Designing SafeMap Based on City Infrastructure and Empirical Approach: Modified a-Star Algorithm for Earthquake Navigation Application

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ABSTRACT

Designing routing systems for earthquakes requires frontend usability studies and backend algorithm modifications. Evaluations from subject-matter experts can enhance the design of both the front-end interface and the back-end algorithm of urban artificial intelligence (AI). Urban AI applications need to be trustworthy, responsible, and reliable against earthquakes, by assisting civilians to identify safe and fast routes to safe areas or health support stations. However, routes may become dangerous or obstructed as regular routing applications may fail to adapt responsively to city destruction caused by earthquakes. In this study, we modified the A-star algorithm and designed an interactive mobile app with the evaluation and insights of subject-matter experts including 15 UX designers, 7 urbanists, 8 quake survivors, and 4 first responders. Our findings reveal reducing application features and quickening application use time is necessary for stressful earthquake situations, as emerging features such as augmented reality and voice assistant may negatively backlash user experience in earthquake scenarios due to over-immersion, distracting users from real world condition. Additionally, we utilized expert insights to modify the A-star algorithm for earthquake scenarios using the following steps: 1) create a dataset based on the roads; 2) establish an empty dataset for weight; 3) enable the updating of weight based on infrastructure; and 4) allow the alteration of weight based on safety, related to human behavior. Our study provides empirical evidence on why urban AI applications for earthquakes need to adapt to the rapid speed to use and elucidate how and why the A-star algorithm is optimized for earthquake scenarios.

CCS CONCEPTS

• **Theory of computation** → **Shortest paths**; **Dynamic graph algorithms**; *Routing and network design problems*; • **Human-centered computing** → Usability testing.

KEYWORDS

Routing, A-Star Algorithm, User Experience, Earthquake, City Infrastructure, Navigation

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1 INTRODUCTION

In everyday scenarios, we rely on routing applications like Google Maps for navigation, gradually leaning on our spatial memories as we familiarize ourselves with recommended routes [40]. However, during earthquakes, these applications may fall short, lacking optimization to guide civilians to safe routes, especially when roads are rendered inaccessible by destruction [24, 49]. In such urgent and stressful earthquake situations, citizens seek refuge in shelters [37], hospitals [36], and open spaces [45]. Relying on regular routing applications poses risks to individual navigation in earthquakes, as these applications are designed to operate under normal conditions, focusing on the shortest routes without considering the impact of seismic destruction on the city. Routes can become impassable due to earthquake-induced damage on city infrastructure [27], and thus the risk of following collapses or aftershocks remains elevated if

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civilians attempt to traverse them. A routing system designed to respond to earthquakes can enhance the disaster resilience of cities and urban areas. In the field of Urban AI, the integration of both frontend user experience design and backend algorithm modification can address the complex challenges faced by cities from studies in urban science, spatial computation, user experience, and artificial intelligence. In this context, our research question is: How can a routing system be designed for earthquake scenarios that integrate algorithm modification and user interface design effectively?

To comprehend the subject of routing systems for earthquakes, it is crucial to involve subject matter experts in the design of such systems. These include urbanists, who analyze the earthquake impact on the city; UX designers, who assess user experience in utilizing mobile routing applications; quake survivors, who offer insights and experiences regarding human behavior and safety during earthquakes; and first responders, who provide perspectives on delivering medical support and emergency rescue to civilians during seismic events. By collaborating with these subject matter experts, we can iteratively refine the design of the routing application, and modify algorithms that are apt for earthquake scenarios.

2 BACKGROUND

2.1 Frontend UI Design: User Experience and Behavior in Earthquake

Disaster risk reduction plans, such as emergency evacuation routes for earthquake events, are challenging due to the complexity of human behavior in hazardous conditions and the configuration of urban spaces that influence route choices, i.e., pathfinding [22]. Risk perception and spatial cognition vary among individuals and groups due to emotional status, age, gender, level of hazard knowledge, familiarity with their surroundings, map comprehension, and other variables that directly affect people's decision-making and route choices [20, 22, 26, 29, 34, 42]. For instance, environmental information such as road network and street geometry influences route choice; however, environmental perception and wayfinding theories show that people do not necessarily take the shortest route because of their familiarity with surroundings and individual risk acceptability [22]. Thus, assessing and including people's perceptions in the design of technologies for emergency evacuation routes is crucial to guarantee civilians' safety during hazardous conditions. A user-centered approach for navigation systems that take into consideration the aforementioned factors may have great potential for earthquake navigation application development. In this line, the proposed methodological approach combining city infrastructure with empirical data from people's perceptions and route preferences offers a fresh insight into this matter.

