Tailoring Map Design Based on Map-Reading and Way-Finding Behaviour in Subway Stations

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Abstract

In task 1, all subjects were asked to reach an exit without reading a map and no one found the shortest way to the nearest exit. In task 2, subjects were asked to read a map, to plan a route for the designated exit, and then to reach it. 2D map subjects’ way-finding performance was superior to that of 3D map subjects. 2D map subjects had problems with stairway connections, but 3D map subjects were confused by the incompleteness of symbols. 2D map subjects used wall and action-based information to construct their route knowledge, but 3D map subjects tended to rely on landmarks.

1. Introduction

1.1. Way-finding at subway stations

In urban cities, large subway stations are the public space most frequented by the general masses, and thus the issue of how people can move smoothly underground has attracted concern. Subway stations

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usually include a lot of areas and floors. Therefore, way-finding behaviour involves not just 2-D navigation, but also that of 3-D navigation. Recently, many studies have worked on 3-D navigation; as observed by Christoph (2006), in a study of way-finding strategy in multi-level buildings that focused on 12 participants to conducting way-finding study in a building which comprises of eight areas and four floors. Participants had to use direction strategy (the horizontal position of the goal) and floor strategy (for level-changes) to reach assigned floor and area. In subway stations, passengers often change levels and areas to reach specific destinations, such as No.3 exit, or No.2 platform. Consequently, it has demonstrated that analysis of direction and floor strategy for way-finding at subway stations is necessary.

1.2. The role of maps at subway stations

Subway stations typically display, there are mainly two categories of spatial information, namely directional sign and map to support way-finding. Directional signs support direction information, while map provide survey knowledge. Many studies shows directional signs were used more frequently than maps. The use of maps is thought to have effects upon cognitive maps and way-finding. Rob (2002) indicated the effects of maps. First, training in map use can provide guidance in how to process and comprehend spatial information. Second, studying a map can lead to greater knowledge of an area by revealing real world spatial information derived from direct experience. Third, maps assist way-finders in conducting way-finding planning before way-finding, as well as in predicting environmental context not traveled before. Consequently, way-finders can effectively exploit maps to enhance way-finding accuracy.

In addition, maps are considered to be of much help as found in escape behaviour study. Based on simulation experiment results obtained by the NIED (2002) research for subway station shelters, this study finds that the complementary use of directional signs and maps can most effectively support action. Escape maps are commonly installed in subway stations so that passengers can understand the escape route as soon as possible before an accident occurs.

1.3. Map-reading and way-finding

Golledge (1998) indicated the cognitive process of way-finding is clear: humans acquire, code, store, decode, and use cognitive information as part of their navigation and way-finding. Way-finding processes were generally considered as two aspects of human navigation. The first aspect is route planning, which aims to facilitate target-oriented navigation. The second aspect addresses route modelling and the understanding of how people navigate their environment (David, 2007). It was known that the cognitive process of way-finding was divided into two parts, cognitive processing and execution. In order to realize the effects of map design, this study defines map-reading to include comprehending map, planning route, and route memorization. Way-finding means walking to the destination. Torgny (1987) also indicated that in complex tasks, map-reading in connection with way-finding can be profitably studied in its highly developed forms. Thus, realizing the cognitive process from map-reading to way-finding is conducive to the completeness of map design.

This study investigates the cognitive processes of travellers when navigating subway stations, specifically when those travellers are asked to perform way-finding tasks involving finding their way from a platform to the exit. Behavioural observation and verbal reports are used to examine the processes from map-reading to way-finding performance. Route description is used to get the data of subjects’ route knowledge. This work explored spatial properties useful to way-finding, and examined the performance of existing maps of the actual environment so as to present suggestions regarding map design for subway stations.
2. Methodology

2.1. Survey

A total of 186 survey questionnaires were returned. All subjects are inhabitants of Taipei who are familiar with Taipei Station. The questionnaire survey was conducted to evaluate subway stations in Taipei. Respondents were asked two main questions: 1) to evaluate Taipei Station based on the Sanja’s criteria (2001); and 2) to evaluate sign and map design at Taipei Station. The questions are graded based on a five-point scale: -2 indicate very poor, -1 indicates poor, 0 indicates fair, +1 indicates good, and +2 indicates very good.

