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Fire Incident Mapping and Navigation System: A* (A-Star) Algorithm Integration with ESP 32-based GPS

Joemari M. Mediavilla[1*], Carl Anthony P. Bismar[1], Aaron Jay L. Besana[1], Nathaniel U. Babanto[1], Nathaniel U. Babanto[1], Nathaniel U. Babanto[1], Charisse S. Ronquillo, MIT[1]

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ABSTRACT

Fire-related incidents have always been an issue that create risks to both lives and properties, requiring an effective and automated response system. The Fire Incident Mapping and Navigation System is developed for fire emergency response and to address the said issue. This system enhances the fire emergency response by using real-time geolocation tracking, cloud-based data management, mobile-based navigation and web-based monitoring to improve the visualization of the location and mitigate emergency response time. The system uses a GPS-based device that has an ESP32 microcontroller and GPS module to communicate with the system sending the coordinates of the fire incident location in the system for mapping. To help responders quickly arrive in the scene, the system gives navigation support by utilizing the A* (A-Star) algorithm to calculate the shortest route so that the responders will have more efficient directions and reduce response time. And if the responders go off the route or choose an alternative route, the system will recalculate and give another route base on its new location and direction. And additionally, the system shows device information to contact the owner and may also help mitigate the damage and also the response time of fire emergency responders.

INTRODUCTION

The Philippines is among the most vulnerable nations to severe urban fire disasters, suffering heavy annual losses from such events (Kurata *et al.*, 2023). Data from the Bureau of Fire Protection (BFP) shows that fire incidents rose from 16,387 in 2023 to 18,217 in 2024. The damages in 2024 amounted to ₱13.83 billion, a 5.1% increase from the ₱13.15 billion recorded the previous year. Civilian deaths also climbed from 320 in 2023 to 338 in 2024 (a 5.8% increase), while injuries surged from 1,047 to 1,332 (Villamente, 2024).

Delays in emergency response often occur because callers struggle to provide precise information under stress, leading to errors in addresses or incident details. Responders also waste time manually verifying routes before mobilization. These inefficiencies can cost lives and worsen fire damage.

To address this, the proposed "Fire Incident Mapping and Navigation System" integrates technological tools to improve response speed and accuracy. Using a GPS-enabled device with an ESP32 microcontroller and GPS module, fire locations are transmitted and displayed on a web-based interactive map via MapLibre GL JS—an open-source mapping library that supports customizable vector and raster tiles (MapLibre JS, 2025). The system also employs the A* (A-Star) pathfinding algorithm, which efficiently calculates the shortest route by balancing speed and accuracy (Brilliant.org, 2025). In case of roadblocks or congestion, the system dynamically reroutes using mobile devices in fire trucks, ensuring responders reach fire zones quickly. The ultimate goal is to enhance emergency services' effectiveness and minimize fire-related losses.

Scope and Limitation

This study develops a Fire Incident Mapping and Navigation System that transmits fire location data via an ESP32 microcontroller with a GPS module. Once a location is reported, the system sends an alert to the Bureau of Fire Protection (BFP) and displays the coordinates, along with details such as the owner's name and address, on an interactive web-based map. Using GIS, responders can visualize the incident site, while the A (A-Star) algorithm* calculates the shortest route from the BFP station to the fire. If responders deviate due to roadblocks or congestion, the system automatically recalculates a new route using updated GPS data. The mapping interface is powered by MapLibre, which supports GeoJSON data, markers, and interactive features.

Although effective in route planning and visualization, the prototype has limitations. It does not integrate real-time traffic, road closures, or hazard data, relying only on static GIS information. GPS accuracy is limited to ±5 meters and can be affected by location or weather. The system cannot detect or suppress fires and uses the standard A* algorithm without enhancements. Despite these constraints, the project demonstrates potential, and future improvements could expand its accuracy and practical use in real-world fire response.

Related Literature And System

Fire incidents remain a major threat to life and property worldwide, with the Philippines particularly vulnerable due to limited resources and outdated technology in its Bureau of Fire Protection (BFP) (Villa & Ceballos, 2021;

[1] College of Engineering and Technology Education, Holy Trinity College, General Santos City, Philippines
[*] Corresponding author's e-mail: joemarimediavilla19@gmail.com

Zadeh *et al.*, 2021). Effective fire response depends not only on manpower and equipment but also on location, planning, and technology (Lagata *et al.*, 2022; Tishi & Islam, 2019). Delays often occur because reporters struggle to provide accurate directions under stress, forcing responders to waste time confirming locations (ESRI, 2011).

