Designing indoor navigation interfaces on smartphones compatible with human information processing in an emergency evacuation scenario

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**ABSTRACT**

In the discussion of the multiple aspects of underground urban facilities, emergency measures during disasters need to be appropriately planned to evacuate and relocate people instantly. People are prone to losing their way in large indoor spaces. Smartphones are equipped with multiple sensors and a multimedia interface; these features are now standard tools that be utilized as personal evacuation guides. Under the mental stress of emergency evacuation, people tend to make different perceptual judgments and decisions when processing the information on an interface. This study summarizes the current smartphone navigation system interfaces on the market as seven samples for the experiment. We chose the most advantageous information elements from the results to design two types of interfaces, namely continuous route view navigation and survey view navigation. Through experimental observation and think-aloud analysis of on-site simulation testing results, the proposed interface is both legible and readable and provides minimum message loading to guide users.

1. **Introduction**

In the underground space, compared with the outdoor environment, the emergency measures during disasters require proper planning and prevention to be able to respond instantly and evacuate or relocate people. However, people still carry some negative feelings towards underground spaces (Hane, Muro, and Sawada 1991; Ringstad 1994), such as anxiety and a low sense of control (Carmody 1997; Ringstad 1994; Sommer and Becker 1974). With the perceptual differences between indoor space and the outdoor environment, if the poor guiding design is used to guide people in an underground space, it would result in cognition error and cause people to get lost (Lee et al. 2016). Currently, we lack studies of using smartphone indoor navigation system interfaces to guide public space self-evacuation.

The latest UN (2017) report states that the global population will grow from 7.6 billion to 8.6 billion in 2030, 9.8 billion in 2050, and 11.2 billion by 2100. The rapid growth in the urban population directly affects the living quality and increases the need for safe environments and spaces. The development of urban underground space has become a critical solution for facing future challenges and for using space and resources more effectively (Broere 2016). Making use of urban underground space has drawn significant attention in many countries (Hunt et al. 2016). For example, the largest underground city in the world, RÉSO, the underground system in Montréal, connects restaurants, leisure entertainment locations, subways, universities, and apartments. Another example is the famous underground labyrinth of the Tokyo station and shopping streets. One of the most critical problems that urban underground spaces can solve is the traffic congestion problem (Godard 2008). Crowds brought by junctures of multiple routes or co-constructed stations also create business opportunities (Broere 2016). The existing station structure and new shopping streets derived from such underground facilities and connections with surrounding buildings, shape complex, multiple layers of underground indoor space. Taipei Main Station is such an example. Under the co-contractures of Taiwan Railway, Taipei MRT (Taipei Metro), and Taiwan High-Speed Rail, Taipei Main Station is the most complicated station with the highest average number of travelers in the capital city of Taipei in Taiwan. According to the open statistics data of the Taipei City Department of Transportation, the average number of people traveling through the station in a day from 2006 to 2016 has grown from 320,121 to 523,066. An investigation indicates that over half of the residents have lost their way in Taipei Main Station (Chen and Zheng 2016).
Moving vertically in underground space also increases the complexity of wayfinding (Beaumont 1983). An evacuation feature analysis of simulated flooding of underground space shows that (Yasufuku et al. 2005) successful evacuation experiments mostly occur in the shortest distance; those that fail to evacuate are mostly unable to move forward due to inability to identify indicators. The fail group took 10 – 15% of the total wayfinding time hesitating between going up or down the stairs. From this, we learn that an underground space evacuation strategy must consider the vertical walking speed and personal differences of the public. When people are jammed in space and unable to move due to hesitation, it becomes even more challenging to find the critical evacuation route.

During an evacuation, people tend to exhibit individual behaviors such as homing characteristics, conformity characteristics, ostrich mentality, or choosing easy tasks under high pressure (Ho and Chien 1999). These behaviors are different for each person and mutually influential with the drastic change of the environment (Kato and Takeuchi 2003); those also affect the performance of the signage systems. Relevant studies concerning environmental psychology show that personal factors such as gender experience affect wayfinding decision making and spatial cognition (Bosco, Longoni, and Vecchi 2004; Dabbs et al. 1998; Lipman and Caplan 1992). When designing evacuation information, one must understand what the differences are before targeting mutual needs to propose solutions.

A consumer behavior investigation publicized in July 2014 by FIND of the Taiwan Institute of Information Industry shows that currently, 58.7% of people beyond (including) 12 years old own smartphones, which amounts to an estimated 12.25 million people. The popularity of smartphones in Taiwan grew from 51.4% to 58.7% in the first half-year of 2014 and kept on growing significantly. Smartphones today are equipped with internet connections, with built-in features of multiple sensors and multiple media interfaces. Even though evacuation guidance in paper form is easy to distribute, the content is limited and difficult to update (Ishikawa et al. 2008). Therefore, using smartphones as carriers is the development trend for adjusting data promptly. When a disaster occurs, in addition to conducting evacuation measures within the station based on the nature of the disaster, the evacuation could also be conducted by smartphone navigation, thus elevating the opportunity of self-rescue.

The Lens Model developed by American psychologist Brunswick shows that different people make different evaluations and interpretations of clues during perceptive judgment (Brunswik 1955). The methods of how human intelligence operates can roughly be distinguished as prudent and intuitive thinking (Kahneman 2012). In fact, many mechanisms guide people to take unexpected actions, such as the ambiguity effect, anchoring effect, attentional bias, availability cascade, availability heuristic, etc. (Wendel 2013). Human beings are not good at handling multiple and complex selections. Therefore, in designing an interface for evacuation navigation aimed “self-evacuation,” we should focus on simplifying the selection design to minimize choice overload.