2.2. Investigation

An empirical investigation related to map-reading and way-finding was conducted with two tasks. Task 1 is to reach an exit without reading a map. Task 2 is to read map, plan a route, memorize the route, describe the route, and find a way to the designated exit. In order to realize this cognitive process, we introduce the verbal reports of way-finders as an additional data source. The thinking aloud method of collecting verbalizations concurrent with task performance is an established method for tapping into those cognitive processes that can be verbally accessed (Ericsson & Simon, 1993; Christoph, 2006). In the map-reading study, Torgny (1987) indicated a direct approach. This consequently means the subjects are encouraged, either concurrently or retrospectively, to explicitly verbalize what they do (or did), and the reason for their action. In the way-finding study, Christoph (2006) followed Passini (1992) by using the collection of way-finding behaviour data to successfully complement the verbal reports of task-concurrent thoughts to obtain a comprehensive picture. Thus, this study is conducted to measure map-reading and way-finding performance, and to analyze protocol reports and verbal route description.

2.3. Participants

In the map-reading and way-finding investigation, the 12 study participants comprised graduates of the Education Department of Tung Hai University of Taichung City. All 12 were at that time working as high school teachers. The average age was 29.6 years old. Six of the participants were males, while the other six were females. Six of the participants were unfamiliar with the station, having visited the place fewer than three times, while six were familiar with station, having lived in Taipei City and having used the Taipei MRT to commute for more than 1 year. Three of the participants who were unfamiliar with Taipei City were assigned to read the 2D map, while the other three were assigned to read the 3D map.

2.4. Procedure

During map-reading and way-finding, participants were asked to express their ideas in complete sentences. Video was used to record the behaviour and protocol reports of individual participants. Before the task, each participant was told about the entire task workflow. During the task, participants could not read other maps nor ask other people for help. If participants were completely lost or reached the wrong exit, they should begin the way-finding task again.

The experimental site was Taipei Station in Taiwan, a large underground station with three tracks (MRT, Taiwan Railway, and High-speed Rail), and with four underground levels. The map sample used in this study is based on the 2D and 3D maps installed in the MRT station. The 2D map is installed at the centre of the platform, gate, and entrance and exit of every floor. The 3D map is installed in front of and
inside the station elevator. To avoid the influence of directional signs on the way-finding task, the exit marker is deleted from the map sample. The map samples used are those shown in Fig.1.

This study examines whether a participant can complete the way-finding task according to the previous way-finding plan under conditions of time pressure and low visibility. Smoke appearing would be the problem encountered in the escape task. Smoke appearing during a disaster can cause blindness, and smoke along escape routes in particular has the potential to cause panic. Participants were thus asked to wear foggy glasses which were made from some opaque material. This reduced visibility to 20-30m (about reduction coefficient at 0.1) (Ding-Lin, 2007). This study confirms that each participant can walk safely wearing foggy glasses and can also see directional signs.

Fig. 1. D map sample (left) and 2D map sample (right). Source: Taipei station, (2008)

2.5. Performance measures and Verbalization

After completing the investigation, the following items were analyzed:
• The performance measures include time required to complete route planning, planned route distance, planned route distance divided by the length of the shortest possible route, time to complete the task on foot, distance walked, stops, stopping time, getting lost, and detour distance or PAO For example, a value of 1.35 can be interpreted as indicating that subjects walk 35% farther than necessary)(Christoph, 2008)
• AN ANOVA test with factors map usage (2D map used, 3D map used) and familiarity (familiar, unfamiliar) conducted for the performance measures.

Verbal protocols for map-reading are classified into three types: smooth, problematic, and route memorization. Verbal protocols for way-finding are classified into four types: recognizing route smoothly, problematic, searching for, and recalling route. Besides these, this study performs coding of verbal protocols for directional and floor strategies, based on the definition by Christoph (2006). Thus, each sentence has two codes. After coding, the verbalization was analyzed by an ANOVA test with factors map usage (2D map used, 3D map used) and familiarity (familiar, unfamiliar).

2.6. Route description

Brosset (2007) indicated that the proposed model incorporates the three main components of a route description, as previously identified by Michon and Denis: namely action, landmark and spatial entities.
An action represents the displacement behavior of a human acting in the environment. A landmark is the most salient feature used in human navigation. Spatial entities denote two-dimensional entities on which moves are executed (e.g. a path) or non-salient and non-punctual entities used in navigation (e.g. a area).

