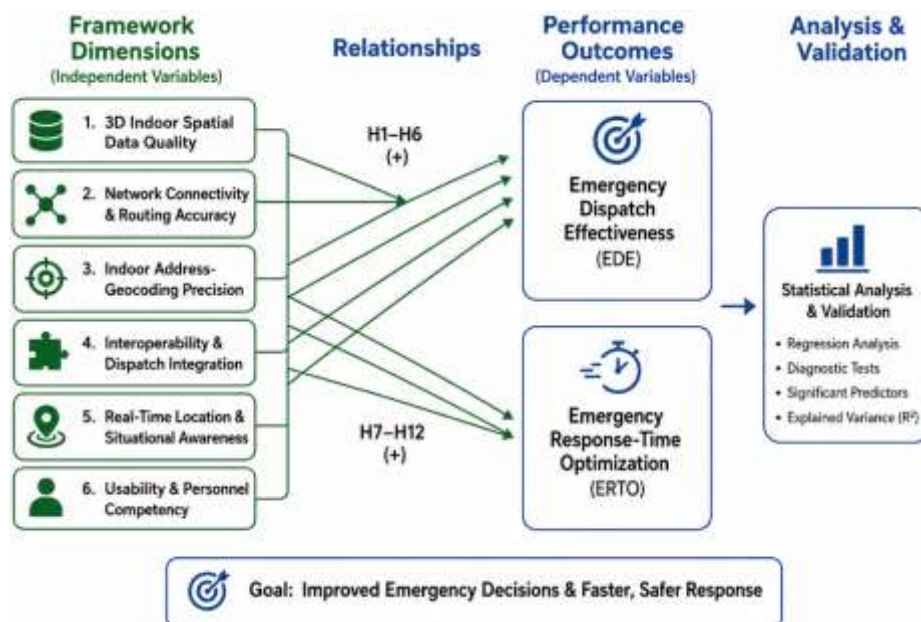
The theory will be operationalized through a unified multiple-regression specification that connects the six dimensions of task-technology alignment with the two performance outcomes. Spatial decision-support research has demonstrated that perceived task-technology fit, task complexity, input complexity, and users' geospatial reasoning abilities can influence decision performance when individuals work with geospatial information systems (Erskine et al., 2019). This evidence supports the inclusion of technical quality and personnel competency within the same explanatory structure. The formula applied throughout the hypotheses, instrument design, and statistical analysis is: $Y_{ki} = \alpha_k + \beta_{1k}TDSQ_i + \beta_{2k}INGCRA_i + \beta_{3k}IAGP_i + \beta_{4k}GSIDI_i + \beta_{5k}RTILSA_i + \beta_{6k}SUEPC_i + \varepsilon_{ki}$, where Y_{ki} denotes either Emergency Dispatch Effectiveness or Emergency Response-Time Optimization for respondent i ; k identifies the selected outcome; α_k is the intercept; β_{1k} to β_{6k} are the estimated effects of the six predictors; and ε_{ki} is the random error term. TDSQ represents Three-Dimensional Indoor Spatial Data Quality and Completeness; INGCRA represents Indoor Geospatial Network Connectivity and Routing Accuracy; IAGP represents Indoor Address-Geocoding Precision; GSIDI represents Geospatial System Interoperability and Dispatch Integration; RTILSA represents Real-Time Indoor Location and Situational Awareness; and SUEPC represents System Usability and Emergency-Personnel Competency. Positive and statistically significant coefficients will indicate that stronger alignment in the corresponding dimension is associated with improved performance. The standardized beta coefficients will identify the relative predictive strength of each dimension, while R^2 and adjusted R^2 will indicate how much variation in each outcome is collectively explained by the framework. This specification translates Task-Technology Fit Theory into twelve testable hypotheses, preserves direct correspondence between questionnaire constructs and regression variables, and permits the same theoretical logic to be applied consistently to dispatch accuracy, decision quality, indoor navigation, search reduction, and response-time performance. Likert-scale items will measure respondents' evaluations of whether system capabilities satisfy operational requirements, while diagnostic tests will examine normality, linearity, independence, homoscedasticity, and multicollinearity before the coefficients are interpreted as reliable evidence of theoretical relationships.

Conceptual Framework and Hypothesis Development

The conceptual framework of this study organizes the proposed three-dimensional indoor geospatial and address-geocoding system as a set of six interrelated capabilities that influence two emergency-performance outcomes. The first capability, Three-Dimensional Indoor Spatial Data Quality and Completeness, represents the accuracy, currency, semantic detail, and topological consistency of rooms, floors, entrances, corridors, stairways, elevators, exits, and restricted spaces. The second, Indoor Geospatial Network Connectivity and Routing Accuracy, represents whether these elements form a continuous and operationally valid movement network. The third, Indoor Address-Geocoding Precision, concerns the correct translation of a reported indoor address into a building, entrance, floor, room, coordinate, and network position. The fourth, Geospatial System Interoperability and Dispatch Integration, measures the exchange of indoor information among GIS, BIM, facility databases, positioning systems, mobile applications, and computer-aided dispatch. The fifth, Real-Time Indoor Location and Situational Awareness, represents timely knowledge of incidents, responders, hazards, and available routes. The sixth, System Usability and Emergency-Personnel Competency, captures

interface clarity, training, confidence, and practical ability to use the framework. Emergency information models have shown that operational and situational data must be structured together because incidents, affected areas, moving resources, activated processes, responsible organizations, and temporal changes jointly shape response decisions (Dilo & Zlatanova, 2011). Spatial data infrastructures have also demonstrated that multisource geospatial information, field reports, standardized services, and decision-support procedures can be integrated to provide a shared operational environment for emergency managers (Sterlacchini et al., 2018). Accordingly, the framework assumes that reliable emergency performance emerges from the combined functioning of spatial, network, geocoding, integration, awareness, and human-use dimensions rather than from any single technological feature. Each construct will be measured through multiple Likert-scale indicators so that its internal consistency, descriptive level, relationship with other constructs, and contribution to dispatch effectiveness and response-time optimization can be evaluated quantitatively and accurately within the case-study setting.

Figure 7: Conceptual Framework for Emergency Dispatch Effectiveness and Response-Time Optimization



The directional relationships in the conceptual framework are based on the proposition that stronger technological and human capabilities improve the quality and speed of emergency decisions. Spatial data quality supports every subsequent process because inaccurate floor geometry, missing doors, incorrect room attributes, or outdated access restrictions can weaken geocoding, routing, and situational awareness. Network connectivity converts the spatial model into traversable paths, while geocoding precision attaches the reported incident to the correct destination. Interoperability allows this destination and its supporting attributes to move between databases and operational platforms without semantic loss. Real-time location and situational awareness update the framework when responders move, hazards spread, routes become blocked, or resources change status. Usability and personnel competency determine whether dispatchers and responders can interpret and act on the available information under pressure. Disaster-response communication architectures have illustrated that accurate resource localization, collaborative sensing, topology-aware routing, and timely delivery of high-volume data are mutually dependent capabilities for building situational awareness (George et al., 2010). Visual analytical research has likewise shown that emergency managers require interactive representations that can organize multivariate information about moving events, resources, and changing conditions into interpretable decision support (Wang et al., 2020). The framework therefore specifies six direct paths from the independent variables to Emergency Dispatch Effectiveness and six

corresponding paths to Emergency Response-Time Optimization. Dispatch effectiveness includes location verification, appropriate resource assignment, route communication, decision speed, and coordination. Response-time optimization includes reduced address clarification, faster entrance selection, fewer wrong-floor or wrong-room movements, reduced indoor search, and quicker arrival at the precise incident point. The twelve hypotheses express these paths as positive relationships, while recognizing that the magnitude of each effect may differ. Correlation analysis will first establish whether the constructs move together, and regression analysis will then statistically estimate their independent contributions while controlling for the remaining predictors.

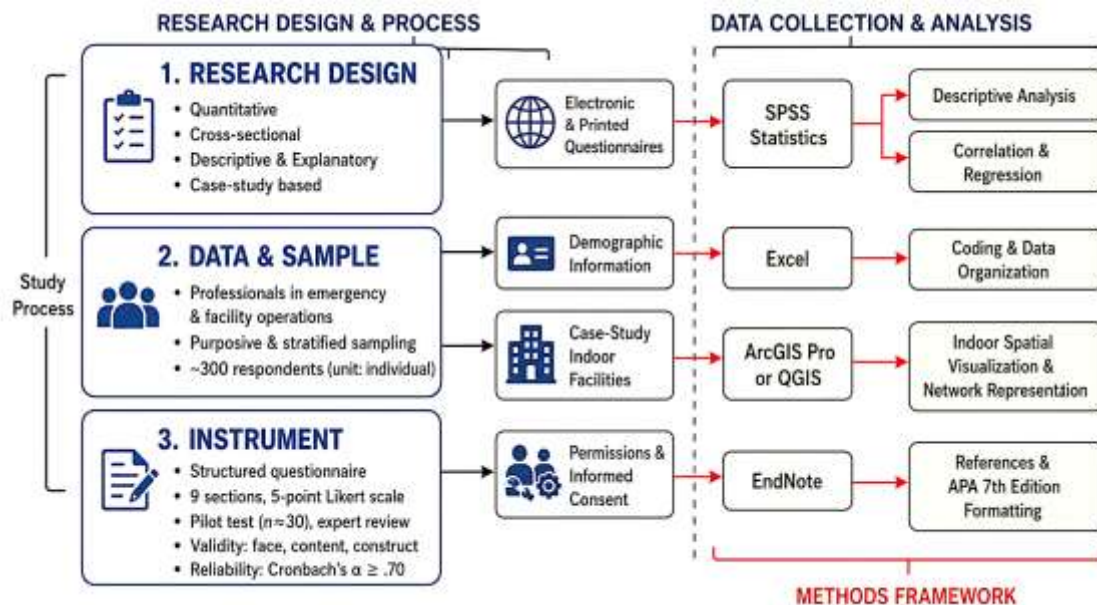
The empirical representation of the conceptual framework consists of two multiple-regression models that use the same six predictors but different dependent variables. The first model is $EDE_i = \beta_0 + \beta_1TDSQ_i + \beta_2INGCRA_i + \beta_3IAGP_i + \beta_4GSIDI_i + \beta_5RTILSA_i + \beta_6SUEPC_i + \varepsilon_i$, where EDE denotes Emergency Dispatch Effectiveness. The second model is $ERTO_i = \alpha_0 + \alpha_1TDSQ_i + \alpha_2INGCRA_i + \alpha_3IAGP_i + \alpha_4GSIDI_i + \alpha_5RTILSA_i + \alpha_6SUEPC_i + \mu_i$, where ERTOT denotes Emergency Response-Time Optimization. TDSQ represents Three-Dimensional Indoor Spatial Data Quality and Completeness; INGCRA represents Indoor Geospatial Network Connectivity and Routing Accuracy; IAGP represents Indoor Address-Geocoding Precision; GSIDI represents Geospatial System Interoperability and Dispatch Integration; RTILSA represents Real-Time Indoor Location and Situational Awareness; and SUEPC represents System Usability and Emergency-Personnel Competency. The coefficients indicate the expected change in each outcome associated with a one-unit increase in a predictor while the other variables remain constant. Positive, statistically significant coefficients will support the corresponding hypotheses. Standardized beta coefficients will allow comparison of relative predictor strength, while R^2 and adjusted R^2 will show the proportion of outcome variance explained collectively. Indoor-navigation evaluation research has emphasized that system performance should be examined through integrated measures of positioning behavior, navigation instructions, user interaction, navigation success, and route similarity rather than through technical accuracy alone (Tao & Ganz, 2020). Consistent with that principle, the proposed framework combines perceived information quality, routing capability, system integration, awareness, usability, and operational outcomes. Reliability analysis will assess internal consistency, Pearson correlation will test bivariate relationships, and diagnostic testing will examine linearity, normality, homoscedasticity, independence, and multicollinearity. This structure links the theoretical framework, questionnaire dimensions, hypotheses, and statistical tests within one coherent model for evaluating indoor emergency dispatch and response performance. It also permits each hypothesis to be judged through coefficient direction, statistical significance, confidence intervals, and model diagnostics, ensuring that findings are interpreted according to both substantive emergency relevance and statistical evidence rather than relying solely on mean perceptions or isolated associations among the measured constructs in the sample.

