Application of 360-degree Video to Extend the Capability of Conventional Behavioral Mapping Method to Resolve the Recurrent Congestion in Taipei Metro Transit Stations

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Abstract. A mobile application was developed to reduce recurrent congestion in Taipei Metro transit stations, following a case study of crowd movement on platforms at Taipei City Hall station. Behavioral mapping was employed to record and analyze crowd movement and behavior. However, conventional behavioral mapping has fundamental drawbacks, and thus cannot be applied to situations where the totality of group behaviors matters. In this study, we propose a practical procedure to perform behavioral mapping with the assistance of 360-degree video recording, which was validated by a case study. By performing 360-degree video scanning, movements and behaviors of groups and individuals were recorded, and the physical locations and behaviors of all individuals were collected as behavioral mapping to study and analyze the interrelationships of group or individual behaviors with the environment. Consequently, the behavior of using smartphones was also identified as a minor factor that caused congestion, leading to the development of a mobile application to reduce passengers' hesitation by directing them confidently to move faster. To facilitate the directing of passengers, a matching system of the closest escalator to every train gate at the platform level was collected in a database. This system used the three-digit reference numbers already in use on every train gate within high-capacity systems, to identify the location of each train gate at the platform level.

Keywords: 360-degree video recording, Behavioral mapping, Recurrent congestion, Taipei Metro
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1 INTRODUCTION

Standing on one side of the escalator and leaving the other side empty for passengers who are in a hurry to walk up or down the escalator is an observable crowd behavior in many regions, including

Taipei City. The common behavior repeated on a daily basis is a human pattern. However, many groups of human patterns cause congestion in public transit, which raises safety concerns, such as emergency evacuations [14][15]. Considerable effort has been made to guide the massive crowd inside Taipei Metro transit stations and assist passengers to move faster during peak commuting hours. Directional signs, official announcements, graphic posters, and moving walkways were placed inside the Taipei Metro transit station to set specific paths for passengers. However, these graphical and physical elements still fail to catch the attention of passengers; numerous passengers still take detours, become lost, and cross each other's paths inside the station, possibly causing congestion. Moreover, slow-moving and stalled crowds in front of escalators can also cause congestion.

Unlike incident congestion caused by unexpected events, recurrent congestion usually occurs under normal circumstances [5][7]. Regardless of whether it is caused by the architecture, passenger behavior, or an identified human pattern, congestions occur on a daily basis in a similar manner. Behavioral mapping is used to reveal specific patterns and the individual behaviors of subjects from the same crowd, and can be used with the correlation research method within an observational study [6]. In general, researchers first design a recording sheet that requires a physical environment map of the area of interest. They then observe and track a person's physical location and behavior at preferred intervals, such as 5–10 s, to identify the relationship between each category of people [9][11]. The idea of this method is to record a reasonable number of passengers to reveal a pattern. Although this method has proven effective in behavioral studies, it has a fundamental drawback. Since a single researcher can only track one person at a time, this technique cannot be applied to situations where all behaviors of every individual in a crowd matter. To address this problem, tracking technologies, such as video imaging, conventional aerial monitoring, Closed Circuit Television (CCTV) [4], and heatmapping [3] have been developed. However, in such systems, the oversimplified tracking record fails to reveal the characteristics of each individual from the same crowd, thus failing to deliver the original intent of the research.

While undertaking behavioral mapping with a conventional method in a previous study; the development of a mobile application to reduce congestion at Taipei Metro transit stations based on behavioral studies [2], two difficulties were observed as follows. 1) It is not possible to track every person from the same crowd simultaneously, and 2) normal perspective video monitoring has the limitation of capturing the entire environment in the frame. Therefore, an omnidirectional camera, known as the 360-degree camera, was used in this study to extend the capability of the conventional behavioral mapping method. An omnidirectional camera has a wider perspective for comprehensively recording the entire environment [10]. A case study was conducted on crowd movement at the Taipei Metro transit station to test the effectiveness of the proposed computational behavioral mapping method. Possible causes were identified for passenger behaviors that lead to congestion and recurrent congestion inside the Mass Rapid Transit (MRT) station. Subsequently, a mobile application based on the identified patterns is proposed.

