ANALYSIS OF DIGITAL MAP-BASED NAVIGATION SYSTEMS AS WAYFINDING AIDS

An Undergraduate Research Scholars Thesis

by

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Research activities involving the use of human subjects, vertebrate animals, and/or biohazards must be reviewed and approved by the appropriate Texas A&M University regulatory research committee (i.e., IRB, IACUC, IBC) before the activity can commence. This requirement applies to activities conducted at Texas A&M and to activities conducted at non-Texas A&M facilities or institutions. In both cases, students are responsible for working with the relevant Texas A&M research compliance program to ensure and document that all Texas A&M compliance obligations are met before the study begins.

I, Isaiah Thomas Villagomez, certify that all research compliance requirements related to this Undergraduate Research Scholars thesis have been addressed with my Research Faculty Advisors prior to the collection of any data used in this final thesis submission.

This project did not require approval from the Texas A&M University Research Compliance & Biosafety office as it was deemed not human research.

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ABSTRACT

Analysis of Digital Map-Based Navigation Systems as Wayfinding Aid

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Wayfinding from the perspective of the scientific domain known as Environmental Cognition is the process in which individuals attempt to orient themselves in space for the purpose of navigation. This process has been identified to be highly susceptible to influence from changes both direct and indirect to the environment in which the individual may be traversing. This acknowledgement along with technological advancement in spatial positioning and systems engineering has led to the development of “Navigation Systems” in which seek to aid their users in their wayfinding tasks. The implementation of these navigation systems very drastically, but

share three key components: Positioning, Routing, and Presentation. Positioning refers to the way in which a system determines the location of a user, Routing refers to how the system determines routes from said positioning to the desired end-destination, and lastly Presentation involves how this information garnered by routing and positioning is summarized and interface to the user of the system. This study analyzes two available navigation systems for how they differ in their implementation of these components and whether these differences led to a difference in user experience. Specifically, these two systems are compared based on a variety of performance metrics such as time spent traversing a route, number of stops taken by study participants to re-orient themselves, as well as some perceptual workload comparisons. The results of this study indicate that the difference in performance metrics and perceptions of workload that arise from the difference between the navigation systems are likely to be highly contextual in terms of the environment being traveled as well as individual preferences.

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1. INTRODUCTION

Advancements in global positioning technology have led to the development of navigation systems designed with the purpose of being utilized to aid in the wayfinding process. These systems are increasingly complex and can differ in the ways in which they present and generate information related to navigational guidance. Evaluations of these systems usually involve analysis of user performance in route traversal, and their subsequent spatial knowledge acquisition. Most of the current research has been framed from the perspective of comparing systems that differ in the mode (visually, auditorily, tactically) in which they present navigational guidance. According to our literature review, a gap in research exists on analyzing how navigational systems that utilize the same mode of presentation but differ in terms of their positioning and routing components differ in their performance in the context of being utilized as a wayfinding aid. Developing an understanding on how systems that differ in this aspect will differ in their usefulness from the perspective of being a wayfinding aid can help to influence navigation system developers in their design decisions to deliver a better user experience.

1.1 Wayfinding

Wayfinding, defined by the study of environmental cognition, is the process in which individuals attempt to orient themselves in physical space for the purpose of navigation [1]. Research attempting to understand the psychological elements involved in wayfinding has led to the emergence of a four-stage theory: Orientation, Route Decision, Route Monitoring, and Destination Recognition [2]. The Orientation stage involves the individuals initial attempt to determine their current location by examining and analyzing their surroundings and determining a general sense of direction in relation to their end destination. The Route Decision stage involves the determination of a route to maneuver from their current location to their end destination. Once the individual begins traversal of their decided route, they enter the Route Monitoring stage in which they monitor their chosen route in relation to whether it is leading them in the direction that they perceive their end destination to be. The final stage referred to as the Destination Recognition stage occurs when an individual sees their end destination and identifies themselves as having completed their journey.

A continuously refined artifact that arises from the four-stage theory is the idea of the individual's environmental image (also referred to as the mental map), or the "generalized picture of the exterior physical world" [3]. The image is developed by "immediate sensations and memories from past experiences" and is used throughout the process to "interpret information and guide action." In relation to the four-stage theory, the environmental image begins its development with the initiation of the Orientation stage and is maintained and utilized throughout the stages following it [4]. The image consists of distinctive features about the physical environment that the individual perceives as important while attempting the wayfinding task, such as the route traveled, the decision points associated with said route, and landmarks [5]. Key factors that researchers have identified that influence an individual's perception of the distinctiveness of a feature include the visual prominence of a feature in accordance with the surrounding environment [6] and previous personal experience with like environments [7].

From the identification of the influence that an individual's psychological perceptions have on the general process of wayfinding research has developed a concept referred to as aided wayfinding [8]. Said research has found that choices in relation to modification of the physical environment such as specific architectural design patterns [9], or the implementation and utilization of signage [10] have a considerable influence on an individual's ability to navigate said environment. However, it is not always possible or permissible to directly modify the physical environment in which individuals will be navigating. In said scenarios the utilization of tools external to direct modification of the physical environment, such as digital map-based navigation systems, can provide users with an enhanced wayfinding experience in comparison to having no aid at all.

1.2 Navigation Systems

Navigation Systems designed to directly aid the wayfinding capability of individual persons have three major components that develop upon one another [11]: Positioning, Routing, and Presentation.

1.2.1 Positioning

Positioning in relation to a navigation system refers to the process in which said system utilizes for determining the location of the individual system user [12]. Some navigation systems utilize the global navigation satellite system for said determination, while others require their users to manually estimate their current location. Depending on the navigation system positioning can occur discretely, typically on the initialization of the system's routing functionality, or continuously.

1.2.2 Routing

In the context of discussing the components of a navigation system, routing refers to the process in which said system attempts to utilize positioning data to determine a route to an end destination determined by the system user [13]. Routing systems are divided into the categories of being static or dynamic. Static routing utilizes a singular positioning location to determine routes to an end location [14], while dynamic routing utilizes continuous positioning information to provide dynamic route instructions based on real-time or near real-time position information [15].