In this study, the landmark and spatial entities are those used by Passini’s Elements of underground space. Statistical analysis was performed on the usage frequency of various elements. According to Passini, the underground space can be classified into five components (Sanja Dumisevic, 2002). Although the elements that Lynch considers are for the city, some parallels can be made and applied to the buildings (Carmody, 1993). Passini (1992) who studied way-finding strategies in underground space draws these parallels as well. He defined them in the following way:

- Paths are the circulation system, which include corridors, promenades that are part of the horizontal circulation and stairs, elevators and escalators are part of the vertical circulation.
- Walls inside the building could be viewed as the edges.
- Districts are considered to be certain areas with specific functional characteristics.
- Nodes are defined as important circulation intersections, like halls and indoor squares.
- Landmarks are clearly remembered elements such as particular shops, sculptures or decorative elements. According to Passini, not only objects but also the space itself, can serve as reference points, and can be considered as landmarks.

3. Questionnaire Results

A total of 200 questionnaires were distributed. 186 valid questionnaires were returned. These included 97 from female respondents and 89 from male respondents. The respondents included 21 commuters, 87 individuals who visited the station over 20 times each year, and 78 individuals who visited the station between 5-20 times each year.

For the evaluation of underground stations in Taipei, the average values of six indicator items are as follows: overview, escape, visibility, management and order, way-finding, attractiveness, physiological comfort, and daylight. The results are shown in Fig 3. The average evaluation for attractiveness, way-finding and escape is more positive than for the other 3 items. The average evaluation for directional sign is positive (+0.02). However, the average evaluation for map is negative (-0.08). The average evaluation is counted according to the evaluation of amounts, location, and comprehension as shown in Fig 4. Respondent satisfaction with using maps receives a negative evaluation, indicating the need to improve map design.
4. Results of investigation

4.1. Task 1

In this task, all participants were asked to find their way to any ground exit from the Danshui line platform in the B4 floor without reading a map. Five participants arrive at the exit of the Danshui line, and seven arrive at the exit of Banqiao-Nangang line (Fig. 5). Only two subjects reached the nearest exit, but no subject took the shortest path to the nearest exit.

All subjects reached the exit successfully, and their performance is shown in Table 1. Stops and stop time differed significantly between those who are familiar and unfamiliar with Taipei Station. Higher stop frequency was observed for subjects unfamiliar with the site (p<0.016), as well as longer stop periods (p<0.029). Additionally, respondents unfamiliar with the site reported greater problems than those familiar with the site (p<0.03). Furthermore, the covered distance was 53% longer than in the shortest possible route. Subjects familiar with Taipei Station moved more smoothly than unfamiliar subjects according to verbalization of problems encountered. Familiar subjects did not perform better in terms of walking distance and duration than unfamiliar subjects. Task 1 asked participants not to read a map while performing their way-finding. The results indicate that no one took the shortest route to the nearest exit, and over half of subjects failed to find the nearest exit at all. Thus, it is not easy for subjects to find the shortest route to the nearest ground exit by showing them directional signs only.
Table 1. The average of performance, behaviour measures, and verbalization

<table>
<thead>
<tr>
<th>Performance</th>
<th>Access</th>
<th>Verbalization</th>
</tr>
</thead>
<tbody>
<tr>
<td>Time (sec)</td>
<td>Distance (m)</td>
<td>PAO</td>
</tr>
<tr>
<td>Unfamiliar</td>
<td>266</td>
<td>214.85</td>
</tr>
<tr>
<td>Familiar</td>
<td>286</td>
<td>252.13</td>
</tr>
<tr>
<td>Total</td>
<td>276</td>
<td>233.49</td>
</tr>
</tbody>
</table>

*PAO: distance covered divided by length of the shortest possible route. This parameter expresses the proportion of superfluous way independent of task length.

4.2. Task 2

4.2.1. Results of the Performance measures

Task 2 involves way-finding from the platform of the Banqiao-Nangang line to exit M4. The figure shows all routes planned by all subjects. Half of the subjects select Route 1. (Fig.5). Those subjects select the nearest stairway in front on the B3 floor, and then select the forward staircase after the gate on the B2 floor. However, it is not the shortest route. The results are shown in Table 2. Subjects using 2D and 3D maps exhibited significant differences in terms of loss. (p<0.001) Five subjects who read 2D maps completed the way-finding task once. Seven subjects got lost or reached the wrong exit (six 3D map subjects, and one 2D map subject). Unfamiliar subjects spent over three times longer on map reading than familiar subjects, and thus required more time to complete the task (p<0.001). All of the 3D map subjects completed the task twice, and the total way-finding time for the 3D map subjects exceeded that of the 2D map subjects (p<0.023). The way-finding and detour distance are also longer for 3D map subjects compared to those of 2D map subjects (p<0.038).