To address this, researchers propose integrating GIS, GPS, and shortest path algorithms into fire response systems. GIS provides spatial data for mapping and route planning, GPS offers real-time location tracking, and algorithms like A (A-Star)* or Dijkstra's calculate optimal routes to fire sites (Panamaldeniya, 2021; Bhanumurthy *et al.*, 2015). These tools can minimize response times, improve navigation, and help firefighters reach incidents faster. IoT devices further enhance functionality by enabling early fire detection and automated alerts (Patil *et al.*, 2024; Jezdović & Ivković, 2017).

Several related projects highlight this approach: the Fire Check Project in Cebu City combined GIS, LiDAR, and satellite imagery to guide responders through congested areas (Bañados, 2023); systems in Ghana and Taguig City used IoT sensors and GPS modules to detect fires and notify authorities (Forkuo & Quaye-Ballard, 2013; Kamil *et al.*, 2022). Studies also emphasize the importance of heuristic algorithms like A*, which outperform Dijkstra in complex urban networks by balancing speed and accuracy (Foead *et al.*, 2021; Widyantoro & Santosa, 2021).

Overall, the proposed system integrates GIS mapping, GPS tracking, IoT-enabled alerts, and shortest path algorithms to improve dispatch, navigation, and response efficiency. While current prototypes face challenges such as GPS accuracy, static data reliance, and lack of real-time traffic integration, further development could transform fire response in urban areas—reducing delays, saving lives, and protecting property.

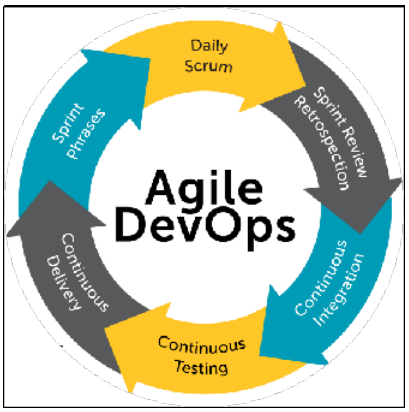


Figure 1: Agile DevOps Mode

Design And Methodology

Software Development Life Cycle

Agile DevOps unite the Agile development with DevOps methodologies to boost the collaboration of development and operations team (August, 2023). In the Agile DevOps methodology, the development of the Fire Incident Location Mapping and Shortest Path Navigation System Using A*(A-Star) Algorithm follows the following step-by-step process.

Daily Scrum (Summarized & Rephrased)

The team met two to three times weekly to monitor progress, resolve issues, and adjust priorities.

Week 1 focused on gathering data about fire response practices and exploring MapLibre for real-time mapping. The team also drafted Chapter 1 of the documentation.

In Week 2, the researchers reviewed builds, modeled the system's data flow, and updated the introduction based on new insights.

Week 3 was spent refining system diagrams and finalizing the system architecture. The team also conducted interviews with the BFP to better understand real operations.

By Week 4, the group documented Chapters 3 and 4, detailing system design and methodology.

Week 5 involved revising diagrams, refining documentation, and discussing potential system issues, such as incorrect GPS reports and possible validation mechanisms.

Throughout all scrums, the team adapted continuously, addressed obstacles quickly, and ensured the system matched real operational needs.

Sprint Review and Retrospective (Summarized & Rephrased)

During the Sprint Review, the team tested the GPS device, data pipeline, alert system, and A* routing to confirm accurate mapping, real-time updates, and correct shortest-path calculations.

The Retrospective allowed the team to reflect on issues such as inconsistent GPS data, server communication challenges, and opportunities to improve visualization and route accuracy. They also reviewed workflow efficiency and planned improvements for the next development cycles.

Continuous Integration (Summarized & Rephrased)

The team regularly merged new code to avoid integration problems and maintain a stable system. Key features—such as alerts, map tracking, and backend data flow—were gradually improved. Real-time notifications were tested to ensure responders receive timely updates, and data security and reliability were prioritized.