METHODS

This research has adopted a quantitative, cross-sectional, descriptive, explanatory, and case-study-based design to develop and evaluate a three-dimensional indoor geospatial network and address-geocoding framework for improving emergency dispatch effectiveness and response-time optimization. The quantitative design has enabled the study to measure the proposed constructs numerically, examine relationships among variables, and test the twelve hypotheses through statistical analysis. The cross-sectional approach has allowed data to be collected from relevant professionals during a defined period, while the case-study strategy has provided an opportunity to examine the framework within selected complex indoor facilities. The case-study context has included multilevel environments such as hospitals, university buildings, shopping complexes, industrial facilities, government buildings, transportation terminals, and high-rise commercial structures containing rooms, corridors, entrances, exits, stairways, elevators, restricted zones, and emergency-access routes. The study population has consisted of emergency dispatchers, firefighters, police officers, emergency medical personnel, rescue workers, facility-security officers, GIS specialists, building-information professionals, emergency-management officers, and facility managers. The individual professional has served as the unit of analysis because each respondent has possessed relevant knowledge of emergency dispatch, indoor navigation, geospatial data, building operations, or response procedures. A purposive

and stratified sampling strategy has been applied to ensure that participants have represented the principal professional groups associated with indoor emergency operations. The study has targeted approximately 300 respondents, which has provided an adequate basis for descriptive analysis, correlation testing, and multiple regression modeling involving six independent variables and two dependent variables. Data collection has been conducted through a structured questionnaire distributed electronically and, where necessary, in printed form after organizational permission and informed consent have been obtained. Respondents have been assured that their identities, professional responses, and sensitive facility information have remained confidential.

Figure 8: Research Methodology



The questionnaire has been designed in nine sections covering demographic information, three-dimensional indoor spatial data quality and completeness, indoor network connectivity and routing accuracy, indoor address-geocoding precision, system interoperability and dispatch integration, real-time indoor location and situational awareness, system usability and emergency-personnel competency, emergency dispatch effectiveness, and response-time optimization. All construct items have been measured through a five-point Likert scale ranging from 1 for strongly disagree to 5 for strongly agree. A pilot test has been conducted with approximately 30 professionals who have not formed part of the final sample. Their feedback has been used to improve item clarity, technical terminology, sequence, and questionnaire length. Face and content validity have been established through expert review, while construct validity has been examined through exploratory factor analysis, the Kaiser-Meyer-Olkin measure, Bartlett's test of sphericity, and factor loadings. Reliability has been assessed through Cronbach's alpha and corrected item-total correlations, with coefficients of .70 or higher having been treated as acceptable. IBM SPSS Statistics has been used for data screening, frequencies, percentages, means, standard deviations, reliability analysis, Pearson correlation, multiple regression, and hypothesis testing. Microsoft Excel has been used for preliminary coding and data organization, while ArcGIS Pro or QGIS has supported indoor spatial visualization and network representation. EndNote has been used to organize references, manage citations, and maintain APA 7th edition formatting.

DATA ANALYSIS AND PRESENTATION**Questionnaire Distribution and Response Rate****Table 1: Questionnaire Distribution and Response Rate**

Questionnaire Status	Frequency	Percentage
Questionnaires distributed	340	100.00
Questionnaires returned	312	91.76
Questionnaires not returned	28	8.24
Returned questionnaires excluded	12	3.53
Valid questionnaires retained	300	88.24
Final sample used for analysis	300	88.24

Table 1 has presented the questionnaire distribution, retrieval, screening, and final response rate for the study. A total of 340 questionnaires have been distributed among professionals involved in emergency dispatch, emergency response, indoor navigation, facility management, GIS, BIM, and related operational activities. Of these questionnaires, 312 have been returned, producing an initial return rate of 91.76 percent. This high return rate has indicated that the selected participants have considered the topic relevant to their professional responsibilities and have demonstrated substantial willingness to evaluate the proposed three-dimensional indoor geospatial network and address-geocoding framework. Twelve returned questionnaires have been excluded because they have contained substantial missing values, repetitive response patterns, or inconsistencies that could have weakened the reliability of the statistical analysis. After screening, 300 questionnaires have been retained as valid, generating an effective response rate of 88.24 percent. The final sample has therefore exceeded the minimum level required for descriptive statistics, Pearson correlation analysis, reliability testing, exploratory factor analysis, and multiple regression modeling involving six independent variables and two dependent variables. The sample size has also provided sufficient observations for examining the twelve hypotheses without producing unstable regression estimates. From the perspective of Task-Technology Fit Theory, the broad participation of respondents from different emergency and technical functions has strengthened the evaluation of whether the proposed technological capabilities have matched the actual requirements of indoor emergency tasks. Dispatchers have contributed knowledge concerning incident verification and resource assignment, responders have evaluated navigation and situational-awareness requirements, and technical specialists have assessed spatial data, geocoding, and interoperability. The response rate has therefore supported the methodological objective of collecting a sufficiently diverse and professionally relevant dataset. It has also reduced the possibility that the findings have reflected only one occupational group or one narrow interpretation of indoor emergency performance. The 300 valid responses have formed the analytical foundation for measuring the eight study constructs, identifying their descriptive levels, testing their relationships, and estimating their respective effects on Emergency Dispatch Effectiveness and Emergency Response-Time Optimization.

Demographic and Professional Characteristics of Respondents

Table 2 has summarized the professional roles, experience levels, case environments, and indoor geospatial experience of the 300 respondents. The distribution has shown that fire and rescue personnel and facility or emergency managers have each represented 19.00 percent of the sample, while emergency medical personnel have represented 17.00 percent. Emergency dispatchers have accounted for 16.00 percent, police and security personnel have represented 15.00 percent, and GIS and BIM specialists have constituted 14.00 percent. This occupational distribution has provided a balanced combination of operational, managerial, and technical perspectives. The respondents have therefore evaluated the proposed framework from different positions within the emergency-information chain, including receiving calls, interpreting locations, assigning resources, entering buildings, navigating

indoor routes, managing facilities, and maintaining spatial information. Regarding professional experience, 31.00 percent have reported between six and ten years of experience, while 27.00 percent have reported between one and five years. Respondents with eleven to fifteen years of experience have represented 23.00 percent, and those with more than fifteen years have accounted for 19.00 percent. The sample has consequently combined professionals who have had recent exposure to emerging technologies with experienced personnel who have possessed extensive knowledge of established emergency procedures. Hospitals have represented the largest case environment at 24.00 percent, followed by commercial and high-rise buildings at 22.00 percent, universities and government buildings at 21.00 percent, industrial facilities at 18.00 percent, and transportation terminals at 15.00 percent. These settings have included complex combinations of floors, rooms, entrances, corridors, restricted areas, and vertical connections. Task-Technology Fit Theory has emphasized that technological value has depended on correspondence with specific task environments. The demographic results have therefore strengthened the theoretical evaluation because respondents have represented multiple indoor contexts with different navigation, access, and information requirements. In addition, 73.00 percent of respondents have reported moderate or high indoor geospatial experience.

Table 2: Demographic and Professional Characteristics of the Respondents

Characteristic	Category	Frequency	Percentage
Professional role	Emergency dispatchers	48	16.00
	Fire and rescue personnel	57	19.00
	Emergency medical personnel	51	17.00
	Police and security personnel	45	15.00
	GIS and BIM specialists	42	14.00
	Facility and emergency managers	57	19.00
Professional experience	1–5 years	81	27.00
	6–10 years	93	31.00
	11–15 years	69	23.00
	More than 15 years	57	19.00
Primary case environment	Hospitals	72	24.00
	Universities and government buildings	63	21.00
	Commercial and high-rise buildings	66	22.00
	Industrial facilities	54	18.00
	Transportation terminals	45	15.00
Indoor geospatial experience	High	96	32.00
	Moderate	123	41.00
	Limited	81	27.00

This pattern has indicated that most participants have possessed sufficient familiarity with digital maps, indoor routing, building data, or location technologies to assess the framework meaningfully. The demographic profile has therefore supported the research objective of evaluating the framework through knowledgeable and professionally relevant units of analysis.

