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TRCLC 15-12
June 30, 2016

Analysis of walking facility performance guidelines for individuals with disabilities

FINAL REPORT

Keith Christensen, Anthony Chen, Mohammad Sadra Sharifi



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16. Abstract

It is necessary to design and evaluate the effectiveness of walking facilities to accommodate the needs of all pedestrian groups, including individuals with disabilities. The Highway Capacity Manual (HCM) defines walking facility performance using a qualitative measure describing operational conditions, or level of service (LOS). However, how closely pedestrian LOS thresholds correspond to actual conditions are questionable. To overcome the limitations, a controlled large-scaled walking experiment involving individuals with disabilities was conducted at Utah State University (USU). A temporary circuit with the necessary walking facilities was constructed using eight foot self-standing walls. In total, 202 (160 without and 42 with disabilities) individuals were recruited to participate in the experiments and they were asked to pass through the circuit repeatedly. Individuals were tracked using the camera system and trajectory data extraction was accomplished using a software platform suite. During each experiment session, some participants were randomly selected and asked to complete a questionnaire assessing their walking experience. Using both trajectory and survey data sources, this study explored how a heterogeneous mix of pedestrians perceive and evaluate operational performance of walking facilities. Specifically, an ordered statistical approach was applied to investigate effects of environmental density on pedestrians' perceptions. Results indicated that individuals with disabilities were less tolerant of extreme congested environments. Furthermore, analysis showed that the LOS criteria provided in HCM is inadequate in quantifying service performance of walking facilities based on the actual perceptions of individuals participated in the controlled experiment. The findings are expected to improve operational guidelines used to assess walking facility performance.

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Executive summary

It is necessary to design and evaluate the effectiveness of walking facilities to accommodate the needs of all pedestrian groups, including individuals with disabilities. The Highway Capacity Manual (HCM) defines walking facility performance using a qualitative measure describing operational conditions, or level of service (LOS). However, how closely pedestrian LOS thresholds correspond to actual conditions are questionable. To overcome the limitations, a controlled large-scaled walking experiment involving individuals with disabilities was conducted at Utah State University (USU). A temporary circuit with the necessary walking facilities was constructed using eight foot self-standing walls. In total, 202 (160 without and 42 with disabilities) individuals were recruited to participate in the experiments and they were asked to pass through the circuit repeatedly. Individuals were tracked using the camera system and trajectory data extraction was accomplished using a software platform suite. During each experiment session, some participants were randomly selected and asked to complete a questionnaire assessing their walking experience. Using both trajectory and survey data sources, this study explored how a heterogeneous mix of pedestrians perceive and evaluate operational performance of walking facilities. Specifically, an ordered statistical approach was applied to investigate effects of environmental density on pedestrians' perceptions. Results indicated that individuals with disabilities were less tolerant of extreme congested environments. Furthermore, analysis showed that the LOS criteria provided in HCM is inadequate in quantifying service performance of walking facilities based on the actual perceptions of individuals participated in the controlled experiment. The findings are expected to improve operational guidelines used to assess walking facility performance.

1. Introduction

Walking facilities are important infrastructure in a community's transportation systems. The pedestrians who use these facilities (e.g., transit transfer stations, shopping malls, urban plazas, etc.) are diverse. Therefore, it is imperative to design and evaluate the effectiveness of these facilities to meet the walking needs of diverse pedestrian groups, including individuals with disabilities who represent a significant population in the United States (12.1% of the total U.S. population) (U.S. Census Bureau, 2010). The Americans with Disabilities Act (ADA) (ADA, 1990) requires that all pedestrian facilities in the public right-of-way should provide equal rights for disabled people. Thus, it is necessary to test existing design and evaluation frameworks to investigate whether they consider all pedestrian groups' needs.

Generally, designers use guidelines provided in Highway Capacity Manual (HCM) (HCM, 2010) to assess walking facilitates performances. HCM defines walking facility performance using a qualitative measure describing operational conditions, or level of service (LOS). The six proposed levels of service in the latest version of the HCM are categorized from A to F, in which A represents the best and F represents the worst operational conditions. The HCM's pedestrian LOS thresholds are based on space, average speed, flow rate, and the ratio of volume to capacity. How close different pedestrian groups evaluate the walkway's quality of service according to these thresholds is questionable. There is very little empirical study of individuals with disabilities' walking behavior and perceptions. The reason for this shortcoming is related to the lack of empirical studies on individuals in disabilities walking behavior.

To overcome the limitations, a controlled large-scale walking experiment involving individuals with disabilities was conducted at Utah State University (USU) to empirically investigate the perceptions of pedestrian groups including individuals with disabilities. The purpose of this paper is to describe how pedestrian groups, which include individuals with disabilities, perceive the walkway quality of service. Specifically, the objectives are: (1) to quantify the effects of environment density on walkway level of service evaluations, and (2) to examine and compare different pedestrian groups' perceptions of walking facility performance with existing LOS design guidelines.

2. Background

Planners and public agencies extensively use guidelines to assess the design of walking infrastructures. Highway Capacity Manual (HCM) (HCM, 2010), TCRP report 100: Transit Capacity and Quality of Service Manual (TCQSM) (TCQSM, 2010), and Florida Quality/Level of service Handbook (Florida Quality/Level of service Handbook, 2013) are the most common reference manuals in the United States. Generally, these manuals provide LOS definition, thresholds, and estimation methods for various types of walking facilities. These guidelines evaluate walking facility performance using a qualitative measure describing operational conditions, or level of service (LOS). The six proposed levels of are categorized from A to F, in which A represent the best and F represents the worst operational conditions. At LOS A pedestrian can move in desired path with freely selected walking speed. In contrast, pedestrian movements are severely restricted and there is frequent conflict between pedestrians at LOS F.

Chapters 16 and 17 of HCM guideline develop methods for assessing performance measure of urban walking facilities and urban street segments respectively. These environments such as intersections are typically shared by different travel modes (e.g., auto, pedestrian, bicycle, and transit). Thus, the manual proposes a multimodal evaluation framework, considering interactions between different modes. Effective sidewalk width, pedestrian delay at intersection, average space and pedestrian travel speed are key criteria affecting urban walkway performance evaluations. Chapter 23 provides LOS estimation methodologies for off-street pedestrian and bicycle facilities (e.g., walkways separated from highway traffic). Walkway width, pedestrian flow, and average pedestrian space are examined to evaluate performance of exclusive pedestrian facilities.

TCQSM is a comprehensive reference source providing frameworks for designing and assessing public transportation systems. The manual proposes various LOS criteria for various station elements (e.g., walkways, stairs, queuing and waiting area) based on surveys that identified important factors affecting pedestrian perceptions. Similar to the HCM, pedestrian space and flow are considered as key elements for LOS assessments. Quality/Level of service Handbook (Q/LOS Handbook) published by Florida Department of Transportation (FDOT) is another guideline based on local research in Florida. The manual suggests LOS evaluation criteria for different travel modes including auto, transit, bicycle, and pedestrian. Specifically, the guideline only accounts for

urban walkways and it considers multiple factors including existence of a sidewalk, lateral separation of pedestrians from motorized vehicles, motorized vehicle volumes, and motorized vehicle speeds for LOS assessments. A statistical model using 1315 observations was developed to evaluate walking systems assigning a score ranging from 0.5 to 6.5. The LOS score was obtained from the following model (NCHRP Report 616, 2008):

$$\text{LOS score} = -1.2276 \ln (W_{ol} + W_l + f_p \times \%OSP + f_b \times W_b + f_{sw} \times W_s) + 0.0091 \left(\frac{Vol_{15}}{L}\right) + 0.00004\, SPD^2 + 6.0468 \quad (6.1)$$

where W_{ol}, W_l, W_b, and W_s represent width of outside lane, width of shoulder or bicycle lane, buffer width, and width of sidewalk respectively. f_p, and f_{sw} indicate on-street parking effect coefficient, and sidewalk presence coefficient respectively. Vol_{15}, L, $\%OSP$, and SPD stand for count of motorized vehicles in the peak 15 minute period, total number of directional through lanes, percent of segment with on-street parking, and average running speed of motorized vehicle traffic in mi/hr. The determined LOS score can be converted to a corresponding LOS letter grade using provided LOS score thresholds.

Several studies in the literature examined pedestrian LOS perceptions. These studies identified the key variables affecting LOS perceptions for various walking environments including intersection crossing (Muraleetharan et al., 2004; Chilukuri and Virkler, 2005; Lee et al., 2005; Petritsch et al., 2005; Bullock et al., 2006; Hubbard et al., 2007), sidewalk (Landis et al., 2001; Sisiopiku et al., 2002; Muraleetharan et al., 2004; Hummer et al., 2005; Byrd and Sisiopiku, 2006; Jensen, 2007; Bian et al., 2007; Muraleetharan and Hagiwara, 2007), midblock crossing (Chu and Baltes, 2001; Chu et al., 2004), and stair (Lee and Lam, 2003). Three survey methods were generally applied to assess the perception and preference of pedestrians on walking facility quality of service: (1) photo/video surveys, (2) visual simulation surveys, and (3) field observations.

In the photo/video survey method, different pictures/video clips showing different conditions are shown to different users and their evaluations are recorded according to HCM LOS definitions. For example, Lee et al. (2005) examined LOS standards for signalized crosswalks in commercial/shopping areas in Hong Kong. They used stated preference survey by providing a set

of five photographs to the pedestrian samples. Respondents were presented with descriptions of the quality of flow and they were requested to choose one of photographs which they felt did notmeet the descriptions. Their analysis showed that the key variables affecting LOS evaluations were area density, pedestrian flow, and walking speed. Jensen (2007) studied pedestrian and bicyclist LOS perceptions on roadway segments in Denmark. He collected perceived LOS from 407 respondents (223 female and 184 male) using video clips recorded from 56 roadway segments. Ordinary generalized linear models were used to identify key determinants of LOS at roadway segments. The developed model revealed that presence of pedestrians and width of bicycle facilities are the most important factors affecting perceived LOS. While these photo/video survey approaches are a convenient method for exposing interview subjects to a wide range of conditions, the obtained perceptions are not from the pedestrians' actual experience.

Simulation survey techniques use computer simulations of different conditions to elicit user evaluations. Miller et al. (2000) applied visualization techniques to collect pedestrian LOS perceptions on improvement options (e.g., adding a level crosswalk, widening the median, etc.) for a suburban intersection in the city of Charlottesville, Virginia. A group of 56 subjects was presented with improvement scenario animations and they were asked to rate each option from A to E and give a numerical score from 1 to 75. The analysis results suggested scale ranges according to different LOS. Although a computer-aided visualization approach is more costly than photo/survey method, it can add more flexibility to survey interviews by varying environment situations. However, this approach is not able to record pedestrian perceptions based on their real experiences.