Due to differences in occupation, age, knowledge, and experience in earthquake evacuation, not everyone can ensure their safety, their families, and friends [42]. In such situations, designing an application that can effectively navigate people to medical stations and safe areas becomes particularly important to support people's survival needs. However, in urgent and tense situations, the way people use navigation systems may be vastly different from normal circumstances, due to negative emotion [26, 34] or various risk perception [20]. Therefore, we need to deeply study the design of navigation systems, considering the actual usage needs of people in earthquake situations. This involves considerations and analyses in multiple aspects, including mobility aid, age, income, education, building structure, and previous experience with an earthquake [5]. By considering these confounding factors comprehensively, we can develop more humane, practical, and effective navigation applications to help people better protect themselves and others in earthquakes and other emergency situations.

2.2 Backend Algorithm Modification: Routing Algorithms in Earthquake

Research in different disciplines has focused on using ICT and AI to enhance disaster management. However, existing research lacks a common vision towards convergence [13]. Using everyday routing systems to respond to earthquakes can be extremely dangerous. This is because the algorithms of conventional navigation systems may not accurately understand the actual impact of earthquakes on road conditions. Before and after an earthquake occurs, urban buildings and roads may be damaged, and certain sections will become exceptionally congested or blocked [24, 49]. Therefore, we need to select and optimize the navigation algorithms that are most suitable for dealing with earthquake scenarios. We must make necessary modifications and adjustments to these algorithms to ensure that the algorithm can more effectively cope with earthquakes, thereby better-safeguarding people's lives. Researchers have been trying to accelerate and optimize the route recommendation algorithms to perform real-time responses for internet users to retrieve route information. The KIT research institute in Germany has produced several accelerated path-finding algorithms, among which the more well-known ones are contraction hierarchies and highway hierarchies [14]. Moreover, Stanford Research Institute published A-star algorithms [18], and Microsoft Research developed Customizable Route Planning algorithm [8]. However, emergency navigation algorithms still deserve more attention. Some early emergency navigation algorithms attempted to simulate a real-time traffic network to respond to hazards [50]. Other studies provided algorithms for the shortest possible routes, yet relying on the high resistance of road traffic infrastructures that do not collapse [7, 46]. However, the chance of road collapses and blocks is self-evidently possible in real conditions [24]. Thus, research in applicable emergency navigation algorithms presents a significant research gap that is under consideration in this research study.

The current research in AI has utilized the ant colony optimization [21, 51], A-Star, and the Dijkstra algorithm to explore the near-optimal pathfinding solutions. If we are trying to find the shortest route between two points in a large city or even an entire country, standard algorithms can struggle due to limited memory and CPU resources. However, there is a solution to this problem: the Hierarchical A-Star algorithm. By introducing a hierarchical mechanism to the traditional A-Star algorithm, this approach can efficiently navigate big maps while preserving resources [48]. The weight of the roads will be changed based on the in our algorithm is the GPS data of civilians' traveling trails. Thus, our application identifies the safe routes by checking where the majority of civilians are going. Hazards will jeopardize the civilians' lives, necessitating the evacuation model for large group evacuation from the hazardous area to the safe one, thus the goal of the evacuation model is to reduce the evacuation time [3]. Many researchers have tried to polish the A-Star algorithm to react to emergency crises [3, 30]. Our algorithm attempts to find the safe route by considering city layer infrastructures affected by hazards.

2.3 City Infrastructures Affected by Hazards

Understanding cities' vulnerability and resilience is crucial in determining the risks associated with staying sheltered during disasters [24, 33]. Critical infrastructure damages can happen suddenly, and the resulting disruptions can change over time. It is crucial to comprehend how people behave during earthquakes to develop effective software and algorithms to plan for such situations. Evaluations have demonstrated that there are statistically significant differences between the regular mobility and social behavior of a population before a disaster and the reactions observed during and after a natural disaster [15]. Social sensing allows for the collection and analysis of large amounts of user-generated data from different sources, especially social media, to monitor local events such as infrastructure disruptions and community needs [11].

A comprehensive perspective analysing disaster management systems and processes can considers the diverse interconnected systems and processes operating across various spatial and temporal scales [12]. In natural disasters, individuals organize themselves to be safe, yet, the official emergency services need crisis management applications to get a full picture of what is happening to keep people safe [28, 32, 44]. Also, crisis management needs to collaborate and coordinate in real-time by accurate information of the wide range of data including geographical and weather conditions [25]. Google Maps has also identified the necessity to provide real-time information in maps amid a crisis or disaster by providing crowdsourcing SOS alerts from government agencies, first responders, trusted media outlets, and NGOs; This idea has contingencies on teams providing real-time information, which might not be possible in a disaster-affected area during a crisis [16].