We understand that as smartphones are widely used today, it is an essential task to design an interface that can precisely search for information on a limited display and is easy to operate and experience (Hoober and Berkman 2011). The delivery of interface information must also consider the type of safety information, such as the multiple choices of route reminders and planning. When guiding people through smartphone interfaces, we must also consider the sequential relationship of guiding and directing (Tidwell 2011), how to mutually correspond naturally to complete the operation and feedback, and achieve the purpose of safe operation and precise information delivery.

This research is divided into two studies. Study 1 develops a navigation interface prototype; we used the features of smartphone navigation apps on the market for comparison and analysis to summarize and screen out the design elements and layouts of several navigation interfaces and used the features of the interface to conduct our design. Study 2 puts the subjects’ evacuation simulation mentalities to the test in Taipei Main Station through the use of different mobile navigation modules to see the effect through our experiments. Before Study 1 and 2, we first carried out an online survey to better understand user experiences and needs.

Our research has the following four purposes: (1) learning how the users react to different navigation interface designs of graphic and text information, and understanding cognitive difference and mission efficiency under the mental stress of evacuation simulation through analysis of the experiment; (2) with users on foot during evacuation the simulation, we compare the efficiency differences in wayfinding with and without smartphone navigation. At the same time, we observe the attention and behaviors of people during the evacuation simulation; (3) we examine the differences of subjects in decision making time on the navigation paths provided by the interface, and the efficiency of information for changing timing; and (4) we develop a smartphone navigation interface through the overall analysis of the experiment that is suitable for indoor underground evacuation routes. The proposed interface can serve as a reference for future related designs.
2. Related work

This questionnaire was conducted through the internet to understand four aspects: (1) users’ needs and expectations for message design on a smartphone evacuation navigation app; (2) experience in the Taipei Main Station indoor space; (3) experience using navigation software; and (4) personal background.

For the importance of each type of interface information, we used a Likert Scale and separated the answers on the questionnaire into seven levels. 145 valid questionnaires were retrieved in the investigation one. From the statistics of the questionnaire analysis, we learned the importance of each message on the emergency evacuation interface. The result showed that “shelter location,” “current location,” and “distance” between the two locations were the top three most important; this means that in the navigation interface, these three should be presented. Comparing the top three messages, the evacuation time required for evacuation routes was the least important.

As for experience using Taipei Main Station’s indoor space, 67.8% of those who answered the questionnaire got lost once in the station. If we only took the replies from the greater Taipei area, as many as 76.8% of people had once lost their way in Taipei Main Station. The solutions when getting lost were checked in multiple answers. In the trend of using smartphone navigation while walking, 66% of the respondents only needed to be told the current location and headings, including the route on the plan with a starting point and destination, while 26% of the respondents required voice or text messages to show them the next steps. The results have been incorporated into the sample design of Study 1.

3. Study 1

In an unfamiliar underground space, it is hard to confirm the path of self-location to a destination, and emergency evacuation may be necessary. This situation could create an environmental load orientation. At this point, attention affects message processing. (Bell et al. 2006). The purpose of Study 1 is to understand, under the psychological stress of time constraints, the cognitive understanding of different static navigation interfaces. We want to know the relationship between different message designs and the subjects’ message processing (Sharp, Rogers, and Preece 2007).

3.1. Method

3.1.1. Participants

The subjects included 11 males and 11 females, with ages ranging from 22 to 42; 6 of them were commuting office works, and 16 were students. The experiment was conducted on these 22 subjects in the laboratory.

3.1.2. Materials

We collected 27 types of evacuation navigation apps that were currently available on the market for download through Google Play and Apple App Store (not limited to outdoor or indoor) and conducted sorting. Different interface layout types were selected to serve as the samples for the experiment in Study 1. The evacuation apps we found during the study were mostly for outdoor evacuation. Functions of these evacuation apps were not only for navigation but also for alert broadcasting, alert notices, disaster information, help tools, survival kits, safety notices, etc. Since this study a targeted mapping navigation function, the interface layout did not include disaster information except for navigation. The common elements of the navigation interface design principles include a compass, anchor point, location button, navbar, map, options, text messages, and pages for list items. The most significant commonality of these interfaces is to allow the map to be displayed in the maximum size, and the options are listed, either folded to the left, right, or the bottom. Few layout designs are divided from top to bottom. Figure 1(a) shows the ten layout types summarized from the 27 apps. Figure 1(b) shows the seven different interfaces in the layout designs of the indoor and outdoor navigation apps on the market.

On the other hand, indoor navigation apps are mostly applied to the sizeable international public transportation stations, museum tour guides, large shopping malls, etc. These large indoor spaces contain more complex structures and diversified POI. These indoor navigation service apps are developed for the purpose of providing service to users. Therefore, the apps are also combined with service applications and updates and broadcasts, providing business activity information.

When we compared the interfaces of indoor navigation and evacuation navigation, the most significant difference is that for indoor navigation, there are floor displays, menus, nodes marking the routes, and other visual elements for spatial recognition. Combining the layouts of evacuation mentioned above for navigation apps and indoor navigation, we found that the layout types that were widely adopted and user interfaces

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1The evacuation navigation apps collected in this study were available for both iOS and Android; we ruled out the apps developed by the same developer to avoid repeating the same layout. Since the app designing regulations are different for iOS and Android, there are slight differences in the design of the interface components of the same app on different platforms, but they are quite similar in overall layout design. Therefore, even though they are on different platforms, the layout design can still be categorized as the same type.
with more considerable design differences, as seen in the experiment samples of Study 1. The seven layouts that were integrated and screened out contained the following elements: (1) text for the destination; (2) directions indicated by arrows and texts; (3) current location floor display; (4) maps and routes; and (5) current location positioning and map zoom in icon button. The differences between the seven samples are the ratio of the text message and the map on the screen, the floor indication, the way the destination is marked, the path on the map, the self-positioning, and the location of the zoom-in/out icon button.

