Hindawi Publishing Corporation
Mathematical Problems in Engineering
Volume 2012, Article ID 701852, 12 pages
doi:10.1155/2012/701852

Research Article

Adaptability Analysis of Service Facilities in Transfer Subway Stations

Liya Yao,[1] Lishan Sun,[2] Wuhong Wang,[1] and Hui Xiong[1]

[1] *Department of Transportation Engineering, Beijing Institute of Technology, 5 South Zhongguancun Street, Haidian District, Beijing 100081, China*
[2] *Key Laboratory of Traffic Engineering, Beijing University of Technology, 100 Pingleyuan, Chaoyang District, Beijing 100124, China*

Correspondence should be addressed to Liya Yao, yaoliya@bit.edu.cn

Received 19 July 2012; Accepted 4 November 2012

Academic Editor: Huimin Niu

Copyright © 2012 Liya Yao et al. This is an open access article distributed under the Creative Commons Attribution License, which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.

Service capability and matching degree of transfer facilities are directly related to the operational efficiency and safety of a subway station. Owing to differences in planning and construction, the transfer subway stations in developing countries have some defects in facility size and serviceability, which cause a decline in service performance, operation efficiency, and security level. In order to solve the problems, traffic investigations were conducted on the form, size, and operation status of several typical transfer subway facilities. The service facilities were classified within a subway station in this research by considering service objects, service forms, service functions, and several other features. In addition, pedestrian behavior and pedestrian flow characteristics in different service facilities were analyzed in detail. The research results are deemed meaningful for the optimization of service facilities in subway stations and for the development of urban pedestrian transportation systems.

1. Background

As important modes of public transportation, the subway has become part of daily commuter life in China, especially in Beijing. During the past half century, a great amount of changes have taken place both in the construction conditions and design standards of subways. Moreover, the design scale of transfer facilities and the connecting modes in each subway line have become dramatically different. Along with the rapid construction of the subway network in Beijing, subway lines that were constructed under different standards during different periods are now linked at transfer hubs. As a result, unreasonable infrastructures and mismatched capacities for subway facilities led to pedestrian interweaving and jamming. Several research interests on subway facilities have emerged, including service level of various transfer facilities, subway facilities match, characteristics of pedestrian flow at different subway facilities, and efficiency of a subway station.

The method of adaptability has been broadly used in the biological and engineering domains in the past years [1, 2]. The service level of facilities was first recommended in the *Highway Capacity Manual* 2000 (HCM2000) [3]. Pedestrian facility service level is divided based on the quantitative observation of pedestrian parameters, such as velocity, density, and flow. Fruin [4] proposed an algorithm for calculating the service level in pedestrian facilities, including footways, stairs, and queuing areas. The division of the level is based on pedestrian velocity, space, and conflict probability. Domestic scholars have obtained preliminary results in the characterization of pedestrians and facilities [5–7].

Indexes such as walking time, speed, waiting time, walking distance, choice of walking route, selection of stairways, or elevators were studied for the traffic characteristics of a single pedestrian. Lam et al. [8, 9], Young [10], and Paul [11, 12] obtained pedestrian walking speed at different facilities for different pedestrian characteristics. Hoskin [13] stated the definition of facility volume. Ayano et al. [14] studied the influence of different pedestrian volumes on actual capacity by cellular automata, which yielded the maximum pedestrian volume in a single direction, in two directions, and in four directions. Thompson [15] described pedestrian behavior and divided it into five types: route-selecting behavior, crash-avoiding behavior, pursuing behavior, arriving and leaving behavior, and lingering behavior. Hine [16] showed that traffic circumstance has a great influence on pedestrian behavior. Lam et al. [17–19] and Delft [20] studied the rule of pedestrian flow characteristics and route selection at subway stations and surveyed and simulated facility service level. Wang et al. [21, 22] conducted numerous studies on the theory of behavior simulation. Christian et al. [23] studied the distribution of walking speed and route selection behavior. Helbing et al. [24] performed numerous experiments on emergency evacuation.