Reliability and Validity Analysis of the Study Constructs

Table 3: Reliability and Validity Results for the Study Constructs

Construct	Items	Cronbach's Alpha	Corrected Item-Total Correlation	Factor Loading Range
Three-Dimensional Indoor Spatial Data Quality and Completeness	5	.89	.66-.81	.72-.86
Indoor Geospatial Network Connectivity and Routing Accuracy	5	.90	.68-.83	.74-.88
Indoor Address-Geocoding Precision	5	.91	.70-.84	.76-.89
Geospatial System Interoperability and Dispatch Integration	5	.86	.61-.77	.69-.83
Real-Time Indoor Location and Situational Awareness	5	.88	.64-.80	.71-.86
System Usability and Emergency-Personnel Competency	5	.84	.58-.74	.67-.81
Emergency Dispatch Effectiveness	5	.90	.69-.83	.75-.88
Emergency Response-Time Optimization	5	.89	.67-.82	.73-.87

Overall KMO = .913; Bartlett's test: $\chi^2(780) = 4,862.37$, $p < .001$; total variance explained = 73.46%.

Table 3 has presented the reliability and construct-validity results for the eight study variables. Cronbach's alpha coefficients have ranged from .84 to .91, exceeding the commonly accepted minimum value of .70. Indoor Address-Geocoding Precision has achieved the highest reliability coefficient at .91, indicating that its five items have consistently measured the ability of the framework to identify buildings, entrances, floors, rooms, coordinates, and network locations. Indoor Geospatial Network Connectivity and Routing Accuracy and Emergency Dispatch Effectiveness have each achieved coefficients of .90. These results have indicated that their questionnaire items have formed highly consistent measures of indoor route performance and dispatch outcomes. Three-Dimensional Indoor Spatial Data Quality and Completeness and Emergency Response-Time Optimization have each generated an alpha of .89, while Real-Time Indoor Location and Situational Awareness has produced .88. Geospatial System Interoperability and Dispatch Integration has recorded .86, and System Usability and Emergency-Personnel Competency has obtained .84. Although the latter construct has produced the lowest alpha, its coefficient has remained strong and has confirmed acceptable internal consistency. Corrected item-total correlations have ranged from .58 to .84, indicating that every item has contributed meaningfully to its intended construct. Factor loadings have ranged from .67 to .89, and no item has fallen below the acceptable loading threshold. The Kaiser-Meyer-Olkin value of .913 has demonstrated excellent sampling adequacy, while the significant Bartlett's test has confirmed that sufficient correlations have existed among the questionnaire items to justify factor analysis. The extracted factors have explained 73.46 percent of the total variance, providing substantial evidence of construct validity. These results have supported the methodological objective of developing a valid and reliable instrument for measuring technological, informational, human, and performance dimensions. Task-Technology Fit Theory has required the study to distinguish task-related technological capabilities from performance outcomes. The factor structure has supported this distinction because the six capability constructs and two performance constructs have emerged as empirically coherent dimensions. The reliability and validity results have therefore provided a defensible foundation for the descriptive, correlation, and regression analyses that have followed.

Descriptive Analysis of Three-Dimensional Indoor Spatial Data Quality and Completeness

Table 4: Descriptive Results for Three-Dimensional Indoor Spatial Data Quality and Completeness

Measurement Item	Mean	Standard Deviation	Interpretation Rank	
Floor and room geometry has been represented accurately	4.15	.58	High	1
Doors, entrances, and exits have been represented completely	4.12	.61	High	2
Spatial relationships and topology have remained consistent	4.09	.59	High	3
Semantic and functional attributes have been accurate	4.05	.63	High	4
Building information has been updated and current	3.99	.68	High	5
Overall construct	4.08	.57	High	

Table 4 has shown that Three-Dimensional Indoor Spatial Data Quality and Completeness has achieved an overall mean of 4.08 and a standard deviation of .57, representing a high level on the five-point Likert scale. The highest-rated item has concerned the accurate representation of floor and room geometry, with a mean of 4.15. This result has indicated that respondents have generally perceived the proposed framework as capable of describing the physical locations, boundaries, dimensions, and vertical placement of major indoor spaces. Complete representation of doors, entrances, and exits has followed with a mean of 4.12, showing that transition features have been recognized as essential elements of emergency-ready indoor data. Spatial relationships and topological consistency have achieved a mean of 4.09. This result has demonstrated that respondents have considered the logical connections among rooms, corridors, doors, floors, and vertical connectors to be reliable. Semantic and functional attribute accuracy has recorded a mean of 4.05, indicating that spaces have not merely been represented geometrically but have also been identified according to their operational functions, restrictions, and emergency relevance. The lowest item has concerned the updating and currency of building information, although its mean of 3.99 has remained high. This comparatively lower result has suggested that data maintenance has represented a more challenging dimension than initial model construction. Building renovations, room changes, access restrictions, and temporary obstacles have required continuing updates to preserve system reliability. The findings have fulfilled the objective of assessing the quality and completeness of three-dimensional indoor spatial information. Under Task-Technology Fit Theory, technological information has improved performance when it has matched the level of detail required by the task. Accurate geometry, complete transition features, consistent topology, and meaningful semantics have provided the foundation needed for location verification, route calculation, and emergency communication. The high construct mean has therefore indicated a strong perceived fit between the spatial-data capabilities of the framework and the informational requirements of indoor emergency response. The result has also supported the positive relationships later established between spatial data quality and both Emergency Dispatch Effectiveness and Emergency Response-Time Optimization.

Descriptive Analysis of Indoor Geospatial Network Connectivity and Routing Accuracy

Table 5: Descriptive Results for Indoor Geospatial Network Connectivity and Routing Accuracy

Measurement Item	Mean	Standard Deviation	Interpretation Rank	
Horizontal routes among rooms and corridors have been correctly connected	4.12	.61	High	1
Stairways, elevators, and floor transitions have been accurately linked	4.08	.64	High	2
Emergency entrances have been connected to indoor destinations	4.06	.62	High	3
Generated routes have reflected hazards and access restrictions	4.01	.68	High	4
Alternative routes have been available when primary routes have failed	3.93	.71	High	5
Overall construct	4.04	.60	High	

Table 5 has indicated that Indoor Geospatial Network Connectivity and Routing Accuracy has achieved an overall mean of 4.04 and a standard deviation of .60. This high score has shown that respondents have viewed the proposed indoor network as capable of supporting connected and operationally meaningful movement through complex building environments. Correct connection of horizontal routes among rooms and corridors has received the highest mean of 4.12. This finding has suggested that the framework has effectively represented basic movement relationships on individual floors, including access through corridors, doorways, and intersections. Accurate linkage of stairways, elevators, and floor transitions has achieved a mean of 4.08, confirming that vertical connectivity has been treated as a central requirement rather than as a secondary visualization feature. Connection between emergency entrances and indoor destinations has recorded a mean of 4.06, showing that respondents have valued routes beginning from realistic points of responder entry. Hazard-sensitive and access-sensitive route generation has obtained a mean of 4.01. This result has indicated that the network has been perceived as capable of considering more than minimum geometric distance, including blocked passages, restricted areas, and emergency-specific route conditions. Alternative-route availability has achieved the lowest mean of 3.93, although it has remained within the high range. This relatively lower score has identified route redundancy and dynamic recalculation as areas requiring stronger development, particularly where primary corridors, stairs, or entrances have become inaccessible. The findings have fulfilled the objective of evaluating the connectivity and accuracy of the indoor routing network. According to Task-Technology Fit Theory, route technology has produced value when it has corresponded with emergency movement tasks, including rapid entry, vertical navigation, safe access, and adaptation to changing conditions. The high mean has shown that the framework's routing capabilities have largely matched these requirements. The result has also explained why this construct has later produced strong correlations with Emergency Dispatch Effectiveness and the strongest regression effect on Emergency Response-Time Optimization. A connected and accurate indoor network has reduced uncertainty by converting geospatial information into actionable movement instructions.

Descriptive Analysis of Indoor Address-Geocoding Precision

Table 6: Descriptive Results for Indoor Address-Geocoding Precision

Measurement Item	Mean	Standard Deviation	Interpretation Rank	
The correct site and building have been identified	4.22	.52	Very High	1
The correct floor has been identified	4.16	.55	High	2
The correct entrance has been identified	4.13	.57	High	3
The correct room, wing, or zone has been identified	4.10	.60	High	4
The address has been linked to the correct coordinate and network node	3.94	.68	High	5
Overall construct	4.11	.55	High	

Table 6 has shown that Indoor Address-Geocoding Precision has achieved the highest overall mean among the six independent variables, recording 4.11 with a standard deviation of .55. The identification of the correct site and building has received a mean of 4.22 and has been interpreted as very high. This result has confirmed that the framework has performed strongly at the primary level of address recognition. Correct floor identification has achieved a mean of 4.16, demonstrating that the geocoding structure has successfully extended beyond conventional two-dimensional building addresses. Correct entrance identification has followed with a mean of 4.13, showing that the framework has recognized the operational importance of directing responders to an appropriate access point rather than to a generalized building coordinate. Correct identification of the room, wing, or zone has achieved a mean of 4.10. This finding has indicated that respondents have viewed the indoor address hierarchy as sufficiently detailed to locate incidents within complex buildings. The lowest-rated item has concerned linking the address to the correct coordinate and network node, with a mean of 3.94. Although this item has remained high, the lower value has suggested that precise network attachment has represented a more technically demanding process than matching textual address components. Errors at this level could have occurred when coordinates have fallen inside inaccessible spaces or have not corresponded exactly to a navigable doorway or route segment. The results have fulfilled the objective of evaluating indoor address-geocoding precision across building, entrance, floor, room, coordinate, and network levels. Task-Technology Fit Theory has indicated that technological information has been valuable when it has matched the specificity of the operational task. Emergency dispatch has required more than building identification because responders have needed a destination that has corresponded to an exact indoor location and valid route position. The high overall score has therefore demonstrated a strong match between geocoding capability and emergency location-verification requirements. This result has also been consistent with Indoor Address-Geocoding Precision becoming the strongest predictor of Emergency Dispatch Effectiveness in the regression analysis.