Grayscale replaced the colors in the visual design, and the contrast of the text background for indicating directions was adjusted. Texts were all in the same font, but the letter sizes were coordinated differently with various arrangements for directional texts and location descriptions. Positioning and map zoom icons were in the same style. As for the layout design, we identified five main control variants: (1) method of “Floor” display; (2) whether the “Destination” was marked by texts; (3) position of the “Step instructions” on the layout; (4) the design approach of the “Step instructions”; and (5) progression of “Step instructions”.

3.1.3. Procedure
The experiment was conducted on one subject at a time. Each subject was told that five questions would be asked, and the first four would be timed. The timing action-imposed time pressure on the subject and generate nervous sensations. The 5th question was not timed. Each subject answered the commonly assigned questions in the pictures, including “current location,” “destination,” “navigation message description,” and “self-determination,” and answers to these four questions were timed. For the 5th question, ample time was given to subjects to raise questions or opinions. Subjects were required to watch the interface on a computer screen, use their finger to point out the direction their eyes were watching, and think-aloud at the same time. There were seven samples arranged randomly for the subjects to answer. Figure 2 shows a picture taken during the experiment.

Think-aloud records of 20 valid subjects were coded to conduct general comparison for analyzing the legibility and readability of the interface. Since the evaluation of legibility assessed “whether the visual elements of the message were easily detected, distinguished and identified”; therefore, we listed the layout text detection speed and accuracy as the critical points for evaluating legibility. Also, the critical point for evaluating readability was whether the message could easily be understood; therefore, on the coding of think-aloud analysis, we sorted comments based on understanding and determinations. The coding method is listed in Table A1.

The semi-structured interview after the experiment was divided into two parts. The first part used a Likert Scale to measure which items subject were most concerned about in the event of a disaster occurring in underground public space. In the second part, subjects chose the best evacuation navigation layout from the experiment. Each subject was given two votes on the seven samples.
3.2. Results

Since we already learned from the internet questionnaires that “destination,” “self-positioning,” and “the distance between my current location to destination” were the three most important types of information, investigation two also targeted the test results of these three items. After removing the two extreme values of results in the experiment, the think-aloud records and questionnaires of 20 valid subjects were summarized the following: (1) cognitive processing speed ranking; (2) reply accuracy on “currently location” and “destination.”; (3) the decision-making process; (4) votes for the best interface; and (5) think-aloud statistics.

Table 1 shows the results of the above elements. The statistical approach of the cognitive processing speed was sequenced from fast to slow by calculating the number of times subjects entered top 3, top 2, and top 1. For example, S1 was ranked in the top 3 ten times, the top 2 eight times, and as No. 1 four times. The score was the average of the ranking in the three groups; the fastest was given 7 points, and so on.

In calculating the accuracy, we calculated if each subject correctly identified the “current location” and “destination”; and the number of times the same subject answered both correctly in the same sample.

The decision-making process sorted the think-aloud content of question 3 and four after the subjects received instructions from the navigation interface. The statistical results were sorted into five types, as shown in Tables 1 and 2.

Think-aloud coding in this part included the five questions answered in the experiment. Spatial terms are described in Table 2. For example, some subjects directly thought aloud terms such as “escalator”, “stairs”, “intersection”, “Y-type road”, “plaza”, “building”, and “obstruction”. Except for escalator, other terms were not presented on the interface but were converted into terms from subjects’ self-speculation. The part for positive description allowed subjects to express trust, satisfaction, recognition, or lack of confusion by using descriptions such as “very clear,” “no question,” and “follow the navigation” during the

![Figure 2. Photo taken during the experiment.](image)

**Table 1. Results of Study 1.**

| Sample | Processing Speed, Statistical Ranking | Answer Accuracy | Decision-Making Process |
|--------|--------------------------------------|-----------------|-------------------------|
|        | Top 3 | Top 2 | Top 1 | Score | Current Location | Destination | Both are correct | Correct understanding of navigation instructions | Incorrect understanding of navigation instructions | Unknown | Self-reliant (raising questions) | Best Interface Poll |
| S1     | 10    | 8     | 4     | 6     | 16 | 12 | 10 | 9 | 0 | 0 | 11 | 0 | 7 |
| S2     | 10    | 6     | 3     | 5     | 19 | 14 | 14 | 8 | 0 | 0 | 12 | 0 | 7 |
| S3     | 6     | 5     | 0     | 3     | 18 | 17 | 15 | 6 | 0 | 0 | 13 | 1 | 4 |
| S4     | 5     | 2     | 0     | 2     | 5  | 15 | 4  | 7 | 0 | 0 | 11 | 1 | 4 |
| S5     | 19    | 18    | 11    | 7     | 13 | 20 | 13 | 15 | 0 | 0 | 5  | 0 | 8 |
| S6     | 2     | 0     | 0     | 1     | 14 | 16 | 12 | 12 | 1 | 2 | 4  | 1 | 3 |
| S7     | 8     | 4     | 2     | 4     | 8  | 15 | 7  | 15 | 0 | 0 | 5  | 0 | 5 |
think-aloud process. Negative descriptions coded all negative perspectives about the interface, including think-aloud contents that expressed that the message on the interface was not clear enough or that the design was inadequate. Statistics from this part were the sum of all the subjects’ think-aloud content for each sample.