The characteristics of pedestrian flow, pedestrian volume, density, and average speed were studied weightily. Hughes [25] revealed the maximum speed and density of pedestrian flow. The relationship between pedestrian speed and density was studied by Ando et al. [26], Thompson and Marchant [27], Hughes [28], Hankin and Wright [29], and so on. Cheung and Lam [18] and Tanaboriboon et al. [30] studied the relationship between pedestrian volume and density. However, existing methods fail to consider the matching of various transfer facilities and to evaluate the adaptability of facilities with pedestrian flow characteristics. This paper conducts an in-depth study on the adaptability of subway transfer facilities with a consideration to pedestrian flow characteristics.

The remainder of the paper is structured as follows. Section 2 briefly discusses the current status of subway lines and the classification of transfer facilities in Beijing. Section 3 introduces the basic methods of the survey and the behavior indicators of pedestrian flow on transfer facilities. Section 4 presents the relationship among density, volume, and speed on stairways, corridors, platforms, and so on. Section 5 presents the adaptability analysis. Finally, Section 6 presents the conclusions.

2. Transfer Facility Classification

No references for a uniform design standard concerning the early years of subway construction in China are available. Subway designers had to refer to specifications abroad, which resulted in the difference in transfer facility capabilities among different subway lines. Arbitrary design became a serious problem in the first decades of subway construction

Table 1: Design parameter comparison between the new and old standards of China.

Minimum width	GB50157-92	GB50157-2003
Corridor	2.5 m	2.4 m
Stair	2 m	2.4 m
Island platform	8 m	8 m
Interisland platform	2 m	2.5 m
Column-free side platform	3.5 m	2.5 m
Column side platform	3 m	3.5 m

in China. In 1992, the first national standard for subway design (underground railway design standard (GB50157-92)) was issued by the Ministry of Housing and Urban-Rural Development of China. This design standard was replaced by a completely revised version in 2003: subway design standard (GB50157-2003). Numerous differences exist between these two standards, especially in the design parameter requirements of transfer facilities. Design parameter comparisons are given in Table 1 [31, 32].

According to the national standard, plenty of existing studies classified transfer facilities as traffic service facilities, information service facilities, assistant service facilities, and so on. In this paper, traffic service facilities, such as stairs, corridors, and platforms are used as examples to analyze the adaptability of a facility.

3. Research on Characteristics of Transfer Facilities

3.1. Investigation Scheme Design

Pedestrian behavior depends largely on the adaptability of transfer facilities. We investigated pedestrian behavior in typical service facilities of transfer subway stations in Beijing in December, 2011, to obtain typical pedestrian characteristics at various facilities, with reference to the classification of the aforementioned transfer facilities.

3.1.1. Investigation Time

The great pressure of pedestrian flow in transfer facilities and the significance of pedestrian flow characteristics presented in peak periods were taken into account when choosing investigation times; thus, the morning peak hour (8:00–9:00) and evening peak hour (17:00–18:00) were selected.

3.1.2. Investigation Area

The selected stations for investigation were Jianguomen Subway Station, where early-built lines are connected; Dongzhimen Subway Station, where early-built, midterm-built, and newly-built lines are connected, Haidianhuangzhuang Subway Station, where recently-built lines are connected (Figure 1). Our investigations focused on the different forms of staircases, corridors, and platforms to analyze the adaptability of transfer facilities in different eras under different criteria.

Figure 1: Distribution of subway lines and subway stations investigated in Beijing.

Table 2: Design parameters of main transfer facilities of subway stations in different years.

Construction year	Staircase width/m	Corridors width/m	Platform width/m	Reference standard
1960~1990	3.5	3.5	7	Soviet standard
1991~2003	2.5–5	3.5	7	GB50157-92
2003~2010	4	4	10	GB50157-2003

3.1.3. Data Collection Method

Artificial methods and video data collection of pedestrian behavior characteristics were adopted in the investigation with regards to heavy pedestrian flow transfer and high pedestrian walking speed.

3.2. Characteristics of Transfer Facilities

3.2.1. Width Parameters of Main Transfer Facilities

Service facilities of various subway stations differ in size, connecting characteristics, location, service level, and so on. The parameters of recently constructed service facilities are better compared with earlier ones (Table 2).

