Title:
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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Introduction:
Mobile application was developed to reduce recurrent congestion in Taipei Metro transit stations, following a case study of crowd movement on platforms of Taipei City Hall station. Behavioral mapping was employed as a research tool to record and analyze movement and behavior of the crowd. However, conventional behavioral mapping has fundamental drawbacks, and thus, cannot be applied to situations where the totality of group behaviors matter. This study proposed a practical procedure to perform behavioral mapping with the assistance of 360-degree video recording, which was then validated by a case study. By performing 360-degree video scanning, movements and behaviors of groups and individuals were recorded; then, 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 directing passengers, a matching system of closest escalator to every train gate on platform level was collected into a database using the three-digit reference numbers already in use that can be found on every train gate within high-capacity systems, to identify the location of each train gate at platform level.

Main Idea:
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 stations to set specific paths for passengers. However, these graphical and physical elements still failed to catch passengers' attention; numerous passengers still take detours, become lost, and cross each other's paths inside the station, which possibly causes congestion. Moreover, slow-moving and stalled crowds in front of escalators can cause congestion. Behavioral mapping is used as a research technique to reveal specific patterns as well as the individual behaviors of subjects from the same crowd, which is considered as part of the correlation research method within an observational study [3]. Recurrent congestion usually occurs under normal circumstances [4], and can be found in every MRT station, regardless of whether it is caused by the architecture, passengers' behavior, or an identified human pattern.

In general, researchers first design a recording sheet that requires a physical environment map of the area of interest. Then, they observe and track a person's physical location and behavior at preferred intervals of 5–10 s to identify the relationship between each category of people. 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 does have fundamental drawbacks. Since one 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 technology, such as video imaging and heatmapping [2], has been developed. However, in such systems, the oversimplified tracking record failed to reveal the characteristics of each individual from the same crowd, thus failing to deliver the original intent of the research. Two difficulties were observed while undertaking behavioral mapping with a conventional method in the previously proposed study: Development of a mobile application to reduce congestion at Taipei Metro transit stations based on behavioral studies. 1) It is not possible to simultaneously track every person from the same crowd individually. 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 experimentally 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. A case study was made of crowd movement at the Taipei Metro transit station to attest the effectiveness of the new computational behavioral mapping method. Possible causes were identified for passenger behaviors that lead to congestion and recurrent congestion inside the MRT station. Subsequently, using a mobile application based on the identified patterns was proposed as a solution to conclude this study.

<u>Case Study:</u>
The peak commuting hours, 9 AM and 6 PM, at Taipei City Hall station were selected to perform behavioral tracking. In general, it is one of the busiest stations, which also connects the metro system to the business sector and city bus station. The station has an island platform, [5], which accommodated behavioral mapping assisted by an omnidirectional camera. The Insta 360 ONE X was mounted on a 2.2-m tripod and placed between two platforms, where researchers could record all situations within the specified time from above (Fig. 1).

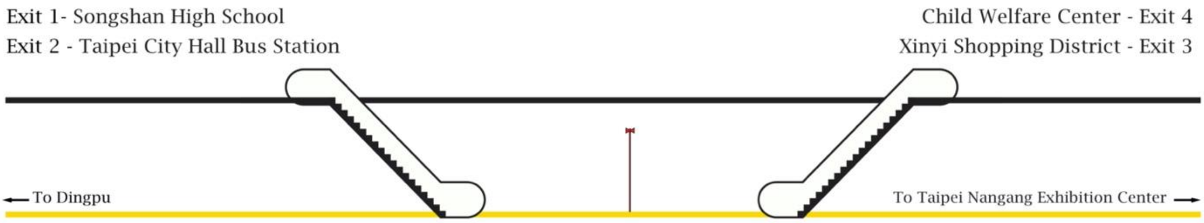


Fig. 1: Omnidirectional camera's location on the platform level.

Behavioral Mapping
The behavioral tracking is conducted by individually monitoring every passenger with a 360-degree camera to reveal all activity within the crowd. Researchers replayed the 360-degree video, and tracked passengers from when they were disembarking a train until they were leaving the platform level by marking their physical locations every 5 s on the designed recording sheet (Fig. 2). Furthermore, the existing three-digit reference numbers [1] were used as a code to identify the physical location of each train gate and carriage at the platform level. The behavioral map shows the passengers' paths, preference in moving between levels, and other behaviors such as showing an inclination to dawdle or using smartphones.