1.2.3 Presentation

The final component of a navigation system is Presentation, or the way in which navigational guidance is presented to the individual utilizing the system [16]. Most commonly this is provided via the utilization of a digital map for visualization [17, 18, 19], however some navigation systems utilize other modes of presentation such as audio [20, 21] or haptic feedback [22, 23].

1.3 Digital Maps

There are four foundational components to a digital map in the context of their utilization as the basis for the presentation component of a navigation system [24, 25]: Basemap, Extent, Layer, and Network.

1.3.1 Basemap

The purpose of a basemap is to serve as a background canvas to the information provided by the digital map [26]. Typically, this involves satellite imagery, or a topographic rendition of contextually essential information to the purpose of the digital map [27]. In digital map-based navigation systems the base map will usually contain buildings, and roads if said navigation system is designed with the intent of traversal of the outdoors.

1.3.2 Extent

The extent of a digital map is the selection of area of a given region shown [28]. Some digital maps, like most traditional paper maps, have a static extent in which they show a fixed area that the user is not able to zoom in or out of [29]. Most modern digital maps employ a dynamic extent in which users can zoom and pan around a specific region to either get more granular or coarse information [30].

1.3.3 Layer

A layer in terms of a digital map represents a grouping of similar geographic features, such as buildings, and roads [31]. The usefulness of layers is their ability to categorize data in a way which is not possible in a basemap [32]. For example, a digital map-based navigation system may choose to provide system users with a particular layer for a group of buildings with similar characteristics such as buildings in which contain classrooms on a university campus, or buildings in which are utilized for administration purposes.

1.3.4 Network

A network in the context of a digital map represents an abstract feature that stores information regarding connectivity between source features [33]. Features present in layers require a network to become "aware" of each other as the networking layer keeps track of coincident [34]. Policies can be put in place on a network data set to regulate what routing is feasible in the network, for the modeling of things like one-way roads or intersecting line features representing highway underpasses.

1.4 Research Proposal

We proposed the study of two navigation systems that differed in the approach of their positioning and routing components in the context of their utilization as wayfinding aids. Study participants were asked to traverse a set of routes utilizing two separate navigation systems that employed either dynamic routing and continuous positioning approach or a static routing and discrete positioning approach. The assignment of what navigation system was used for what route alternated back every other participant: Participant A would traverse route A with navigation system A and route B with navigation system B, Participant B would traverse route A with navigation system B and route B with navigation system A, Participant C would traverse route A with navigation system A and route B with navigation system B, etc. During the traversal, the number of stops lasting longer than 10 seconds was recorded, as well as the total time taken for the entire traversal. At the end of each traversal attempt, participants were asked to complete a survey to garner their workload perceptions. These metrics would give us insight on differences that arose between the systems that could be contextually compared to the findings of prior research.

2. RELATED WORK

The identification of metrics used for the comparison of navigation systems by prior researchers allows us to establish a baseline for metrics we should utilize for our comparison. While these studies did not utilize systems that differed in their approach to their positioning and routing components, they did utilize similar user study approaches and utilized systems in which presented the navigational guidance information via the utilization of a digital map.

2.1 Analysis of Route Traversal Performance

Research on the effectiveness of digital map-based navigation systems in influencing the process of wayfinding has traditionally been conducted under the primary metrics of comparison between the utilization of other wayfinding tools via statistical analysis of quantitative performance metrics and acquired spatial knowledge. Stenius et al [17] sought to conduct research on how time of day changes an individual's quantitative wayfinding performance and preference for a particular wayfinding aid while traversing an unfamiliar environment. Their study utilized a Global Navigation Satellite System supported digital map (i.e., navigation system) and paper map and compass as the aids provided to individual participants. The specific metrics for quantitative performance that were recorded was distance traversed in meters, time for navigation in minutes, time in motion in minutes, time stationary in minutes, average walking speed in km/h, number of stops and time stationary (being defined as not moving for 10 seconds or more) per stop in seconds. The results of the study were in line with previous studies conducted by Tack et al. [35] and Young et al. [36] and found that when participants utilized the digital map-based navigation system, they spent significantly shorter time navigating the route, spent significantly less time stationary, and took less stops when in comparison to when they utilized the paper map and compass. The researchers also established that participants felt a higher sense of mental workload when utilizing the paper map and compass in comparison to that of the digital map-based navigation system.

2.2 Analysis of Spatial Knowledge Acquisition

Krukar et al. sought to analyze the utilization of digital map-based navigation systems while wayfinding from the research perspective of how they can aid in the acquisition of spatial knowledge [18]. They noted that in previous studies [37, 38] it had been found that difference in incidental knowledge acquisition had been reported between individuals who utilized a digital map-based navigation system versus that of a traditional paper map as an aid in the process of wayfinding. Based off the conclusions of previous research, Krukar et al. hypothesized that difference in digital map models themselves may be able to also effect incidental knowledge acquisition. Subsequently they developed a study in which they presented participants with a virtual environment to traverse a set of routes in while utilizing digital map-based navigation systems that differed in the accentuation of various features of the virtual environment. The conclusions of said study found that accentuating different structures led to differences in acquisition of spatial knowledge, specifically that accentuating local features (landmarks) and accentuating a mix of local and global features increased acquisition of route knowledge and survey knowledge in comparison to that of a control in which no features were accentuated in the digital map.