In addition, hazards can affect the city's infrastructure, including routes, bridges, tunnels, and buildings. Road closures are associated with ground failure, bridge, and building collapse [10]. Prior researchers have considered city infrastructure factors for their algorithms, such as vehicle numbers, the road network quality, the budgets, the anticipated demand for emergency supplies, and building aspects [1, 19, 23, 47]. AI Researchers have attempted to simulate human evacuation behavior out of buildings in order to identify potentially inaccessible evacuation paths and urban areas, define related paths/areas safety levels, and evaluate the effect of proposed retrofitting and management strategies on the safety of the population during an emergency [38]. Zhu et al. have used the ACO algorithm to identify routes for post-earthquake to safe spaces [51]. Bernardini et al. suggests using Dijkstra's algorithm to dynamically collect safety factor data and find the safest path to the nearest secure zone [4]. Some of this research focused on the city and human behavior, but none of them suggest a remedy for post-earthquake urban layer and human behavior-related pathways [35].

Table 1: General characteristics of subject-matter experts

ID	Age	Sex	Job	ID	Age	Sex	Job
P1	29	F	UXD	P18	27	F	Urbanist
P2	23	F	UXD	P19	26	F	Urbanist
P3	33	M	UXD	P20	34	M	Urbanist
P4	29	F	UXD	P21	36	F	Urbanist
P5	28	M	UXD	P22	34	M	Urbanist
P6	26	F	UXD	P23	25	F	Quake survivor
P7	38	F	UXD	P24	30	F	Quake survivor
P8	27	M	UXD	P25	60	M	Quake survivor
P9	25	M	UXD	P26	48	F	Quake survivor
P10	22	F	UXD	P27	81	F	Quake survivor
P11	24	M	UXD	P28	32	F	Quake survivor
P12	23	F	UXD	P29	31	F	Quake survivor
P13	24	F	UXD	P30	35	F	Quake survivor
P14	26	F	UXD	P31	28	M	First responder
P15	23	M	UXD	P32	61	M	First responder
P16	28	F	Urbanist	P33	28	M	First responder
P17	33	F	Urbanist	P34	42	M	First responder

3 METHODOLOGY

The methodology of this research paper is meticulously structured to thoroughly delineate the development and validation process of the proposed Modified A-Star Algorithm for Routing in Earthquakes. This research endeavor employs a multi-phased strategy, illustrated in Figure 1, and is anchored in the principles of research through design [52].

The first phase of our research involved conducting an extensive prestudy and literature review, enriched by the insights of two professors specializing in urban planning. This foundational step was pivotal in contextualizing our work within the broader realms of urban planning and algorithmic routing. Subsequently, we crafted the inaugural prototype of the SafeMap application, incorporating a refined A-Star algorithm designed to integrate city infrastructure layers. In the event of an earthquake, this application aims to identify the most secure and efficient routes to designated shelters.

The second phrase encompassed user tests aimed at validating the effectiveness and usability of SafeMap. We employed the pluralistic walkthrough technique [6, 17], engaging 34 participants from diverse areas of expertise, including 15 UX designers, 7 urbanists, 8 quake survivors, and 4 first responders. The invaluable insights provided by these participants were instrumental in refining the application through iterative prototyping. The evaluations concentrated on assessing the user experience, usability, and overall functionality of the system. This phase played a pivotal role in shaping the final design of the application, ensuring its alignment with user needs and experiences.

The third phase was dedicated to expert consultation and refinement of the algorithm across the four identified categories. Initially, collaboration with UX designers, quake survivors, and first responders facilitated the creation of an iterated prototype, grounded in our comprehensive evaluation and spectaculative design [9]. Subsequently, our focus shifted to conducting interviews with professionals in Urbanist and planning, aiming to garner insights into urban resilience and planning. Moreover, engaging in dialogues with specialists allowed us to underscore key components identified by participants, especially those frequently mentioned by quake survivors and first responders. Suggestions for refining the algorithm were developed concurrently, encompassing proposals for compiling a comprehensive road-based dataset, assigning subsequent weights, and integrating safety-related criteria into the routing algorithm. This iterative methodology enabled SafeMap to evolve in alignment with user needs while accommodating the complexities of fluctuating urban landscapes.

To sum up, the research paper utilized a methodical and iterative approach that incorporated feedback from both experts and users to create a routing algorithm that is effective and user-friendly within the SafeMap app. The various phases, including initial algorithm development, consultations with experts, and continuous improvement, played a vital role in shaping the final design of the application. As a result, the app is now capable of testing its assistance to individuals in earthquake drills.