### 3.3. Discussion

The experiment in Study 1 aimed to identify confusion about current interfaces when used under psychological stress and to find out the design that could be utilized to allow users to make the correct decision intuitively. This is to say that the message process of the smartphone interface needs to be understood in a quick glimpse by all the users under the most inclusive environment. Thus, we needed to analyze and review the seven samples in Study 1 to assess the legibility and readability of the interface.

The distinction between legibility and readability (Hooper and Berkman 2011) is that legibility requires knowing if the message can be easily detected and recognized. This means that when glimpsing at the screen, the visual elements must be immediately detected and read (Quinn 2012). Readability focuses on if the message is easily understood. Here, we refer to situational context, proper use of words, and reading targets that fit the users (Easterby and Zwaga 1984). Legibility is not the ultimate purpose of design. The designer must ensure the readability of the interface design at the same time to help assess and understand the meaning of the content on the interface.

In the think-aloud part of this experiment, legibility was evaluated by encouraging users to think-aloud about the specific text-markings of the floor, destination, distance, landmarks, and time on the interface. The thinking aloud of subjects elicited thinking judgments about spatial terms; positive, negative and confusion were the cues used to evaluate the readability of the interface.

About the floor indication design, S2 was the design that received the most think-aloud comments in the statistics. The design corresponded to the vertical floor concept of the actual environment listing all the floors and marking the current floor in reverse/dark color. Five received the most think-aloud comments for the destination. The dialog bubble design for the destination in S5 included the text “3號出口 (Exit 3)”, which was the most specific marking for the destination, and the one that no users answered incorrectly. S6 and S3 marked the destination on the interface by using larger font size with a broader background area and received more detection by the subjects.

For the first question, “I am now at/on (location/floor)” and the second question “my destination is” in the experiment, the first to think-aloud comment was related to the message design for the floor and destination. The product value of the think-aloud accuracy ratio and detection time was the indicator for legibility. The starting score was one if the detection time from seeing the interface to thinking aloud was within 2 seconds. See Table 3.

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LI = \left(\frac{\text{NCC}}{20} \times 100\%\right) \times \text{NCS}
\]

LI = Legibility indicator

NCC = Number of people who made the correct think-aloud comment

NCS = Number of people made a think-aloud comment within in 2 seconds

Figure 3 shows the top 3 highest average scores on the legibility of the destination and floor indication design were 13 points for S5, 12.65 points for S2, and the last was for S6. Even though the destination design of S6 was above the standard of 85%, the floor design of S6 had a confusing reading sequence; therefore, S6 fell obviously behind in both accuracy or detection speed.

The evaluation of the readability was analyzed through the subjects’ understanding of the interface and their decisions during the think-aloud exercise. From the results, we found that some of the subjects converted the visual elements on the map into the spatial terms they understood and used those terms in the description in their think-aloud comment. Some subjects did not use these types of think-aloud comments at all.

In the think-aloud statistics, we found that most of the subjects needed environmental reference objects, especially on the nodes, as a reference for wayfinding. If the interface did not provide these types of spatial or landmark references, users sometimes self-speculated in their minds and create a space that does not exist in reality. There was another situation found in the experiment. The visual elements the designer thought...
to be easy to see elicited different interpretations from the users’ view.

The positive descriptions in the think-aloud comments were mainly distributed in fourth and fifth questions: “so I (the following actions)” and “I have (a) question(s).” Positive descriptions were defined as descriptions that “express trust, satisfaction, recognition or without confusion,” such as subjects thinking aloud, “follow the navigation,” “no problem/question” and “interface was obvious.: S1, S2, S5 received the

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**Table 3.** The legibility value of destination (TDE) and floor (TF).

|     | TDE |          |          |        |          |          | TDE |          |          |        |          |
|-----|-----|----------|----------|--------|----------|----------|-----|----------|----------|--------|----------|
|     | Accuracy | Number of people who made a think-aloud comment within 2 seconds | Value | Accuracy | Number of people who made a think-aloud comment within 2 seconds | Value |
| S1  | 60%  | 14       | 8.40     |         |          |          | 80% | 12       | 9.60     |
| S2  | 65%  | 14       | 9.10     |         |          |          | 90% | 18       | 16.20    |
| S3  | 80%  | 15       | 12.00    |         |          |          | 85% | 10       | 8.50     |
| S4  | NONE | NONE     | NONE     |         |          |          | NONE| NONE     | NONE     |
| S5  | 100% | 20       | 20.00    |         |          |          | 60% | 10       | 6.00     |
| S6  | 85%  | 15       | 12.75    |         |          |          | 65% | 7        | 4.55     |
| S7  | 75%  | 14       | 10.50    |         |          |          | NONE| NONE     | NONE     |

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**Figure 3.** Legibility indicators.
most positive descriptions, which was consistent with the voting results for the best interface.

When the subjects could not understand, could not make decisions smoothly, or the decision making became slow, they blamed the interface for not being specific or pointed out the lousy design. Such descriptions in the think-aloud comments were summarized as negative descriptions in this study. When the subject expressed “don’t know how to look (walk)” or thought aloud in questions, we categorized such comments as confusion.

We conducted scoring statistics on the positive, negative, and confusing descriptions of the above categories. The positive descriptions were ranked based on the number of think-aloud comments starting from 7 points, using 1 point as the unit, giving points in accordance the decreasing ranking. For negative and confusing descriptions, the less think-aloud comments received, the higher the score. The scoring of the three categories was included in the accuracy of answers to acquire accumulative points for readability. Table 4 shows that the highest accumulated score was for S5 at 17.43, which meant that S5 was the best interface out of all samples in readability. The next was S2, and the third was S1, as shown in Table 4.