Ishikawa et al. [19] conducted a study that attempted to produce an analysis focusing on quantitative performance and acquired spatial knowledge metrics. The researchers sought to compare the wayfinding process of individuals utilizing a digital map-based navigation system to that of utilization of paper maps as well as direct route experience. The underlining assumption of their research was that the digital and paper maps would find their functions as aid specifically in the Orientation, Route Decision (referred to in the work as Route Planning), and Route Monitoring (referred to in the work as Route Execution) stages. The results of their study found that participants who utilized the digital map-based navigation system traveled longer distance, traveled more slowly, and garnered less spatial knowledge about their environment than those who utilized either the paper map or who had direct route experience. The researchers correlated the reasoning for their results to be due to three main factors: failures in staying on the route during the Route Monitoring stage, the novelty of the navigation system to the population of participants (only one of the participants had previous experience with a digital map-based navigation system prior to the study) and the fact that the device utilized for the presentation of the navigation system had a very small screen which resulted in a small geographic extent being displayed.

3. METHODOLOGY

We designed and constructed a user study to gather insights on how navigation systems that fundamentally differ in terms of implementation of their positioning and routing components present users with different experiences as wayfinding aids. We chose to quantify performance in terms of how said navigation systems were able to assist a user's ability to complete the traversal of a route accurately and efficiently, as well as the magnitude in which said navigation systems effected perceptions of workload during the attempted completion of said traversal. This within-subject study had participants traverse two routes with similar complexity utilizing a specific digital map implementation for each route.

3.1 Study Goals

The goal of this study was to identify if any differences in various performance metrics and workload perceptions arose when attempting to utilize digital map-based navigation systems that differed in implementation as an aid for route traversal. Current research on the evaluation of digital maps as wayfinding aids has primarily focused on comparison with other forms of wayfinding aids [17, 19] and comparison with digital map-based navigation systems that differ in changes to singular visualization elements [18]. We believe that wayfinding aids that have different implementations for the positioning and routing components will result in a difference in wayfinding aid experience. This study utilized Google Maps [39] and Aggie Map [40] as the two digital map-based navigation systems for analysis.

3.2 Study Design

A within-subject study evaluated the user performance differences in route traversal between the utilization of digital map-based navigation systems that vary in the implementation of their positioning and routing components.

3.2.1 Google Maps Navigation

Google Maps software utilizes continuous positioning to provide dynamic routing for enhancing individuals' wayfinding experience by providing navigation assistance presented via a digital map (Figure 3.1). With a continuous internet connection and GPS signal the software can provide its users with turn-by-turn guidance in the form of text notifications or spoken directions whether they are on foot, in a car, or on a bike. The application, because of its continuous positioning and dynamic routing, also provides automatic rerouting when an individual diverges from the path it originally provided. The underlining basemap utilized by the digital map of the navigation system highlights roads, and areas of vegetation and development. The default extent varies on the size of the route, but the presentation direction depends on the direction in which the device is facing. The application in navigation system mode has no additional feature layers, and the networking layers are not visible.

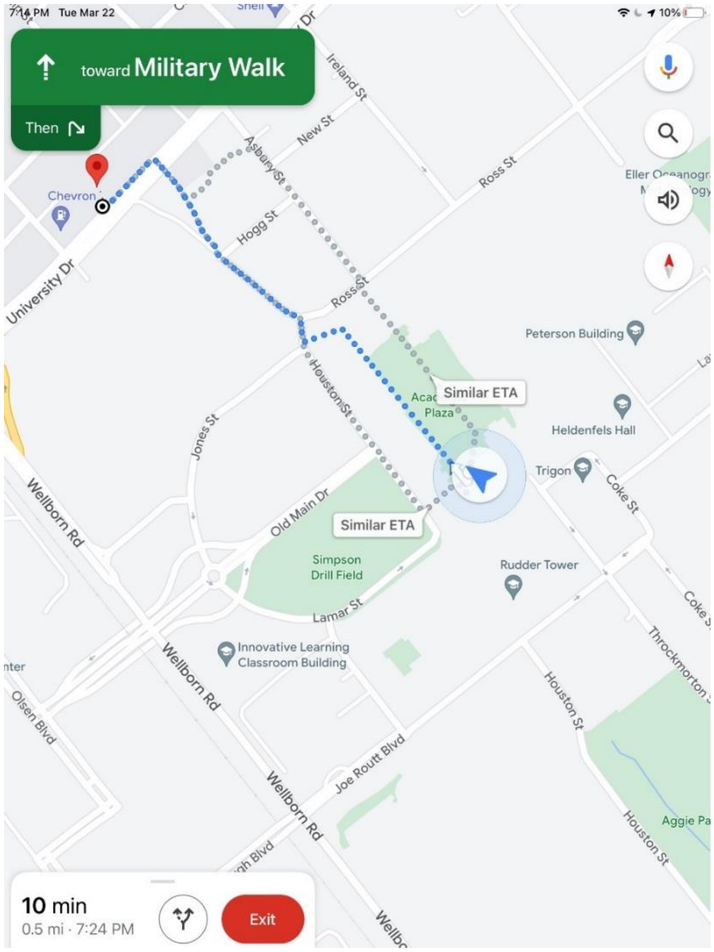


Figure 3.1: Google Maps Interface.

3.2.2 Aggie Map

Aggie Map (Figure 3.2) is the official map for the Texas A&M University College Station Campus. The application provides its users with navigation system functionality with the utilization of sporadic positioning and static routing to present route guidance via the utilization of a digital map. Aggie Map can take a singular positioning point as the user’s current location and provide a route to end destination but is not capable of automatic rerouting due to its static routing nature. However, the application can provide guidance via the modes of transportation of walking, driving, biking, and taking the bus. The underlining basemap utilized by the digital map of the navigation system highlights buildings, roads, walking paths, areas of vegetation, parking lots, and construction zones. The default extent varies on the size of the route. The default direction in which the map is pointing is north facing upwards (which is user adjustable). The application in navigation system mode has toggle feature layers for emergency phone locations, accessible entrance locations, visitor parking locations, lactation room locations, restroom locations, and points of interest locations. The networking layers are not visible.