In field observations, after experiencing a pedestrian environment, participants are asked to assess the walkway quality of service. For instance, Muraleetharan et al. (2004) examined key determinants affecting pedestrian LOS at intersections using direct survey method. They selected four different types of intersections in the city of Sapporo, Japan and questionnaires were distributed to pedestrians who crossed the intersections. The respondents were asked to give a score ranging from 0 to 10, in which 0 represents the worst and 10 represents the best operational conditions. Results obtained from 252 surveys revealed that different factors including space at corner, turning vehicles, delay at signals, and pedestrian-bicycle interactions impact on perceived

LOS. Landis et al. (2001) used a similar approach to measure pedestrian LOS of safety and comforts in sidewalks in Pensacola, Florida. 75 volunteer participants were asked to walk along a 5-mile (8-km) looped walking course. Then, the participants evaluated the safety/comfort of the walkway system using A-F point scale. Impacts of different factors were identified by developing a stepwise linear regression model. However, human factors were not considered in the study. The field observation method has a lower initial cost compared with other approaches, but it is more intensive to conduct. The benefit of the field observation method is that it elicits pedestrian perceptions based on their actual experiences.

Even though several guidelines and studies have been developed to examine pedestrian perceptions on walking facilities' LOS, the literature review revealed that there are still limitations in existing studies. First, existing manuals such as HCM claims to predict LOS based on traveler's perspective. However, there is little evidence to support this claim (NCHRP Report 616, 2008). As a result, how closely pedestrian LOS thresholds provided in guidelines correspond to actual pedestrian perceptions is questionable. Second, there are very limited number of studies that use subjects' revealed walking behavior as part of the LOS perception analysis. For instance, Kim et al. (2013) collected questionnaire and video recording data from 28 commercial, residential, and leisure locations in South Korea and developed a model connecting pedestrian perceptions with revealed behaviors. Specifically, they examined the effects of personal space and pedestrian evasive movements on perceived LOS, However, they didn't consider pedestrian subjective characteristics (e.g., socio-demographic variables including age, gender, etc.) in their model. Third, the guidelines and majority of existing studies overlooked heterogeneity in pedestrian groups for LOS evaluations. Specifically, there are few studies applicable to individuals with disabilities. Recently, Asadi-Shekari et al. (2013) developed a method to consider individuals with disabilities in LOS evaluations. However, they didn't make use of either preference or reveal behaviors. Therefore, further studies are needed to address the current limitations. Table 1 summarizes existing studies on walking facility LOS analysis.

Table 1. Summary of LOS analysis in pedestrian studies.

Reference	Approach			Considering Individuals with disabilities	Facility type
	Survey	Simulation	Field observation		
Lee et al. (2005)	•			No	Signalized crosswalk
Jensen (2007)	•			No	Roadway segment
Miller et al. (2000)		•		No	Crosswalk
Muraleetharan et al. (2004)			•	No	Sidewalk, intersection
Landis et al. (2001)			•	No	Roadway environment
Kim et al. (2013)	•		•	No	Sidewalk
Asadi-Shekari et al. (2013)			•	Yes	Walking facilities on urban streets
Petritsch et al. (2005)		•	•	No	Signalized intersection
Byrd and Sisiopiku, (2006)			•	No	Sidewalk
Chu and Baltes, (2001)	•			No	Midblock crossing

3. Data collection

To study the walking behavior and the perceptions of different types of individuals with disabilities, a large scale controlled walking experiments was carried out by a multi-disciplinary research group (transportation engineering, disability studies, electrical engineering, management information systems, and environmental design) at Utah State University (USU). Participants were a mixture of individuals without disabilities and individuals with mobility-related physical, sensory, or other types of disabilities, including hearing, and other impairments related to mobility disability. In total, 202 individuals (160 without and 42 with disabilities) were recruited. Among the participants with disabilities, about 26% were visual impaired, 38% were physically impaired, and 36% had other types of disabilities (e.g., intellectual, hearing). The study was conducted on a temporary circuit constructed at USU's Motion Laboratory with the necessary walking facilities (e.g., level passageway, right angle, oblique angle, and bottleneck), designed to comply with applicable Americans with Disabilities Act Accessibility Guidelines (ADAAG) and International Building Code (IBC) standards.

For each 10-minute experiment session, participants moved at their maximum comfortable speed through the circuit. Augmented reality technology used for data collection to track participant positions within 0.3 meters or a footstep, enabling tracking and collection of each individual participant's walking trajectory. Augmented reality is the process of injecting virtual objects into an individual's view of reality using video goggles and a camera. ARToolKitPlus (ARTKP) is a software library that allows the tracking of up to 512 identifiable markers at once. To utilize this system, markers were attached to participants using mortar boards, or graduation caps, and read by cameras suspended above the experimental area. Power-over-Ethernet (POE) cameras, which only need one cable, were used. The chosen POE camera is compact at 29 x 29 x 41 mm, but still affords a high resolution of 1280x1024 pixels at a maximum frame rate of 50 frames per second. Twelve cameras provided full coverage with overlap for the circuit experiments. For detailed information on the experiments and tracking technology, please see (Stuart et al., 2013; Sharifi et al., 2015a; Sharifi et al., 2015b). Figures 1 and 2 show tracking equipments and a snapshot of walking experiments, respectively.



(a) (b) (c)

Figure 1. Tracking hardware: a) Power-over-Ethernet (POE) camera, b) encoded tracking pattern, and c) camera gimbal.

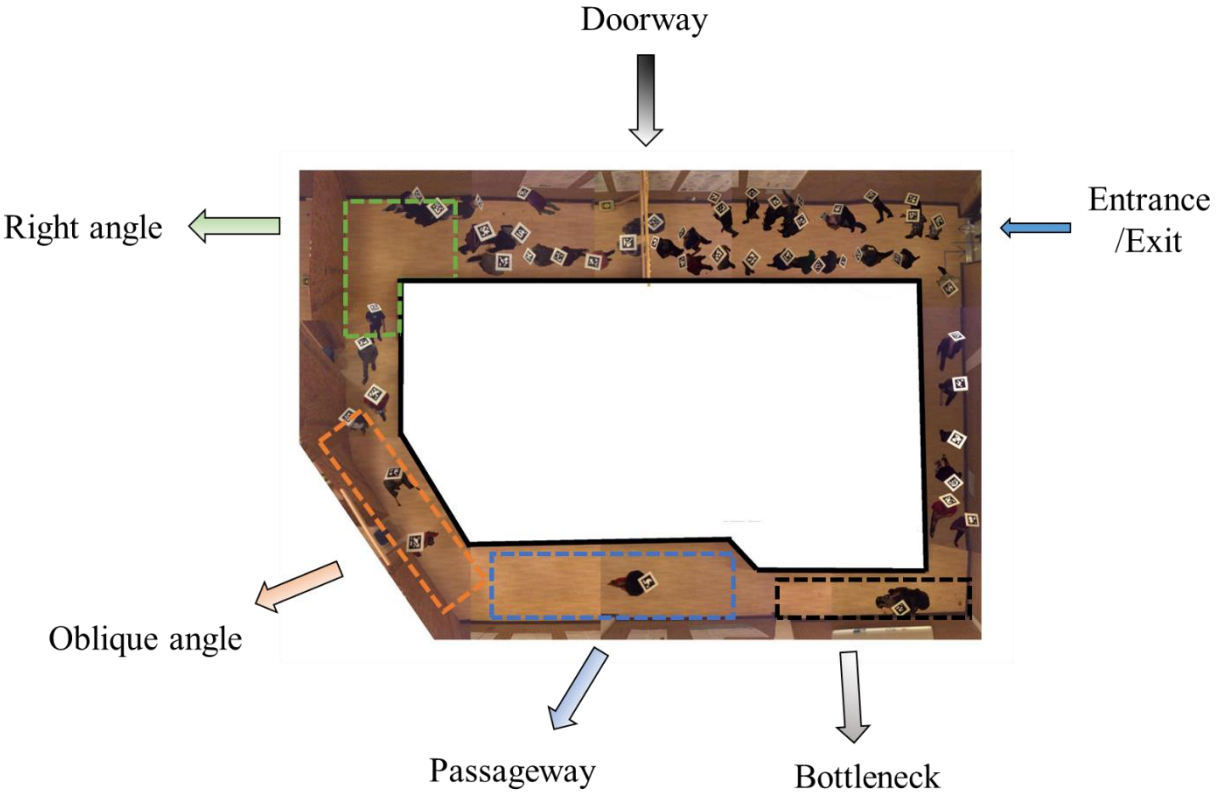


Figure 2. A snapshot of walking experiments.

To examine and compare individuals with disabilities' perceptions of walking facility performance with existing LOS design guidelines, individuals with and without disabilities provided their perceptions prior to, during, and following participation in each experiment session. Prior to each experiment session, participants completed a questionnaire to collect socio-demographic information (e.g., gender, age, walking habits, etc.), each participant's expected grouping behavior (platooning) with regard to individuals with disabilities, and an indication of their spacing behavior toward individuals with disabilities (e.g., How comfortable do you feel around individuals with disabilities? Very comfortable, Comfortable, Neutral, Less comfortable, Not very comfortable). During each experiment session, some participants were randomly selected and asked to complete a questionnaire concerning their walking experiences. After each experiment session is completed, all participants were asked to assess their walking experiences. The questions include participant's perception of walking facility performance by providing a graphical representation of each HCM LOS to which participants indicated their experience (Figure 3). Follow-up questions are used to assess the thresholds of different LOS values (e.g., for the last lap I completed, my ability to maneuver/walk freely was affected by the presence of an individual with a disability in the following areas? Narrow corridor, Wide corridor, where the corridor width changed, Corner, Doorway).

Please select the image representing the conditions of the last lap you completed.