3.2.2. Characteristics of Pedestrian Behavior at Main Transfer Facilities

Staircases, corridors, and platforms are not only the main function facilities for pedestrian transfer within the spatial dimensions but also important routes for pedestrian emergency evacuation. The following indicators were selected after taking into account the characteristics of the distribution and interweaving of high-density pedestrian flow: average walking speed, average space, average flow rate, and peak 15-min volume of pedestrian traffic flow. These indicators were used to describe the characteristics of various types of transfer facilities.

Average walking speed (V): average pedestrian walking distance in a specified direction per unit time is generally expressed in m/s.

Table 3: Indicators describing characteristics of pedestrian flow at stairways and corridors.

Subway station	Facility	Average width (m)	Average space (m^2/per)	Average speed (m/s)	Average flow rate (per/min · m)	Pek-15min volume (per/15 min)
Jianguomen	Staircase	2.5	0.59	0.42	37.65	1412
	Corridor	3.5	1.76	1.22	37.45	1966
Dongzhimen	Staircase	3.5	1.00	0.46	29.04	1525
	Corridor	4.0	1.21	1.01	53.25	3195
Haidianhuan-gzhuang	Staircase	4.0	1.23	0.51	25.05	1503
	Corridor	3.0	1.98	1.17	42.00	1890

Table 4: Indicators describing characteristics of pedestrian flow at platforms.

Platform	Jianguomen		Dongzhimen		Haidianhuangzhuang	
	Line 1	Line 2	Line 2	Line 13	Line 4	Line 10
Average pedestrian space m^2/person	0.31	0.42	0.38	0.59	0.79	0.72

Average pedestrian space (S): average area provided for each pedestrian by the transfer facilities is calculated by Formula (3.1). Average pedestrian space is the reciprocal of pedestrian density, generally expressed as m^2/person:

$$S = \frac{V \times W_E}{Q}, \tag{3.1}$$

where W_E is effective width of facilities, m; Q is pedestrian flow volume, person/h.

Peak 15-min pedestrian volume (Q_{15}): maximum pedestrian flow volume in 15 minutes, generally expressed as person/15 min.

Pedestrian flow rate (P): the number of pedestrians passing through per unit width of a certain section of the facilities per unit time is generally expressed as person/min·m:

$$P = \frac{Q_{15}}{15 \times W_E}. \tag{3.2}$$

Pedestrians naturally slow down while arriving at stairs or corridors because of changes in facility types, leading to serious congestions or queues in front of stairs or corridors. The characteristics of moving pedestrian flow at stairways and corridors, such as average speed, average flow rate, and peak 15-min pedestrian volume, are described by the survey data (Table 3).

Subway station platforms provide a place for pedestrians to realize traffic functions, such as waiting, getting on and disembarking from the train, evacuating, and transferring. Intertwined pedestrian flow frequently occurs on the platform in all directions, causing significant changes in pedestrian density and walking space. The characteristics of pedestrian flow at platforms are described by the average pedestrian space in this paper (Table 4).

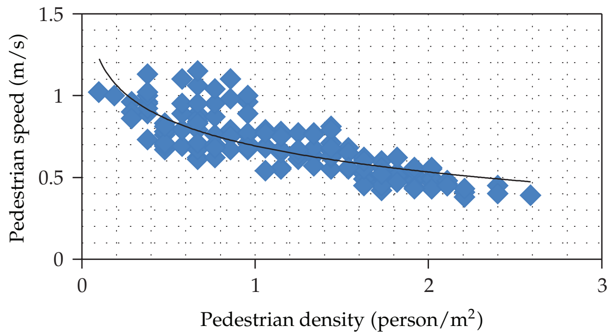

Figure 2: Relationship between pedestrian density and speed at stairways.

4. Relationship among Density, Volume, and Speed at Typical Service Facilities

4.1. Stairways

Pedestrian characteristics at stairways are not only influenced by the stairway itself but also by pedestrian gravity and interaction. Based on video observations, we found that walking speed is decreased when going downstairs. The down stairway located in the west of the Haidianhuangzhuang Subway Station was taken as an example. The investigation point was very crowded because all pedestrians converge at this location from the south and north of the transfer corridors of subway Line 10.