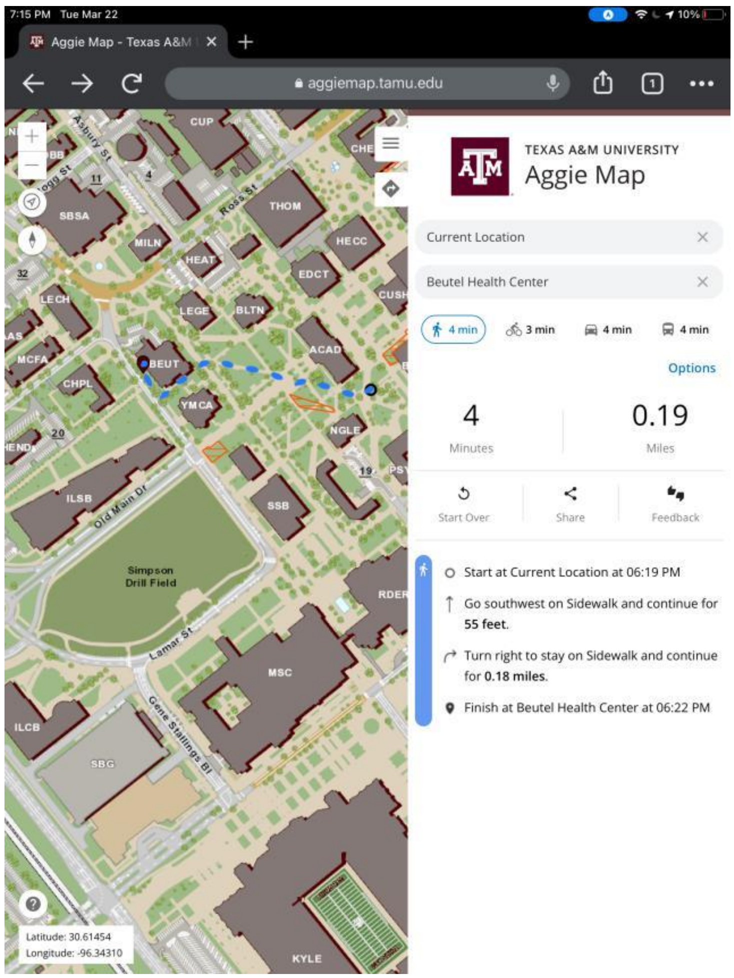


Figure 3.2: AggieMap Interface.

3.2.3 Procedure

Two routes referred to as Route A (Figure 3.3) and Route B (Figure 3.4), are of similar complexity in terms of total distance, and number of decision points. Route A saw participants navigating from the Biological Sciences Building West to the Beutel Health Center which presented participants with six decision points over a total distance of 0.23 miles. Route B saw participants navigating from Duncan Dining Hall to Eppright Residence Hall which presented participants with seven decision points over a total distance of 0.19 miles. Each Route had numerous distinctive landmarks such as buildings with unique architectural styles and varying vegetation.

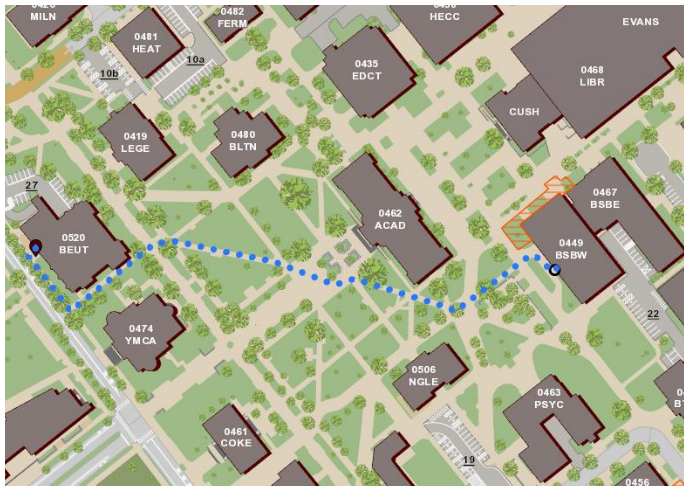


Figure 3.3: Route A, Biological Science Building West to Beutel Health Center.