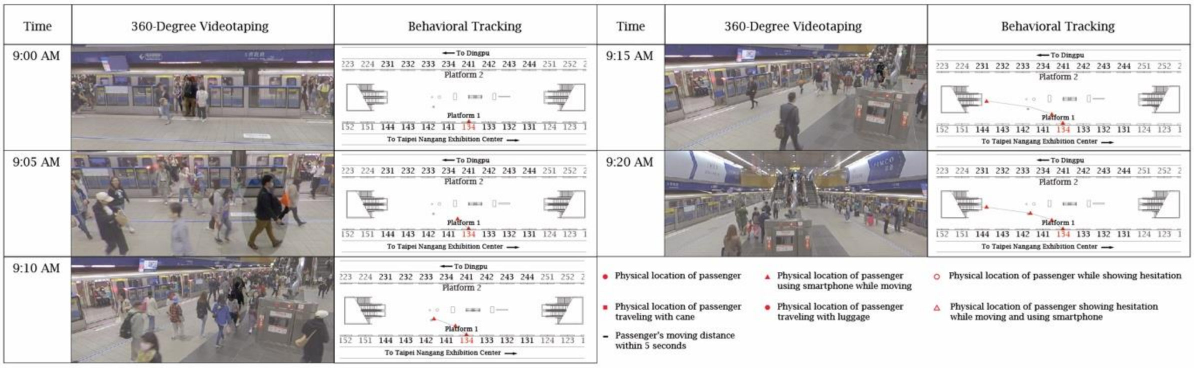


Fig. 2: Physical location and behavioral mapping of a passenger.

Each individual's recording sheets were collected according to their disembarkation time, which indicates that passengers move differently in the mornings and evenings. In the morning, the majority of passengers disembarked the train from the train gate closest to their preferred exit (Fig. 3 top), and moved quickly to take the stairs to avoid stalling the crowd in front of the escalator.