3.1 Subject-Matter Experts for Earthquake

Given the intricate interplay between humans and cities during earthquakes, we recruited representatives from four categories of subject-matter experts to assess and refine our design. These experts comprised 15 UX Designers (UXD), 7 Urban Planners, 8 quake survivors, and 4 First Responders. Within simulated earthquake scenarios, we engaged quake survivors to test our app, UX designers to refine the app's design, urban planners to evaluate modifications to the algorithm, and first responders to assess the app's utility in earthquake rescue scenarios. This multifaceted approach ensured a comprehensive evaluation and refinement of the app, addressing the diverse needs and insights arising from different perspectives and experiences related to earthquake response and urban navigation. The subject-matter experts are listed in Table (Table 1).

3.2 Prototyping Urban AI Navigation Application For Earthquakes

The initial prototype was designed using Figma and encompasses three principal features: 1) a call function for emergencies, facilitating contact with first responders services for medicinal and rescue supports; 2) navigation to shelters and hospitals; and 3) a messenger feature to request assistance. In the process of creating the mock-up for nearby shelters, we utilized Google Maps to search for "shelters near our researched location." However, the search yielded no results for our specified location, prompting us to search for hospitals instead. This scenario exemplifies the limitations of conventional navigation applications like Google Maps in providing assistance during earthquake situations.

3.3 Subject-Matter Experts Evaluation And Appropriation

To ensure a comprehensive evaluation and refinement of the application, a multifaceted approach was employed, involving representatives from four categories of subject-matter experts: UX Designers, urbanists, quake survivors, and first responders. The appropriation phase involved semi-structured interviews and observation methods to gain insights into the user's interaction with the system. During the observation sessions, videos capturing user interactions, the screen of the primary Android tablet, and the interviewer's voice were recorded. This method allowed for a detailed examination of the interaction between the users and the system, enabling the identification and understanding of user complaints and the reasons behind them. The usability test approach was grounded in the Think-Aloud Protocol technique of usability testing [43]. Participants were required to vocalize their cognitive processes while interacting with the program, accomplishing specific activities designed to assess various aspects of the application. Researchers provided prompts and questions to encourage participants to verbalize their thoughts and feedback on the system continuously. The activities were presented in print or on a laptop, and participants were encouraged to express their opinions verbally as they navigated through them. Researchers monitored the sessions closely, intervening as necessary to address technical difficulties and ensure the progression of the test. Participants were allowed to explore the program freely, with no imposed order of completing activities, allowing for an intuitive interaction with the system. This meticulous process of appropriation and evaluation, involving diverse subject-matter experts, was pivotal in enhancing the app's usability and effectiveness in real-world earthquake response and urban navigation scenarios.

During the study, the facilitator presents participants with the user interface images and asks participants to think aloud about what interaction they would do to achieve specific tasks. After the participants have given their answers on how they would perform the interaction to achieve their tasks, the facilitators provide further information to participants to invite discussion. In order to gather user data to test our algorithm and this first prototype, we collected users' preferences on path choices. We edited three routes in Google Maps to ask our participants which path they would choose. Each route has different safety levels, shown as red, yellow, and green. Green is the safest. We gathered data about 1) participants' path choice before and after additional information about city infrastructures affected by hazards, 2) heuristic strategy about participants' judgment on what they consider safe to reflect on city infrastructures, and 3) participants' suggestions for prototype iteration. During the Pluralistic walkthrough, a set of questions were answered by participants. The most important points are as follows:

- Walkthrough. Tell the crisis context. No wifi, no internet.
- For the section today, we will imagine you were at school when an earthquake happened, and you have an emergency navigation map called SafeMap on your phone for your evaluation of the nearby shelter.
- There are a few tasks during our test. For each task, I will explain what I would like you to do.
- Show me which shelter you would choose, and tell me why.
- What do you see? What do you perceive?

In the following, there are examples of our semi-structured interview questions to guide experts to provide their perspectives to help us understand how to design a navigation system for earthquakes:

- "Could you share your experiences with earthquakes? What were they like? What actions did you take, and what were your feelings during those times?"
- "Could you describe how you would identify safe locations after exiting a building during an earthquake? Where would