The data obtained at the down stairway area yielded the scatter diagram between pedestrian density and speed. Furthermore, the curve between density and speed should be fitted. Comparisons of all regression equations reveal that the logarithm model is best used in the regression analysis of pedestrian density and speed at stairways. The scatter diagram and regression curve are shown in Figure 2.

The logarithm equation obtained by fitting is expressed as

$$y = 0.23 \ln(x) + 0.6928. \tag{4.1}$$

Pedestrian flow volume is the number of pedestrians passing through per unit width, which is calculated by the product of pedestrian speed and density. Based on the calibrated parameters, the maximum pedestrian flow volume and the corresponding pedestrian density of the unit width were obtained and called pedestrian flow rate.

The analyzed data obtained at the down stairway yielded the scatter diagram between pedestrian density and volume. Furthermore, the curve between density and speed should be fitted. Comparisons of all regression equations reveal that the quadratic model is best used for the regression analysis of pedestrian density and volume at down stairways (Figure 3).

The quadratic equation obtained by fitting is expressed as

$$y = 0.2473x^2 + 0.9796x + 0.0065. \tag{4.2}$$

The maximum pedestrian flow rate and the corresponding pedestrian density were calculated according to the parameters obtained by fitting. Based on Figure 3, the maximum

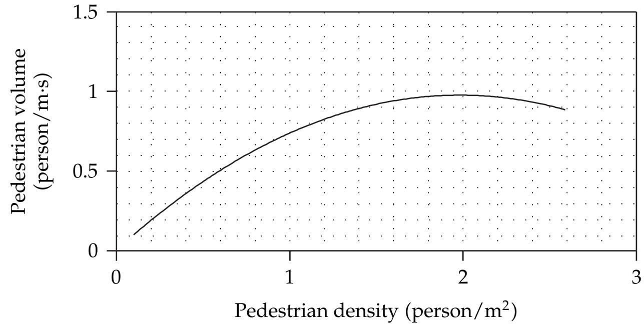

Figure 3: Relationship between pedestrian density and volume at stairs.

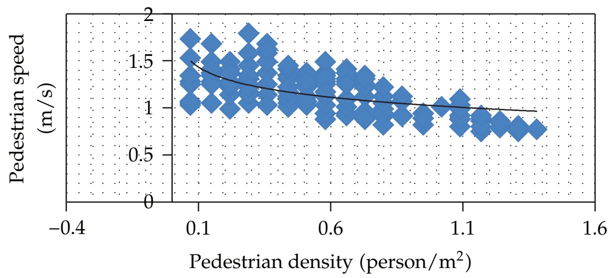

Figure 4: Relationship between pedestrian density and speed at corridors.

pedestrian flow rate is 0.97 person/m·s, and the corresponding pedestrian density is 1.98 person/m^2.

The curve begins to embody the falling trend at this point, which is the passing capacity of the stairways. As this trend develops, the stairways will become unstable for pedestrian flow, which means that pedestrian volume exceeds the capacity of the stairways. Queuing phenomenon will occur, and pedestrian volume will decrease instead of increase until the pedestrian volume becomes zero, and the corresponding density is called jamming density.

4.2. Corridor

Similar to stairways, corridors also belong to passing facilities where pedestrian characteristics are influenced by connecting service facilities, such as platforms. The corridor in the south channel from subway Line 10 to Line 4 of Haidianhuangzhuang Subway Station was taken as an example. From the investigation and video observations of the selected corridor, we found that pedestrian flow is more fluent at the corridor compared with the selected stairway. The fluent pedestrian flow is mainly because of the square-built connecting area, where the phenomenon of crowding is infrequent.

The analyzed data obtained at the corridor yielded the scatter diagram between pedestrian density and speed. Furthermore, the curve between density and speed should be fitted. Comparisons of all regression equations revealed that the logarithm model is best used in the regression analysis of pedestrian density and speed at corridors. The scatter diagram and regression curve are shown in Figure 4.