2 METHODOLOGY

2.1 360-Degree Video Recording

The peak commuting hours at 9 AM and 6 PM at the Taipei City Hall station were selected for behavioral tracking. In general, it is one of the busiest stations that connects the metro system to the business sector and city bus station. The station has an island platform [13] that is suitable for behavioral mapping via an omnidirectional camera. The Insta 360 ONE X [8] was mounted on a 2.2-m tripod, placed between two platforms, where all situations were recorded within the specified time (Figure 1).

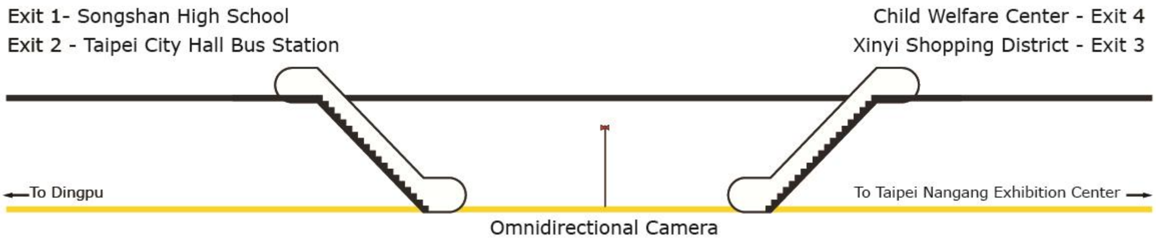

Figure 1: Omnidirectional camera location on the platform level.

2.2 Behavioral Tracking

Behavioral tracking was conducted by individually monitoring every passenger with a 360-degree camera to reveal all activities within the crowd. Researchers replayed the 360-degree video and tracked passengers one by one (from when they each disembarked a train, until they left the platform level), by marking their physical locations every 5 s on a recording sheet (Figure 2). Furthermore, the existing three-digit reference numbers [2] were used as codes to identify the physical location of each train gate and carriage at the platform level. As illustrated in Figure 3, the first digit refers to the direction or destination of a train, second digit refers to the carriage number, and last digit refers to a specific door on each carriage. The behavioral map shows the passengers' paths, preference in moving between levels, and other behaviors, such as showing an inclination to dawdle or use smartphones. Behaviors related to the use of smartphones included looking at a screen and making a call, while passengers who had smartphones on hand but did not perform these behaviors were not considered in the smartphone category.