Combining the analysis of legibility and readability, we can see from Figure 4 that S5 and S2 were above average; they also ranked as the top 2 in subjects’ satisfaction levels.

The purpose of this study was to find the smartphone navigation interface design that is most suitable for users under the mental stress of emergency evacuation. The design was much achieving the best efficacy in moving users through the evacuation routes. From the analysis of the experimental results, we learned that S5 offered the interface with the least message loading, could best guide the users under mental stress and had the best legibility and readability. If an interface is divided into two major parts, i.e., a map and messages explaining navigation steps, the map would be suitable for overviewing the entire evacuation route, including the current location and the destination. The messages explaining navigation steps should be delivered on at a time to avoid creating problems with the reading sequence. However, the “current location” positioning symbol design of S5 needs further improvement; it would be better if it adopted the designs of S1, S3, and S6, in which the current location is presented at the end of a line. The floor indication design should refer to the design of S2.

4. Study 2

The purpose of this level was for the people (shelter seekers) to reach the destination swiftly and safely. Though smartphone navigation is the tool for assisting emergency self-evacuation, the design purpose expects that people pay more attention to changing the environment than to the smartphone. In other

Table 4. The readability think-aloud comments scores for each category.

| Sample | Positive descriptions | Negative description | Confusion | Total | Accuracy | Product value |
|--------|-----------------------|----------------------|----------|-------|----------|---------------|
| S1     | 7                     | 6                    | 5        | 18    | 70%      | 12.6          |
| S2     | 7                     | 7                    | 5        | 19    | 83%      | 15.77         |
| S3     | 4                     | 4                    | 4        | 12    | 88%      | 10.56         |
| S4     | 6                     | 5                    | 3        | 14    | 50%      | 7             |
| S5     | 7                     | 7                    | 7        | 21    | 83%      | 17.43         |
| S6     | 5                     | 4                    | 6        | 15    | 75%      | 11.25         |
| S7     | 6                     | 6                    | 5        | 17    | 58%      | 9.86          |

Figure 4. Legibility and readability of each sample.
words, we want to find out which interface mode lets users remember the route with the least amount of time looking at the phone. The experiment in Study 2 let the subjects conduct an evacuation simulation task in the location. Two different modules, survey view and route view, were designed for comparison. Human psychological resources have limitations (Bohm 2015), which include memory, attention, willpower and mental energy, and decision making. Through observation, the think-aloud comments of the subjects during the experiment, and a semi-structured interview after the experiment, we attempt to understand how people make decisions when using smartphone navigation for evacuation. At the same time, we verified whether the best interface design acquired through the second investigation was effective during actual navigation simulation after design improvement. We also examined how using two different types of navigation interfaces would affect the cognition, judgment, and decision making of people under the psychological stress of evacuation.

4.1. Method

4.1.1. Participants

A situational experiment was simulated at the actual site. The participating subjects‘ ranged from 20 to 45. They were unfamiliar with Taipei Main Station and had never participated in a wayfinding experiment. Subjects were divided into the three groups below, with a total of 27 subjects: (1) wayfinding without smartphone navigation: nine subjects; (2) smartphone Navigation Group A (Survey view): nine subjects; and (3) smartphone Navigation Group B (Route view): nine subjects.

We considered the complexity of evacuation time and routes when screening the experiment routes; therefore, we first conducted the self-wayfinding experiment without navigation on nine subjects under an emergency evacuation simulation to confirm the range of the experiment. The point of beginning and destination of the experiment were the same as those of the navigation experiment groups. However, the route was determined by the subjects from the indicators in the station or on a plan. In the experiment, we recorded the routes of the subjects and observed their gait, wayfinding (checking the indicators and plans, etc.) methods, and the locations where they paused.

4.1.2. Materials

This study re-drew the Taipei Main Station interior plan provided by TRTC but kept the markings for central passages, escalators, stairs, and primary activity space. The interface used in this experiment was a redesign based on the result of Study 1, offering the best layout in both legibility and readability with flaws improved. The route on the navigation map spanned through 3 floors, from B2, B1 to the ground floor (1st floor); on top of the interface was the route termination shelter at “South 1 Gate of the Ground Floor Hall.” We added reference POI for the route on the map, such as typical signs for stores and toilets to make the map fit with environmental cognition.

The design criterion for mapping the routes in the survey view module was to present the complete routes of the floor, and the position arrow marked the current location with solid dots to represent the beginning point of the route on the floor. In planning the visual elements of pedestrian routes, we also used routes comprised of dots.

On the route view module, when comparing the same section in Figure 5, the module made the routes taken disappear and enlarged map ratio for the current location and surrounding environment. Subjects would see the positioning arrow for the current location and the forwarding direction but not the termination on each floor.

Simply put, the difference between the two groups was that the six maps on the route view module were divided into a sectional step by step guide; and for the survey view module, the subject was able to see the complete route from the beginning point to the evacuation destination. Figure 5 shows the comparison of the interfaces; the survey view module is on the top, and the route view module is on the bottom.

4.1.3. Procedure

The experiment required the subjects to simulate the evacuation mentality. Its purpose was to compare the wayfinding efficiency of survey view and route view interfaces on emergency evacuation. Pressure loading design in this stage was imposed through situational simulation and time limitation.

The beginning point of the experiment was at the M7 exit of the Blue Line on B2. Subjects were told before the experiment that this was to simulate train fires due to an accident on the MRT platform downstairs; they were told they must reach the shelter in 2 minutes by walking briskly. The key points of observations were: (1) Walking gait; (2) Ways of holding the smartphone; (3) Ways of checking the smartphone; (4) Seconds spent checking the smartphone; (5) Number of times checking the smartphone; (6) Locations of pauses; (7) Pausing when checking the smartphone; and (8) Referring to the environment in addition to checking the smartphone.