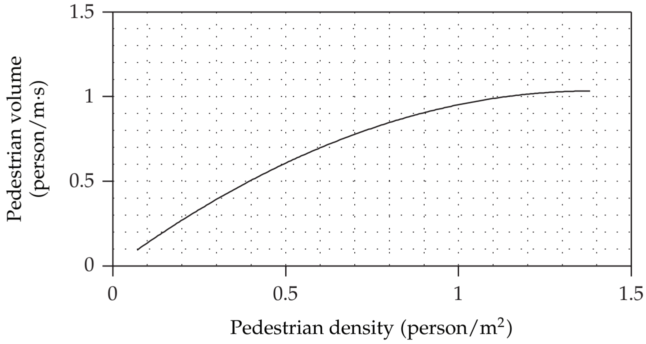

Figure 5: Relationship between pedestrian density and volume at corridors.

The logarithm functional relation obtained by fitting is expressed as

$$y = 0.178\ln(x) + 1.0224. \tag{4.3}$$

The analyzed data obtained at the corridors yielded the scatter diagram between pedestrian density and volume. Furthermore, the curve between density and speed should be fitted. Comparisons of all regression equations reveal that the quadratic model is best used in the regression analysis of pedestrian density and volume at corridors (Figure 5).

The quadratic functional relation obtained by fitting is expressed as

$$y = 0.5417x^2 + 1.5025x + 0.0087. \tag{4.4}$$

The maximum pedestrian flow rate and the corresponding pedestrian density were calculated according to the parameters obtained by fitting. Based on Figure 5, the maximum pedestrian flow rate is 1.04 person/m·s, and the corresponding pedestrian density is 1.42 person/m^2.

The curve is smooth at this point, and the theoretic maximum value is still not reached. However, calculating the service level of such points is also meaningful because of the potential service capacity at such points.

4.3. Platform

Pedestrian characteristics, such as flow density and speed, are influenced by connecting service facilities. The platform in the east of the Haidianhuangzhuang Subway Station at Line 4 was taken as an example. According to the investigation, pedestrian flow density is largest at the point where the platform and stairs connect.

The analyzed data obtained at the platform area yielded the scatter diagram between pedestrian density and speed. Furthermore, the curve between density and speed should be fitted. Comparisons of all regression equations reveal that the logarithm model is best used in the regression analysis of pedestrian density and speed at platforms. The scatter diagram and regression curve are shown in Figure 6.

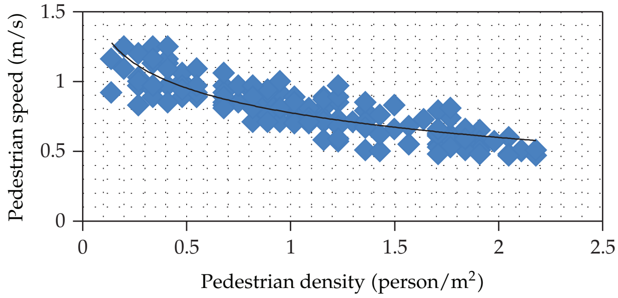

Figure 6: Relationship between pedestrian density and speed at platform.

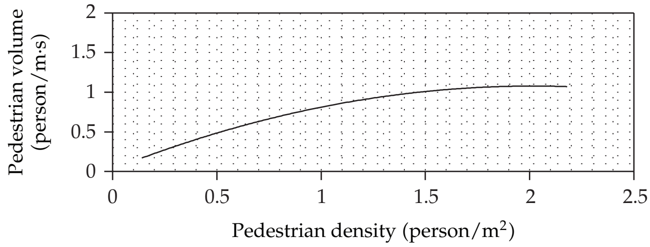

Figure 7: Relationship between pedestrian density and volume at platform.

The logarithm functional relation obtained by fitting is expressed as

$$y = 0.255 \ln(x) + 0.7758. \tag{4.5}$$

The analyzed data obtained at the platforms yielded the scatter diagram between pedestrian density and volume. Furthermore, the curve between density and volume should be fitted. Comparisons of all regression equations reveal that the quadratic model is best used in the regression analysis of pedestrian density and volume at the platforms (Figure 7).