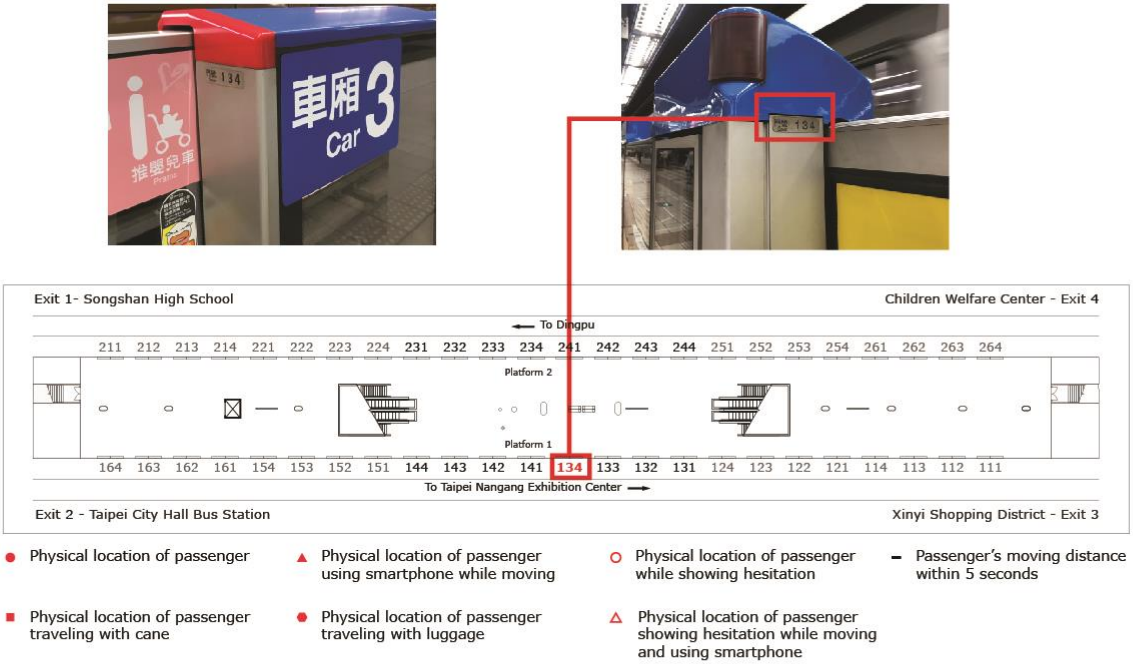

Figure 2: Three-digit reference numbers on the Bannan line platform (top photos) and behavioral recording sheet (bottom diagram).

The distances from the passengers' physical locations to escalators and stairs were identified by the three-digit reference numbers at every train gate and on both sides of the platform. The distances between passengers and train gates were determined by the floor tiles and perspective from replays of the 360-degree video. Figure 3 shows an example of behavioral tracking assisted by the 360-degree video. At 9:00:00 AM, the tracked passenger moved between train gates 134 and 141 (three-digit reference numbers) and twelve tiles away from the platform edge. As a result, the visual information from the video can be transferred to a continuous path on the map of the recording sheet.

Figure 3: Physical location and behavioral mapping of a passenger.

3 BEHAVIORAL MAPPING

Morning and evening time are the busiest times of the Taipei City Hall station, while MRT staff are trying to help passengers disembark the train and leave the platform quickly. Each individual's recording sheets were collected according to their disembarkation time to aid in the study of the causes of recurrent congestion at different times. The recording sheets overlapped for all tracked individuals, as illustrated in Figure 4, indicating that passengers moved differently during the morning and evening. In the morning, most passengers disembarked the train from the train gate closest to their preferred exit (Figure 4, top) and moved quickly to take the stairs to avoid the crowd congestion in front of the escalator. In contrast, the behavioral map illustrated that more passengers were using smartphones and preferred taking the escalator after disembarking the train in the evening (Figure 4, bottom). Several passengers hesitated and took a detour after disembarking from a train gate far from their preferred exit. The difference in the behavior of passengers disembarking a train during the morning and evening time was compared using a statistical analysis with respect to the collected data, as well as the relationship between time and passenger behavior.