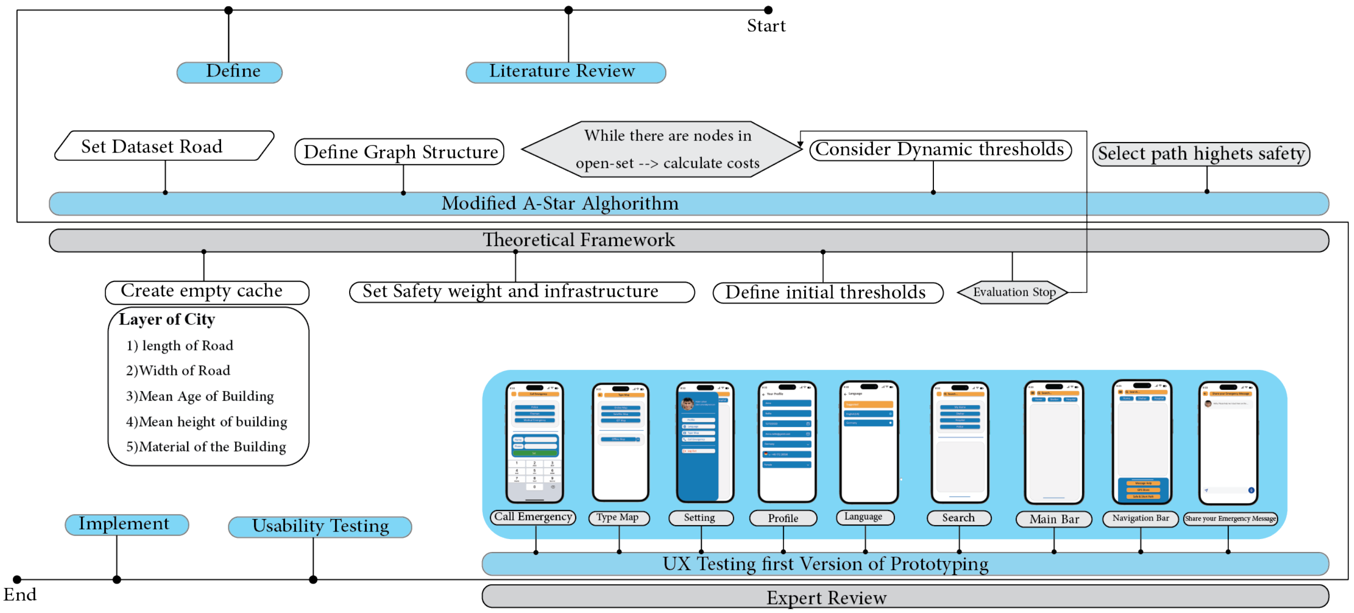

Figure 1: Research Framework to develop Safemap application

you go, how would you get there, and why would you choose those specific locations?"

- "Imagine you are experiencing an earthquake and have exited the building. You have access to an app designed to help you navigate to a safe shelter. Would you use it? If so, why, and if not, why not?"
- "If you are unfamiliar with the area or city, would you rely on the app to guide you, or would you prefer to use an alternative like Google Maps?"
- "Given that some roads may be impassable due to earthquake damage, collapsed buildings, and blocked roads, and considering that this app is designed to identify paths that are deemed 'safe' and 'passable,' could you share your experience using the prototype? What would you suggest for improvement? Were there aspects that confused you? What were your expectations during each interaction?"

4 RESULT

Our primary findings are categorized into two main components: User Experience Design and Algorithm Modification.

The first component, User Experience Design, involves insights related to the design of the navigation user interface. It emphasizes the imperative nature of ensuring the rapid usability of the earthquake navigation app, a crucial element given the heightened tension and time sensitivity users experience during an earthquake. The prompt usability of the app is pivotal to guarantee that the app's response and feedback are immediate and efficient, necessitating a design free of complicated operations. Additionally, our expert user research reveals a cautious view regarding the integration of augmented reality and voice assistant technologies during earthquakes, due to the limited field of view and over-immersion, making users becomes engrossed in the digital interaction and distracted from real world condition. This skepticism stems from the understanding that, in high-pressure scenarios, the operation of these systems could potentially extend the user's interaction time with the app. The implications of our user research suggest a significant need to minimize technological disruptions for users of an earthquake navigation app. This is crucial as any delay, such as waiting for AR to initialize or adjusting the volume to hear voice assistant instructions, can escalate psychological stress for users, especially in life-threatening situations during an earthquake.

4.1 Iterated Prototype

In the iteration, quake survivors suggested reducing the cognitive load [41] to use our app in a stressful crisis condition. The interviews have helped us to empathize with users' minds as we repeated the design thinking process to iterate our prototype. Based on our users' evaluation, we kept two main features 1) call emergency, and 2) shelter or hospital navigation. Our iterated prototype is shown in Figure 2. If users are trapped in the building, the app will provide a button to call for rescue and should automatically share users' locations. Our application should also provide information on users' current addresses, in case the GPS location needs to be verbally reported to the rescue facility. If users just escaped from the building, and want to look for a nearby safe place, the app will provide navigation to both hospitals and shelters nearby with only one safest route with a relatively short path.