Continuous Testing (Summarized & Rephrased)

Simulated fire location data was injected into the system to test accuracy, mapping display, and A* routing. Stress tests checked the system's performance during multiple alerts, while security and integration tests ensured safe and seamless communication between the web interface, server, and device.

Continuous Deployment (Summarized & Rephrased)

This phase involved preparing firmware updates, publishing the mobile and web applications, and securing

the database. The team trained users on managing devices, viewing fire incidents, and using navigation features. Deployment began in General Santos City and

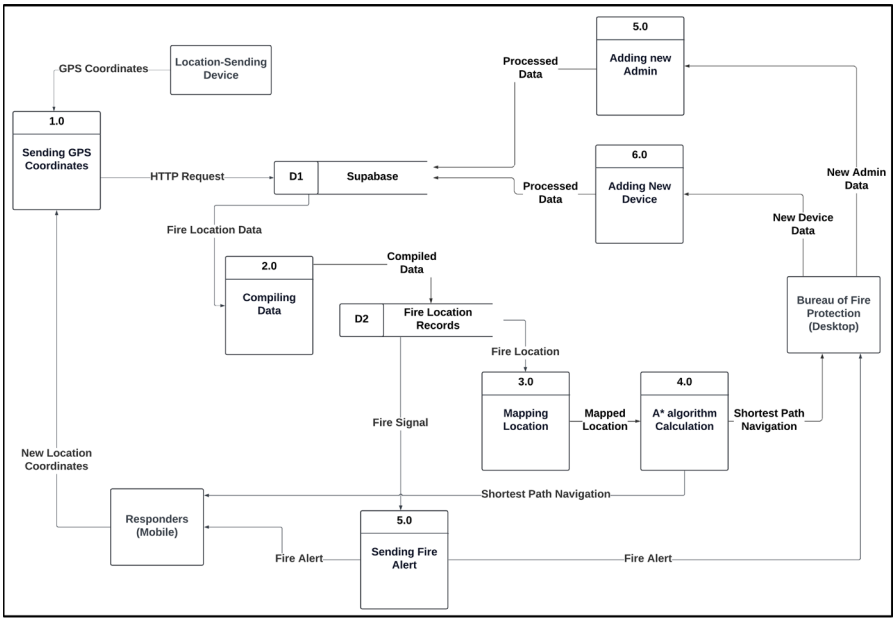


Figure 2: Level 0 Data Flow Diagram

Polomolok, with plans for expansion to nearby areas
The device sends its GPS coordinates to the Supabase Cloud Server, which stores the data in PostgreSQL before displaying the location on MapLibre. Once the
fire location appears on the map, the system identifies possible routes and calculates the three shortest paths to guide responders. These routes are automatically sent to users along with the fire alert. If responders take another path because of traffic or roadblocks, the system continuously reads their updated GPS coordinates and recalculates a new shortest route. This ensures quicker, safer, and more efficient navigation during emergency