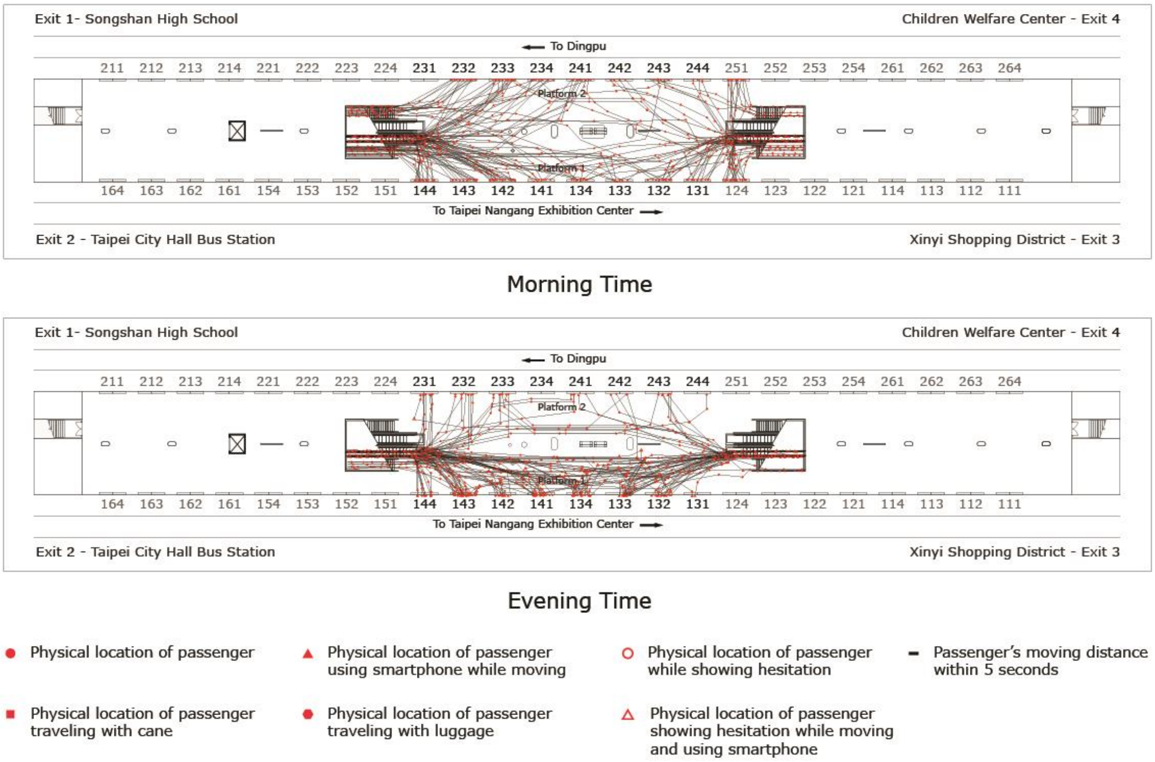

Figure 4: Behavioral mapping of passengers disembarking trains in the morning (top) and evening (bottom) at Taipei City Hall station.

The behavioral mapping results indicate that stalling and slow-moving crowds can possibly lead to recurrent congestion at the platform level. A stalling crowd occurs when an MRT train makes a quick stop during rush hours; the passengers disembark the train and leave the platform level. In addition, the stalling crowd can be directly related to the preference of how passengers choose to move vertically from the platform to the upper level that leads to the exits. The fastest route is to walk on the left side of the escalator, followed by walking on the stairs, and finally standing still on the right side of the escalator. As the escalator can only accommodate one path for both walking and standing at a time, how passengers prefer to slowly line up for the escalator or go ahead to take the stairs often determines how slow the stalling crowd is.

Table 1 shows the passengers' preferences for moving from the platform to the upper level during the rush hours of the morning and evening. This indicates that more passengers took the stairs in the morning than in the evening. A statistical analysis with chi-square further confirmed this observation, as the chi-square statistic x^2 = 26.768 exceeds the critical value for α = .001 (13.82). Therefore, it is statistically significant that time (morning or evening) affects passengers' preferences in moving between levels; a post hoc analysis further revealed that the preference of taking stairs differs in the morning and evening crowds (Table 2).

	Preferences of moving to the upper level		
	Escalator standing	Escalator walking	Stair
Morning	67	57	54
Evening	89	48	13
Total	156	105	67

Table 1: Passengers' preferences of moving to the upper level in the morning and evening.

Chi-square = 26.782, P=0.0000		
Pairwise comparison		
Pair 1:2 → Chi-square =	3.267,	p = 0.1952
Pair 1:3 → Chi-square =	36.299,	p = 0.0000 (p <.05)
Pair 2:3 → Chi-square =	14.737,	p = 0.0006 (p <.05)

Table 2: Chi-square and post hoc pair-wise comparisons of the passengers' preferences of moving to the upper level in the morning and evening.