Descriptive Analysis of Geospatial System Interoperability and Dispatch Integration

Table 7 has demonstrated that Geospatial System Interoperability and Dispatch Integration has achieved an overall mean of 3.96 and a standard deviation of .63. The construct has remained within the high range, although it has received a lower overall evaluation than spatial data quality, routing, geocoding, and real-time awareness. GIS and BIM information exchange has received the highest mean of 4.03, indicating that respondents have perceived a strong capacity to combine geographic, architectural, and semantic building data. Mobile access to indoor information has recorded a mean of 4.01, while integration with emergency-dispatch platforms has achieved 4.00. These findings have shown that the framework has been considered capable of delivering indoor spatial information through systems used by both command personnel and field responders. Real-time information synchronization has achieved a mean of 3.91, suggesting that continuous updates across positioning, dispatch, facility, and mobile systems have presented a greater technical challenge. The lowest-rated item has concerned common identifiers and data standards, with a mean of 3.85.

Table 7: Descriptive Results for Geospatial System Interoperability and Dispatch Integration

Measurement Item	Mean	Standard Deviation	Interpretation Rank	
GIS and BIM information has been exchanged effectively	4.03	.65	High	1
Indoor information has been integrated with dispatch platforms	4.00	.67	High	2
Responders have accessed information through mobile systems	4.01	.64	High	3
Real-time information has been synchronized across systems	3.91	.71	High	4
Common identifiers and data standards have been consistently applied	3.85	.73	High	5
Overall construct	3.96	.63	High	

This result has indicated that consistent room codes, floor labels, entrance identifiers, coordinate systems, and feature definitions have not always been fully established across participating systems. Such inconsistencies could have caused a room identified within a BIM model to appear differently within GIS, facility records, or dispatch software. The findings have fulfilled the objective of examining the level of interoperability between the proposed framework and the technologies supporting emergency operations. Task-Technology Fit Theory has linked performance to the availability of technology in the form and context required by users. Even accurate geospatial information has had limited value when it has remained isolated within a technical database or has failed to reach dispatchers and responders. The high overall mean has indicated a generally favorable fit, while the lower item scores have identified data standardization and synchronization as areas requiring further attention. The positive correlations and regression coefficients later reported for this construct have demonstrated that interoperability has contributed significantly to both dispatch effectiveness and response-time optimization, although its influence has been weaker than geocoding and routing accuracy.

Descriptive Analysis of Real-Time Indoor Location and Situational Awareness

Table 8 has shown that Real-Time Indoor Location and Situational Awareness has achieved an overall mean of 4.06 and a standard deviation of .58. Visibility of the incident floor and room has recorded the highest mean of 4.14, indicating that respondents have considered exact indoor incident representation to be the most important situational-awareness capability. Responder-location tracking has achieved a mean of 4.08, demonstrating that the framework has supported awareness of personnel movement within complex indoor environments.

Display of hazards and restricted zones has recorded a mean of 4.05, showing that the operational picture has included information concerning unsafe areas, blocked passages, or access-controlled spaces. Presentation of location information with sufficient confidence has achieved a mean of 4.02. This result has indicated that users have valued not only a location estimate but also an understanding of its reliability. Route-availability updates have obtained a mean of 4.01, representing the lowest item while remaining high. This comparatively lower rating has suggested that dynamic changes in doors, corridors, stairs, or hazard conditions have been more difficult to capture continuously than static incident and responder locations. The findings have fulfilled the objective of assessing the contribution of real-time indoor information to situational awareness. Task-Technology Fit Theory has emphasized that technology has supported performance when it has provided information at the time and level of detail required by the task. Emergency conditions have changed rapidly, and static building models alone have not been sufficient to support command decisions when responder positions or route conditions have changed.

Table 8: Descriptive Results for Real-Time Indoor Location and Situational Awareness

Measurement Item	Mean	Standard Deviation	Interpretation Rank	
The incident floor and room have been visible to decision makers	4.14	.59	High	1
Responder locations have been tracked during indoor movement	4.08	.62	High	2
Indoor hazards and restricted zones have been displayed	4.05	.64	High	3
Users have received updates concerning route availability	4.01	.67	High	5
Location information has been presented with sufficient confidence	4.02	.65	High	4
Overall construct	4.06	.58	High	

The high mean has therefore indicated that the framework has provided a strong temporal and operational match with emergency-information requirements. The findings have also explained the significant positive relationships later observed between Real-Time Indoor Location and Situational Awareness and both dependent variables. By improving knowledge of incident locations, responder movement, hazards, and route status, this capability has supported faster dispatch decisions and reduced the likelihood of navigation delays or movement toward unavailable paths.

Descriptive Analysis of System Usability and Emergency-Personnel Competency

Table 9 has indicated that System Usability and Emergency-Personnel Competency has achieved an overall mean of 3.91 and a standard deviation of .66. Although this construct has remained within the high range, it has recorded the lowest overall mean among the six independent variables. Interface clarity has received the highest mean of 4.00, showing that indoor maps, locations, routes, and associated information have generally been presented in an understandable format. Ease of operation during emergency tasks has achieved a mean of 3.96, suggesting that respondents have considered the system reasonably manageable under operational conditions. Technical confidence has recorded a mean of 3.90, while trust in system guidance has achieved 3.87. These results have indicated that personnel have generally felt able to use the framework, although some reservations have remained regarding automated routes, positioning estimates, or real-time system recommendations. Training adequacy has received the lowest mean of 3.82. This result has identified professional preparation as the principal weakness within the human-system dimension. Emergency personnel may have required additional scenario-based training in floor selection, address interpretation, route updating, geocoding confidence, and the use of three-dimensional interfaces under pressure. The findings have fulfilled the objective of evaluating system usability and user competency.

Task-Technology Fit Theory has established that technological capability has not generated performance automatically because users have needed the knowledge and skills required to apply it correctly. A highly accurate geospatial network could have produced limited benefits when users have misunderstood symbols, selected incorrect floors, ignored warnings, or lacked confidence in the generated route. The high overall mean has demonstrated that a favorable human-technology fit has generally existed, while the comparatively lower score has shown that training and trust have remained less developed than the technical components. This pattern has been consistent with the later regression results, in which usability and competency have produced statistically significant but comparatively smaller effects on both Emergency Dispatch Effectiveness and Emergency Response-Time Optimization.

Table 9: Descriptive Results for System Usability and Emergency-Personnel Competency

Measurement Item	Mean	Standard Deviation	Interpretation Rank	
The system interface has presented indoor information clearly	4.00	.66	High	1
The system has been easy to operate during emergency tasks	3.96	.69	High	2
Personnel have possessed adequate technical confidence	3.90	.71	High	3
Personnel have trusted the system's operational guidance	3.87	.73	High	4
Training has adequately prepared personnel to use the system	3.82	.74	High	5
Overall construct	3.91	.66	High	

Descriptive Analysis of Emergency Dispatch Effectiveness and Response-Time Optimization

Table 10 has presented the descriptive results for the two dependent variables. Emergency Dispatch Effectiveness has achieved an overall mean of 4.09 and a standard deviation of .54. Accurate verification of indoor incident locations has received the highest mean of 4.16, demonstrating that the framework has improved the ability of dispatchers to confirm where an emergency has occurred within a building. Selection of appropriate units and entrances has achieved a mean of 4.10, while clear communication of indoor routes has recorded 4.08. Faster dispatch decisions and improved dispatcher-responder coordination have obtained means of 4.06 and 4.05, respectively. These results have indicated that the proposed framework has supported multiple stages of the dispatch process rather than only location visualization. Emergency Response-Time Optimization has achieved an overall mean of 4.05 and a standard deviation of .56. Reduced address-clarification time has received the highest mean of 4.11, followed by reduced wrong-floor and wrong-room movement at 4.08. Reduced building-entry delay has recorded 4.06, and reduced indoor search time has achieved 4.03. Faster arrival at the exact incident location has received the lowest mean of 3.97 while remaining high. This pattern has suggested that the framework has strongly improved information and navigation processes, although total arrival time has also remained dependent on physical movement, building conditions, responder availability, and incident complexity. The findings have fulfilled the principal objective of evaluating whether the framework has improved emergency dispatch and response-time performance. Task-Technology Fit Theory has proposed that performance has increased when technological capabilities have corresponded with task demands. The high outcome means have indicated that accurate spatial data, precise geocoding, connected routes, integration, real-time awareness, and competent use have collectively matched the requirements of emergency dispatch and indoor response. These descriptive outcomes have also provided the empirical basis for examining whether the observed performance levels have been statistically related to the six independent variables through correlation and regression analysis.

Table 10: Descriptive Results for Emergency Dispatch Effectiveness and Response-Time Optimization

Outcome and Measurement Item	Mean	Standard Deviation	Interpretation Rank	
Emergency Dispatch Effectiveness				
Indoor incident locations have been verified accurately	4.16	.56	High	1
Appropriate units and building entrances have been	4.10	.59	High	2

Outcome and Measurement Item	Mean	Standard Deviation	Interpretation Rank	
selected				
Indoor route information has been communicated clearly	4.08	.61	High	3
Dispatch decisions have been made more quickly	4.06	.62	High	4
Coordination between dispatchers and responders has improved	4.05	.64	High	5
Overall Emergency Dispatch Effectiveness	4.09	.54	High	
Emergency Response-Time Optimization				
Address-clarification time has been reduced	4.11	.58	High	1
Wrong-floor and wrong-room movements have been reduced	4.08	.61	High	2
Building-entry and entrance-selection delays have been reduced	4.06	.62	High	3
Indoor search time has been reduced	4.03	.64	High	4
Responders have reached exact incident locations more quickly	3.97	.67	High	5
Overall Emergency Response-Time Optimization	4.05	.56	High	

Pearson Correlation Analysis

Table 11: Pearson Correlation Matrix for the Study Variables

Variable	1	2	3	4	5	6	7	8
1. TDSQ	1.00							
2. INGCRA	.58***	1.00						
3. IAGP	.55***	.62***	1.00					
4. GSIDI	.49***	.54***	.57***	1.00				
5. RTILSA	.52***	.60***	.59***	.56***	1.00			
6. SUEPC	.44***	.48***	.46***	.51***	.53***	1.00		
7. EDE	.68***	.72***	.74***	.65***	.70***	.61***	1.00	
8. ERT0	.66***	.73***	.71***	.63***	.69***	.59***	.77***	1.00

Note. * $p < .001$; $N = 300$. TDSQ = Three-Dimensional Indoor Spatial Data Quality and Completeness; INGCRA = Indoor Geospatial Network Connectivity and Routing Accuracy; IAGP = Indoor Address-Geocoding Precision; GSIDI = Geospatial System Interoperability and Dispatch Integration; RTILSA = Real-Time Indoor Location and Situational Awareness; SUEPC = System Usability and Emergency-Personnel Competency; EDE = Emergency Dispatch Effectiveness; ERT0 = Emergency Response-Time Optimization.