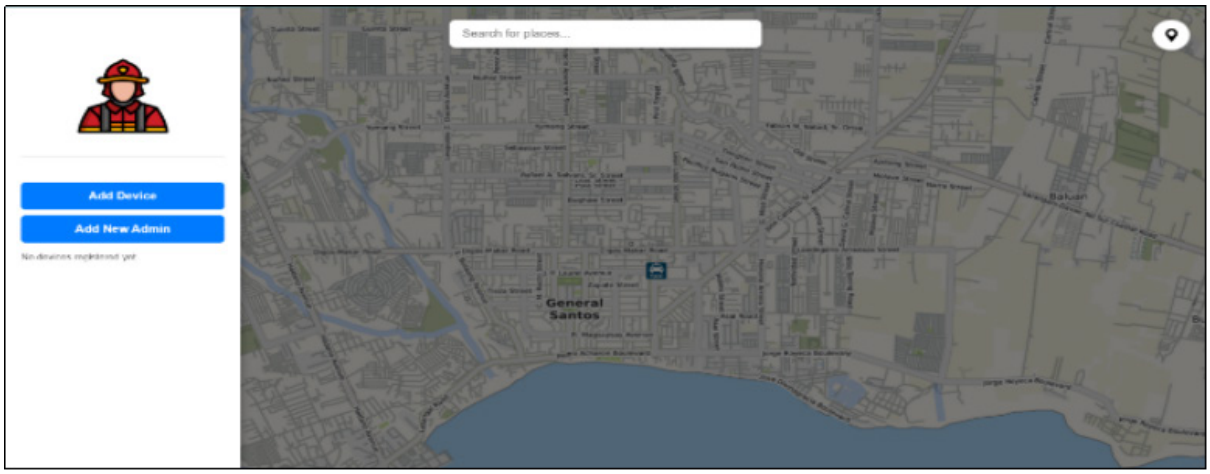


Figure 3: Desktop User Interface Design

response.
Upon receiving an alert and coordinates, an alarm will pop up in this web based mapping system. After clicking the alert, directions will be given by the system. And if the responders want to be new users and devices, there are options on the side. Adding devices and users requires log in to ensure that only authorized personnel can perform these actions, as this collects and holds data. This prevents unauthorized access and maintaining the

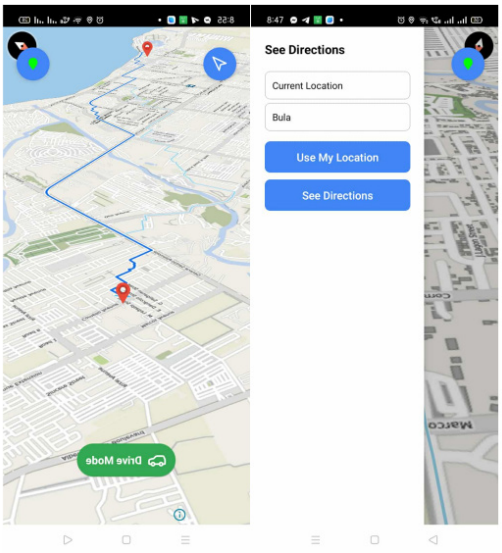


Figure 4: Mobile Application User Interface Design

security and integrity of the system.

The system also send fire location directions in the mobile app and also offers navigaton support for the responders to easily and quickly arrive to fire location.

In here, users can choose which location they want to use and also gives rerouting incase the responders drift off

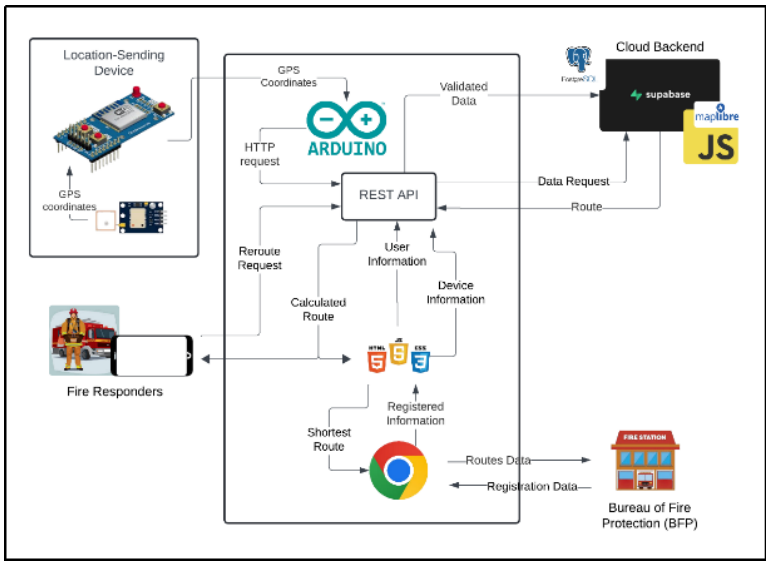


Figure 5: System Architecture

from the main route.