An interesting finding was that people preferred to take the escalator standing still because they were engaged in using their mobile phones. Standing still on the rising escalator allowed passengers to safely move to the upper level while paying attention to their mobile devices. Table 3 shows the recorded behavior of the passengers using their smartphones, such as playing a game, reading/ texting messages, or watching video, while moving from the platform to the upper level. The results show that the percentage of smartphone use is significantly higher in the evening than that in the morning (41.3% versus 19.6%; x^2 = 18.354 exceeds the critical value of 10.83 for α = .001). This observation suggests that passengers constantly engaging with their mobile phones may prefer to wait in line to use the escalator. Not only will they move up more slowly, but this slow-moving crowd can also block the way for the passengers who decide to take the stairs. As a result, two key principles were drawn from this observational study to develop a solution for the identified recurrent congestion problem:

1) Stalling in front of the escalator seems unavoidable because the behavioral pattern of using a smartphone while commuting is difficult to change. The problem is how to direct the passengers to disembark from an MRT and move to the escalator via the shortest route to one's destination exit, so that the overall congestion is reduced.

2) Instead of a physical sign, solutions mediated on mobile applications can be effective because the slow-moving crowd are likely to be heavy users of mobile phones.

Preferences	Morning	Evening
Using smartphone	35	62
Not using smartphone	143	88
Total	178	150

Table 3: Passengers' behaviors of using and not using smartphones while disembarking a train in the morning and evening.

4 PROTOTYPE MOBILE APPLICATION SOLUTION

A mobile application named "Gate-to-Go" to reduce recurrent congestion inside the Taipei Metro was proposed and developed. The main concept is to develop a system that can guide the passenger to board the cart of transit that would be the one closest to the escalator, leading to the intended exit with the shortest route at the destination. In this prototype system, train gates from every station within the high-capacity MRT system were matched to the closest escalator using a three-digit reference numbers database. The mobile application recommends a train gate for passengers to board and disembark from, and the train gate closest to the escalator or to each passenger's preferred exit to avoid recurrent congestion based on the three-digit reference numbers system. A database was created that matches every train gate within the high-capacity MRT system to the closest escalators, stairs, and elevators. Table 4 lists the data for one of the MRT lines.

Matching of Three-Digit Reference Numbers Database

Station	***Exit***								
	1	2	3	4	5	6	7	8	9
Tamsui-Xinyi Line									
Xiangshan	124		162						
	131		214						
	252		221						
Taipei	121		161						
101/	252		221						
World	253		222						
Trade									
Center									
Xinyi-	124			154					
Anhe	251			221					
	252			222					
Daan		114			153				
		121			154				
		262			221				
Daan Park		114			162				
		253			214				
		254			221				
Dongmen	151	152			131				
	223	321			243				
	322	454			244				
					353				
					423				
					424				

Station	***Exit***								
	1	2	3	4	5	6	7	8	9
Tamsui-Xinyi Line									
CKS	162		113						
Memorial	254		114						
Hall	261		211						
	324		212						
			351						
	424		451						
NTU	144		132						
Hospital	151		244						
	231		251						
Taipei	121		151						
Main	252		223						
Station	254		224						
(M)									
Zhongshan	154		113		154				
	161		261		161				
	214		262		214				
Shuanglian	153	114							
	154	253							
	221	254							
Minquan	131		152						
W. Rd.	243		153						
	244		222						

Station	**Exit**								
	1	2	3	4	5	6	7	8	9
Tamsui-Xinyi Line									
Yuanshan	161	121							
	221	122							
	222	261							
Jiantan	122	153							
	253	221							
	254	222							
Shilin	112	151							
	262	222							
	263	223							
Zhishan	152	122							
	153	123							
	221	254							
Mingde	153	122							
	154	123							
	214	254							
Shipai	121	154							
	122	222							
	261	223							
Qilian	153	121							
	154	252							
	214	253							

Station	**Exit**								
	1	2	3	4	5	6	7	8	9
Tamsui-Xinyi Line									
Qiyan	121								
	252								
	253								
Beitou	153	153							
	154	154							
	221	221							
	222	222							
	321	321							
	322	322							
	422								
	423								
Fuxinggang	134								
Zhongyi	141								
Guandu	241								
Zhuwei	242								
Hongshulin									
Tamsui	152	141							
	153	142							
	223	241							

Table 4: Matching of the three-digit reference numbers database of the Tamsui-Xinyi line.