The quadratic functional relation obtained by fitting is expressed as

$$y = 0.2576x^2 + 1.0387x + 0.0305. \tag{4.6}$$

The maximum pedestrian flow rate and the corresponding pedestrian density were calculated according to the parameters obtained by fitting. Based on Figure 7, the maximum pedestrian flow rate is 1.08 person/m·s, and the corresponding pedestrian density is 2.02 person/m^2.

The curve begins to embody the falling trend at this point. The curve is stable although the decreasing pedestrian flow at the platform is not as obvious as that at the stairs.

5. Adaptability Analysis of Transfer Facilities

The adaptability of transfer facilities can be defined as the adaptation degree of the facilities faced with pedestrian volume based on physical properties and abilities. Based on the design parameters of the studies, such as the connecting layout and usage status, this paper analyzed

Table 5: Service level of main transfer facilities in peak hours.

Subway station	Jianguomen			Dongzhimen			Haidianhuangzhuang		
	Stairs	Corridor	Platform	Stairs	Corridor	Platform	Stairs	Corridor	Platform
v/c	0.77	0.50	—	0.59	0.71	—	0.51	0.56	—
Service level*	E	D	D	D	E	D	C	D	C

Service level*: according to *Highway Capacity Manual* 2000 (HCM2000).

the service level of subway station facilities. Furthermore, the capability of the facilities to meet the transfer needs of pedestrians was also determined. The service level of the selected transfer facilities in the three subway stations at peak hour was obtained according to investigation data of pedestrian flow characteristics at certain facilities in the subway stations (Table 5). The service level was obtained using the aforementioned method and the existing standard on facility service level as a reference.

Based on Table 5, the service level of various transfer facilities is low during peak hours and the service ability of most facilities is able to meet the basic transfer demand of pedestrians. The stairs at the Jianguomen Station and the corridors at the Dongzhimen Station are the key facilities in improving the service level of the subway station. The main reasons that lead to e-class are as follows.

(1) Imbalance between the service level of old facilities at subway stations and the increasing transfer demand of pedestrians: the subway stations constructed in the 1970s, such as the Jianguomen Station, mainly referred to the subway design standard of the former Soviet Union, which mostly adhered to combat readiness and evacuation protocols, and only took into account a few concepts of traffic function. Along with the rapidly increasing pedestrian volume, existing transfer facilities are not prepared to meet the traffic demand. In addition, the adaptability of the facilities is poor. For example, the Jianguomen Subway Station has four-segmented stairways that connect subway Line 1 to subway Line 2. Excessive stairways promote pedestrian queuing before the stairways, which even spreads to the station platform during peak hours. Pedestrian queuing not only occupies platform space but also decreases transfer efficiency.

(2) Unbalanced service level of transfer facilities built in different periods: because of different standards referred to during different periods, subway facilities face balance problems, which occur when two or more subway lines connect to the same subway station. Three subway lines are connected at Dongzhimen Station: subway Line 2, built in 1970; subway Line 13, built in 1999; the airport express line, built in 2008. Differences in scale, size, and layout exist among these transfer facilities. The sudden change in the size or layout of the transfer facility makes crowding and interweaving of pedestrians at the corridor entrances common.

6. Conclusions

The transfer facilities of numerous subway stations in Beijing obviously vary in terms of form, scale, and layout because of difference in design ideas and standards. A systematic analysis of the adaptability of transfer facilities in transfer subway stations is important in enhancing the overall performance of Beijing's public transport system. This paper conducted an adaptability analysis framework using commonly available variables in response to the absence of a pedestrian behavior model for transfer facilities.

This paper investigated and analyzed the design scale, layout form, and operating status of typical transfer subway stations in Beijing. The service adaptability of transfer facilities was studied based on the investigation data. This paper will enable subway designers to match different transfer facilities effectively and improve the operation performance of transfer subway stations according to comparisons between pedestrian behavior and facility adaptability. The main conclusions are as follows.