Table 2. Results of route planning and way-finding for subjects map usage and familiarity

<table>
<thead>
<tr>
<th>Map usage</th>
<th>Familiarity</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Map-reading</td>
<td>Planning route distance (m)</td>
<td>184.2</td>
</tr>
<tr>
<td></td>
<td>Planning time (sec)</td>
<td>175.83</td>
</tr>
<tr>
<td></td>
<td>Planning distance/ the shortest distance</td>
<td>0.32</td>
</tr>
<tr>
<td>Way-finding</td>
<td>Way-finding distance (m)</td>
<td>221.04</td>
</tr>
<tr>
<td></td>
<td>Detour(m)</td>
<td>34.34</td>
</tr>
<tr>
<td></td>
<td>Way-finding time (sec)</td>
<td>275.17</td>
</tr>
<tr>
<td></td>
<td>Stops(n)</td>
<td>3.67</td>
</tr>
<tr>
<td></td>
<td>Stop time (sec)</td>
<td>27.00</td>
</tr>
<tr>
<td></td>
<td>getting lost (n)</td>
<td>0.17</td>
</tr>
<tr>
<td></td>
<td>Total task time (sec)</td>
<td>465.5</td>
</tr>
</tbody>
</table>

*getting lost: the participant is completely lost, and cannot continue with his way-finding task
*detour distance: the participant is not following the planned route and consequently is walking further than necessary
4.2.2. Results of Subjects’ Verbalizations

The results of verbalizations are shown in Table 3. The verbalizations of planning problem for 2D map subjects are lower than those for 3D map subjects (p<0.37). The 2D and 3D map subjects differ significantly in terms of direction and floor strategy (p<0.002). The frequency of verbalization regarding direction and floor strategy is almost identical for 2D map subjects. However, the frequency of floor strategy is half of that of direction strategy for 3D map subjects (Fig 7). Figure 6 shows that 3D readers mostly have problems with direction planning, corridor, turnover-gate, stairway, and the spot from turning in the B1 floor and the entire façade of space and facility expressions of these locations cannot be fully represented as it is a 3D map. 2D readers have problems with staircases. The results show that subjects using 2D maps have greater difficulty in making floor changes than 3D map users. The verbalizations of the way-finding problem for 2D map subjects are also fewer than those of 3D map subjects.
Table 3. Results of verbalization on map-reading and way-finding in Task 2

<table>
<thead>
<tr>
<th></th>
<th>2D map</th>
<th>3D map</th>
<th>total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Map-reading</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Planning smoothly (n)</td>
<td>113(82%)</td>
<td>120(75%)</td>
<td>133(69%)</td>
</tr>
<tr>
<td>Problematic (n)</td>
<td>13(9%)</td>
<td>30(19%)</td>
<td>43(22%)</td>
</tr>
<tr>
<td>Memorizing route (n)</td>
<td>12(9%)</td>
<td>6(6%)</td>
<td>18(9%)</td>
</tr>
<tr>
<td>Total</td>
<td>137(100%)</td>
<td>160(100%)</td>
<td>194(100%)</td>
</tr>
<tr>
<td>Way-finding</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>recognizing route smoothly (n)</td>
<td>59(50%)</td>
<td>78(45%)</td>
<td>137(47%)</td>
</tr>
<tr>
<td>problematic (n)</td>
<td>24(20%)</td>
<td>45(26%)</td>
<td>69(24%)</td>
</tr>
<tr>
<td>search (n)</td>
<td>8(7%)</td>
<td>9(5%)</td>
<td>17(6%)</td>
</tr>
<tr>
<td>recalling route (n)</td>
<td>28(23%)</td>
<td>39(23%)</td>
<td>67(23%)</td>
</tr>
<tr>
<td>Total</td>
<td>119(100%)</td>
<td>171(100%)</td>
<td>290(100%)</td>
</tr>
</tbody>
</table>

4.2.3. Results of route description

The results of route description show that 60% of verbalizations relate to elements of underground space, and 40% relate to action. Most of the subjects described the routes using path and landmark information, as listed in Table 4.