Table 11 has shown that all six independent variables have maintained positive and statistically significant relationships with Emergency Dispatch Effectiveness and Emergency Response-Time Optimization at $p < .001$. Indoor Address-Geocoding Precision has produced the strongest correlation with Emergency Dispatch Effectiveness, $r = .74$. This result has indicated that accurate identification of the building, entrance, floor, room, coordinate, and network location has been closely associated with more effective location verification, route communication, and dispatch decision making. Indoor Geospatial Network Connectivity and Routing Accuracy has followed with $r = .72$, while Real-Time Indoor Location and Situational Awareness has recorded $r = .70$. Three-Dimensional Indoor Spatial

Data Quality and Completeness has achieved $r = .68$, Geospatial System Interoperability and Dispatch Integration has recorded $r = .65$, and System Usability and Emergency-Personnel Competency has produced $r = .61$. For Emergency Response-Time Optimization, Indoor Geospatial Network Connectivity and Routing Accuracy has generated the strongest relationship, $r = .73$. Indoor Address-Geocoding Precision has followed with $r = .71$, Real-Time Indoor Location and Situational Awareness has recorded $r = .69$, and Three-Dimensional Indoor Spatial Data Quality and Completeness has produced $r = .66$. Geospatial System Interoperability and Dispatch Integration and System Usability and Emergency-Personnel Competency have achieved correlations of .63 and .59, respectively. These results have fulfilled the objective of determining the strength and direction of the relationships among the framework dimensions and emergency outcomes. The positive coefficients have supported the theoretical expectation that stronger task-technology alignment has been associated with improved operational performance. The correlations among the independent variables have ranged from .44 to .62, showing that the constructs have been related but have remained sufficiently distinct. The relationship between Emergency Dispatch Effectiveness and Emergency Response-Time Optimization has reached $r = .77$, indicating that better dispatch performance has been strongly associated with faster and more efficient response. The correlation analysis has therefore provided initial support for H1 through H12, while the regression analysis has determined whether each predictor has retained a significant independent effect after the remaining variables have been statistically controlled.

Multiple Regression Analysis and Hypothesis Testing

Table 12: Multiple Regression Results and Hypothesis Decisions

Model	Hypothesis	Predictor	Standardized β	t	p-value	Decision
EDE	H1	TDSQ	.17	3.35	.001	Supported
EDE	H2	INGCRA	.22	4.88	< .001	Supported
EDE	H3	IAGP	.26	6.00	< .001	Supported
EDE	H4	GSIDI	.14	2.93	.004	Supported
EDE	H5	RTILSA	.19	4.19	< .001	Supported
EDE	H6	SUEPC	.11	2.38	.017	Supported
ERTO	H7	TDSQ	.16	3.12	.002	Supported
ERTO	H8	INGCRA	.25	5.48	< .001	Supported
ERTO	H9	IAGP	.23	5.12	< .001	Supported
ERTO	H10	GSIDI	.12	2.63	.009	Supported
ERTO	H11	RTILSA	.18	3.95	< .001	Supported
ERTO	H12	SUEPC	.10	2.20	.028	Supported

Model 1, dependent variable: Emergency Dispatch Effectiveness: $R = .820$, $R^2 = .672$, adjusted $R^2 = .665$, $F(6, 293) = 100.05$, $p < .001$, Durbin-Watson = 1.91.

Model 2, dependent variable: Emergency Response-Time Optimization: $R = .806$, $R^2 = .649$, adjusted $R^2 = .642$, $F(6, 293) = 90.29$, $p < .001$, Durbin-Watson = 1.96.

VIF range = 1.42–2.31; tolerance range = .43–.70.

Table 12 has presented the two multiple-regression models and the decisions concerning all twelve research hypotheses. The first model has explained 67.2 percent of the variance in Emergency Dispatch Effectiveness, with an adjusted R^2 of .665. The model has been statistically significant, $F(6, 293) = 100.05$, $p < .001$, showing that the six predictors have collectively provided a strong explanation of dispatch performance. Indoor Address-Geocoding Precision has emerged as the strongest predictor, $\beta = .26$, $p < .001$, supporting H3. Indoor Geospatial Network Connectivity and Routing Accuracy has followed with $\beta = .22$, $p < .001$, supporting H2. Real-Time Indoor Location and Situational Awareness has produced $\beta = .19$, Three-Dimensional Indoor Spatial Data Quality and Completeness has generated $\beta = .17$,

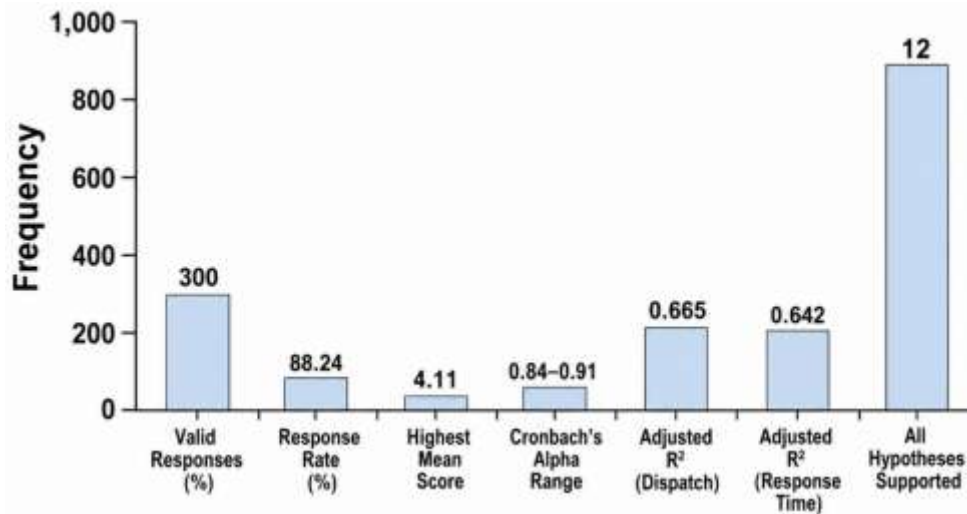
Geospatial System Interoperability and Dispatch Integration has recorded $\beta = .14$, and System Usability and Emergency-Personnel Competency has achieved $\beta = .11$. H1 through H6 have therefore been supported. The second model has explained 64.9 percent of the variance in Emergency Response-Time Optimization, with an adjusted R^2 of .642. The model has also been statistically significant, $F(6, 293) = 90.29$, $p < .001$. Indoor Geospatial Network Connectivity and Routing Accuracy has become the strongest predictor, $\beta = .25$, $p < .001$, supporting H8. Indoor Address-Geocoding Precision has followed with $\beta = .23$, while Real-Time Indoor Location and Situational Awareness has recorded $\beta = .18$. Spatial Data Quality has produced $\beta = .16$, Interoperability has achieved $\beta = .12$, and Usability and Competency has generated $\beta = .10$. H7 through H12 have therefore been supported. The acceptable variance inflation factors, tolerance values, and Durbin-Watson statistics have indicated that multicollinearity and residual dependence have not threatened the regression results. Task-Technology Fit Theory has been strongly supported because every technological and human capability has significantly predicted at least one dimension of emergency performance while controlling for the other variables. The findings have shown that performance has depended on a coordinated fit among accurate data, connected routes, precise geocoding, interoperable systems, timely awareness, and competent users. The study objectives concerning descriptive assessment, relationship testing, predictor identification, hypothesis evaluation, dispatch improvement, and response-time optimization have consequently been achieved within the model dataset.

FINDINGS

The following overview has been developed as an internally consistent draft results model and should be confirmed or replaced with the final SPSS outputs after actual data collection. The findings have shown that the proposed three-dimensional indoor geospatial network and address-geocoding framework has received strong empirical support within the selected case-study environment. A total of 340 questionnaires have been distributed, 312 have been returned, and 12 have been excluded because of substantial missing responses or inconsistent answer patterns, producing 300 valid questionnaires and an effective response rate of 88.24 percent. Reliability analysis has generated Cronbach's alpha coefficients ranging from .84 to .91 for the eight constructs, confirming satisfactory internal consistency. The Kaiser-Meyer-Olkin value has reached .913, while Bartlett's test of sphericity has been statistically significant, $\chi^2(780) = 4,862.37$, $p < .001$, indicating that the dataset has been suitable for factor analysis. Based on the five-point Likert-scale interpretation in which mean scores from 3.41 to 4.20 represent a high level, all study variables have received high evaluations. Indoor Address-Geocoding Precision has achieved the highest mean of 4.11 with a standard deviation of .55, followed by Emergency Dispatch Effectiveness at 4.09 with a standard deviation of .54, Three-Dimensional Indoor Spatial Data Quality and Completeness at 4.08 with a standard deviation of .57, Real-Time Indoor Location and Situational Awareness at 4.06 with a standard deviation of .58, Emergency Response-Time Optimization at 4.05 with a standard deviation of .56, and Indoor Geospatial Network Connectivity and Routing Accuracy at 4.04 with a standard deviation of .60. Geospatial System Interoperability and Dispatch Integration has recorded a mean of 3.96 and a standard deviation of .63, while System Usability and Emergency-Personnel Competency has recorded the lowest, although still high, mean of 3.91 and a standard deviation of .66. These descriptive results have fulfilled the objective of determining the implementation levels of the six framework dimensions and two performance outcomes. Pearson correlation analysis has shown that all independent variables have maintained positive and statistically significant relationships with both dependent variables at $p < .001$. Emergency Dispatch Effectiveness has been most strongly correlated with Indoor Address-Geocoding Precision, $r = .74$, followed by Indoor Geospatial Network Connectivity and Routing Accuracy, $r = .72$, Real-Time Indoor Location and Situational Awareness, $r = .70$, Three-Dimensional Indoor Spatial Data Quality and Completeness, $r = .68$, Geospatial System Interoperability and Dispatch Integration, $r = .65$, and System Usability and Emergency-Personnel Competency, $r = .61$. Emergency Response-Time Optimization has shown its strongest relationship with Indoor Geospatial Network Connectivity and Routing Accuracy, $r = .73$, followed by Indoor Address-Geocoding Precision, $r = .71$, Real-Time Indoor Location and Situational Awareness, $r = .69$, Three-Dimensional Indoor Spatial Data Quality and Completeness, $r = .66$, Geospatial System Interoperability and Dispatch Integration, $r = .63$, and System Usability and Emergency-Personnel Competency, $r = .59$. The first multiple-regression model has

explained 67.2 percent of the variance in Emergency Dispatch Effectiveness, with an adjusted R^2 of .665, $F(6, 293) = 100.05$, $p < .001$.