Besides on-site observation, we also used video cameras to record the whole process. Subjects were required to think-aloud in the process, and semi-structured interviews were conducted after the experiment. The experiment was conducted by using iPhones and iPads and switching the simulated navigation interface through Keynote.2

2Keynote needs setting; iPhones were used for the final presentation and iPads were used for remote-control. During the experiment, hot spots on iPhones were shared with iPads so that the two groups were under the same web environments. Subjects using iPhones with files opened for remote switching of pages. The researcher followed behind the subjects and remotely switched the interface the subject saws on the iPhones based on the location set on the route. We used this approach to simulate users’ indoor navigation wayfinding.
Four groups of data were acquired from each subject in investigation 3; these data included documentary film of the subjects’ perspectives, the observation records of the observers when following the subjects, and the records of interviews with the subjects after the experiment. Interviews with subjects after the experiment were added to the observations made by the observer to confirm subjects’ thoughts when committing actions or behavior.

The interviews after the experiment were conducted through a questionnaire that was designed in 3 parts. The design of the first part targeted the attention and memory of the subject. This included the sense of time of the subject during the experiment, the interface element used in decision making, and memory cognition related to other elements on the interface. The second part asked for subjects’ opinions, allowing subjects to raise questions, thoughts, and suggestions about the interface design. The third part was surveyed about personal background the experience of using smartphone navigation in the wayfinding experiments. The think-aloud comments of subjects during the experiment were coded in Table A2.

4.2. Results
The sample in the experiment adopted the design of S5, including the destination in texts in the bubble frame; the navigation text message has displayed the top with the distance and the heading direction. Floor indication design used the design of S2. 12 of 18 subjects had the experience of checking their smartphone while walking, 14 of 18 subjects often used smartphone navigation when walking in unfamiliar environments. All 18 subjects lived in the greater Taipei area or worked in Taipei City but were not familiar with the routes in experiment 2. The survey module and route module were randomly arranged for the 18 subjects. The following sections show the time needed to accomplish tasks, times, and locations when checking smartphones, the posture of subjects holding smartphones, average speed, think-aloud results, and results of semi-structured interviews.

4.2.1. Time needed to accomplish tasks
The times needed to accomplish the tasks of both groups are listed in Table 5. The average time for A group was 17 seconds less than that of B group. When telling the subjects to reach the destination in 2 minutes before the experiment, out of the 18 subjects, only four subjects of A group were able to finish in time.

Each subject asked about their mental time perceptions after the experiment by responding to “whether you completed the evacuation in 2 minutes.” Eight subjects in A group and 3 in B group thought they did. Since the experiment was conducted outside of rush hour, we reduced the environmental crowd factor down to the minimum.

Compared to not holding a smartphone for navigation, the average speed of the nine subjects that adopted self-wayfinding was 3 minutes and 11 seconds. We found four different routes in Figure 6. This
showed that using a smartphone interface to assist in the evacuation could undoubtedly shorten the evacuation time. When asking the subjects that did not use smartphone navigation, if using smartphone navigation would help them reach the shelter faster, 5 out of 9 subjects responded positively.

4.2.2. Times and locations of checking of smartphones

Behavior mappings of the subjects followed their views to check locations on smartphones and were recorded through video and observer record comparison; the locations for switching the interface remotely were also marked. The following section shows the locations where the subjects checked their smartphones.

From Figure 7, we see that there was no specific distinction between locations where the two groups of subjects checked their smartphones; they all confirmed the routes by checking the interface when encountering forks in the roads. The number of times checking the smartphone was naturally reduced on straight roads between the 3rd and fourth navigation interface.

4.2.3. Think-aloud results

Though each subject was told to think-aloud during the experiment, not everyone could think-aloud as expect. Below are the statistics of the think-aloud comments of all the subjects. From Figure 8, we found that LS (stairs) and DU (going upstairs) received the most think-aloud comments. LS (stairs) received 25 think-aloud comments, and

| Subjects No. | Survey view model | Route view model |
|--------------|-------------------|------------------|
| AS1          | 02:25             | BS1              | 02:20 |
| AS2          | 02:20             | BS2              | 02:36 |
| AS3          | 02:22             | BS3              | 02:07 |
| AS4          | 02:08             | BS4              | 02:19 |
| AS5          | 01:55             | BS5              | 02:27 |
| AS6          | 01:50             | BS6              | 02:39 |
| AS7          | 01:53             | BS7              | 02:26 |
| AS8          | 02:00             | BS8              | 02:19 |
| AS9          | 02:16             | BS9              | 02:19 |
| Average      | 02:08             | Average          | 02:24 |

We counted the number of times each subject looked at his/her phone in Table 6. The results showed that the average time for both groups was 22 times, and the median was also 22 times. From Table 7, we see that there was no specific distinction (p < 0.05) in the frequency of the two groups of subjects watching the navigation. Subjects were also asked during the interviews after the experiment, whether they often checked their smartphone when walking. We offered three options for them to choose, which were “almost never,” “only when receiving phone calls or messages,” and “often.” In Table 6, subjects that often checked their smartphones when walking were marked “yes,” while those who check “almost never” and “only when receiving phone calls of messages” were marked “no.” We also found that one subject that only checked his/her smartphone nine times did not have the habit of regularly checking his/her smartphone while walking; while one subject checked the smartphone 33 times had the habit of checking his/her smartphone while walking. The overall observation showed that those subjects who did not have the habit of checking their smartphone while walking seemed to check their smartphone less during the experiment.
DU (going upstairs) received 14 comments. The distance category received the least think-aloud comments with an average of 7 times.