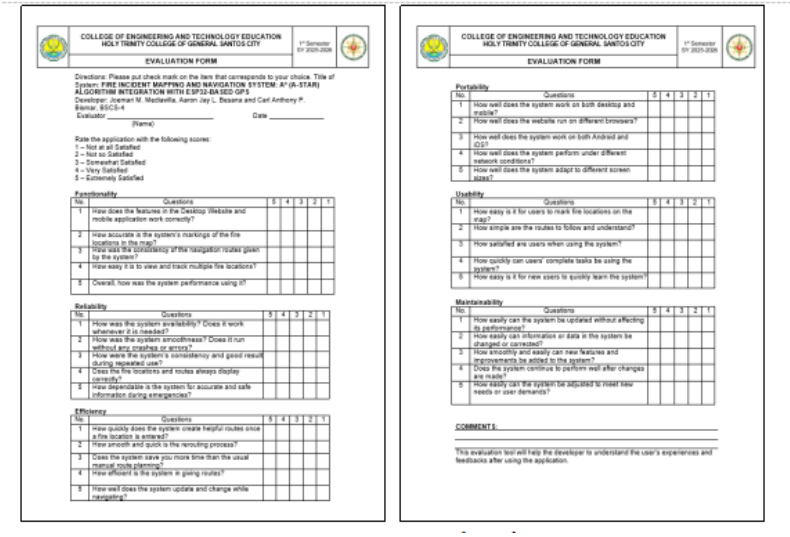
The Fire Incident Mapping and Navigation System: A (A-Star) Algorithm Integration with an ESP32-Based GPS* is designed to display real-time GPS coordinates, process fire-related information, and provide shortest-path navigation with automatic rerouting to support faster and safer emergency response. The system consists of the Location-Sending Device, Supabase Cloud Server with PostgreSQL, the responders' mobile app, and the BFP web platform. The device sends GPS coordinates, which the Arduino converts into an HTTP request and forwards to the REST API for validation before being stored in PostgreSQL through Supabase.

Supabase then enables JavaScript and MapLibre to compute the shortest routes from the BFP station to the fire location using the A* algorithm. Once processed, the calculated routes are sent back through the REST API to both the mobile app and the web-based map. If responders take another path due to traffic or roadblocks, the mobile app automatically sends a reroute request, allowing the system to recalculate and send an updated route. User account creation and device registration also pass through the REST API for validation and proper database handling, ensuring secure and efficient system operations.

RESULT AND DISCUSSION

During the evaluation phase, the researchers test the

Fire Incident Mapping and Navigation System in real field conditions. Feedback from users is gathered to improve the system's performance and reliability. Before testing, researchers will orient participating fire officers and responders on connecting the device, sending fire location data, viewing alerts on the map, and using the navigation feature. After each test, evaluation forms will be collected and analyzed based on six criteria: Functionality, Reliability, Efficiency, Portability, Maintainability, and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EVALUATION FORM

Figure 6: User Evaluation Form

Table 1: Scale Indication

5- EXTREMELY SATISFIED	**The statement is highly accurate and meets or exceeds expectations in all areas.**
4- VERY SATISFIED	The statement is generally accurate and meets most expectations with minor areas for improvement.
3- SOMEWHAT SASTISFIED	The statement is somewhat acceptable—it has some correct points but also several parts that need clearer improvement.
2- NOT SO SATISFIED	The statement is mostly inaccurate and does not meet expectations in many areas.
1- NOT AT ALL SATISFIED	The statement is highly inaccurate and fails to meet expectations in almost all areas.

Usability.

Table 1 presents the scale used to interpret the respondents' satisfaction ratings for the Fire Incident Mapping and Navigation System. The scale is based on a five-point Likert format using whole numbers from 1 to 5, where each number corresponds to a specific verbal description of user satisfaction. A rating of 5 indicates that users were Extremely Satisfied, while a rating of 1 signifies that they were Not at All Satisfied. This scale provides a clear and standardized framework for summarizing and interpreting user feedback on the system's usability, accuracy, responsiveness, and overall

Table 2: Functionality Result

Functionality	**MEAN**	**Description**
1. How does the features in the Desktop Website and mobile application work correctly?	4	Very Satisfied
2. How accurate is the system's markings of the fire locations in the map?	3.91	Very Satisfied
3. How was the consistency of the navigation routes given by the system?	4.05	Very Satisfied
4. How easy it is to view and track multiple fire locations?	3.86	Very Satisfied
5. Overall, how was the system performance using it?	3.95	Very Satisfied
Total Mean:	3.95	Very Satisfied

performance.