Table 4. Results of route description

<table>
<thead>
<tr>
<th>Elements of underground space</th>
<th>Action</th>
<th>Total*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Path</td>
<td>Wall**</td>
<td>Districts</td>
</tr>
<tr>
<td>2D map</td>
<td>11</td>
<td>5</td>
</tr>
<tr>
<td>3D map</td>
<td>18</td>
<td>0</td>
</tr>
<tr>
<td>Total</td>
<td>29</td>
<td>5</td>
</tr>
</tbody>
</table>

Subjects regarded paths as stairways, landmarks as signs, gates, exits, shops, elevators, underground shopping streets, information centers, and districts as floors, MRT line areas, and traffic systems. The quantity of verbal reporting regarding space elements and actions used by 2D map subjects exceeded that used by 3D map subjects. Since the way-finding effect of 2D map subjects is better than that of 3D map subjects, this study finds that the way-finding effect by using action for route memorization is more...
effective in subway stations. Notably, 2D map subjects use walls in route description. For instance, when a subject says: “I just walk along the wall, and then I can reach the stairway”. Wall surfaces are being used to memorize spatial features. On the other hand, 3D map subjects do not use wall surfaces in their route description.

The reasons for the mistakes made by participants are explored via route description and their verbalizations of way-finding. All of the erroneous turns occur in the B1 floor. The reasons for erroneous turns are divided into two categories:

- Failing to check landmark: Two subjects (PJ, WY) failed to locate the information centre. Three subjects (LJ, SY, TW) failed to find the elevator. Subject CS failed to find a stairway to go upwards. Subject ZH failed to find the required directional sign;
- Erroneous or inaccurate route memorization: Subject CE made the erroneous turn due to failure to remember. Subject YS was not sufficiently precise regarding his description of actions as the difference between left u-turn and right u-turn caused him to make way-finding mistakes. Thus, generally, way-finding errors often occur when subjects expect to find a landmark in an expected location based on map-reading but then discover that the landmark is not where they expect it to be. Maps do not indicate the obstruction of wall surface and the location of directional signs, so map users can identify it by their anticipation and eventually fail in their way-finding. Therefore, differences are to be expected between the information obtained from map-reading and that obtained from the environment during way-finding, and these differences must also be considered during map design.

5. Conclusions

The results of the questionnaire survey reveal map design at Taipei Station is insufficient. In task 1, all subjects were asked to reach an exit without reading a map and no one found the shortest way to the nearest exit. Those who were familiar with the set were shown the homing feature, and thus select the more distant but familiar exit. Those who were unfamiliar with the set could not predict whether they would arrive at the closer or more distant exit but just followed the directional signs.

Task 2 explored the difference between the use of 2D and 3D maps via observation of subjects’ behavior, verbal reports, and route description. 2D map subjects’ way-finding performance was superior to that of 3D map subjects. 2D map subjects had problems with stairway connections, but 3D map subjects were confused by the incompleteness of symbols. 2D map subjects used wall and action-based information to construct their route knowledge, but 3D map subjects tended to rely on landmarks. However, this approach made subjects vulnerable to erroneous turns and detours as a result of missing landmarks during their way-finding. Based on the investigation, the results regarding the map design of the subway station are presented as follows:

- Support direction and floor strategies for 3-D navigation
  In the 2D map, each element of space can be completely presented. In the 3D map, the connection of levels can be obviously presented. Travellers can obtain subway spatial information from both 2D and 3D maps. Subway space can be comprehended quickly and routes can be planned efficiently. So, a 3D map should be installed near a 2D map.
- Strengthen the presentation of stairway symbols and wall surface symbols
  2D map subjects were confused in stairway location and walking direction during way-finding because all stairway symbols on the map are the same. The legibility of stairway symbols on maps should be strengthened and seriously considered in map design.
- Reduce the difference between real world and map
  Way-finding tasks indicate that most erroneous decision-making results from subjects overestimating the amount of environmental information they are likely to obtain. Scale is the most important tool for
distance identifying on a general map. However, scale in an indoor map is usually ignored. Maps of large subway stations are drawn according to a small scale, so the distance determination becomes difficult. Therefore, scale should also be clearly marked in a subway station map. Moreover, marking the location of important directional signs and strengthening landmarks with photos can help users remember routes and understand the space easily.

- Labeling of the nearest exit and landmark near it

Task 1 results showed that insufficient distance information was provided by the directional sign. Maps thus can help people reduce the distance and time spent on way-finding provided the location of the nearest exit and landmark near to this exit are clearly indicated.

Future studies and investigations of map-reading to way-finding can be used to understand way-finding behaviour in other large-scale public spaces including airports, hospitals, and schools. Map design can also be improved with data from more intensive way-finding investigations.

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