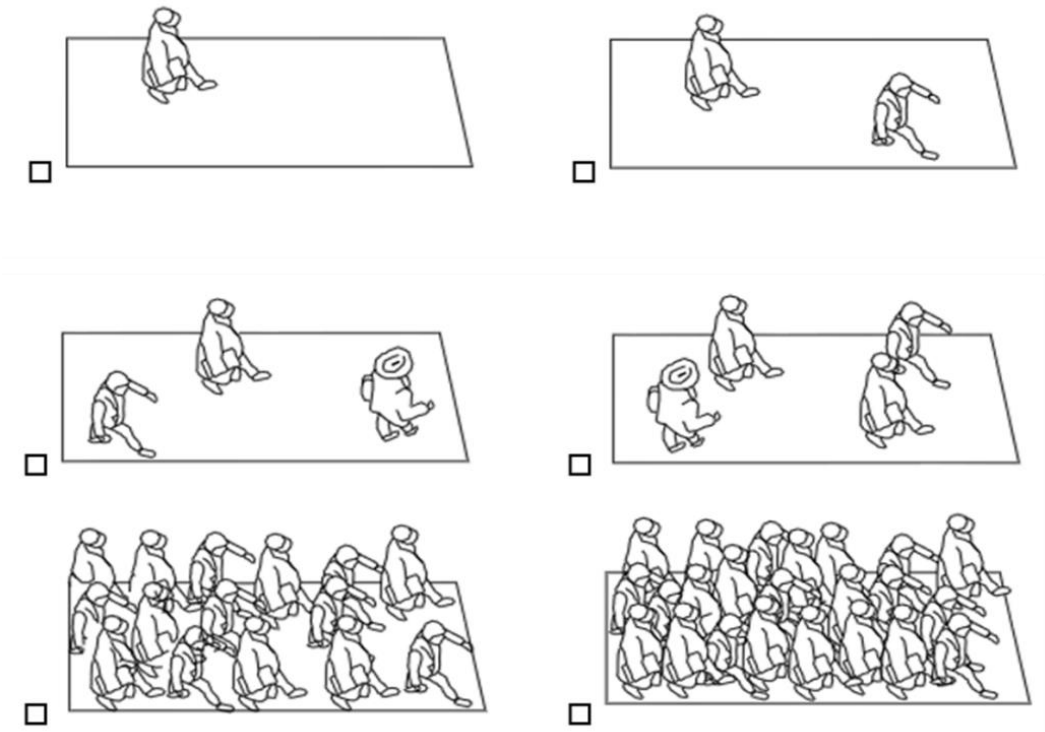


Figure 3. Graphical LOS definitions.

4. Data processing

Due to the large amount of video data collected from the large-scale controlled experiments, extraction software with a Graphical User Interface (GUI) was developed. This user-friendly GUI is able to manage, process, and visualize the video data collected from the walking experiments. The developed GUI consists of three main components: visualization, processing, and behavioral data extraction. To visualize the experimental process, a simple CAD drawing of the study area was incorporated into the GUI on which the pedestrian movements are depicted according to their identification IDs during the experiments. The processing component makes it possible to extract the raw trajectory data for a selective area or selected time duration for all pedestrians or for a selective group of pedestrians (e.g. pedestrians with disabilities). In addition, microscopic behavioral variables (e.g., instantaneous speed and acceleration longitudinal and lateral spacing, time headway, orientation, local speed, flow and density) can be extracted using the GUI. The

software can extract the behavioral data for all pedestrians or for a particular target pedestrian. Figures 4 and 5 present the GUI components and preliminary trajectory results, respectively. The data shows formations consistent with the facility configurations.

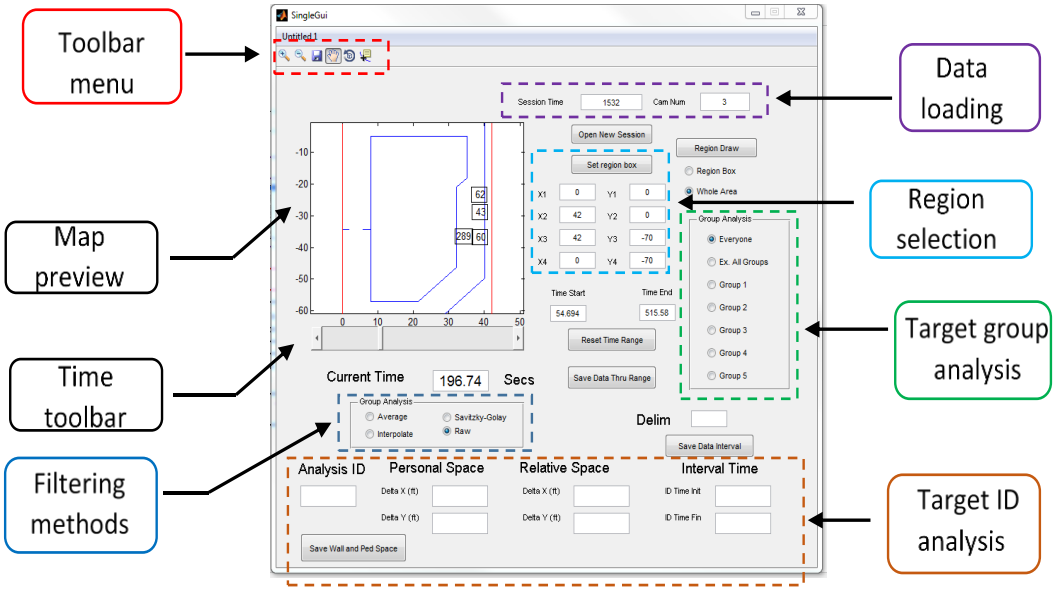
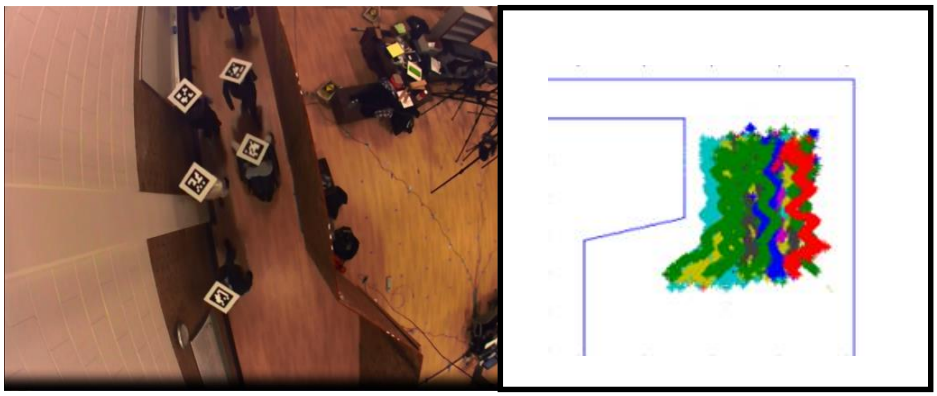


Figure 4. Snapshot of GUI.



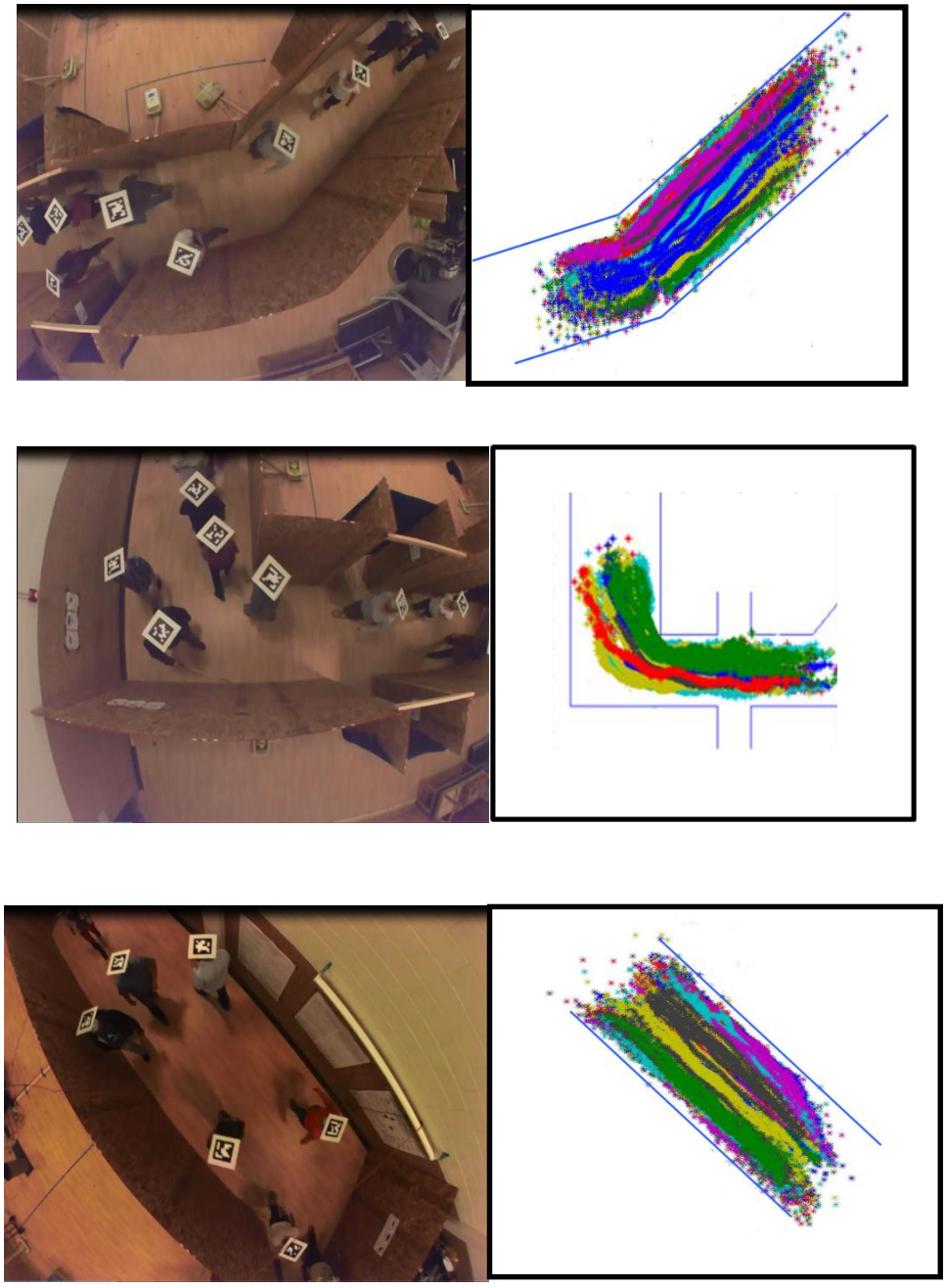


Figure 5. Tracking results.

5. Methodological approach

The purpose of this study was to understand how density of walking environments affects walkway level of service evaluations. To achieve this goal, different data sources including video data and survey data were used. Pedestrian socio-demographic variables and their stated perceptions on quality of service were obtained from the pre-surveys and post-surveys, respectively and circuit density was extracted from collected video data. The conventional way to determine the circuit density is to obtain total number of participants during the survey time duration and divide it by circuit area. But, this method may not reflect the actual experienced density by the surveyed participants. To overcome this limitation, the circuit area was divided to different facilities and density of each facility was calculated during the time that the surveyed individuals passed through each facility. The experienced density can be obtained by calculating the average density of each facility. Figures 6 and 7 present the layout of walking facilities and a graphical idea of calculating the experienced density, respectively. Figure 7 shows the time-space diagram for all individuals with a particular focus on tracing a surveyed individual to calculate the experience density. This time-space diagram was created by plotting the position of each participant, given at a distance from a reference point (e.g., entrance of the circuit) against time. The dashed line shows the trajectory of the surveyed individual during the surveyed time and boxes show the time intervals that the surveyed ID passed through different facilities. Experienced density was obtained by calculating the average density of different boxes (i.e., different facilities).