The table 2 presents the respondents' evaluation of the Fire Incident Mapping and Navigation System's functionality. In item #1, which assesses whether the features in the desktop website and mobile application work correctly, the system obtained a mean score of 4.00, indicating that users were Very Satisfied. For item #2, which evaluates the accuracy of the system's fire location markings on the map, the mean score of 3.91 also reflects Very Satisfied. In item #3, which measures the consistency of the navigation routes generated by the system, it achieved a mean of 4.05, interpreted as Very Satisfied. Item #4, referring to the ease of viewing and tracking multiple fire locations, received a mean score of 3.86, likewise indicating Very Satisfied. Lastly, item #5, which evaluates the system's overall performance, obtained a mean of 3.95, also interpreted as Very Satisfied. Overall, the functionality category achieved a total mean of 3.95, showing that users were Very Satisfied with the system's ability to operate effectively and support them in responding to fire incidents.

Table 3: Reliability Result

Reliability	**MEAN**	**Description**
1. How was the system availability? Does it work whenever it is needed?	4.27	Very Satisfied
2. How was the system smoothness? Does it run without any crashes or errors?	3.95	Very Satisfied
3. How were the system's consistency and good result during repeated use?	4.09	Very Satisfied
4. Does the fire locations and routes always display correctly?	3.82	Very Satisfied
5. How dependable is the system for accurate and safe information during emergencies?	4.05	Very Satisfied
Total Mean:	4.04	Very Satisfied

Table 3 presents the summarized results for the Reliability criteria of the Fire Incident Mapping and Navigation System. In item #1, which evaluates the system's availability and its ability to operate whenever required, the respondents said that the system is accessible when needed, as reflected in its mean score of 4.27, interpreted as Very Satisfied. In item #2, which assesses how smoothly the system performs without crashes or errors, the respondents said that the system runs smoothly, resulting in a mean score of 3.95, also interpreted as Very Satisfied. For item #3, which measures the system's consistency and its capability to deliver reliable results during repeated use, the respondents said that the system provides consistent performance, leading to a mean score of 4.09, indicating Very Satisfied. Item #4 examines the accuracy of fire location displays and routes, and the respondents said that the system correctly shows these details, as supported by the mean score of 3.82, likewise interpreted as Very Satisfied. Lastly, in item #5, which evaluates the dependability of the system in providing accurate and safe information during emergencies, the respondents said that the system is dependable, resulting in a mean score of 4.05, interpreted as Very Satisfied. With an overall mean of 4.04, the data show that the respondents were Very Satisfied with the system's overall reliability.

Table 4: Efficiency Result

Efficiency	**MEAN**	**Description**
1. How quickly does the system create helpful routes once a fire location is entered?	4.18	Very Satisfied
2. How smooth and quick is the rerouting process?	4.18	Very Satisfied
3. Does the system save you more time than the usual manual route planning?	4.14	Very Satisfied
4. How efficient is the system in giving routes?	4.09	Very Satisfied
5. How well does the system update and changes while navigating?	3.82	Very Satisfied
Total Mean:	4.08	Very Satisfied

The overall results for the Efficiency criteria of the Fire Incident Mapping and Navigation System are presented in the table above. In item #1, which assesses how fast and effectively the system provides the optimal route once a fire location is entered, the respondents said that the system is quick and effective, reflected in a mean score of 4.18, interpreted as Very Satisfied. In item #2, which evaluates the smoothness and speed of the rerouting process, the respondents said that the system handles rerouting efficiently, resulting in a mean score of 4.18, also interpreted as Very Satisfied. For item #3, which compares the system's performance with manual route planning, the respondents said that the system performs better than manual methods, with a mean score of 4.14, indicating Very Satisfied. Item #4, assessing how

efficiently the system provides routes to users, received a mean score of 4.09, and the respondents said that the system is effective in giving directions, interpreted as Very Satisfied. Lastly, item #5, which measures how well the system keeps track of and manages changes during navigation, achieved a mean score of 3.82, with the respondents saying that the system manages navigation changes efficiently, also interpreted as Very Satisfied. The total mean of 4.08 shows that respondents were Very Satisfied with the system's overall efficiency.