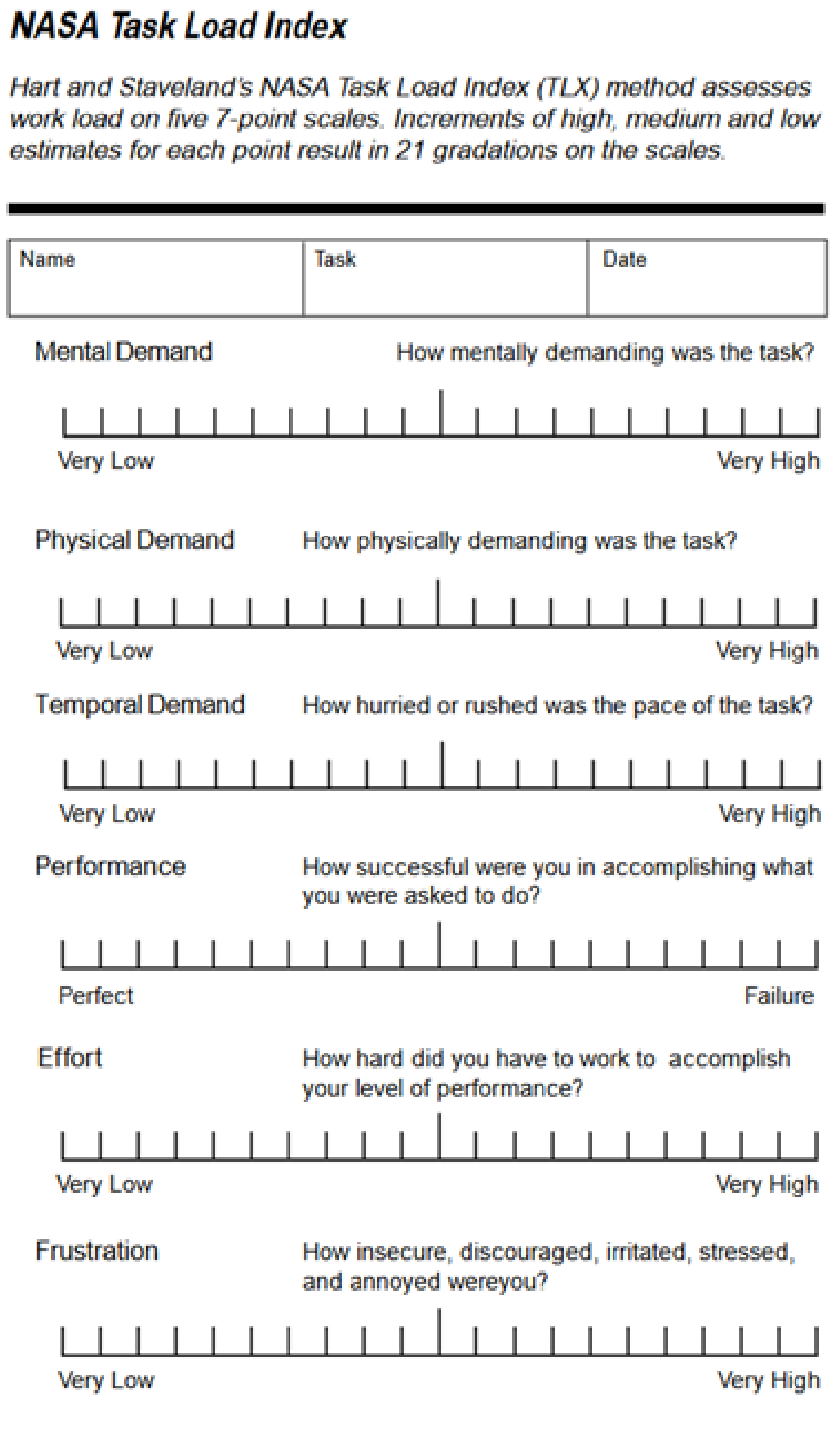
Figure 3.4: Route B, Duncan Dining Hall to Eppright Residence Hall.

The study began with a questionnaire to garner some basic demographic information about participants as well as information regarding their previous experience with the utilization of a navigation system for on foot wayfinding. Assignment of a specific navigation system to a particular route utilized a rotation mechanism: Participant A would be presented with Google Maps for Route A and Aggie Map for Route B, Participant B would then be presented with Aggie Map for Route A and Google Maps for Route B, Participant C would be presented with Google Maps for Route A and Aggie Map for Route B, etc. Participants then received an iPad with the navigation system software preloaded. Researchers allowed the participants to familiarize themselves with the application for a few moments, and then loaded the route in which they would be traversing onto the software and relayed a brief description of the study. Researchers then told Participants to follow the guidance provided by the navigation system software, and to verbalize when they had reached their end destination according to said system. A researcher followed behind the participant as they traversed the route recording the duration of the time taken for the attempt, and how many stops for re-orientation the individual made (defined as coming to a stop for longer than 10 seconds). At the end of the attempted traversal of the route participants completed a paper version of the NASA TLX questionnaire to garner insight into their perceptual workload associated with utilizing the aid in the context of the wayfinding task.

3.2.4 Questionnaire and Interviews

A pre-study questionnaire to gain an understanding about the demographics of the sample population. The questionnaire asked about the participants age, gender, and familiarity with wayfinding aids and the university campus. When a participant completed an attempt at following a route, they then completed printed NASA-Task Load Index questionnaire (Figure

3.5). The choice for administering the questionnaire via pen and paper over a digital format was due to some studies discovering that digital implementations of the NASA-Task Load Index can skew results to be higher than when utilizing the traditional pen and paper method [41]. This questionnaire measures the subjective workloads associated with the attempted completion of a task [42] It presents the user with the ability to rate their perceived mental demand, physical demand, temporal demand, performance, effort, and frustration experience during their attempted task completion on a 21-point scale. Participants were also presented with a definition sheet shown in Figure 3.6. This study utilized the Raw Task Load Index modification [43] to the NASA-Task load index procedure, which meant the removal of the weighting step.



NASA Task Load Index

Hart and Staveland's NASA Task Load Index (TLX) method assesses work load on five 7-point scales. Increments of high, medium and low estimates for each point result in 21 gradations on the scales.

Name	Task	Date

Mental Demand — How mentally demanding was the task?

Very Low — Very High

Physical Demand — How physically demanding was the task?

Very Low — Very High

Temporal Demand — How hurried or rushed was the pace of the task?

Very Low — Very High

Performance — How successful were you in accomplishing what you were asked to do?

Perfect — Failure

Effort — How hard did you have to work to accomplish your level of performance?

Very Low — Very High

Frustration — How insecure, discouraged, irritated, stressed, and annoyed wereyou?

Very Low — Very High

Figure 3.5: NASA-Task Load index questionnaire. Adapted from [44]

RATING SCALE DEFINITIONS

Title	Endpoints	Descriptions
MENTAL DEMAND	*Low/High*	How much mental and perceptual activity was required (e.g., thinking, deciding, calculating, remembering, looking, searching, etc.)? Was the task easy or demanding, simple or complex, exacting or forgiving?
PHYSICAL DEMAND	*Low/High*	How much physical activity was required (e.g., pushing, pulling, turning, controlling, activating, etc.)? Was the task easy or demanding, slow or brisk, slack or strenuous, restful or laborious?
TEMPORAL DEMAND	*Low/High*	How much time pressure did you feel due to the rate or pace at which the tasks or task elements occurred? Was the pace slow and leisurely or rapid and frantic?
PERFORMANCE	*good/poor*	How successful do you think you were in accomplishing the goals of the task set by the experimenter (or yourself)? How satisfied were you with your performance in accomplishing these goals?
EFFORT	*Low/High*	How hard did you have to work (mentally and physically) to accomplish your level of performance?
FRUSTRATION LEVEL	*Low/High*	How insecure, discouraged, irritated, stressed and annoyed versus secure, gratified, content, relaxed and complacent did you feel during the task?