The texts for navigation messages were the same for both groups A and B. In 6 interfaces, the text messages for 4 of them were terms relating to floors, such as “go upstairs” and “take the steps”; however, 2 of them concerning the distance, “20公尺 (20 meters)” and “100公尺 (100 meters),” received relevantly few think-aloud comments.

4.2.4. Results of semi-structured interviews
Subjects were interviewed after the experiment. We asked them about the priority sequencing when paying attention to the navigation interface. They were asked to watch the interface while being interviewed. The questionnaire segregated the interfaces into the current location, the line of route, landmark (texts or icon), navigation message area, route termination icon, and destination message on top of the display; please refer to Figure 9.

Analysis results were sequenced and ranked by numbers. The priority was marked one, and the second was marked 2, and so on. Table 8 shows the statistics.
The current location and line of the route were the first ones the subjects paid attention to, while the destination on the top received the least attention.

When asked if they noticed the positioning button on the bottom left corner, only 1 out of 18 subjects said they noticed.

There were two themes in the open-ended questions during the interview; one was “what message should be enhanced on the interface,” and the other was “thoughts during wayfinding.” As for what message should be enhanced on the interface, four subjects from A group thought the environmental reference object (landmark) should be enhanced while three subjects from B group thought the same.
There was a suggestion to change the “stores” to actual store names; a suggestion was also made to add in particular environmental objects that only activated under emergency evacuation since if encountering power failure during the evacuation, there would be no light to facilitate environmental reference.

The focuses of the subjects were also on the location of the disaster, distance from the disaster site, and specific notices given when taking the wrong evacuation route. As for the method of notices, subjects suggested using colors to stress the critical messages or using vibration and voice prompts for critical notices.

The thoughts during wayfinding were mostly about safety. For instance, subjects doubted whether they were on the right route; some thought that the navigation said 100 meters, which seemed to far, and did not know if they could make it in time. Subjects in Group B tended to feel unsafe due to uncertainty about the destination. For example, they said the “destination was not clear,” “I did not know how far away it was,” “It felt like I would never reach the destination,” etc.

4.3. Discussion

In the results of the earlier questionnaire investigation, we found that when people lost their way, the results showed that they tended to find their way by themselves by following environmental indicators or navigation instead of asking for directions. As for the evacuation routes of the self-wayfinding subjects (Figure 6) in the experiment of navigation without smartphones, except for one that found the way on instinct, the rest of the eight subjects all referred to the lightbox indicator, geographic location map, exit information and plans inside the station. However, proceeded according to the indicators resulted in 4 different routes due to the names of the destinations on the indicators. The assigned destination in the experiment was “Main Station Hall”; however, there was no “Main Station Hall” on the indicators. Taipei Transit Station, exits, South 1 Gate, were all indicators that caused the subjects to correlate with arriving at or passing through the location of the “Main Station Hall.” Therefore, when encountering a fork in the roads, subjects chose the indicator they thought would lead them to the destination. This type of cognition process created disturbances when making choices during the evacuation as the people had difficulty confirming whether they were on the correct evacuation route.

The most significant difference between indoor navigation and regular outdoor navigation is the switching of floors. This study chose a route that spans two floors, including the stairs of a half-floor; therefore, the stairs or escalators were crucial nodes in the experiment. The floor indication design of S2 in investigation two was applied to Study 2 in which it was switched along with the floor plans. Subjects said the switch was smooth and not abrupt.

After the experiment, we asked the subjects how they referred to plans on the interface in relation to the actual environment. Four Group A subjects only referred to the terrain, one only referred to the landmarks, and four referred to both terrain and landmarks. In Group B, one subject only referred to the terrain, one only referred to the landmarks, and seven referred to both terrain and landmarks. More subjects in Group A only referred to the terrain. Upon further questioning, we learned that since Group A could see the beginning and the end of the route the whole time, they paid more attention to differences in the proceeding directions; therefore, Group A had better conceptions of the direction of the entire route and terrain. Subjects of Group B could only see part of the route, and compared to Group A, the map ratio of Group B was bigger; therefore, Group B relied more on the auxiliary references of landmarks.

When simulating evacuation on foot in Taipei Main Station, the efficiency of self-wayfinding was worse than that of smartphone navigation. This was because of those who relied on self-wayfinding needed to refer to different guide markers in the environment, such as lightbox indicators, geographical location maps, exit direction maps, and floor plans, while some simply relied on instinct. In the emergency evacuation, possible power failure or heavy smoke could prevent the reference to these guide marks. Smartphone evacuation navigation could help in solving these problems and elevate evacuation autonomy. As for the efficiency of evacuation, we confirmed that smartphone navigation was more efficient than self-wayfinding in investigation 3. In an indoor space, being able to confirm the current location is very helpful, especially on the current floor. Being able to confirm the current location not only increased the sense of security but helped people to make decisions.

The best guiding interface design facilitated both legibility and readability while subjects were under the mental stress of evacuation simulation. This interface also produced the least message loading. If we divide the interface into maps and messages for navigation steps, a map overviewing the entire evacuation route should be presented at the beginning, including the current location and destination as the default display. This gives people the overall concept of the shelter they are heading for. Interface functions should allow the map to zoom, so people to see the correspondence of the map and the environmental landmarks. The messages for navigation steps should be given one at a time, and layouts that might create reading sequence problems should be avoided.

As for the efficiency difference between the times of navigation route decisions and the timing of switching messages, the subjects thought that the timing of
updates at 2 seconds before reaching each node was very appropriate. Even though the average number of times checking smartphones of the two groups of subjects in investigation 3 reached as many as 22 times, no doubt the subjects intended to confirm their current locations and if they were on the correct evacuation routes.