The second component, Algorithm Modification, discusses alterations made to the algorithm. We posit that the superiority of the A-Star algorithm over other routing algorithms is its capability to execute swiftly, its minimal reliance on extensive CPU power, and its ability to function locally in scenarios where the internet is unavailable, a common occurrence during earthquakes due to network

Figure 2: Iterated Version of SafeMap Application Based on the Users' Evaluation

disruptions. Furthermore, we have enhanced the algorithm by incorporating considerations of city layers and infrastructure. We have also integrated concepts from the ant colony algorithm, acknowledging the human inclination to seek safe zones, thereby imbuing the A-Star algorithm with this capability. The enhancements to the A-Star algorithm are segmented into four steps: 1) creating a dataset based on roads; 2) establishing an empty dataset for weight; 3) enabling the updating of weight contingent on infrastructure; and 4) permitting the modification of weight based on safety, correlated to human behavior. Subsequent sections will delve into the detailed process of these specific algorithmic improvements.

4.2 Modification on A-Star algorithm

The shortest route has been intensively investigated in computer science in path-finding issues owing to its broad applications such as network routing protocols, traffic management, and transportation systems [39]. A-Star search method, Dijkstra, and Ant Colony Optimization are been studied among all other algorithms documented in the literature that address the shortest route between two geographical places. While Dijkstra obtains the best answer by investigating all potential pathways, A-Star search utilizes a heuristic function to determine the shortest path [31]. A-Star is a BFS algorithm that uses a heuristic function to find the shortest path from a source node to a destination node in a grid [2].

This research presents an efficient algorithm based on A-Star search to find the safest route dynamically between two locations. Safety and infrastructure data are integrated into a graph representation of the environment. Adaptive thresholds are used to filter out hazardous routes. A-star search guided by a cost function combining safety and appearance scores can rapidly find optimal routes. The algorithm is extended to work in real time by continuously updating the graph with simulated live data and re-running route searches to deal with dynamic changes. The algorithm is implemented in four steps:

In the first step, we initialize the data structure of the graph that shows the city centers and the connections (the edges) between them. Each edge in the chart contains information about safety, distance, and urban layers. Safety–Weight and urban–layer–Weight are defined to assign different weights to safety and infrastructure criteria. These weights determine the relative importance of each criterion in the optimization process. These thresholds determine whether a road is considered safe or has enough infrastructure to choose the route as a safe path (Algorithm 1).

Algorithm 1 Define the Graph and Initial Parameters in A-Star algorithm

```
procedure A-STAR(Input)
    Initial safety and urban layer thresholds
    Initialize Values:
        Define graph structure with nodes and edges, including safety, distance, and urban layer.
        Set safety-weight and urban-layer-weight to determine their relative importance.
        Define initial-safety-threshold and initial-urban-layer-threshold.

    Procedure Steps:
        Initialize the graph structure with safety, distance, and urban layer data.
        Set the weights for safety and urban layer criteria.
        Define initial thresholds for safety and urban layer.
end procedure
```

Here, we set up a route–cache dictionary. This cache is used to store calculated routes and their associated safety and infrastructure thresholds. It helps to avoid extra calculations by checking if a path has already been calculated (Algorithm 2).

Algorithm 2 Create a Cache for Computed Routes in A-Star algorithm

```
procedure A-STAR((Input))
    Initialization:
        Create: an empty cache for computed routes
    Procedure:
        intialize an empty cache(route−chche to store computed routes
end procedure
```

This is the core of the code, the A-Star algorithm. It is responsible for finding the safest route by taking into account the safety and appearance criteria. The algorithm checks whether the route from start to target is calculated with the safety and apparent thresholds given before using the route–cache. If the cache is cached, it retrieves the path from the cache to avoid recomputing. The algorithm maintains a priority queue (open–set) to explore the path efficiently. It calculates a dynamic safety threshold (dynamic–safety–threshold) and appearance threshold (dynamic–urbanlayer–threshold) based on current conditions. The safety and infrastructure threshold are used to determine whether a road is suitable for being on track. The algorithm selects a path with the highest safety and infrastructure stability while minimizing the overall cost (taking into account both safety weight and infrastructure weight). Once the safest route is found, it is stored in the route–cache to avoid additional calculations. This step consists primarily of the A-Star customized algorithm according to the demands of the research which includes several mathematical components.