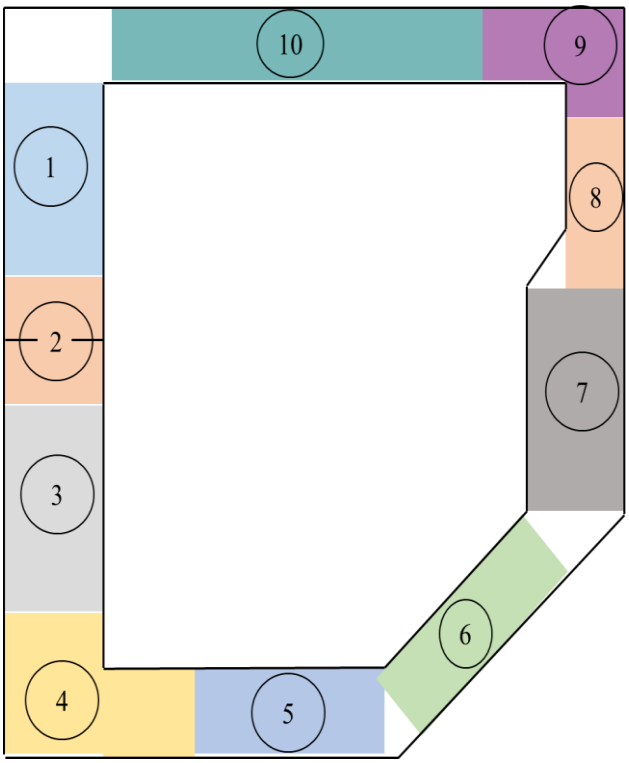


Figure 6. Circuit segmentation.

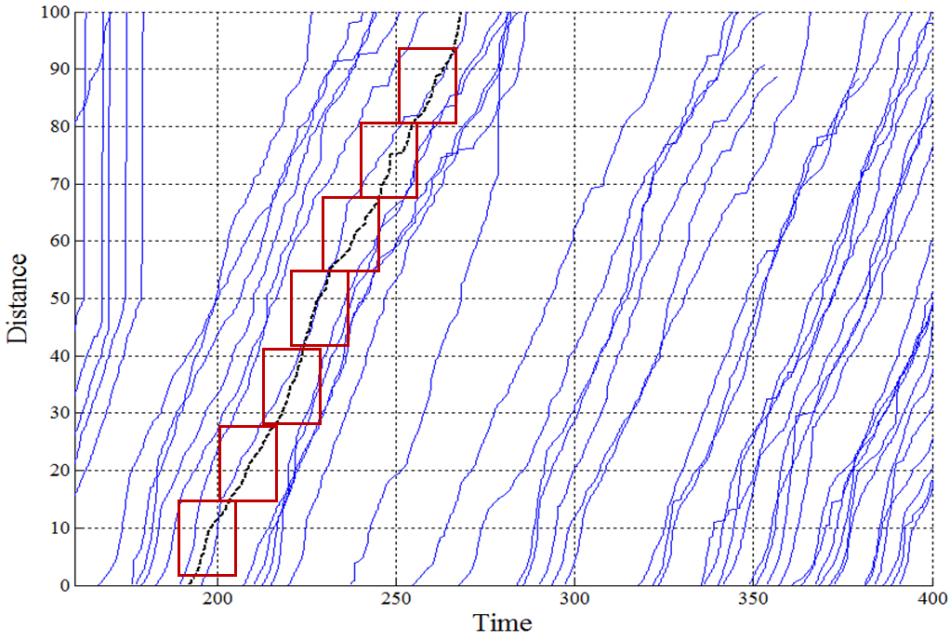


Figure 7. Time-space diagram for a surveyed participant.

To examine how pedestrians perceive LOS, a statistical method is needed to account for both the discrete and ordered nature of responses. Econometric models such as the ordered probability approach is an appropriate method that has been widely used in many Transportation Engineering applications (for example see Asgari et al., 2014; Asgari and Jin, 2015; Asgari and Jin, 2016a; Asgari and Jin, 2016b; Baratian and Zhou, 2015, Khalilikhah et al., 2016). In this approach, an unobserved variable *z* is defined to represent the perceived LOS as a linear function for each observation *n* as follows:

$$z_n = \beta X_n + \varepsilon_n \quad (1)$$

where X_n is a vector of independent variables (e.g., density), β is a vector of coefficients, and ε_n is a random disturbance. In the ordered probit model, the random error term is assumed to be normally distributed across observations with mean=0 and variance=1. Using this equation, the observed LOS y_n for each observation *n* (i.e., y=1, 2, 3, 4, 5, and 6, which correspond to LOS A, B, C, D, E and F, respectively) is written as

$$\begin{aligned}
&y_n = 1 \quad \text{if} \quad z_n \le \mu_1 \\
&y_n = 2 \quad \text{if} \quad \mu_1 < z_n \le \mu_2 \\
&y_n = 3 \quad \text{if} \quad \mu_2 < z_n \le \mu_3 \\
&y_n = 4 \quad \text{if} \quad \mu_3 < z_n \le \mu_4 \\
&y_n = 5 \quad \text{if} \quad \mu_4 < z_n \le \mu_5 \\
&y_n = 6 \quad \text{if} \quad z_n \ge \mu_5
\end{aligned} \quad (2)$$

where μ is the cut-off value that defines y_n. These μ values are jointly estimated together with the coefficients β using the maximum likelihood procedure (Choocharukul et al., 2004). Since only the relative values are important, μ_1 can be arbitrarily set to any value (e.g., μ_1=0 for convenience). With this setting, an ordered probit model can be written as follows:

$$
\begin{aligned}
P(y_n = 1) &= \phi(-\beta X_n) \\
P(y_n = 2) &= \phi(\mu_2 - \beta X_n) - \phi(-\beta X_n) \\
P(y_n = 3) &= \phi(\mu_3 - \beta X_n) - \phi(\mu_2 - \beta X_n) \\
P(y_n = 4) &= \phi(\mu_4 - \beta X_n) - \phi(\mu_3 - \beta X_n) \\
P(y_n = 5) &= \phi(\mu_5 - \beta X_n) - \phi(\mu_4 - \beta X_n) \\
P(y_n = 6) &= 1 - \phi(\mu_5 - \beta X_n)
\end{aligned}
\tag{3}
$$

where Φ is the cumulative normal distribution. Figure 8 presents an overall framework for the perception LOS analysis.

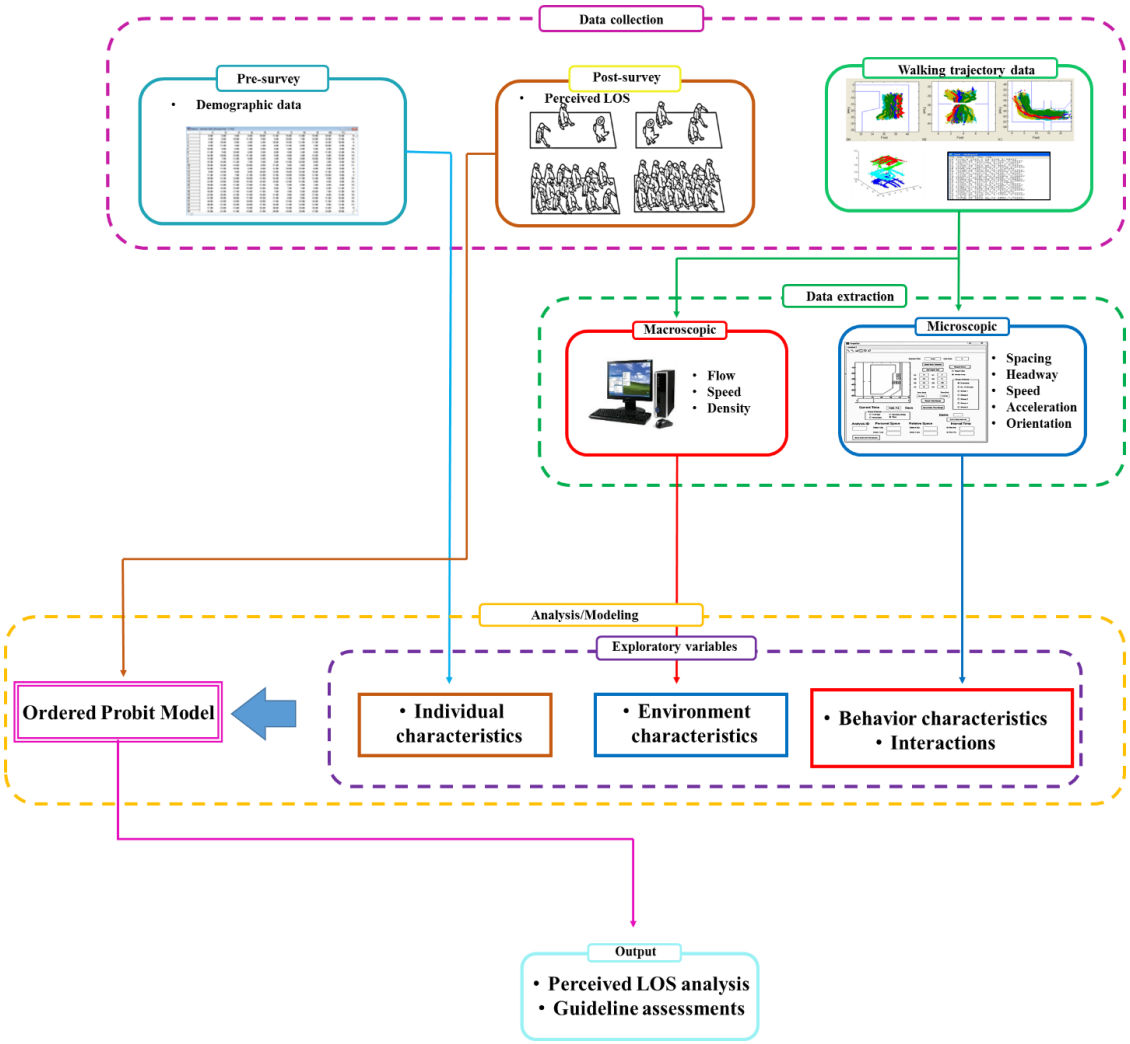


Figure 8. LOS perception analysis framework.