Table 5: Portability Result

Portability	MEAN	Description
1. How well does the system work on both desktop and mobile?	4.18	Very Satisfied
2. How well does the website run on different browsers?	4.05	Very Satisfied
3. How well does the system work on both Android and iOS?	3.86	Very Satisfied
4. How well does the system perform under different network conditions?	3.82	Very Satisfied
5. How well does the system adapt to different screen sizes?	4.05	Very Satisfied
Total Mean:	3.99	Very Satisfied

The table above presents the overall results for the Portability criteria of the Fire Incident Mapping and Navigation System. In item #1, which evaluates how well the system works on both desktop and mobile, the respondents said that the system operates effectively across devices, reflected in a mean score of 4.18, interpreted as Very Satisfied. In item #2, which assesses how well the website performs on different browsers, the respondents said that the system runs smoothly across browsers, with a mean score of 4.05, also interpreted as Very Satisfied. For item #3, which pertains to the system's performance on both Android and iOS, the respondents said that the system works reliably on different mobile platforms, achieving a mean score of 3.86, showing Very Satisfied. Item #4, which measures the system's performance under various network conditions, received a mean score of 3.82, and the respondents said that the system performs well even with changing network conditions, interpreted as Very Satisfied. Lastly, item #5, which assesses how well the system adapts to different screen sizes, obtained a mean score of 4.05, with the respondents saying that the system adjusts effectively to varying screen dimensions, also interpreted as Very Satisfied. The total mean of 3.99 indicates that respondents were Very Satisfied with the system's overall portability.

Table 6: Maintainability Result

Maintainability	MEAN	Description
1. How easily can the system be updated without affecting its performance?	4.14	Very Satisfied
2. How easily can information or data in the system be changed or corrected?	4.00	Very Satisfied
3. How smoothly and easily can new features and improvements be added to the system?	3.77	Very Satisfied
4. Does the system continue to perform well after changes are made?	4.0	Very Satisfied
5. How easily can the system be adjusted to meet new needs or user demands?	3.91	Very Satisfied
Total Mean:	3.96	Very Satisfied

Table 6 presents the overall results for the Maintainability criteria of the Fire Incident Mapping and Navigation System. In item #1, which evaluates how easily the system can be updated without affecting its performance, the respondents said that updates are implemented smoothly, reflected in a mean score of 4.14, interpreted as Very Satisfied. Item #2, which assesses how easily data in the system can be changed or corrected, received a mean score of 4.00, with the respondents saying that data management is straightforward, also interpreted as Very Satisfied. For item #3, which measures how smoothly new features and improvements can be added, the respondents said that enhancements are integrated efficiently, resulting in a mean score of 3.77, showing Very Satisfied. Item #4, which examines whether the system continues to perform well after changes are made, obtained a mean score of 4.00, with the respondents saying that the system remains reliable after updates, interpreted as Very Satisfied. Lastly, item #5, which evaluates how easily the system can be adjusted to meet new user demands, achieved a mean score of 3.91, with respondents saying that the system adapts effectively to user needs, also interpreted as Very Satisfied. The total mean of 3.96 indicates that respondents were Very Satisfied with the system's overall

Table 7: Usability Result

Usability	MEAN	Description
1. How easy is it for users to mark fire locations on the map?	4.32	Very Satisfied
2. How simple are the routes to follow and understand?	4.14	Very Satisfied
3. How satisfied are users when using the system?	4.14	Very Satisfied
4. How quickly can users' complete tasks be using the system?	4.14	Very Satisfied
5. How easy is it for new users to quickly learn the system?	4.14	Very Satisfied
Total Mean:	4.17	Very Satisfied

maintainability.

The table 7 presents the overall results for the Usability criteria of the Fire Incident Mapping and Navigation System. In item #1, which evaluates how easy it is for users to mark fire locations on the map, the respondents said that the system allows them to mark locations effortlessly, reflected in a mean score of 4.32, interpreted as Very Satisfied. Item #2, which assesses how simple and easy the routes are to follow and understand, received a mean score of 4.14, with the respondents saying that the routes are clear and easy to follow, also interpreted as Very Satisfied. For item #3, which measures user satisfaction while using the system, the respondents said that they are satisfied with the overall experience, resulting in a mean score of 4.14, interpreted as Very Satisfied. Item #4, which examines how quickly users can complete tasks using the system, obtained a mean score of 4.14, with the respondents saying that tasks can be completed efficiently, also interpreted as Very Satisfied. Lastly, item #5, which evaluates how easy it is for new users to quickly learn the system, achieved a mean score of 4.14, with the respondents saying that the system is easy to learn, also interpreted as Very Satisfied. The total mean of 4.17 shows that respondents were Very Satisfied with the system's overall usability.