Figure 3.6: Workload Definitions for NASA-Task Load Index questionnaire. Adapted from [44]

4. RESULTS

4.1 Study Participant Demographic Overview

A total of 10 individuals participated in this study with each completing the two route traversal scenarios as well as the two administered questionnaires. Of the 10 individuals who participated, 8 were first-year students with the remaining two being first year on campus sophomores (all students of Texas A&M University). All the participants indicated little to no experience with utilizing a navigation system for on foot wayfinding, little to no knowledge of the campus environment, and lack of expertise with digital maps. The participants were sampled via the utilization of convince sampling, specifically being recruited from the Texas A&M Colleges of Engineering and Geosciences respective mailing lists.

4.2 Data Analysis

4.2.1 Overview

The results of the study sessions were analyzed to garner insights into performance and workload experiences of the participants. As previously stated, data recorded during the sessions included the time an attempted route traversal was taken, the number of stops taken for re-orientation (a stop lasting longer than 10 seconds), perceptions of workload, and unstructured interview responses. Google Sheets was utilized to obtain averages, t-test results, and graph visualizations. The statistical analysis conducted and presented allows for some conclusion to be drawn regarding how differences in implementation of digital map-based navigation systems can lead to different user experiences.

4.2.2 Average time taken and statistical significance for route traversal per navigation system

At the completion of each route traversal by a participant the time taken for the attempt was recorded. For both routes the average time taken per navigation system was calculated, as well as the statistical significance of the difference between said averages. The average time taken for traversing route A with Aggie Map was 208.2 seconds (about 3 and a half minutes), while the average time utilizing Google Maps was 217.2 (Figure 4.1). However, a two-tailed independent t-test resulted in a p-value of 0.40 meaning we cannot reject the null hypothesis that there is no statistically significant difference between the samples. The average time taken for traversing route B with Aggie Map was 214.6 seconds (about 3 and a half minutes), while the average time utilizing Google Maps was 251.6 (Figure 4.1). A two-tailed independent t-test resulted in a p-value of 0.0169, meaning that we can reject the null hypothesis that there are no statistically significant differences between the samples.

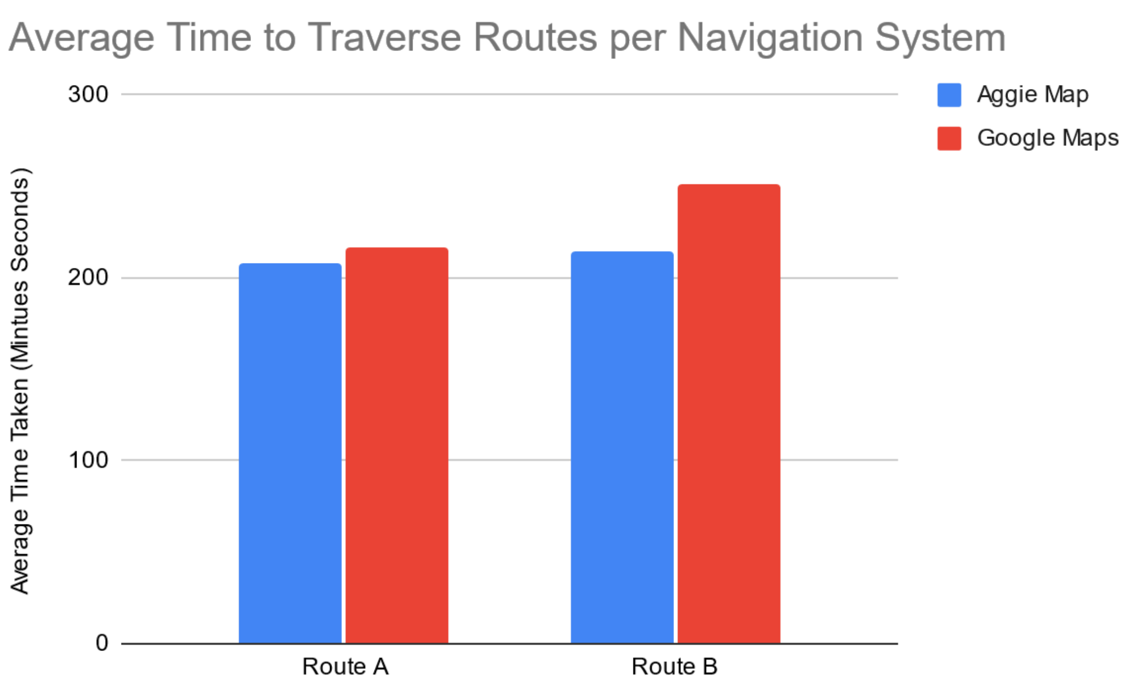


Figure 4.1: Bar Graph of Average Time (in seconds) to Traverse Routes per Navigation System.

4.2.3 Average number of stops taken for route traversal per navigation system

During the traversal of a route, stops that lasted longer than 10 seconds were recorded. The average number of stops for route A while using Aggie Map was 0.2, and the average number of stops while utilizing Google Maps was 0.2 (Figure 4.2). The average number of stops for route B while using Aggie Map was 0.2, but the average number of stops while utilizing Google Maps was 0.6 (Figure 4.2).