6. Analysis and results

A total of 257 valid post-surveys (i.e., 212 from individuals without disabilities and 45 from individuals) were collected from 202 participants (some participants surveyed more than one). Figure 9 presents distribution of responses on stated LOS. The figure show that most of stated LOS observed at LOS D and E and stated LOS toward extremely low density level is much less than other groups. Most of participants were surveyed in the middle duration of experimental process where the circuit density was toward higher density levels indicating that the observed results are plausible. To verify the collected survey data, data visualization technique was used to show the distribution of LOS responses. Figure 10 presents two parallel coordinate plots for individuals with and without disability responses. The first axis presents experienced density, the second axis shows individuals' responses on LOS perception (i.e., 1 means LOS A, 2 means LOS B,…), and the third axis shows the corresponding LOS according to HCM guideline. The concentrations of lines show the distribution of collected data. For instance, the figure shows that lines connecting first axis to second axis are ticker in density ranges between 0.5 to 0.9 ped/m^2 for indicating that most of observations were in this density range. The parallel diagrams also indicate that how close were the participants' respondents to actual conditions. Observing lines connecting second and third axes, it can be inferred that although collected perceived LOS responses didn't exactly follow the HCM guideline but they were not too far away implying that participants didn't responded randomly and collected surveys are valid.

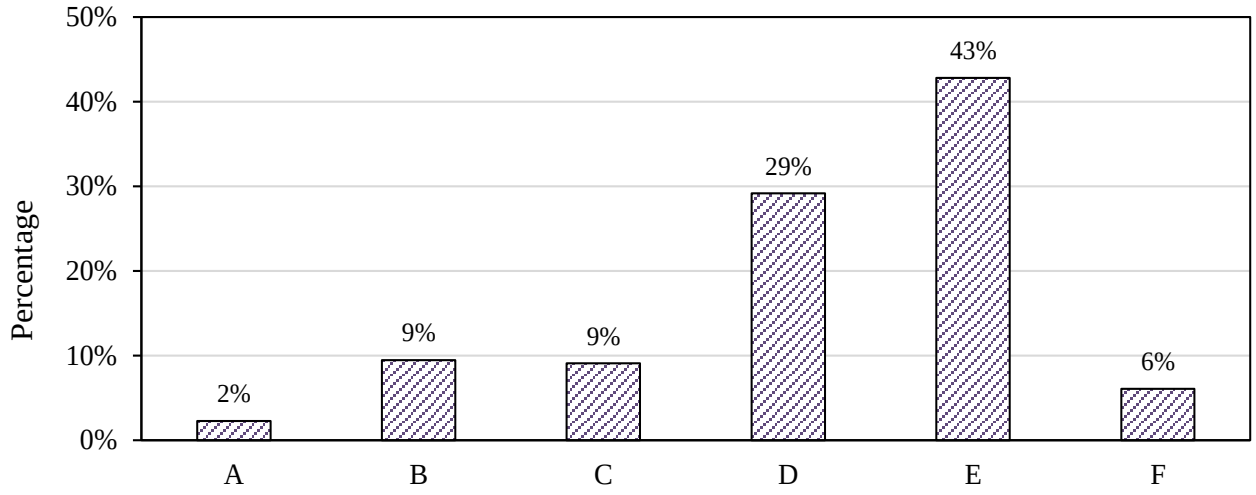
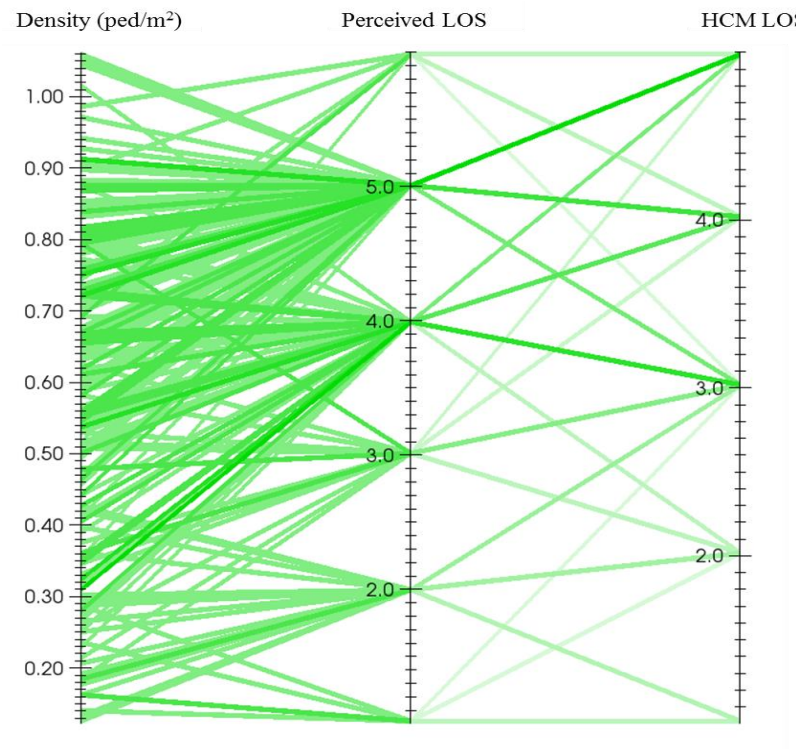
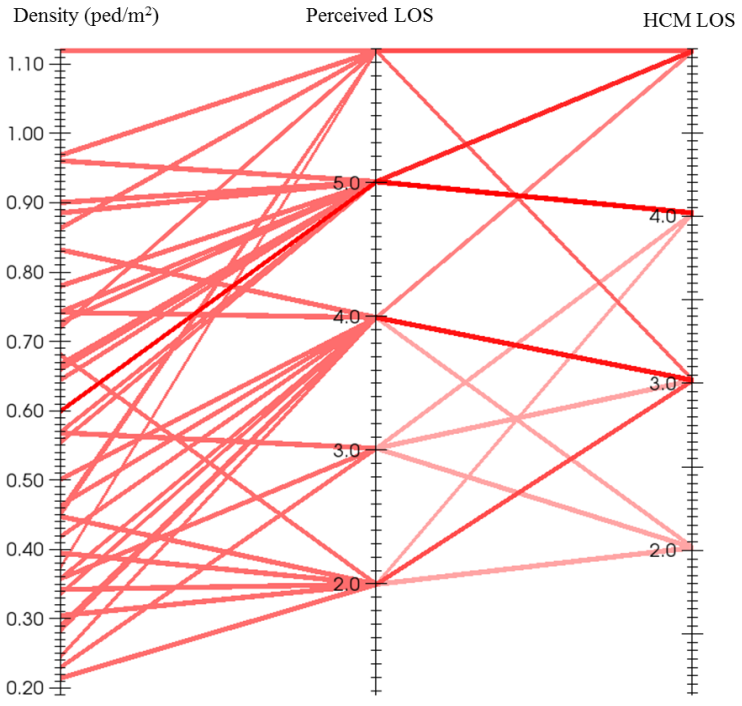


Figure 9. Observed LOS distribution.



(a)



(b)

Figure 10. Survey data visualization for a) individuals without disabilities, and b) individuals with disabilities.

SAS statistical software was used to calibrate the ordered probit model. Based on initial analysis it was observed that there were not enough data collected for LOS A. Figure 9 shows that only 2% of respondents stated LOS A for their walking condition and treating it as an independent group would affect the significance of the estimation results. Therefore, LOS A and LOS B were grouped together as one LOS, which results in five LOS categories in the estimation process. 90% of the data were used for calibration and 10% of data were reserved for model validation purpose. An ordered probit model was calibrated with density as the only independent variable for individuals without and with disabilities. Table 2 shows the estimation results including constant, coefficient for the density variable, estimated cut-off values, and their corresponding statistics including t-statistics, P-values, and log likelihood value. The P-values for the coefficients (β_0 and β_1) and cut-off values (μ_2, μ_3, μ_4) are less than 0.01, indicating that the coefficients and thresholds are highly significant. Positive signs for density variable indicate that all pedestrian groups perceived worse LOS in higher density levels.

Table 2. Model estimation results.

	Model					
	Individuals without disabilities			Individuals with disabilities		
Variables	Coefficients	t-statistics	p-value	Coefficients	t-statistic	p-value
Constant	-0.78	-3.23	0.0015	-0.62	-1.35	0.1835
Density (Ped/m^2)	4.37	9.66	< 0.01	3.35	3.98	< 0.01
Cut-offs						
μ2	0.58	4.46	< 0.01	0.32	1.83	0.074
μ3	1.92	10.45	< 0.01	1.23	4.21	< 0.01
μ4	4.11	14.62	< 0.01	2.46	6.59	< 0.01
Number of observations	191			41		
Log likelihood at convergence	-197.26			-53.17		

To investigate the validity of estimated models, 10% reserved data were used to check how close the model results can match the stated results by individuals. Figure 11 presents the comparison results between successful prediction of calibrated models and responses of surveyed

individuals. It can be observed that the models could predict the LOS responses relatively accurate. The model for individuals without disabilities predicted almost all of surveys in LOS E and F and calibrated model for individuals with disabilities could predict all of reserved LOS responses. The overall success prediction for individuals without and with disabilities were about 75% and 100%, respectively indicating that the accuracy of models were acceptable.