(1) Obvious differences exist in the type and size of transfer facilities in subway stations constructed in different periods and according to different criteria. Differences in design standards are the most important factors that lead to the low operational efficiency of subway networks.

(2) Old facilities in subway stations are unable to cater to heavy pedestrian volume in Beijing. Heavy pedestrian volume is reflected by a sudden increase in pedestrian density, reduced walking speed, and the frequent occurrence of interweaving pedestrians at the connecting points of old facilities.

Acknowledgments

This research was supported by National Nature Science Foundation of China (no. 51108028), Beijing Municipal Natural Science Foundation (no. 8122009), Programme of Introducing Talents of Discipline to Universities (no. B12022), and 973 Program (no. 2012CB725403).

References

[1] R. Cattelani, D. Corsini, L. Posteraro, M. Agosti, and M. Saccavini, "The Italian version of the Mayo-Portland adaptability inventory-4. A new measure of brain injury outcome," *European Journal of Physical and Rehabilitation Medicine*, vol. 45, no. 4, pp. 513–519, 2009.

[2] L. S. Kang and B. C. Paulson, "Adaptability of information classification systems for civil works," *Journal of Construction Engineering and Management*, vol. 123, no. 4, pp. 419–426, 1997.

[3] National Research Council (NRC), *Highway Capacity Manual*, National Research Council (NRC), Washington, DC, USA, 2000.

[4] J. J. Fruin, *Pedestrian Planning and Design*, Metropolitan Association of Urban Designers and Environmental Planners, New York, NY, USA, 1971.

[5] S. H. Cao, Z. Z. Yuan, and D. Zhao, "Queuing mechanism of passengers at exit stairs of urban rail transit," *Journal of Jilin University*, vol. 39, no. 6, pp. 1463–1468, 2009.

[6] C. Ran and D. Liyun, "Observations and preliminary analysis of characteristics of pedestrian traffic in Chinese metropolis," *Journal of Shanghai University*, vol. 11, no. 1, pp. 93–97, 2005.

[7] H. F. Jia, L. L. Yang, M. Tang, and D. Meng, "Micro-characteristics and modeling requirement of pedestrians in muti-modal transport hub," *Journal of Transportation Systems Engineering and Information Technology*, vol. 9, no. 2, pp. 17–22, 2009.

[8] W. H. K. Lam and C. Y. Cheung, "Pedestrian speed/flow relationships for walking facilities in Hong Kong," *Journal of Transportation Engineering*, vol. 126, no. 4, pp. 343–349, 2000.

[9] W. H. K. Lam, J. Y. S. Lee, and C. Y. Cheung, "A study of the bi-directional pedestrian flow characteristics at Hong Kong signalized crosswalk facilities," *Transportation*, vol. 29, no. 2, pp. 169–192, 2002.

[10] S. B. Young, "Evaluation of pedestrian walking speeds in airport terminals," *Transportation Research Record*, no. 1674, pp. 20–26, 1999.

[11] J. L. Paul, "A personal perspective on research, consulting and codes standards development in fire-related human behavior, 1969–1999, with an emphasis on space and time factors," *Fire and Materials*, vol. 23, no. 1, pp. 265–272.

[12] J. L. Paul, "Suggestions on evacuation models and research questions," in *Proceedings of the 3rd International Symposium on Human Behavior in Fires*, pp. 23–33, Inter-science communications, London, UK, 2004.