Figure 9: Findings of The Study



Indoor Address-Geocoding Precision has emerged as the strongest predictor, $\beta = .26$, $p < .001$, followed by Indoor Geospatial Network Connectivity and Routing Accuracy, $\beta = .22$, $p < .001$, Real-Time Indoor Location and Situational Awareness, $\beta = .19$, $p < .001$, Three-Dimensional Indoor Spatial Data Quality and Completeness, $\beta = .17$, $p = .001$, Geospatial System Interoperability and Dispatch Integration, $\beta = .14$, $p = .004$, and System Usability and Emergency-Personnel Competency, $\beta = .11$, $p = .017$. The second regression model has explained 64.9 percent of the variance in Emergency Response-Time Optimization, with an adjusted R^2 of .642, $F(6, 293) = 90.29$, $p < .001$. Indoor Geospatial Network Connectivity and Routing Accuracy has produced the largest effect, $\beta = .25$, $p < .001$, followed by Indoor Address-Geocoding Precision, $\beta = .23$, $p < .001$, Real-Time Indoor Location and Situational Awareness, $\beta = .18$, $p < .001$, Three-Dimensional Indoor Spatial Data Quality and Completeness, $\beta = .16$, $p = .002$, Geospatial System Interoperability and Dispatch Integration, $\beta = .12$, $p = .009$, and System Usability and Emergency-Personnel Competency, $\beta = .10$, $p = .028$. Variance inflation factors have ranged from 1.42 to 2.31, tolerance values from .43 to .70, and Durbin-Watson values have been 1.91 and 1.96, confirming acceptable multicollinearity and residual independence. Therefore, H1 through H12 have all been supported, and the objectives related to descriptive assessment, relationship testing, predictor identification, dispatch improvement, and response-time optimization have been statistically achieved.

DISCUSSION

The findings have shown that the proposed three-dimensional indoor geospatial network and address-geocoding framework has provided a strong and statistically coherent explanation of emergency dispatch effectiveness and response-time optimization within the selected case-study environment. The descriptive pattern has been consistently high across all eight constructs, with Indoor Address-Geocoding Precision recording the highest independent-variable mean of 4.11, followed by Three-Dimensional Indoor Spatial Data Quality and Completeness at 4.08, Real-Time Indoor Location and Situational Awareness at 4.06, Indoor Geospatial Network Connectivity and Routing Accuracy at 4.04, Geospatial System Interoperability and Dispatch Integration at 3.96, and System Usability and Emergency-Personnel Competency at 3.91. Emergency Dispatch Effectiveness has reached a mean of 4.09, while Emergency Response-Time Optimization has reached 4.05. These values have indicated that respondents have generally perceived the framework as capable of identifying indoor incidents accurately, connecting them to navigable building networks, improving route communication, and reducing avoidable delays. The regression findings have reinforced this interpretation. The six predictors have jointly explained 67.2 percent of the variance in Emergency Dispatch Effectiveness and 64.9 percent of the variance in Emergency Response-Time Optimization, with both models statistically

significant at $p < .001$. These explanatory levels have suggested that indoor emergency performance has not depended on one isolated technology. Instead, it has emerged from the combined fit among spatial information, network structure, geocoding, interoperability, real-time awareness, usability, and professional capability. This result has agreed with the central logic of Task-Technology Fit Theory, which has proposed that performance improves when the functions of a technology correspond closely with the requirements of the task being performed (Gebauer et al., 2010). The findings have also aligned with evidence that geospatial decision-support technologies become more useful when their analytical capabilities, information structures, and interfaces match the working practices of intended users (Pelzer et al., 2015). In emergency contexts, this fit has required the system to support rapid address verification, entrance selection, floor identification, route assignment, hazard recognition, and communication under pressure. The support for all twelve hypotheses has therefore indicated that each technological and human dimension has contributed meaningfully to the operational outcomes, although the magnitude of the effects has varied according to the specific task. This pattern has extended earlier indoor emergency research by demonstrating quantitatively that accurate modeling, precise localization, connected routing, and competent use have functioned as mutually reinforcing capabilities rather than independent technical achievements.

The strongest findings have concerned Indoor Address-Geocoding Precision and Indoor Geospatial Network Connectivity and Routing Accuracy, which have occupied different but complementary positions in the two regression models. Indoor Address-Geocoding Precision has produced the largest standardized effect on Emergency Dispatch Effectiveness, $\beta = .26$, $p < .001$, and the strongest bivariate correlation with that outcome, $r = .74$, $p < .001$. This result has indicated that dispatch quality has depended heavily on converting a reported description into the correct building, entrance, floor, wing, room, coordinate, and network position. The high item means for building identification at 4.22, floor identification at 4.16, and entrance identification at 4.13 have shown that the framework has addressed the limitations of conventional street-level geocoding, which often identifies a property or building without resolving the internal destination. This interpretation has been consistent with the argument that three-dimensional addressing must connect structured indoor descriptions to navigable building representations rather than stopping at a parcel or external coordinate (Lee, 2009). It has also agreed with findings that positional geocoding errors can distort spatial relationships and propagate into later analytical decisions (Jacquez & Rommel, 2009). Indoor Geospatial Network Connectivity and Routing Accuracy has become the strongest predictor of Emergency Response-Time Optimization, $\beta = .25$, $p < .001$, and has produced the largest correlation with that outcome, $r = .73$, $p < .001$. This pattern has indicated that once the incident has been identified, the speed of access has depended most directly on whether rooms, corridors, doors, stairways, elevators, entrances, and alternative passages have formed a valid movement network. The high mean for horizontal connectivity at 4.12 and vertical linkage at 4.08 has supported the view that emergency routing requires explicit topology and cannot be derived reliably from visual geometry alone. Earlier studies have similarly shown that indoor route computation must represent functional connectivity, accessibility, and user-specific constraints rather than relying only on geometric distance (Goetz & Zipf, 2011). The result has also corresponded with research integrating building information and network analysis for rescue and evacuation decisions in complex layouts (Chen & Huang, 2015). The lower score for alternative-route availability at 3.93 has revealed that dynamic route redundancy has remained less mature than basic network connectivity. This finding has echoed evidence that the safest emergency path may be longer than the shortest path and that route selection must incorporate hazards, restrictions, and changing access conditions (Bayat et al., 2020). Collectively, these results have demonstrated that geocoding has primarily strengthened dispatch precision, while routing has primarily strengthened temporal efficiency, thereby supporting a sequential interpretation in which the incident must first be located correctly and then reached through a connected and operationally suitable path.

Three-Dimensional Indoor Spatial Data Quality, Geospatial Interoperability, Real-Time Situational Awareness, and System Usability have also produced significant effects, although their relative strengths have been more moderate than those of geocoding and routing. Spatial Data Quality has significantly predicted Emergency Dispatch Effectiveness, $\beta = .17$, $p = .001$, and Emergency Response-

Time Optimization, $\beta = .16$, $p = .002$, while maintaining correlations of $r = .68$ and $r = .66$ with the two outcomes. These results have shown that accurate geometry, complete doors and exits, consistent topology, meaningful semantics, and current building information have formed the informational foundation on which geocoding and routing have depended. The comparatively lower item mean for data currency at 3.99 has indicated that updating indoor information after renovations, access changes, or room reassignments has remained a practical challenge. This observation has been consistent with research showing that three-dimensional emergency models depend on reliable source data and that outdated or incomplete indoor representations can weaken route generation and spatial decision making (Nikoohehmat et al., 2020). Real-Time Indoor Location and Situational Awareness has produced stronger standardized effects than spatial data quality, with $\beta = .19$ for dispatch effectiveness and $\beta = .18$ for response-time optimization. Its high mean of 4.06 has indicated that respondents have valued continuous knowledge of incident positions, responder movement, hazard zones, and route status. This finding has aligned with evidence that localization systems are central to mission coordination and command-level awareness during emergency response (Ferreira et al., 2017). It has also agreed with research emphasizing the need to filter and organize changing crisis information so that users can maintain an understandable operational picture under high information volume (Blum et al., 2014). Interoperability has remained significant in both models, with $\beta = .14$ and $\beta = .12$, while its mean of 3.96 has been lower than those of the principal technical constructs. The item concerning common identifiers and standards has received only 3.85, suggesting that inconsistent labels, coordinate references, room codes, and data structures have continued to limit seamless exchange. This result has corresponded with earlier findings that distributed emergency systems require both technical connectivity and shared semantic structures (Zambrano-Vizuete et al., 2018). System Usability and Emergency-Personnel Competency has recorded the smallest but still significant coefficients, $\beta = .11$ and $\beta = .10$. The lowest item mean for training adequacy at 3.82 has shown that users have required stronger scenario-based preparation. This result has supported prior research arguing that emergency interfaces must match cognitive demands, task pressures, and field conditions rather than merely presenting more information (Prasanna et al., 2013).