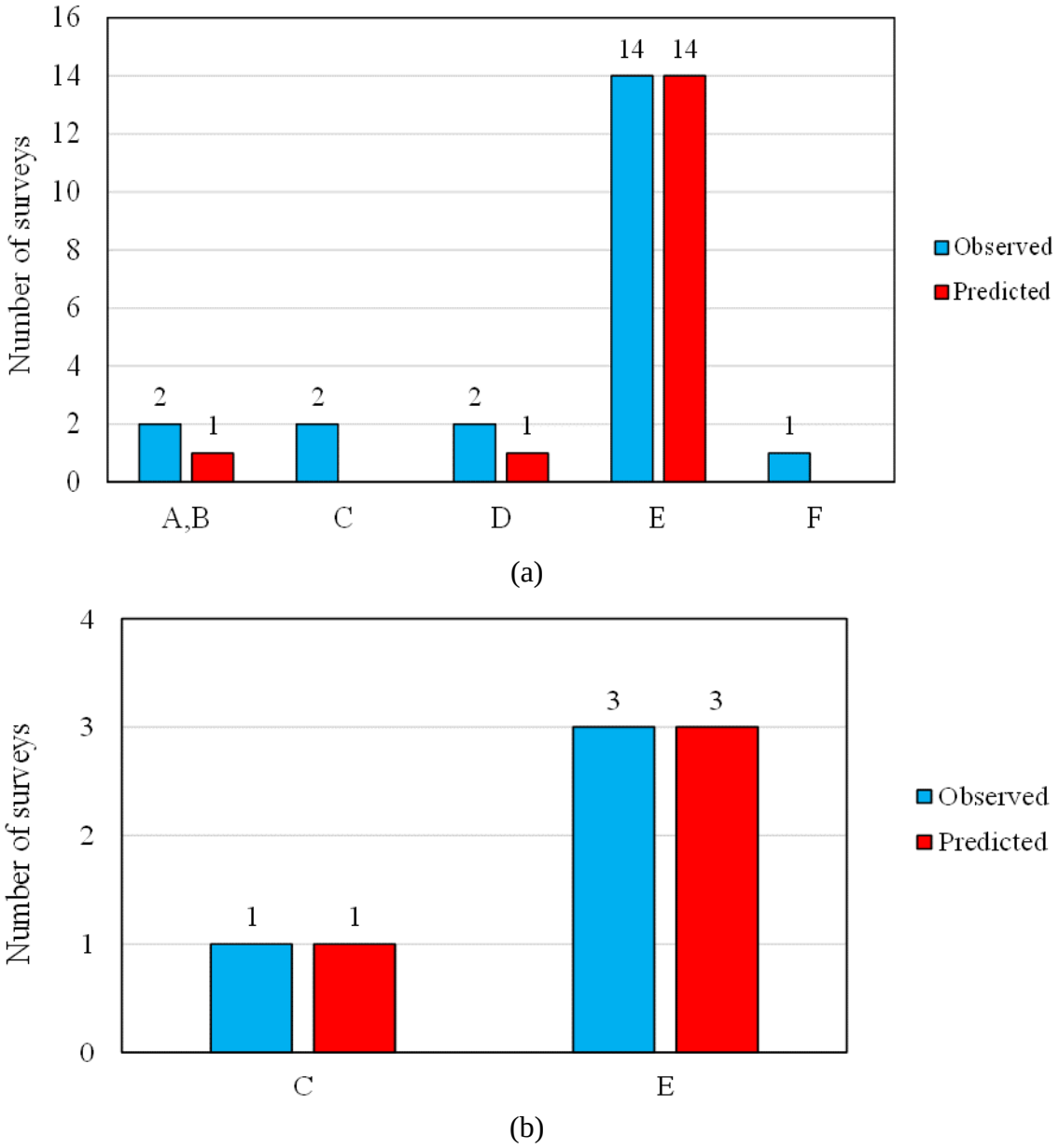


Figure 11. Model validations for a) individuals without disabilities, and b) individuals with disabilities.

LOS thresholds can be obtained using estimated coefficients and cut-offs. The thresholds can be calculated as $(\mu_k-\beta_0)/\beta_1$ where k is cut-off values and β_0 and β_1 are intercept and density coefficient, respectively. Figure 12 depicts estimated thresholds for different pedestrian groups (individuals without disabilities, individuals with disabilities, and all participants). Also, proposed LOS thresholds by HCM is provided in the figure to examine and compare different pedestrian groups' perceptions of walking facility performance with existing LOS design guidelines. Figure 12 presents the density ranges for each LOS category. Comparing thresholds for individuals without and with disabilities, it can be found that there is a visible difference between LOS E and F perception thresholds. While individuals with disabilities rated density levels beyond than 0.92 ped/m^2 as LOS F, individuals without disabilities perceived LOS E up to 1.12 ped/m^2 density level indicating that individuals with disabilities had lower tolerance for crowded conditions. LOS thresholds for all surveyed participants can be compared with provided LOS criteria in HCM guideline to investigate that how close the HCM guideline follows the pedestrian perceptions. Results indicate that there are apparent differences between perceptions thresholds and HCM propose values. Surveyed individuals had lower tolerance for all LOS groups. For instance, participants rated density ranges from 0.61 ped/m^2 to 1.07 ped/m^2 as LOS E while HCM considers density ranges from 0.72 ped/m^2 to 1.35 ped/m^2 as LOS E implying that HCM underestimates LOS rates compared to pedestrian perceptions.

LOS concept is widely used in walking facilities design and evaluations. Given projected demand and length of a walking facility, designers can estimate the minimum required width to achieve desired LOS. Therefore, the findings can be examined to investigate the impacts of overlooking individuals with disabilities in design process. Results show that the minimum required width for individuals without disabilities is about 80% of minimum width for individuals with disabilities to achieve LOS E. Further, effects of overlooking perceptions in design process can be investigated by comparing LOS perception thresholds for all pedestrians and HCM guideline. Results indicate that considering LOS B as the target, design plan based on HCM guideline would be about 63% of minimum width obtained from heterogeneous pedestrian perceptions.

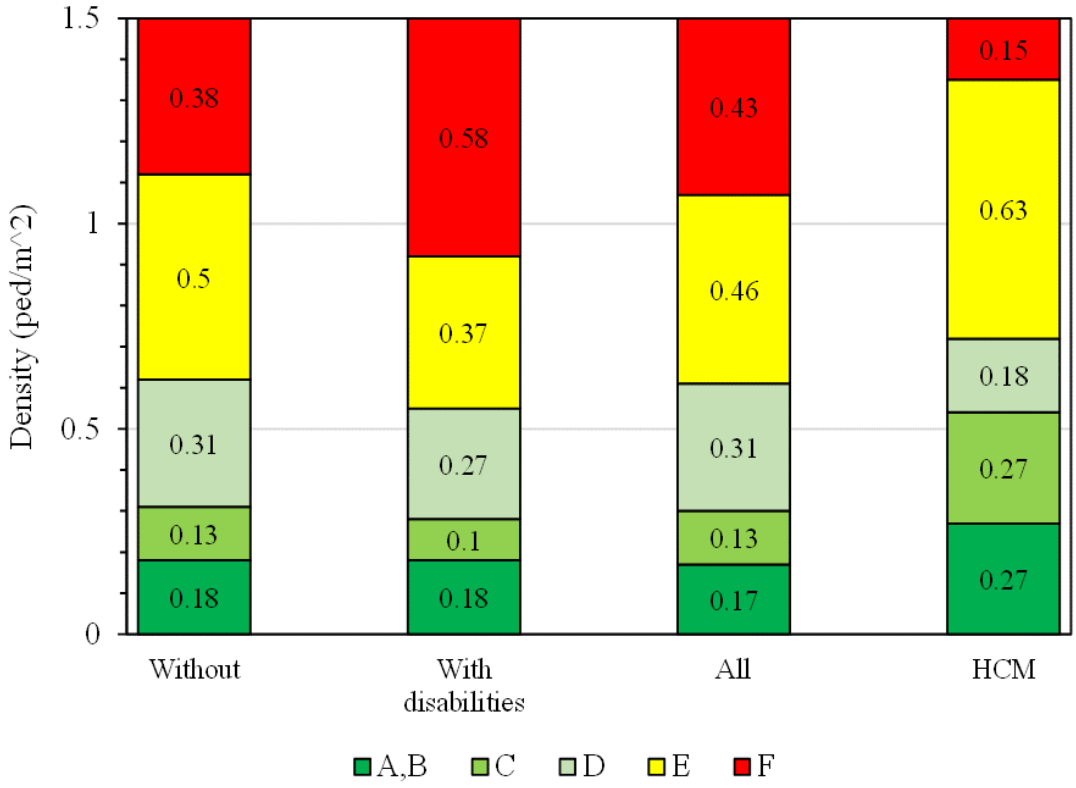


Figure 12. LOS graphical comparisons.

7. Summary and conclusions

The LOS criteria provided by the HCM guideline has been widely used by planners for design and assessment purposes. This paper examined whether the HCM guideline is applicable for all pedestrian groups and how close pedestrian's perceptions were to guideline LOS recommendations. To achieve the goals, a large scale controlled walking experiments was carried out at Utah State University (USU). Participants were a mixture of individuals without disabilities and individuals with mobility-related physical, sensory, or other types of disabilities. The revealed walking behavior and perceptions on walking environment conditions were observed through video records and survey collection methods. A statistical framework was used to make a connection between the questionnaire and the walking trajectory data to specify how environment density can impact on pedestrians' perceptions of walking facility performance. The results suggest that there are differences between perceptions of individuals without and with disabilities and these differences are more visible in high density levels (i.e., LOS E and F). Also, it was found

that pedestrian LOS perception thresholds are lower than HCM LOS implying that the current thresholds provided in HCM guideline don't follow pedestrian perceptions and using them may lead to inappropriate design plans. The findings in this chapter are expected to enhance design of walking environments. Designers can test and evaluate their design plans using the findings in this research to determine how well their design can meet the needs of different users and they can change their plan while changes are possible.

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APPENDIX A: Pre-survey form

1. What is your age? _____
2. What is your gender? ☐Male ☐Female
3. What is your height? _____
4. How would you categorize your disability/impairment?
   - ☐ Vision
   - ☐ Hearing
   - ☐ Physical/Spinal Cord Injury
   - ☐ Intellectual
   - ☐ Other _____
   - ☐ None
5. If you possess a disability/impairment, how is your pedestrian movement primarily affected?_____
6. In addition to your disability/impairment, do you have a chronic health condition or impairment? _____
7. How far do you generally walk each day?
   - ☐ less than 1/4 mile
   - ☐ 1/4 mile to 1/2 mile
   - ☐ 1/2 mile to 1 mile
   - ☐ more than 1 mile
8. How many days per week do you walk at least 10 continuous minutes per day?
   - ☐ 0
   - ☐ 1
   - ☐ 2
   - ☐ 3
   - ☐ 4 or more

9. What is your purpose for walking?

   ☐To work

   ☐To or within school

   ☐To shop

   ☐To exercise/For pleasure

   ☐Other _____

10. How comfortable do you feel around **individuals with disabilities** compared with others?

    ☐ Very comfortable

    ☐ Comfortable

    ☐ Neutral

    ☐ Less comfortable

    ☐ Not very comfortable

11. How likely would you be to pass another **individual** when they are walking more slowly than you?

    ☐ Very likely

    ☐ Likely

    ☐ Neutral

    ☐ Not likely

    ☐ Not very likely

12. How likely would you be to pass an **individual with a disability** when they are walking more slowly than you?

    ☐ Very likely

    ☐ Likely

    ☐ Neutral

    ☐ Not likely

    ☐ Not very likely

13. How likely would you be to change your walking behavior toward another **pedestrian with disabilities**? For example, letting them go through the door first or give them extra room.
    - ☐ Very likely
    - ☐ Likely
    - ☐ Neutral
    - ☐ Not likely
    - ☐ Not very likely

14. How likely would your walking behavior be impacted by encountering an **individual with a disability** in a wide corridor?
    - ☐ Very likely
    - ☐ Likely
    - ☐ Neutral
    - ☐ Not likely
    - ☐ Not very likely

15. How likely would your walking behavior be impacted by encountering an **individual with a disability** in a narrow corridor?
    - ☐ Very likely
    - ☐ Likely
    - ☐ Neutral
    - ☐ Not likely
    - ☐ Not very likely