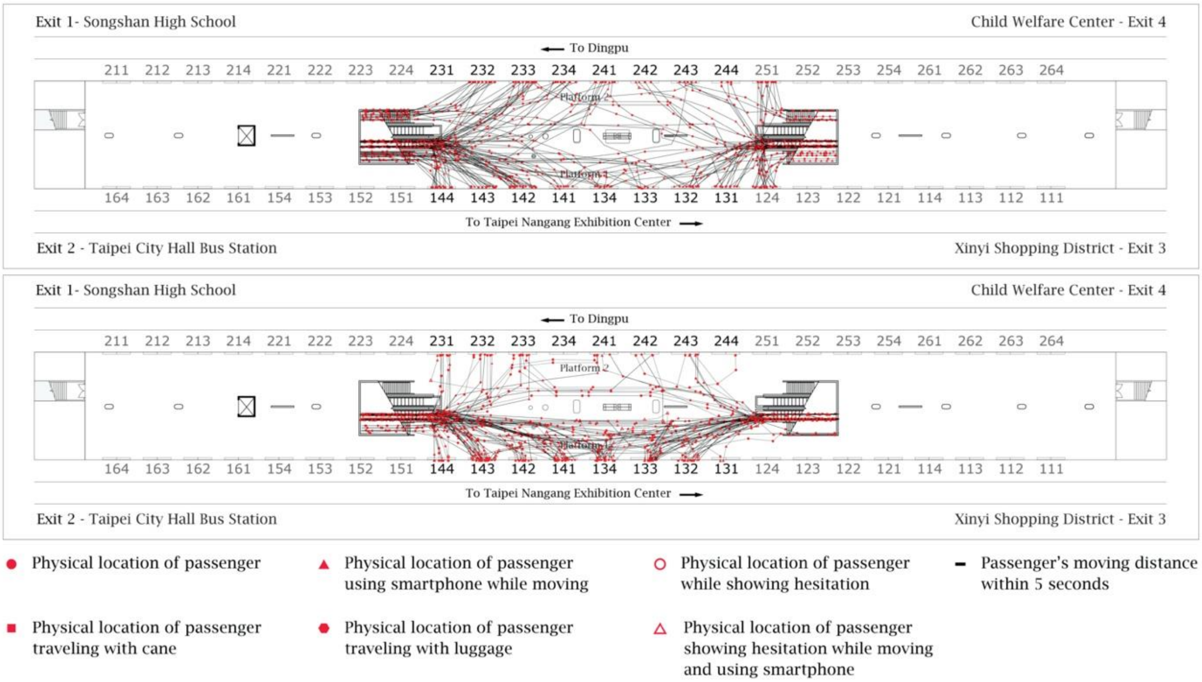


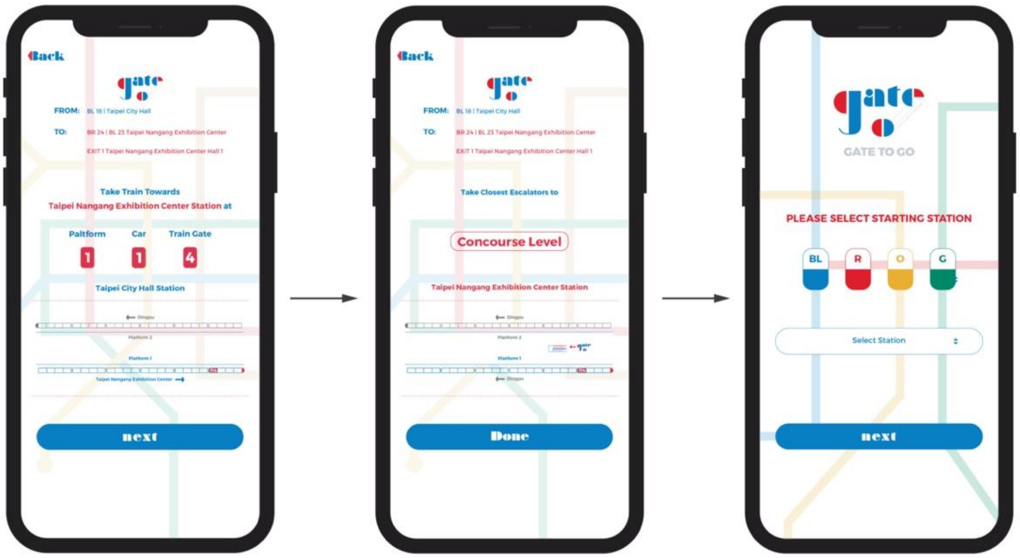
Fig. 3: Behavioral mapping of passengers disembarking trains in the morning (top) and evening (bottom) at Taipei City Hall station.

In contrast, the behavioral map shows that more passengers were using smartphones and preferred taking the escalator after disembarking the train in the evening (Fig. 3 bottom). Several passengers hesitated and took a detour after disembarking from a train gate far from their preferred exit.

Behavioral mapping indicates that stalling and slow-moving crowds possibly lead to recurrent congestion on the platform level. A stalling crowd can be found when every MRT train makes a quick stop until the passengers disembark the train and leave the platform level; whether the passengers prefer to stand on the right side or walk on left side of the escalator depends on the number of passengers trying to use the escalator simultaneously. In addition, a slow-moving crowd can be noticed, as passengers took longer to exit the platform level because they had to move through a stalling crowd in front of the escalator. Although more passengers took the stairs in the morning, the difference in numbers between the stairs and escalator was significant.

Using the collected data, chi-square was conducted to compare and find the correlation between the time and passengers' behavior. It is statistically significant that time affects passengers' preferences in moving between levels; more passengers took the stairs in the morning, while using the escalator is more popular in the evening. There is no significant difference between preferring to stand or walk on the escalator. It is also significant that time affected the behavior of using a smartphone while disembarking the train, which led the design of a mobile application being proposed to reduce recurrent congestion caused by stalling and slow-moving crowds.

Mobile Application to Reduce Recurrent Congestion
The mobile application recommends a train gate for passengers to board and disembark that is closest to the escalator or leads to each passenger's preferred exit, which is based on the three-digit reference number system. For a database, this research matched every train gate within the MRT high-capacity system to the closest escalators, stairs, and elevators.



Recommended Train Gate to Board with Three-Digit Reference Numbers

Recommended Escalator Towards Selected Station Exit

Trip Ended

Fig. 4: Wireframe of "Gate to Go" application—three-digit reference number navigation.

Conclusion:
Assisted by 360-degree video recording, the efficiency of conventional methods for performing behavioral mapping was improved, which is confirmed by a case study of crowd movement at the Taipei Metro transit station. Notwithstanding the passenger's physical locations, the 360-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-videos, data were collected as behavioral mappings, and statistical analysis was performed. The results show that time is the most important factor affecting passengers' behavior while disembarking the train. The 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 taking the stairs to avoid the slow-moving and stalling crowd in front of the escalator. The study also showed that 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 pattern of passengers. However, a smartphone can become a handy tool to assist passengers to navigate the MRT stations more efficiently. A mobile application to reduce identified recurrent congestion inside the Taipei Metro transit station is proposed, which employs a database of the three-digit reference number system for numeric navigation. Passengers only need to use the application before they enter the MRT gate to know the recommended train gate they should use to board a train so that they could automatically disembark the train through the train gate closest to their preferred exit. Passengers do not need to use the application while they are walking inside the station.

This study only focused on the escalators and stairs as choices for moving between levels for the majority of passengers since the elevator is provided for passengers with special needs. However, matching the elevators' proximity to train gates should also be collected for further development.

The mobile application shows good potential for reducing congestion; numerous passengers from the same crowd simultaneously using it will demonstrate its impact.

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