[13] K. Hoskin, *Fire protection and evacuation procedures of Stadia Venues in New Zealand [Ph.D. dissertation]*, Department of Civil Engineering University of Canterbury, Christchurch, New Zealand, 2004.
[14] N. Ayano, I. Mai, and H. Hisamoto, "Uni-directional pedestrian movement model based on Voronoi diagrams," in *Proceedings of the 8th International Symposium on Voronoi Diagrams in Science and Engineering*, pp. 123–126, 2011.
[15] P. A. Thompson, *Developing new techniques for modeling crowd movement [Ph.D. dissertation]*, Edinburgh University of Edinburgh, 1994.
[16] J. Hine, "Assessing the impact of traffic on behaviour and perceptions of safety using an in-depth interview technique," *Journal of Transport Geography*, vol. 4, no. 3, pp. 179–199, 1996.
[17] C. Y. Cheung and W. H. K. Lam, "A study of the Bi-directional pedestrian flow characteristics in the Hong Kong mass transit railway stations," *Journal of Transportation Engineering*, vol. 2, no. 5, pp. 1607–1619, 1997.
[18] C. Y. Cheung and W. H. K. Lam, "Pedestrian route choices between escalator and stairway in MTR stations," *Journal of Transportation Engineering*, vol. 124, no. 3, pp. 277–285, 1998.
[19] J. Y. S. Lee and W. H. K. Lam, "Levels of service for stairway in Hong Kong underground stations," *Journal of Transportation Engineering*, vol. 129, no. 2, pp. 196–202, 2003.
[20] W. Delft, *Modeling Passenger Flows in Public Transport Facilities*, Delft University, Delft, The Netherlands, 2004.
[21] W. Wang, W. Zhang, H. Guo, H. Bubb, and K. Ikeuchi, "A safety-based behavioural approaching model with various driving characteristics," *Transportation Research Part C-Emerging TechNologies*, vol. 19, no. 6, pp. 1202–1214, 2011.
[22] W. Wang, Y. Mao, J. Jin et al., "Driver's various information process and multi-ruled decision-making mechanism: a fundamental of intelligent driving shaping model," *International Journal of Computational Intelligence Systems*, vol. 4, no. 3, pp. 297–305, 2011.
[23] R. Christian, M. Thomas, S. Stefan, and B. Dietmar, "Can walking behavior be predicted? Analysis of calibration and fit of pedestrian models," *Transportation Research Record*, vol. 2264, no. 1, pp. 101–109, 2011.
[24] D. Helbing, L. Buzna, A. Johansson, and T. Werner, "Self-organized pedestrian crowd dynamics: experiments, simulations, and design solutions," *Transportation Science*, vol. 39, no. 1, pp. 1–24, 2005.
[25] R. L. Hughes, "A continuum theory for the flow of pedestrians," *Transportation Research Part B*, vol. 36, no. 6, pp. 507–535, 2002.
[26] K. Ando, H. Ota, and T. Oki, "Forecasting the flow of people," *Railway Research Review*, vol. 45, no. 8, pp. 8–14, 1988.
[27] P. A. Thompson and E. W. Marchant, "A computer model for the evacuation of large building populations," *Fire Safety Journal*, vol. 24, no. 2, pp. 131–148, 1995.
[28] R. L. Hughes, "The flow of large crowds of pedestrians," *Mathematics and Computers in Simulation*, vol. 53, no. 4–6, pp. 367–370, 2000.
[29] B. D. Hankin and R. A. Wright, "Passenger flow in subways," *Operational Research Quarterly*, vol. 9, no. 2, pp. 81–88, 1958.
[30] Y. Tanaboriboon, S. S. Hwa, and C. H. Chor, "Pedestrian characteristics study in Singapore," *Journal of Transportation Engineering*, vol. 112, no. 3, pp. 229–235, 1986.
[31] Beijing Urban Engineering Design Research Institute, *Code for Metro Design (GB50157-92)*, China planning press, Beijing, China, 1992.
[32] Beijing Urban Engineering Design Research Institute, *Code for Design of Metro (GB50157-2003)*, China planning press, Beijing, China, 2003.


Advances in
Operations Research
Advances in
Decision Sciences
Journal of
Applied Mathematics
Algebra
Journal of
Probability and Statistics
The Scientific
World Journal
International Journal of
Differential Equations
Hindawi
Submit your manuscripts at
http://www.hindawi.com
International Journal of
Combinatorics
Advances in
Mathematical Physics
Journal of
Complex Analysis
Journal of
Mathematics
Mathematical Problems
in Engineering
Abstract and
Applied Analysis
Discrete Dynamics in
Nature and Society
International
Journal of
Mathematics and
Mathematical
Sciences
Journal of
Discrete Mathematics
Journal of
Function Spaces
International Journal of
Stochastic Analysis
Journal of
Optimization