16. How likely would your walking behavior be impacted by encountering an **individual with a disability** on a wide stairway?
    - ☐ Very likely
    - ☐ Likely
    - ☐ Neutral

- ☐ Not likely
- ☐ Not very likely

17. How likely would your walking behavior be impacted by encountering an **individual with a disability** on a narrow stairway?
    - ☐ Very likely
    - ☐ Likely
    - ☐ Neutral
    - ☐ Not likely
    - ☐ Not very likely

18. How likely would your walking behavior be impacted by encountering an **individual with a disability** at a wide doorway?
    - ☐ Very likely
    - ☐ Likely
    - ☐ Neutral
    - ☐ Not likely
    - ☐ Not very likely

19. How likely would your walking behavior be impacted by encountering an **individual with a disability** at a narrow doorway?
    - ☐ Very likely
    - ☐ Likely
    - ☐ Neutral
    - ☐ Not likely
    - ☐ Not very likely

20. How likely would your walking behavior be impacted by encountering an **individual with a disability** at a wide corner?
    - ☐ Very likely

- ☐ Likely
- ☐ Neutral
- ☐ Not likely
- ☐ Not very likely

21. How likely would your walking behavior be impacted by encountering an **individual with a disability** at a narrow corner?
    - ☐ Very likely
    - ☐ Likely
    - ☐ Neutral
    - ☐ Not likely
    - ☐ Not very likely

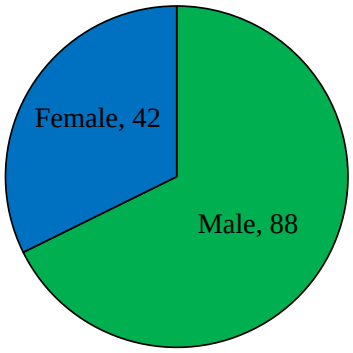
22. Please make any comments or suggestions you feel would be beneficial.

APPENDIX B: Pre-survey descriptive analysis

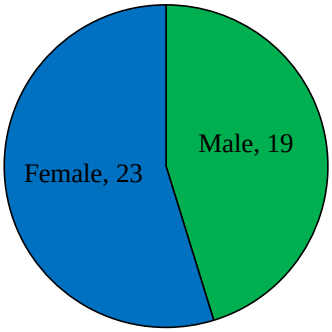
Number of participants

Number of IWD participants in circuit experiments = 42

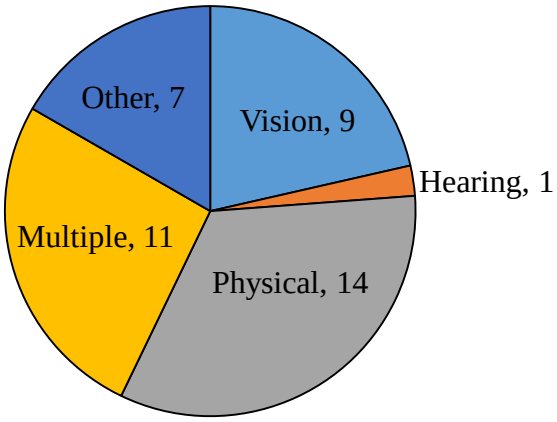
Gender distribution (without disability)



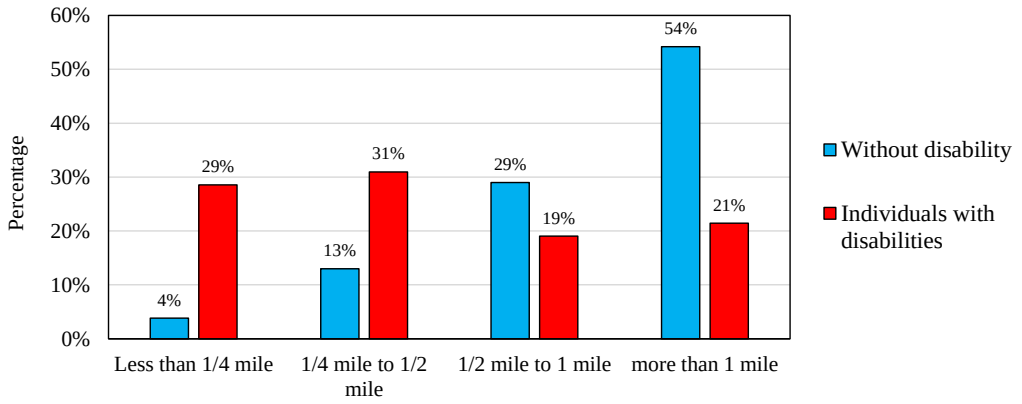
Gender distribution (Individuals with disabilities)



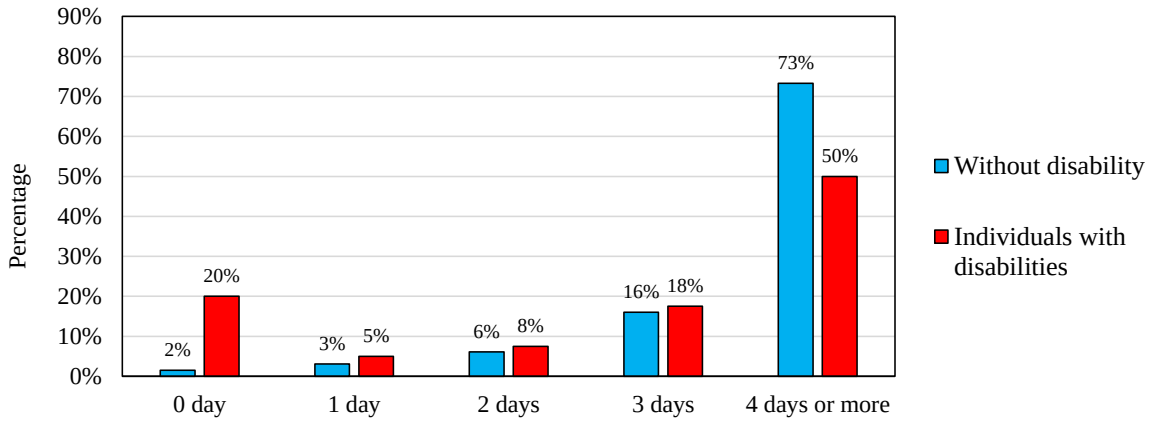
How would you categorize your disability/impairment?



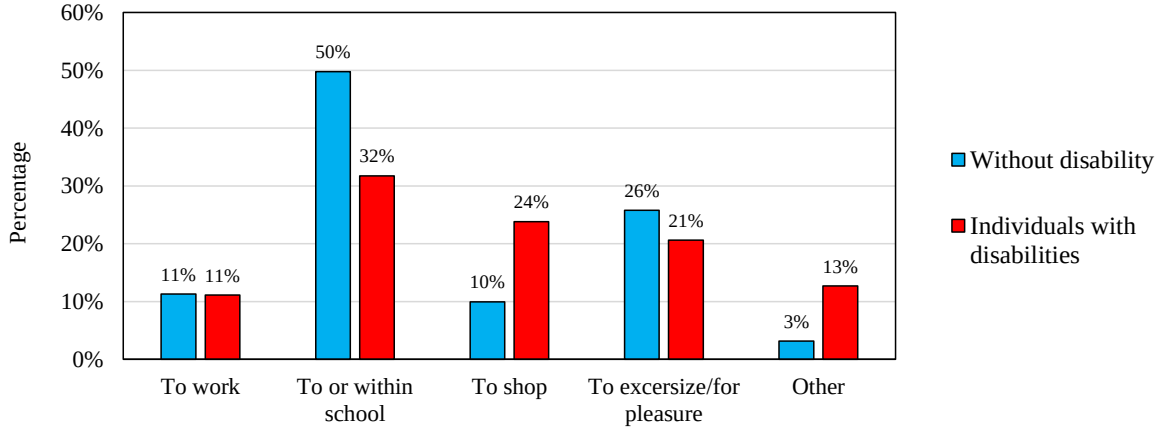
How far do you generally walk each day?



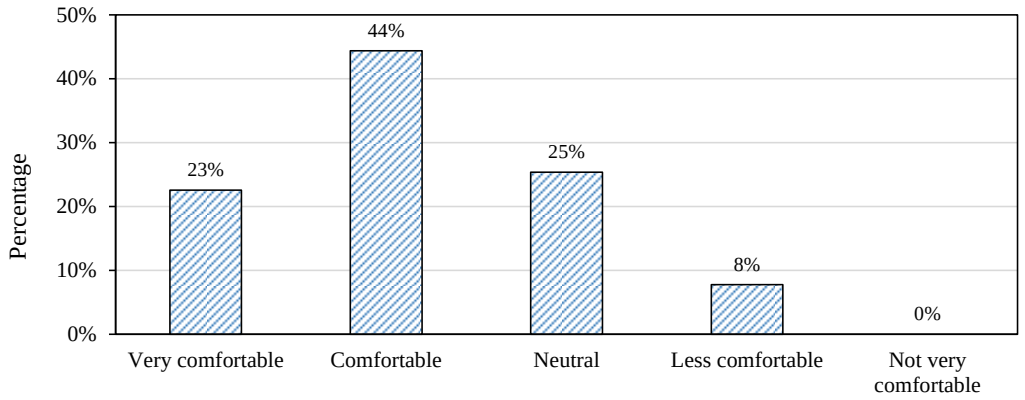
How many days per week do you walk at least 10 continuous minutes per day?



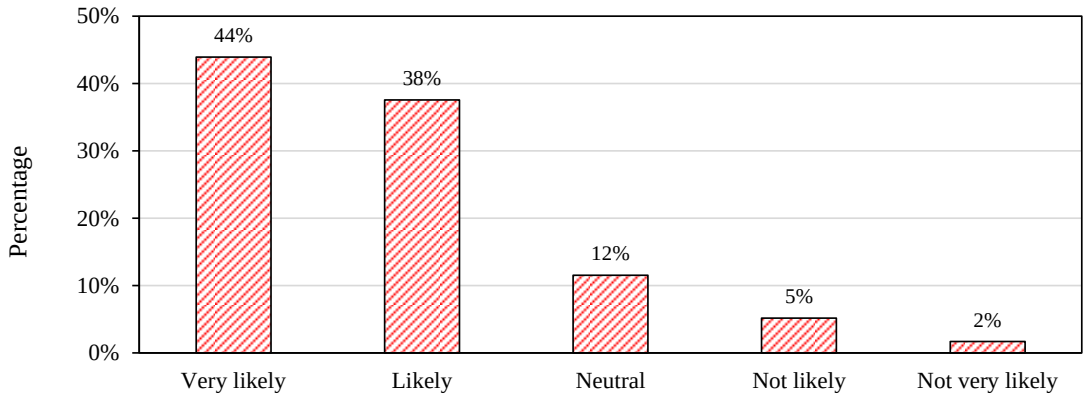
What is your purpose for walking?