First of all, the heuristic function estimates the cost from the current node to the target node using Euclidean distance or a similar metric. Second, dynamic thresholds are calculated based on current conditions. These thresholds can be defined based on specific criteria or conditions, depending on the scope of the problem. Third, cost calculations or Probation cost (tentative–g–cost) for each neighboring node is calculated based on the cost of the current node, the distance to the neighbor and the domain-specific factors. The combined cost (f–cost) is calculated as the weighted sum of safety and infrastructure scores.

$$\text{heuristic}(node, goal) = \text{euclidean\_distance}(node, goal) \tag{1}$$

$$\text{f\_cost} = (\text{safety\_weight} \times \text{safety}) + (\text{infra\_weight} \times \text{infra}) \tag{2}$$

Safety–weight are user–defined weights that reflect the relative importance of safety and infrastructure metrics. These weights can be adjusted based on the needs of the problem. Safety and infrastructure represent safety scores and the infrastructure associated with the edge being considered (Algorithm 3).

Algorithm 3 Implement the A-Star Algorithm with Customization

```
procedure A-Star((Input))
        Input: Graph representing city center and roads
            Start and goal nodes
            Safety and infrastructure thresholds

    Procedure:
    intialize data structure:
    for the A-Star algorithm: open_set, came_from, and g_cost
    While Nodes in open_set:
    Explore neighboring nodes and calculate costs,
    Consider dynamic thresholds based on real-time data,
    Select Route
    If Route in highest safety and infrastructure thresholds:
    Cache the computed route,
        Return the safest path,
    If else Route Not in safety and infrastructure thresholds:
        Return None
    End if
     End while
end procedure
```

This step defines the function calculate route–features which calculates the level of safety, total distance, and overall infrastructure of a given path. Through each edge (road) in the path it repeats, retrieves the safety data, distance, and infrastructure from the graph, and sums up values. The function returns a dictionary containing these trajectory properties. In this step, the safety level of a route is calculated as the product of the safety score along the path. For each edge on the path, the safety score is multiplied.

$$\text{Safety level} = \prod_{i=1}^{n} \text{Safety score}_i \tag{3}$$

Safety Score i indicates the safety score associated with edge i on the route. n is the total number of route edges. Also, the total distance of the route is the sum of distances of all edges in the path which is calculated by the formula below. In this formula, n is the total number of route edges, and distance i indicates the distance associated with edge i on the route.

$$\text{Safety Level} = \prod_{i=1}^{n} \text{Safety Score}_i \tag{4}$$

The infrastructure score(urban layer) is the sum of apparent points for all edges of the path. The i infrastructure represents the apparent score associated with edge i in the route. And n The total number of edges in the route.

$$\text{Total Appearance} = \sum_{i=1}^{n} \text{infrastructure}_i \tag{5}$$

Finally, these steps together enable the code to continuously update safety and infrastructure data, apply the A-Star algorithm with customizations, and calculate and display track properties in real time. This code ensures efficient route optimization while considering dynamic thresholds and minimizing redundant computations (Algorithm 4).

Algorithm 4 Calculate and Display Route Features in A-Star Algorithm with Customization

```
procedure A-Star((Input))
        Input: Safest path computed by A-Star algorithm
            Graph representing city centers and roads
    Initialize variables:
    intialize data structure:
    safety level, total distance, and total infrastructure
    For edges in routes:
        Update safety level by multiplying safety scores,
    Calculate the total distance by summing distances,
    Calculate the total infrastructure by appearance scores
        Return the computed safety and route features
     End loop
end procedure
```

The proposed techniques were implemented in Python. Our quantitative evaluation, using sample data on a 1000-node random graph, revealed that the A-Star algorithm is superior to the basic Dijkstra's in terms of both speed and memory usage under different conditions, specifically with and without the use of caching.

Table 2: Quantitative analysis results on time efficiency between A* and Dijkstra's algorithm for a graph with 1000 nodes.

Approach	No cache	With cache	Result no cache	Result cache
Dijkstra	145 ms	110 ms	x 1.9	x 1.8
A*	75 ms	60 ms		

Without caching in place, Dijkstra's algorithm took a notable 145 milliseconds to complete its search. On the other hand, the A-Star algorithm, with its advanced heuristics and optimized data structures, managed to conclude its search in a mere 75 milliseconds. This stark difference highlights A-Star's superior performance, making it approximately 1.8 times faster than the traditional Dijkstra's method in this scenario. Introducing caching into the mix further accentuated the performance differences. When caching was enabled, Dijkstra's algorithm improved its search time to 110 milliseconds. In comparison, the A-Star algorithm, already impressively fast, further optimized its performance to clock in at 60 milliseconds. With caching, A-Star proved itself to be roughly 1.9 times swifter than Dijkstra's.