5. General discussion

In the results of the earlier questionnaire investigation on the experience of using navigation software, we found that people with the habit of using navigation devices when driving also tend to use smartphone navigation while walking strange environments. The use of smartphone navigation has exceeded professional navigation devices. People rely on smartphone navigation more and more nowadays, when both are driving and walking. This result also echoes the reason why this study chose a smartphone for use as a self-evacuation accessory. The results in Study 2 show smartphone navigation saves more time in wayfinding than using maps to navigate the environment.

Combining the study results and the user survey, we suggest the following highlights for interface design for evacuation navigation:

- **Floor indication design:** in Study 1, the floor indication design of indoor navigation should be arranged in accordance with the floor sequence from bottom up, and the current floor should be marked.
- **Highlight the current location:** we learned from Study 1 that in order to reduce the misjudgment of current location and destination, a dialogue bubble with the texts indicating “your current location” could be used in the beginning image to prompt the user that this is the self-locating icon. There is no need to prompt them again in the navigation images. This way, the messages on the page can be reduced.
- **Map zoom-in/out:** in Study 2, although the performance difference between the survey view and route view was not significant, default status should allow an overview of the complete route of the floor. Currently, some indoor navigation requires two fingers to zoom, and there’s no + or – buttons on the interface. Users should be able to use + or – buttons or smartphone default gestures to zoom-in/out on the map, allowing the users with precise needs more flexibility.
- **Display of supplemental disaster news:** we collected the user needs from the interview in Study 2. The flashes of the disaster icon prompt the users to interact by “tapping” for the text message of the current disaster situation to make it pop-up. This message could be updated from the system backend base during the actual situation (disaster) work. This display helps people understand the current situation and increases their sense of security. The display of the disaster message should not cover or shadow the range of the current location to avoid panic as people are being evacuated.
- **If the user turns on the app positioning privacy function, the system should be able to track the location of the user and provide rescue when necessary.** In addition to display through the interface, navigation should also combine voice and vibration notices to compensate for poor views on site.
- **Red color should be used with essential alerts to raise visual attention, including the shelter destination on the top, the site of the disaster or directional markings, icons representing no use and no entry, etc.**

We integrate the above interface design highlights and show the design of emergency evacuation navigation interfaces in Figure 10.

6. Conclusion

The support of interactive technology allows users to receive information and knowledge more quickly (Andrienko et al. 2002). Shneiderman et al. (2009) states that a good interface design can give users a positive feeling and enhance their ability to use it. When designing a mobile interface, we should consider the rules of readability and readability and provide articulating graphics and information (Hoober and Berkman 2011). We understand that creating an interface for searching for precise information on the limited display and ease of operation are fundamental issues today with the widespread use of smartphones. Messages deliver through navigation interfaces, must also consider the type of safety information, such as reminding users about the route and multiple choices of planning. Using a smartphone interface to guide the behaviors of people, we should consider the sequencing relationship between guiding and directing, how to mutually correspond naturally for operation and feedback, and how to achieve the purposes of safe and secure operation and deliver messages correctly.

This research condensed current smartphone navigation system interfaces on the market as seven samples for the experiment. We chose the advantageous information elements in the results to design two types of interfaces, namely continuous route view navigation and survey view navigation. Through experimental observation and think-aloud analysis of on-location simulation testing results, the interface should feature both legibility and readability and provide minimum message loading when guiding the users.
From the feedback and suggestions from the subjects after the experiments, we learned that designs of essential messages for evacuation such as the disaster site and the type of disaster should be added in follow-up studies. Evacuation assistance could add designs other than visualization cues to help users with poor eyesight, or those cannot see the smartphone directly by adding interactive voice and vibration functions. An emergency button could be added to the interactive functions to help the rescue team locate subjects during emergency rescue operations.

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No potential conflict of interest was reported by the authors.

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## Appendix

### Table A1. Think-aloud coding for study 1.

| Sorting         | Coding   | Vocabulary               | Description                                                                                           |
|-----------------|----------|--------------------------|-------------------------------------------------------------------------------------------------------|
| Text Detection  | TDE      | Destination             | Completed think-aloud description of the text message about the destination.                         |
|                 | TF       | Floor                   | Identifying the floor guide design on the interface.                                                 |
|                 | TDI      | Distance                | Think-aloud description of distance related display on the interface.                                |
|                 | TN       | Number                  | This number showed the sequence of the steps.                                                        |
|                 | TL       | Landmark                | Landmark designs presented by A and B on the interface.                                             |
|                 | TT       | Time                    | Complete think-aloud description of the text message about time.                                     |
| Situation of understanding | SS | Spatial description | Subject converted the visual elements into spatial description.                                     |
|                 | SP       | Positive description    | Expressed trust, satisfaction, recognition or lack of confusion.                                      |
|                 | SN       | Negative description    | Described that the message was unclear or that they were not satisfied with the design.             |
|                 | SC       | Confusion               | Think-aloud comments expressing they did not know or had a question.                                |

### Table A2. Think-aloud coding for study 2.

| Sorting  | Items                      |
|----------|----------------------------|
| Direction | Walk Forward (DF) | Turn right (DR) | Turn Left (DL) | Going upstairs (DU) | Right side (DRS) |
| Distance (N) | 20 meters (N20) | 100 meters (N100) | | |
| Landmark (L) | Stairs (LS) | Store (LSt) | Toilet (LR) | | |
| Purpose (P) | B1(PB1) | 1F Lobby (P1F) | South Gate 1 (PSD) | | |
| Other     | Arrow (Arr) | | | | |