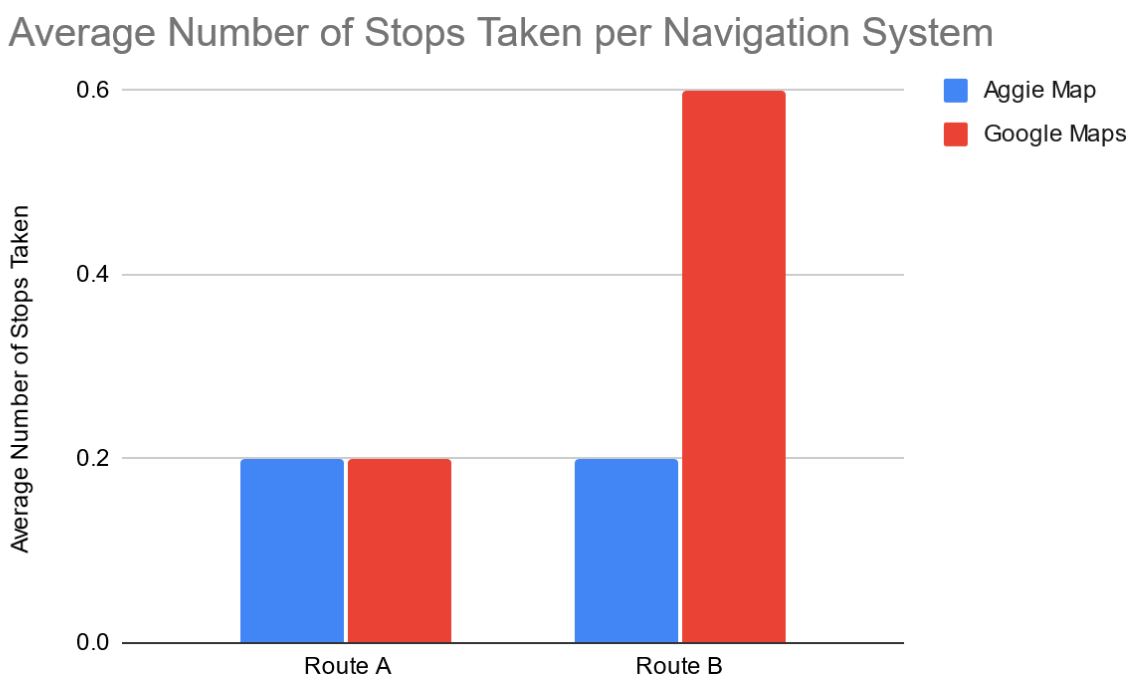


Figure 4.2: Bar Graph of Average Number of Stops Taken to Traverse Routes per Navigation System.

4.2.4 Average measure of perceptual workload after route traversal per navigation system

At the conclusion of an attempted route traversal, participants were asked to complete a NASA Task Load Index Questionnaire to gauge perceptions of workloads encountered. This was administered in a pen and paper format and was later transcribed into Google Sheets for analysis. Traversal of route A utilizing Aggie Map led to higher perceptions of mental, and temporal workload, as well as individuals feeling more frustrated and that the task required more effort than that of the group that utilized Google Maps (Figure 4.3). Considerations of self-performance were also lower (the scale presented on the NASA Task Load Index associates a higher score with lower performance) when utilizing Aggie Map over Google Maps for traversal of route A. The only scenario of workload perception involving route A that had Aggie Map as being better on average was perceptions of physical workload.

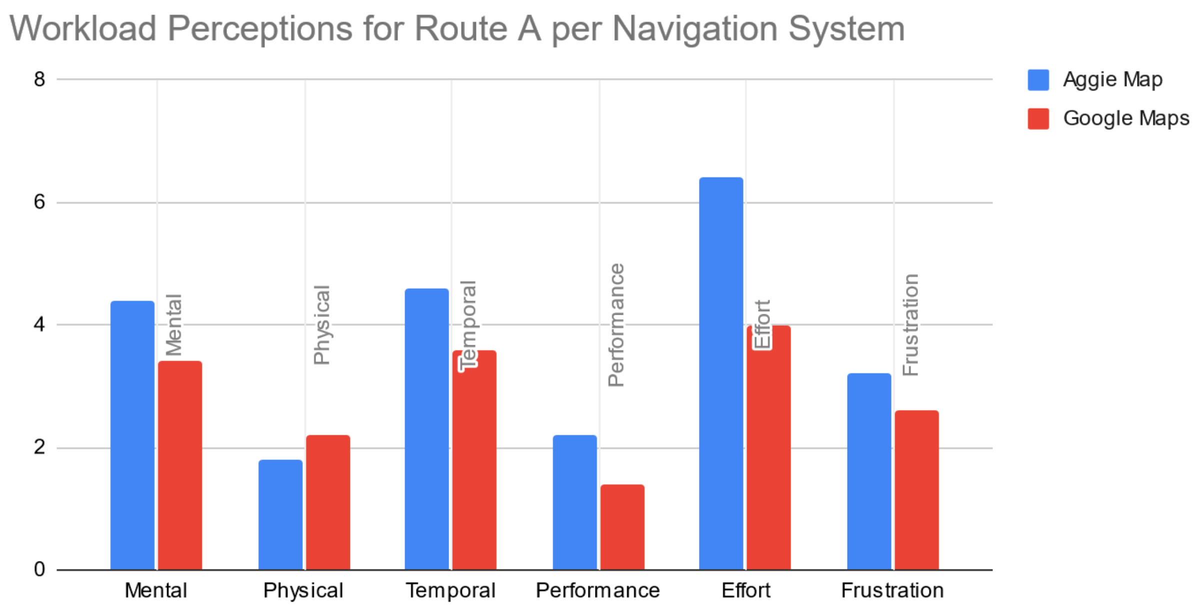


Figure 4.3: Bar Graph of Average Number of Stops Taken to Traverse Routes per Navigation System.

Traversal of route B utilizing the two different navigation systems led to a slightly different outcome. Aggie Map had a slightly higher value for perceptions of mental workload, but for every other workload metric except for performance Google Maps recorded higher values (Figure 4.4). For the factor of personal performance, the reported average was the same for both Aggie Map and Google Maps. Another noteworthy observation is that the average values for each individual workload dimension were higher or near the same of that of route A’s values.