The evaluation of the Fire Incident Mapping and Navigation System shows that respondents were consistently Very Satisfied across all criteria. The system's Functionality was rated highly for correct features, accurate fire location markings, consistent navigation routes, and ease of tracking multiple locations. In terms of Reliability, users noted that the system is available, smooth, consistent, accurate, and dependable during emergencies.

Table 7: Overall Result

Overall	MEAN	Description
1. Functionality	3.95	Very Satisfied
2. Reliability	4.04	Very Satisfied
3. Efficiency	4.08	Very Satisfied
4. Portability	3.99	Very Satisfied
5. Maintainability	3.96	Very Satisfied
6. Usability	4.17	Very Satisfied
Total Mean:	4.03	Very Satisfied

The system also scored well in Efficiency and Portability, as respondents said it quickly provides optimal routes, handles rerouting smoothly, works across devices and browsers, adapts to network conditions, and adjusts to different screen sizes. Maintainability was rated positively, reflecting that updates, modifications, and feature additions can be implemented without affecting performance. Lastly, Usability was highly rated, with users finding the system easy to learn, clear, and efficient for completing tasks.

With total mean score of 4.03, the findings indicate that the system is effective, reliable, user-friendly, and adaptable, making it a valuable tool for tracking fire incidents and planning safe and accurate emergency responses.

Summary Of Findings, Conclusion And Recommendations

Summary of Findings

Developing and implementing Fire Incident Mapping and Navigation System is the main goal of this study. This will help mitigate the fire incident risk to both lives and properties as it will help on route optimization and fire location monitoring. The system's main design is to assist the Bureau of Fire Protection (BFP) and other emergency responders by providing real-time fire location data, accurate and efficient navigation routes and device monitoring features.

The evaluation of the system uses these five major software quality criteria as basis: Functionality, Reliability, Efficiency, Portability, Maintainability, and Usability. To assess users' satisfaction and determine the system's overall performance, a detailed explanation approach was used.

CONCLUSION

The Fire Incident Mapping and Navigation System received high ratings across all criteria, reflecting that users were Very Satisfied. The system's Functionality

earned a mean of 3.95, providing accurate and efficient features for fire location mapping and navigation. Reliability scored 4.04, ensuring smooth operation, correct route displays, and dependable information during emergencies. Efficiency received 4.08, highlighting fast route generation, smooth rerouting, and time-saving compared to manual planning. Portability scored 3.99, with the system performing well across devices, screen sizes, and network conditions. Maintainability earned 3.96, showing that updates and modifications can be implemented without affecting performance. Finally, Usability received the highest score of 4.17, indicating an intuitive interface, clear maps, and ease of use for both new and experienced users.

Overall, with an average total mean of 4.07, the system is reliable, efficient, portable, maintainable, and user-friendly, effectively supporting the Bureau of Fire Protection and responders in locating fire incidents, generating optimal routes, and improving response times during emergencies.

Recommendations

Based on the results and comments of the respondents, the following recommendations are proposed:

Recommendations for Improving the Fire Incident Mapping and Navigation System

1.Improve Mapping Features – Integrate dynamic maps, 3D views, Street View, and regularly updated data for more accurate navigation.

2.Enhance Route and Distance Information – Display estimated travel time and distance, including the distance to the nearest BFP stations for faster decision-making.

3.Improve Detection and Coverage – Add fire alerts or triggers and define coverage areas for all detection devices to ensure complete monitoring.

4.Enhance User Interface – Include more device information, route summaries, and incident details in the desktop view for better usability.

5.Strengthen Alert and Notification System – Use louder and more noticeable alarms, ensuring notifications appear on both desktop and mobile devices.

Following these recommendations, along with future features like real-time fire detection and advanced mapping technologies, would increase the system's accuracy, responsiveness, and effectiveness in emergency response operations.

Acknowledgement

The researchers would like to express their sincere appreciation to everyone who supported and guided them the entire time until the completion of this study. The entire journey is very challenging but also rewarding, and the success of the study is not possible without the people who were so kind to give their time and knowledge.

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