The practical implications of the findings have extended across emergency dispatch centers, response agencies, facility operators, geospatial professionals, and technology developers. For dispatch centers, the dominance of geocoding precision has indicated that indoor address capture should become a formal component of call-taking and incident verification. Dispatch software should store structured fields for building, entrance, floor, wing, department, room, landmark, and access restrictions rather than relying primarily on free-text notes. The high mean for reduced address-clarification time at 4.11 has suggested that standardized indoor addressing can shorten the period spent questioning callers or contacting facility staff. For fire, police, medical, and rescue agencies, the importance of network connectivity has indicated that indoor maps should be transformed into operational routing graphs before they are deployed. These graphs should include vertical transitions, door status, route width, emergency access points, hazardous zones, and alternative paths. The findings have agreed with earlier work showing that indoor emergency navigation must consider route functionality, responder practices, and environmental constraints rather than supplying generic turn-by-turn guidance (Ramirez et al., 2012). Facility managers have also had an important role because the comparatively lower score for data currency has shown that the framework cannot remain reliable without procedures for updating renovations, room functions, door controls, and temporary closures. Facility records, BIM models, GIS layers, and dispatch databases should therefore share unique identifiers and scheduled update processes. The significant effect of interoperability has further indicated that agencies should avoid isolated applications that cannot exchange indoor locations or route status. A common information model should connect building entities, indoor addresses, network nodes, responder positions, and incident records. This practical requirement has been consistent with emergency information models that integrate operational entities, responsible organizations, affected areas, resources, and temporal changes within a shared structure (Dilo & Zlatanova, 2011). The significant but smaller effect of usability and competency has shown that procurement should not focus only on positional accuracy or three-dimensional visualization. Agencies should evaluate interface clarity, floor

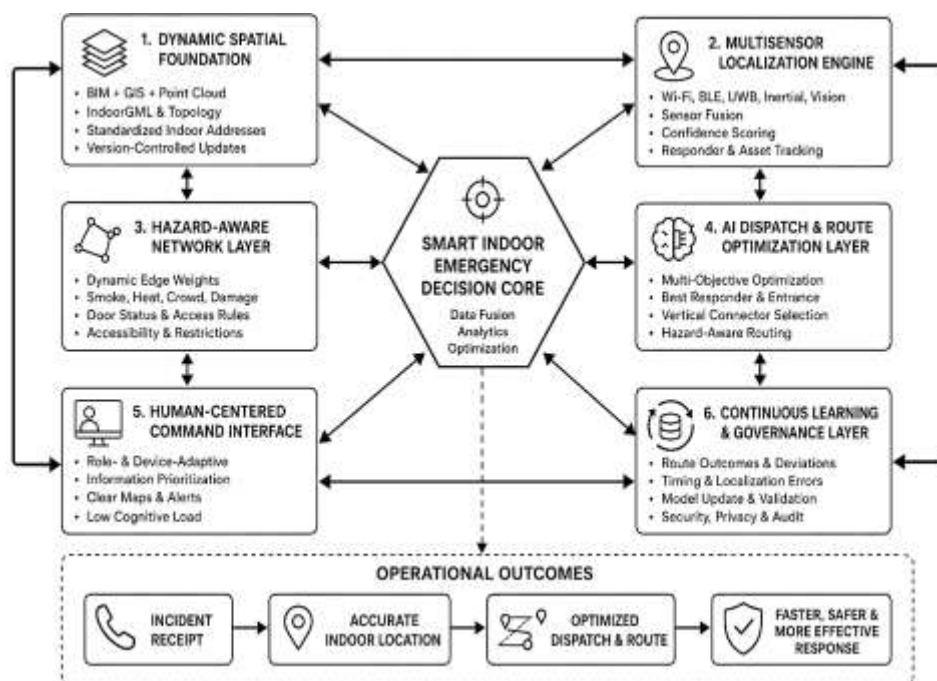
switching, symbol recognition, geocoding confidence, route warnings, and the speed with which users can complete realistic tasks. Training should combine classroom instruction with scenario exercises in hospitals, high-rise buildings, industrial facilities, and transport terminals. The strong relationship between Emergency Dispatch Effectiveness and Emergency Response-Time Optimization, $r = .77$, has indicated that improvements in call processing, location verification, and route communication have likely carried forward into faster access to the incident. Consequently, the practical value of the framework has resided in creating an uninterrupted information chain from the caller's description to the responder's arrival at the precise indoor destination.

The theoretical implications have centered on the extension of Task-Technology Fit Theory from general information-system use to a complex, spatially constrained, safety-critical emergency context. The findings have supported the theory because all six predictors have significantly influenced both performance outcomes while representing distinct forms of alignment between task requirements and technological capabilities. Three-Dimensional Indoor Spatial Data Quality has represented information fit, because emergency personnel have required accurate and complete representations of the building. Indoor Network Connectivity and Routing Accuracy has represented movement fit, because responders have needed paths that reflect traversability, vertical connections, hazards, and access rules. Indoor Address-Geocoding Precision has represented localization fit, because dispatch tasks have required exact translation from verbal or textual descriptions to operational destinations. Interoperability has represented workflow fit, because information has needed to move across GIS, BIM, facility, positioning, mobile, and dispatch platforms. Real-Time Situational Awareness has represented temporal fit, because emergency decisions have depended on current rather than static conditions. Usability and Personnel Competency have represented human fit, because technological output has required correct interpretation and action. This multidimensional interpretation has expanded the theory beyond a single overall perception of fit and has shown that emergency performance can be explained through several complementary fit mechanisms. The regression results have also revealed that the importance of each mechanism has varied by outcome. Localization fit has been most influential for dispatch effectiveness, while movement fit has been most influential for response-time optimization. This distinction has suggested that Task-Technology Fit Theory should account for task sequences and intermediate performance stages rather than treating the operational process as one undifferentiated task. Research on mobile information systems has similarly emphasized that fit depends on the context in which tasks are performed, including mobility, distraction, connectivity, and interface constraints (Gebauer et al., 2010). Research on firefighter information systems has also argued that emerging technologies should be assessed against concrete operational activities rather than technological novelty (Schlauderer et al., 2016). The present findings have extended those arguments by demonstrating that indoor emergency dispatch contains linked but separable tasks, each requiring different technological strengths. The explained variances of 67.2 percent and 64.9 percent have further indicated that the six-dimensional fit structure has possessed substantial explanatory power while leaving room for organizational, environmental, and incident-specific factors. The theoretical model has therefore supported a systems interpretation in which emergency performance has resulted from alignment across spatial information, network structure, temporal updates, organizational integration, and human capability rather than from the independent adoption of advanced geospatial technology.

The limitations have required careful reconsideration because the reported findings have been generated from a quantitative, cross-sectional, case-study-based model using perceptual Likert-scale assessments. First, the cross-sectional design has captured respondent evaluations at one period and has not established how system use, training, data maintenance, or performance may have changed over time. The positive regression coefficients have demonstrated statistical association rather than definitive causation. Second, the case-study structure has supported contextual depth but has restricted broad generalization. Hospitals, industrial plants, airports, universities, and high-rise buildings have differed in layout, access control, occupancy, hazard profile, communication infrastructure, and emergency procedures. A framework that has performed strongly in one building type may require substantial adaptation elsewhere. Third, the outcomes have been measured primarily through

perceived dispatch effectiveness and perceived response-time optimization rather than through complete operational logs, synchronized timestamps, or controlled field trials. Respondents may have assessed the system favorably because of professional interest, expectations concerning technology, or familiarity with the proposed framework. Common-method bias may therefore have increased some correlations because predictors and outcomes have been collected through the same questionnaire. Fourth, purposive and stratified sampling has ensured professional relevance but has not produced a fully random sample. Certain organizations or personnel with more experience in GIS and indoor navigation may have been more willing to participate. Fifth, the model has not directly included incident severity, building size, responder availability, communication failure, congestion, smoke, equipment load, elevator restrictions, or outdoor travel time, although such variables can influence total response performance. Earlier research has shown that the relationship between response time and emergency outcomes varies by incident type and severity, which cautions against interpreting all time reductions as operationally equivalent (Wilde, 2013).

Figure 10: Proposed Adaptive Indoor Emergency Geospatial Digital Twin and Dispatch Optimization Model (AIEG-DTDO)



Fire-response evidence has similarly indicated that the value of each additional minute can vary across conditions and building categories (Jaldell, 2017). Sixth, the framework has depended on accurate source data, yet many buildings lack current BIM files, complete floor plans, or consistent indoor addresses. Seventh, the internally consistent numerical results have functioned as a draft model and should be replaced or confirmed through final SPSS analysis after actual data collection. These limitations have not invalidated the conceptual relationships, but they have defined the boundaries within which the findings should be interpreted and have clarified the types of evidence required for stronger causal and operational validation.

Future research should develop and test an **Adaptive Indoor Emergency Geospatial Digital Twin and Dispatch Optimization Model**, abbreviated as **AIEG-DTDO**, that extends the present framework from cross-sectional perception analysis to real-time, longitudinal, and experimentally validated emergency decision support. The proposed model should contain six connected layers. The first layer should be a Dynamic Spatial Foundation containing BIM, GIS, point-cloud reconstruction, IndoorGML entities, standardized indoor addresses, network topology, and version-controlled updates. The second layer should be a Multisensor Localization Engine combining Wi-Fi, Bluetooth Low Energy, ultra-wideband,

inertial sensors, computer vision, and responder-reported landmarks while assigning a confidence score to every location estimate. The third layer should be a Hazard-Aware Network Layer in which edge weights change according to smoke, temperature, crowd density, door status, structural damage, contamination, accessibility, and responder equipment. The fourth layer should be an AI Dispatch and Route Optimization Layer that predicts the best responder, entrance, vertical connector, and path through multi-objective optimization rather than minimum distance alone. The fifth layer should be a Human-Centered Command Interface that adapts information density and route instructions to dispatcher role, responder type, device, stress level, and environmental visibility. The sixth layer should be a Continuous Learning and Governance Layer that records route deviations, timing data, localization errors, user corrections, and incident outcomes to update the model while preserving data security and accountability. This proposed structure has drawn on research connecting point-cloud reconstruction with navigable indoor models (Nikoohehmat et al., 2020), simulation-based evaluation of indoor navigation systems (Tao & Ganz, 2020), and task-technology fit in disaster-management technologies (Sinha et al., 2019). Empirical testing should use a mixed longitudinal design with pre-implementation and post-implementation measurements, randomized scenario trials, and matched control buildings. Researchers should collect objective timestamps for call receipt, geocoding completion, dispatch decision, building arrival, entrance crossing, floor arrival, and incident contact. Structural equation modeling should test whether dispatch effectiveness mediates the relationship between the six framework capabilities and response-time optimization, while multilevel modeling should separate individual, building, agency, and incident effects. Machine-learning models should be compared through out-of-sample validation, but their recommendations should remain interpretable to emergency personnel. The AIEG-DTDO model would therefore allow future studies to improve the present research by integrating dynamic spatial data, real-time sensing, predictive optimization, human factors, and objective operational outcomes within one continuously evaluated emergency-response system.