4.1 "Gate-to-Go" Application Prototyping

The Gate-to-Go mobile application was prototyped using Xcode 12.5. Xcode is an integrated development environment (IDE) offered by the Apple Company that allows developers to develop mobile applications using the Swift or Objective-C languages to run on a mobile device with iOS [1]. Figure 5 illustrates the operational flow of the proposed mobile application. Select and Next are the only gestural inputs required in the Gate-to-Go mobile application. Before entering the MRT gate, the user selects the boarding MRT line and station, as illustrated in Figure 5 (top). Then, the destination MRT line, station, and preferred station exit are selected. The recommended train gate based on the three-digit reference numbers database will then guide the user where to board the train, as illustrated in Figure 5 (bottom).

The Gate-to-Go mobile application provides a three-digit reference numbers corresponding to the recommended train gate that individual passengers need to board the MRT train. This provides the shortest route for every user to reduce recurrent congestion caused by the behavior of passengers crossing each other paths, as well as slow-moving and stalling crowds. In addition, a pilot study [2] also demonstrated that passengers hesitated while deciding which train gate to board at a platform, as decision-making is one of the factors that leads to passenger hesitation [16]. This proposed solution can therefore also reduce this hesitation by providing a determined suggestion for where to wait, saving the time for the passenger wandering around the platform to decide where to wait based on various reasons, such as how far to walk and the number of people already waiting there.