Table 3: Quantitative analysis results on memory efficiency between A* and Dijkstra's algorithm for a graph with 1000 nodes.

Approach	No cache	With cache	Result no cache	Result cache
Dijkstra	850 KB	600 KB	x 1.3	x 2.4
A*	650 KB	250 KB		

The memory usage of both algorithms was also a pivotal aspect of this analysis. In the tests without caching, Dijkstra's consumed 850 KB of memory, while A-Star used slightly less at 650 KB. When caching was brought into play, Dijkstra's memory usage went down to 600 KB. However, A-Star again showcased its efficiency, slashing its memory consumption down to 250 KB. This implies that, with caching, A-Star utilizes memory that's a significant 2.4 times less than that of Dijkstra's. Beyond the raw numbers, it's essential to recognize the importance of caching in this context. During the experiments, it was observed that the cache had a hit rate of approximately 60%. This suggests that for 60% of the search queries, the optimal path was already available in the cache, thereby speeding up the search process. Such an observation underscores the potential of caching - the higher the cache hit rate, the more pronounced the performance improvements for both algorithms.

In conclusion, the A-Star algorithm, with its intrinsic optimizations, undeniably outperforms Dijkstra's in both speed and memory efficiency. The addition of caching further amplifies these differences, making A-Star a compelling choice for pathfinding tasks, especially in scenarios where rapid response times and efficient memory usage are of paramount importance. This robust performance ensures the system's capability to efficiently scale to extensive city graphs, delivering prompt response times to path inquiries, even amidst variable safety data conditions.

5 LIMITATION

Given the qualitative nature of the study, the conclusions drawn are inherently subjective, reflecting the individual perspectives and experiences of the participants. This inherent subjectivity could introduce biases and limit the applicability of the data to wider settings and diverse user demographics. Predominantly based on interviews, the study largely concentrated on the perceived usability and design aspects of the program, with minimal real-world testing in actual crisis situations, thus drill test would benefit future iteration. The absence of empirical data regarding the application's efficacy in real-world contexts may constrain the reliability of the conclusions reached. The research did not delve into the technical constraints and challenges associated with the development and deployment of the application, such as data precision, real-time updates, and connectivity issues during natural disasters, which are pivotal for the successful implementation and widespread adoption of the application. Most discussions and evaluations were centered around earthquake scenarios. While earthquakes are significant natural disasters, broadening the scope of research to encompass other disaster types like floods, hurricanes, and wildfires could have enriched the understanding of the application's versatility and adaptability. Future research endeavors should aim to include a diverse array of experts from various fields and potential end-users to garner varied opinions and assess the application's universal applicability and acceptance. Conducting empirical studies that include real-world testing and user trials in simulated crisis environments can yield objective data regarding the application's performance, reliability, and user satisfaction. Further research is imperative to explore the technological challenges and solutions inherent in developing a robust, reliable, and efficient application capable of functioning effectively across a spectrum of disaster scenarios. It is vital to extend the research to assess the application's adaptability and efficacy in different kinds of natural disasters, ensuring its relevance in a variety of emergency situations. By exploring the viewpoints, preferences, and acceptance levels of prospective end-users, invaluable insights can be gleaned about the application's user-centricity, practicality, and overall user experience.

6 CONCLUSION AND FUTURE WORK

The urgent need for developing emergency navigation apps is accentuated by the critical requirement to protect lives during seismic activities. In this research, we have presented a refined A-Star algorithm and a user interface, both of which have undergone rigorous assessment through user studies, aimed at addressing the challenges earthquakes present. Insights from subject-matter experts, including UX designers, urban planners, quake survivors, and first responders, formed the basis of our algorithm modification and user interface design. However, the recommendations provided by the algorithm, while suggesting seemingly safe routes and shelters, could potentially result in overcrowding and bottleneck situations under actual conditions. This necessitates continued research to address such outcomes and to bolster the dependability and reactivity of urban AI applications in earthquake contexts. Our research highly emphasis on reducing application complexity for usability during stressful situations, warning against the potential negative effects of over-immersion by augmented reality and voice assistants during earthquakes. Furthermore, our contribution encompasses a user-centered design interface, assessed by quake survivors and first responders. This interface can undergo iterative refinement through subsequent user tests to adapt to diverse disaster and hazard situations. The exploration of potential enhancements in design features, such as voice assistance and GPS sharing, is crucial, and the app's iconography requires further investigation to fine-tune user interaction and trust in emergency navigation apps. This ensures that they stand as trustworthy, accountable, and dependable shields against the devastating consequences of earthquakes.

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