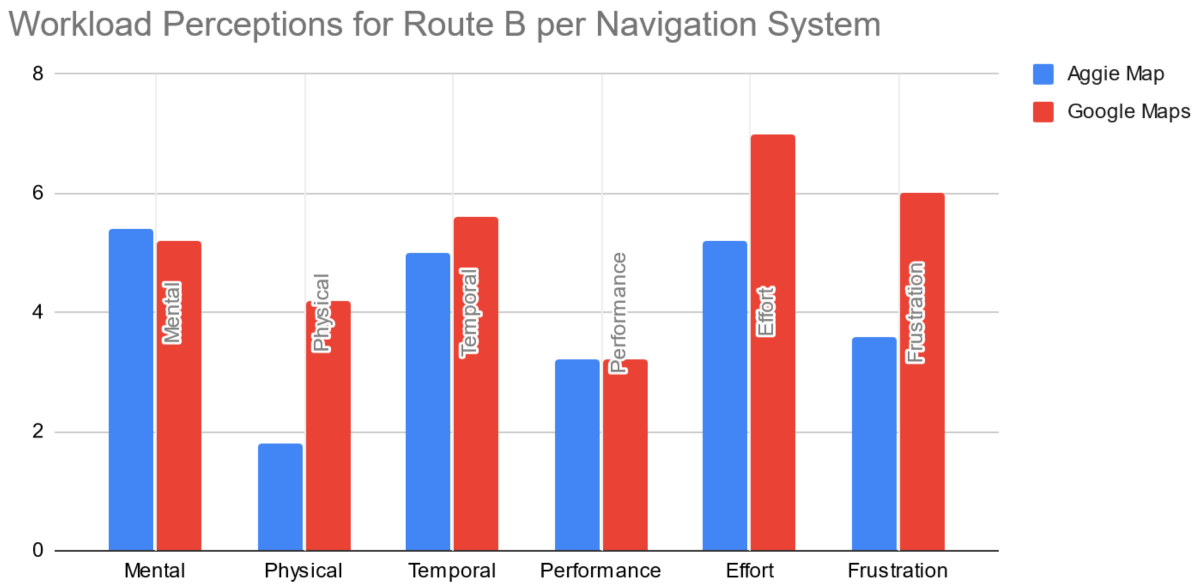


Figure 4.4: Bar Graph of Average Number of Stops Taken to Traverse Routes per Navigation System.

5. LIMITATIONS AND FUTURE WORK

There are limitations to be considered with the study which was conducted in this thesis which may have influenced our results. Future work is needed to empirically identify the effects that these limitations may have had on our results and to develop a more holistic understanding of how the differences between digital map-based navigation systems on an individual component level manifest in terms of the performance metrics and user experience metrics utilized in our study.

5.1 Limitations

Three major limitations have been identified to have maybe influenced the results of this study. The sample size of our study was small at 10 users in total, and the demographic makeup of the sample was entirely composed of students who attend Texas A&M University in person on the campus in which the routes were derived from. While all participants indicated little to no knowledge of the campus environment, they still had all traversed the campus on a regular basis to get from class to class for their academic studies. Ideally, in future work the sample population would utilize a diverse demographic of people in which contained individuals who did not regularly interact with the environment in which the navigation systems are being tested under.

Another limitation of our study emerged after the reviewing of the results of our analysis of the recorded data gathered from the individual routes chosen. While the routes are similar in the context of total length and number of decision points, the surrounding environment of the routes differed in a way in which may have influenced our results in which we did not previously consider. Anecdotal observation indicates that the buildings along routes we chose differ in terms of their average proximity to said route. This difference in average proximity could lead to problems for a navigation system which is reliant on continuous positioning for dynamic routing as buildings and other manufactured structures have been noted to cause interference with signals from the Global Positioning System [45].

The final observed limitation that we noted is the problem of confounding variables when conducting a user study among two navigation systems that differ in implementation and design of multiple components. The results of study should be contextually understood that navigation systems that have component differences deliver different user experiences in terms of user performance for task completion and user workload perceptions. It is not possible, however, with the data that we have gained and analyzed to make definitive statements about to what degree a specific component difference influenced our results.

5.2 Future Work

Future work seeking to expand on the possible conclusions of this study should involve the utilization of a few different approaches. Expanding the sample size and diversifying the demographic of people sampled in terms of familiarity with the environment in which is to be utilized for route traversal would lend more credibility to the results. Conducting analysis on the proximity of signal disruptions to the routes in which individuals will be traversing as well as recording data about the integrity of the signal from the Global Positioning System would allow for greater insights into the influence of these effects on navigation systems which rely on continuous positioning and dynamic routing. The development of new systems to be utilized as the navigation systems understudy that either differ in terms of singular components like positioning, routing, or presentation would allow for the investigation of how drastically a difference in the context of a specific component effects user performance and experience.

6. CONCLUSION

This study sought to analyze the impact that utilization of digital map-based navigation systems with differing implementations for routing and positioning have on route traversal in the context of performance metrics and user experience in terms of workload perceptions. The study utilized pre-developed navigation systems that differed in terms of their implementations of positioning, routing, and presentation of a digital map.

Analysis of the results of our study suggests that:

- Under optimal conditions, digital map-based navigation systems that differ in implementation of various components do not lead to a significant difference in performance metrics of time taken for traversal and number of stops taken. However, differences in workload perceptions do arise and we found that there was a greater sense of workload required for all dimensions recorded by the NASA Task Load Index except for the perception of physical workload for the navigation system that utilized sporadic positioning and static routing when compared to that of the navigation system that utilized continuous positioning and dynamic routing. This also extends to the individual performance, effort and frustration perceptions captured by the questionnaire as well.
- Under conditions in which Global Positioning System signal degradation is likely, navigation systems that differ in implementation of various components do lead to a significant difference in performance metrics of time taken for traversal and number of stops taken. There is a greater sense of workload required for all dimensions recorded by the NASA Task Load Index except for the mental and performance perceptions for the navigation system that utilized continuous positioning and dynamic routing.

Our study suggests that the performance of a navigation system in the context of being utilized as a wayfinding aid for route traversal is dependent on both environmental and design factors.

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