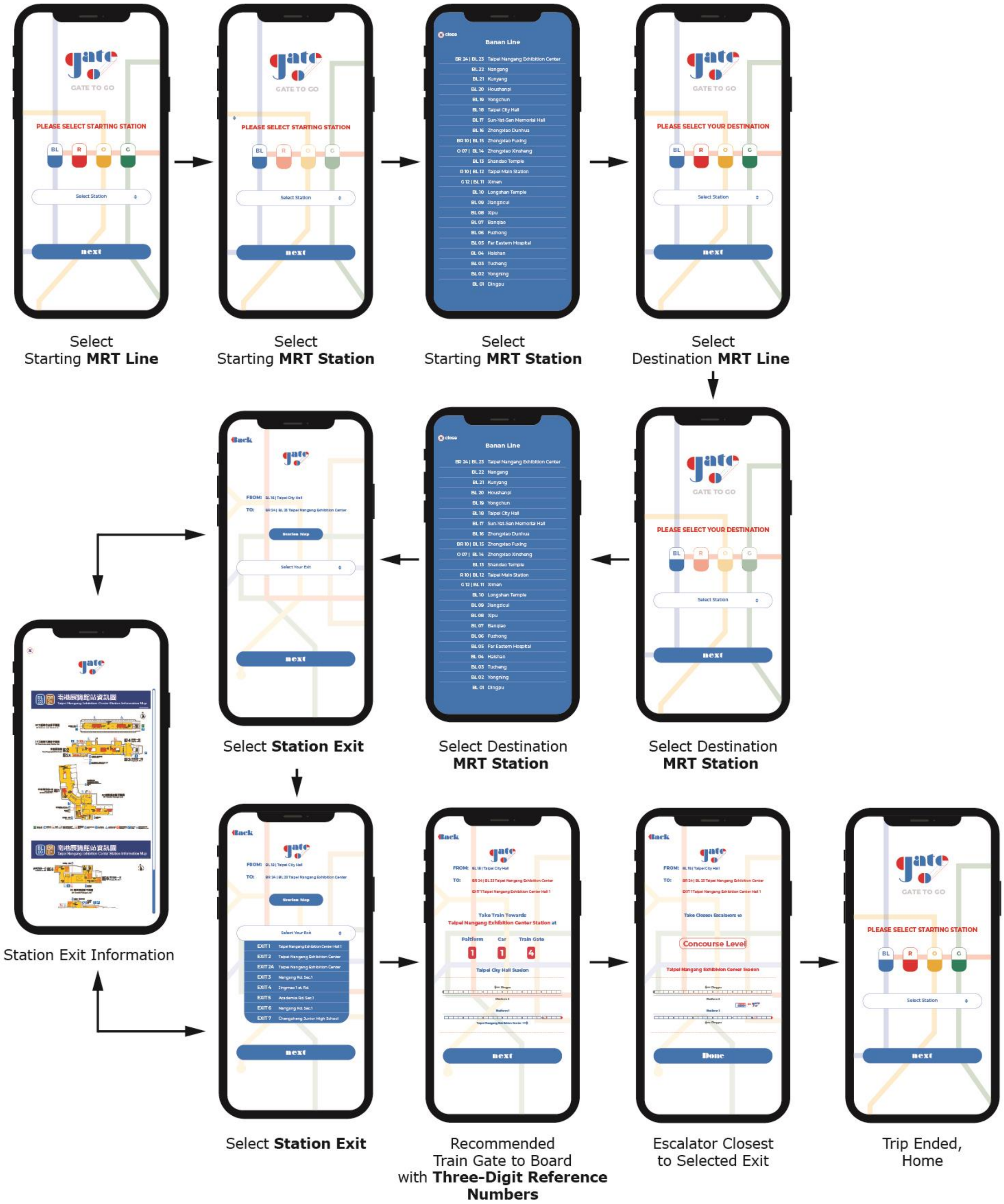

Figure 5: Operational flow of the mobile application of Gate-to-Go.

5 CONCLUSION

Assisted by 360-degree video recording, the efficiency of conventional methods for performing behavioral mapping was improved, as confirmed by a case study of crowd movement at the Taipei Metro transit station. As well as the passengers' physical locations, the 360-degree video simultaneously recorded behaviors of individuals, such as showing an inclination to dawdle or linger, taking detours, using smartphones, crossing each other's paths, and their preferences for moving between levels.

The passengers were tracked using recorded 360-degree videos, data were collected as behavioral mappings, and a statistical analysis was performed. The results show that the time of the day is an important factor affecting passengers' behavior while disembarking a train. Passengers traveling in the morning manage routes and travel time constraints more proficiently, as they are on their way to work, school, or duties. Notably, they moved faster and preferred to take the stairs to avoid the slow-moving and stalling crowd in front of the escalator. The passengers traveling in the evening had fewer constraints; they moved more slowly and showed more hesitation while performing other activities on the go, such as using smartphones.

It is difficult to change the in-transit smartphone usage patterns of passengers. However, the results showed that smartphones may become a useful tool to assist passengers in navigating MRT stations more efficiently. In particular, the passengers that were more likely to cause congestion, were often using a smartphone. A mobile application to reduce identified recurrent congestion inside the Taipei Metro transit station was prototyped, which employs a database of the three-digit reference numbers system for numeric navigation. This study only included escalators and stairs as choices for moving between levels for the majority of passengers, since the elevator is only provided for passengers with special needs. Passengers use the application before they enter the MRT gate to the recommended train gate for train boarding so they can disembark the train through the train gate closest to their preferred exit. Passengers do not need to use the application while walking inside the station. The elevators' proximities to train gates were also collected for further development. Gate-to-Go is currently recommended for only one train gate for each exit to reduce passenger hesitation at the platform level. However, there were multiple train gates close to the same station exit, which were obtained from the three-digit reference numbers database. There is the possibility of future development to organize the waiting order of passengers according to queueing theory [12]. The exact effectiveness of this mobile application for the recurrent congestion observed in the MRT requires future study to ascertain how likely passengers are to use it. Notwithstanding, as one passenger can take a shorter route and less time to exit the platform, it will contribute to reducing congestion. Therefore, the mobile application of Gate-to-Go shows potential in reducing congestion if numerous passengers in the same crowd use it simultaneously.

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