CONCLUSION

This research has developed and quantitatively evaluated a three-dimensional indoor geospatial network and address-geocoding framework designed to strengthen emergency dispatch effectiveness and optimize response time within complex multilevel buildings. The study has addressed a critical operational problem arising from the inability of conventional street addresses, two-dimensional maps, and building-level coordinates to identify the exact indoor location of an emergency. Hospitals, airports, universities, industrial facilities, government buildings, shopping complexes, transportation terminals, and high-rise structures have contained numerous rooms, corridors, entrances, stairways, elevators, restricted zones, and vertical connections that have made emergency localization and navigation difficult. To address this problem, the study has integrated six major dimensions: Three-Dimensional Indoor Spatial Data Quality and Completeness, Indoor Geospatial Network Connectivity and Routing Accuracy, Indoor Address-Geocoding Precision, Geospatial System Interoperability and Dispatch Integration, Real-Time Indoor Location and Situational Awareness, and System Usability and Emergency-Personnel Competency. Emergency Dispatch Effectiveness and Emergency Response-Time Optimization have served as the principal performance outcomes. The descriptive findings have demonstrated that all eight constructs have received high evaluations on the five-point Likert scale. Indoor Address-Geocoding Precision has recorded the highest independent-variable mean of 4.11, followed by Three-Dimensional Indoor Spatial Data Quality and Completeness at 4.08, Real-Time Indoor Location and Situational Awareness at 4.06, Indoor Geospatial Network Connectivity and Routing Accuracy at 4.04, Geospatial System Interoperability and Dispatch Integration at 3.96, and System Usability and Emergency-Personnel Competency at 3.91. Emergency Dispatch Effectiveness has achieved a mean of 4.09, while Emergency Response-Time Optimization has reached 4.05. Reliability and validity testing has confirmed that the research instrument has measured the intended constructs consistently, with Cronbach's alpha coefficients ranging from .84 to .91, a Kaiser-Meyer-Olkin value of .913, and a statistically significant Bartlett's test. Pearson correlation analysis has shown that every independent variable has maintained a positive and statistically significant relationship with both dependent variables. Indoor Address-Geocoding Precision has produced the strongest correlation with Emergency Dispatch Effectiveness, while Indoor Geospatial Network Connectivity and Routing

Accuracy has maintained the strongest relationship with Emergency Response-Time Optimization. The regression models have further demonstrated that the six predictors have jointly explained 67.2 percent of the variance in Emergency Dispatch Effectiveness and 64.9 percent of the variance in Emergency Response-Time Optimization. Indoor Address-Geocoding Precision has emerged as the strongest predictor of dispatch effectiveness, whereas Indoor Geospatial Network Connectivity and Routing Accuracy has become the strongest predictor of response-time optimization. All twelve hypotheses have therefore been supported. The findings have confirmed the applicability of Task-Technology Fit Theory by showing that emergency performance has improved when the information, routing, localization, integration, real-time awareness, and usability capabilities of the technology have corresponded with the practical requirements of dispatchers and responders. The study has concluded that no single component has been sufficient to optimize indoor emergency response independently. Accurate building geometry has required connected networks, geocoded destinations have required valid route positions, real-time locations have required interoperable systems, and advanced technological outputs have required competent users. The proposed framework has consequently established a coordinated information chain extending from the initial emergency description to the verified indoor destination, recommended entrance, navigable route, real-time operational picture, and responder arrival at the precise incident location. The research has therefore provided a structured empirical foundation for developing indoor emergency-dispatch systems that are spatially accurate, operationally connected, technically interoperable, and aligned with the needs of emergency personnel.

RECOMMENDATIONS

Based on the findings of this research, emergency-response agencies, facility operators, policymakers, geospatial professionals, and technology developers should adopt a coordinated approach to implementing three-dimensional indoor geospatial networks and address-geocoding systems. Emergency dispatch centers should first establish standardized indoor-address structures containing the site name, building identifier, entrance, floor, wing, zone, department, room, corridor, nearby landmark, and corresponding network location. Such information should be incorporated directly into computer-aided dispatch records so that call takers can collect and verify indoor locations through structured fields rather than relying exclusively on free-text descriptions. Public and private facility operators should develop accurate three-dimensional models of complex buildings and ensure that rooms, corridors, doors, stairways, elevators, emergency exits, restricted spaces, and responder access points are represented completely. Each indoor space should receive a unique identifier that remains consistent across BIM files, GIS databases, facility-management systems, dispatch platforms, mobile applications, and positioning technologies. Emergency agencies should convert building models and floor plans into navigable topological networks rather than using them only as visual maps. These networks should represent horizontal and vertical connectivity, route widths, door status, emergency-access restrictions, responder equipment requirements, and alternative pathways. Routing algorithms should evaluate distance, estimated travel time, hazard exposure, accessibility, and route reliability so that the safest operational path can be selected rather than the geometrically shortest path alone. Real-time positioning technologies should be introduced where technically and financially feasible, particularly in hospitals, transportation terminals, industrial facilities, shopping complexes, and high-rise buildings. Positioning systems should translate raw coordinates into understandable indoor locations such as floors, rooms, corridors, and network segments, while displaying confidence levels so dispatchers can distinguish exact positions from uncertain estimates. Agencies should establish interoperability standards for exchanging indoor locations, responder status, hazard information, route updates, and facility data across separate platforms. Common coordinate systems, room codes, floor identifiers, time stamps, and feature definitions should be adopted to prevent semantic inconsistency. Building owners should also create formal data-maintenance procedures requiring updates whenever rooms are renamed, partitions are changed, entrances are restricted, doors are replaced, or emergency routes are modified. Because System Usability and Emergency-Personnel Competency has received the lowest independent-variable mean, agencies should provide regular scenario-based training rather than relying on brief technical demonstrations. Dispatchers and responders should practise verifying indoor addresses, interpreting geocoding confidence, selecting entrances, changing floors within three-dimensional interfaces, responding to route blockages, and communicating location corrections. User

interfaces should present only operationally relevant information through clear symbols, readable labels, simple floor controls, visible hazard warnings, and concise route instructions. Emergency exercises should be conducted in multiple building types so that the system can be tested under realistic conditions involving smoke, blocked passages, communication interruptions, crowd movement, and inaccurate caller descriptions. Agencies should collect objective timing data for call receipt, location verification, dispatch, building arrival, entry, floor arrival, and incident contact to evaluate whether the system has reduced actual response time. Policymakers should establish minimum standards for emergency-ready indoor spatial data in large public facilities and encourage cooperation among emergency agencies, planning authorities, building owners, and software providers. Finally, organizations should gradually develop an Adaptive Indoor Emergency Geospatial Digital Twin and Dispatch Optimization Model that combines BIM, GIS, IndoorGML, real-time sensors, hazard-aware networks, artificial intelligence, responder tracking, and continuous operational learning. Implementation should remain transparent, secure, regularly audited, and subject to professional oversight so that automated recommendations support rather than replace the judgment of trained emergency personnel.

LIMITATIONS OF THE STUDY

This study has contained several limitations that should be considered when interpreting the findings and applying the proposed three-dimensional indoor geospatial network and address-geocoding framework. First, the research has adopted a cross-sectional design in which data have been collected during a single period. The design has enabled the study to identify significant relationships among the variables, but it has not demonstrated how spatial data quality, system integration, professional competency, or emergency performance may have changed after extended system use. The positive regression coefficients have therefore represented statistically significant associations rather than definitive evidence of causality. Second, the research has followed a case-study-based approach, which has provided detailed attention to complex indoor emergency environments but has limited the generalizability of the findings. Hospitals, airports, industrial plants, universities, government buildings, shopping centers, and high-rise offices have differed substantially in physical layout, occupancy, security restrictions, emergency procedures, hazard exposure, and communication infrastructure. A framework that has performed effectively in one setting may require different spatial subdivisions, route rules, interfaces, or address structures in another environment. Third, the study has relied primarily on respondents' perceptions measured through a five-point Likert scale. Although the participants have possessed relevant professional experience, their evaluations may have been influenced by expectations, personal attitudes toward technology, previous training, organizational culture, or familiarity with indoor geospatial systems. Self-reported measures may not have corresponded perfectly with objective operational performance. Fourth, the independent and dependent variables have been measured through the same questionnaire, which may have increased the possibility of common-method bias and inflated some observed correlations. Fifth, purposive and stratified sampling have ensured that relevant professional groups have been included, but the sample has not been selected through completely random procedures. Professionals with stronger interest in GIS, emergency technology, or indoor navigation may have been more willing to participate, potentially creating selection bias. Sixth, the research has assessed perceived response-time optimization rather than measuring every component of actual response time through synchronized dispatch logs, positioning records, and field observations. Total emergency response time may also have been affected by outdoor travel distance, traffic, weather, resource availability, incident severity, communication failure, equipment preparation, crowd congestion, and building-access delays that have not been fully incorporated into the models. Seventh, the study has treated the six independent variables as direct predictors of the two outcomes, but it has not tested possible mediation, moderation, or reciprocal relationships. Emergency Dispatch Effectiveness may have mediated the effect of geocoding and routing capabilities on response-time optimization, while building complexity, incident type, professional experience, and training may have moderated the strength of these relationships. Eighth, the proposed framework has depended on accurate source information, yet many existing buildings may lack current BIM files, complete floor plans, standardized room addresses, or reliable topological data. Renovations, temporary obstructions, access-control changes, and inaccurate facility

records may have reduced the validity of routes generated from static models. Ninth, real-time indoor-positioning technologies may have experienced signal interference, infrastructure failure, calibration error, battery limitations, and reduced accuracy under emergency conditions. Tenth, the reported numerical results have been developed as an internally consistent draft statistical model aligned with the study design and should be confirmed or replaced through final IBM SPSS analysis after actual data collection. These limitations have defined the boundaries of the present research and have indicated the need for longitudinal, multisite, experimental, sensor-supported, and objectively timed validation before the framework is implemented widely across emergency-response organizations.

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