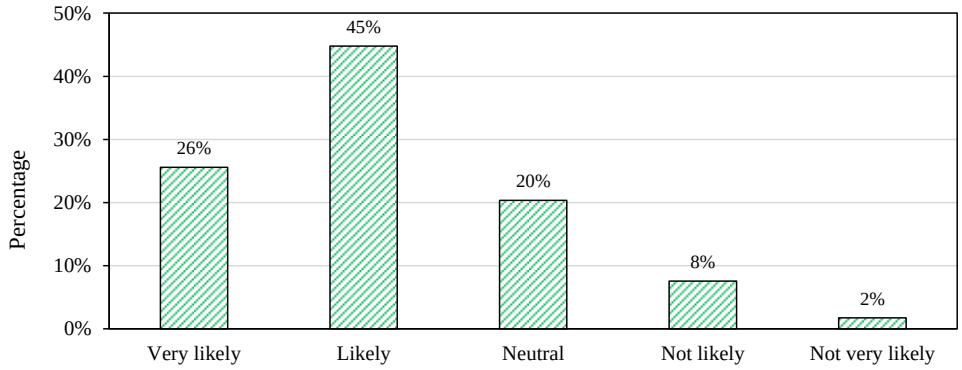
How comfortable do you feel around **individuals with disabilities** compared with others?



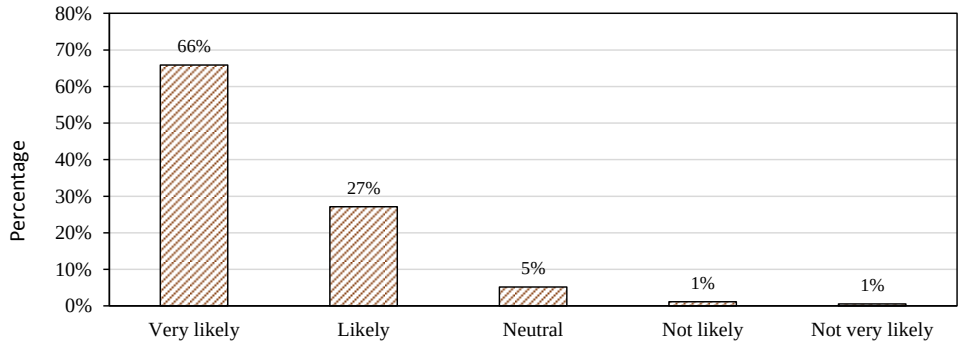
How likely would you be to pass another **individual** when they are walking more slowly than you?



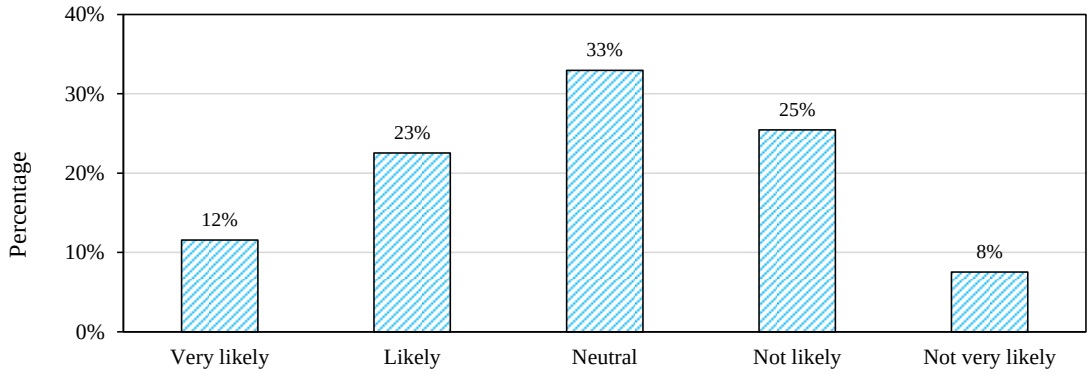
How likely would you be to pass an **individual with a disability** when they are walking more slowly than you?



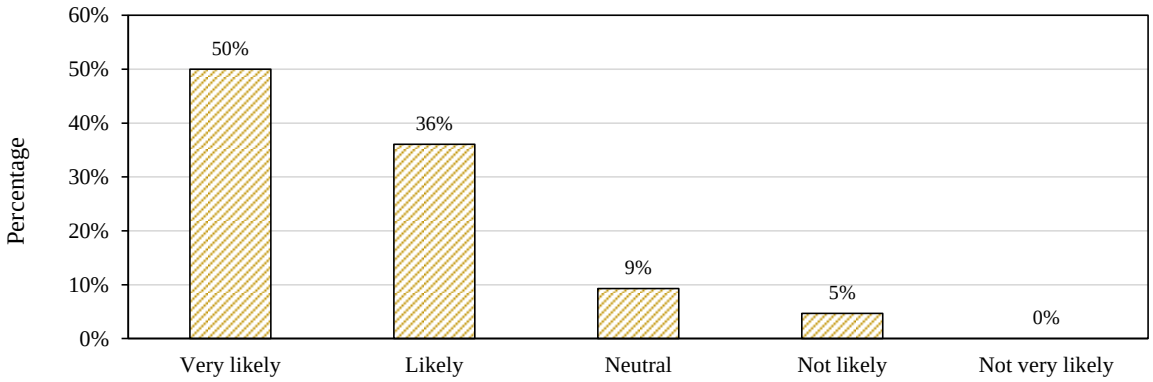
How likely would you be to change your walking behavior toward another **pedestrian with disabilities**? For example, letting them go through the door first or give them extra room.



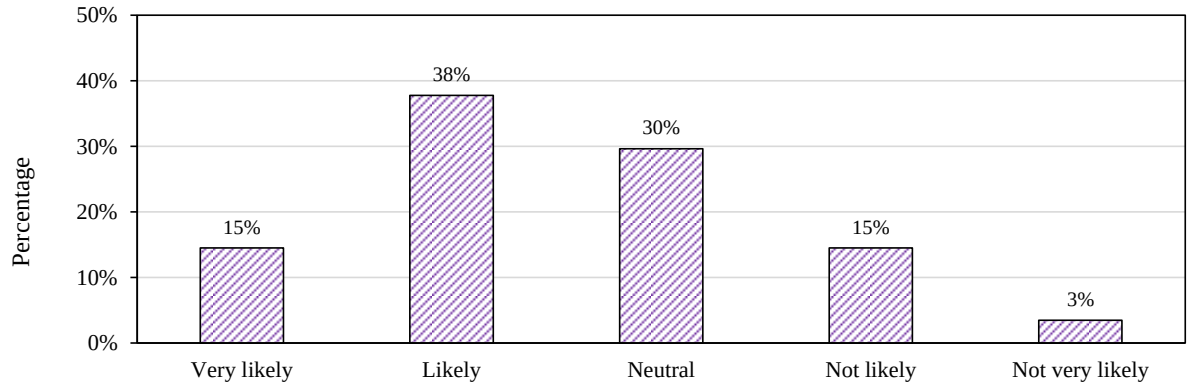
How likely would your walking behavior be impacted by encountering an **individual with a disability** in a wide corridor?



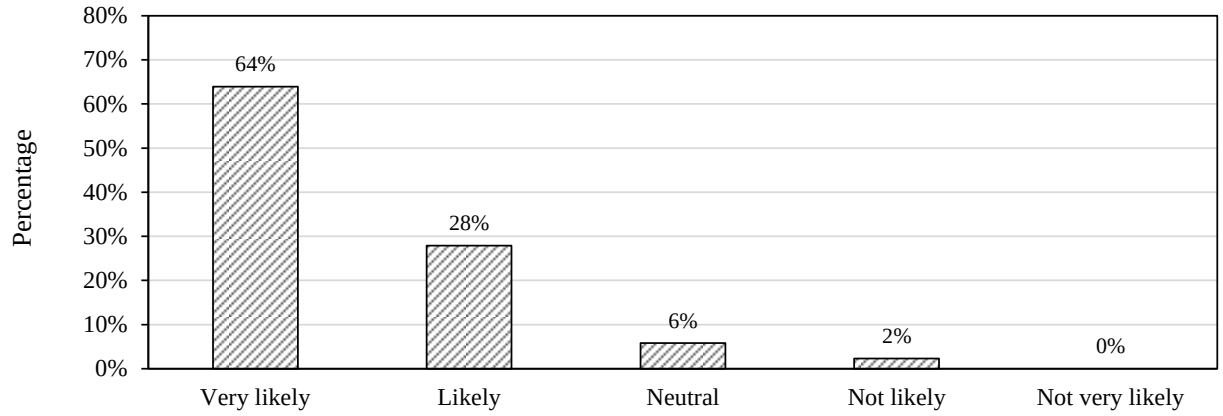
How likely would your walking behavior be impacted by encountering an **individual with a disability** in a narrow corridor?



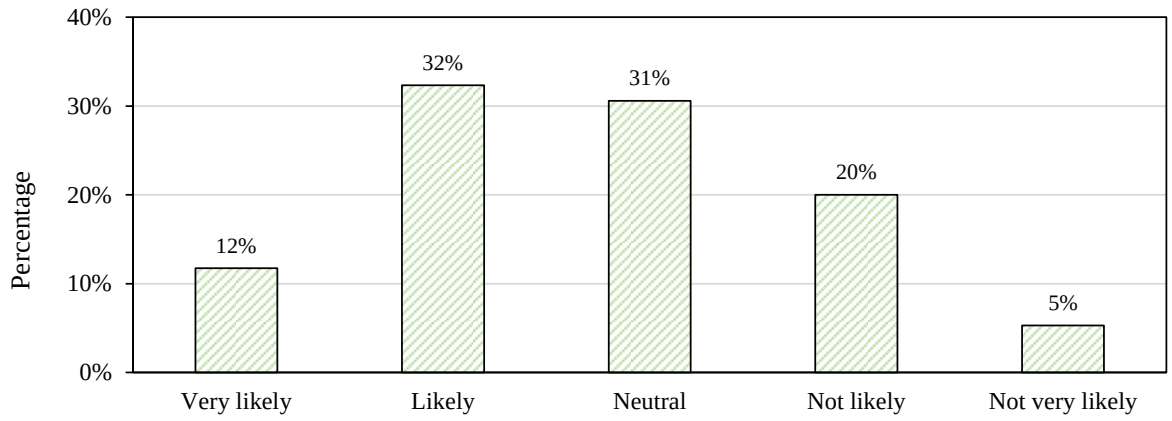
How likely would your walking behavior be impacted by encountering an **individual with a disability** at a wide doorway?



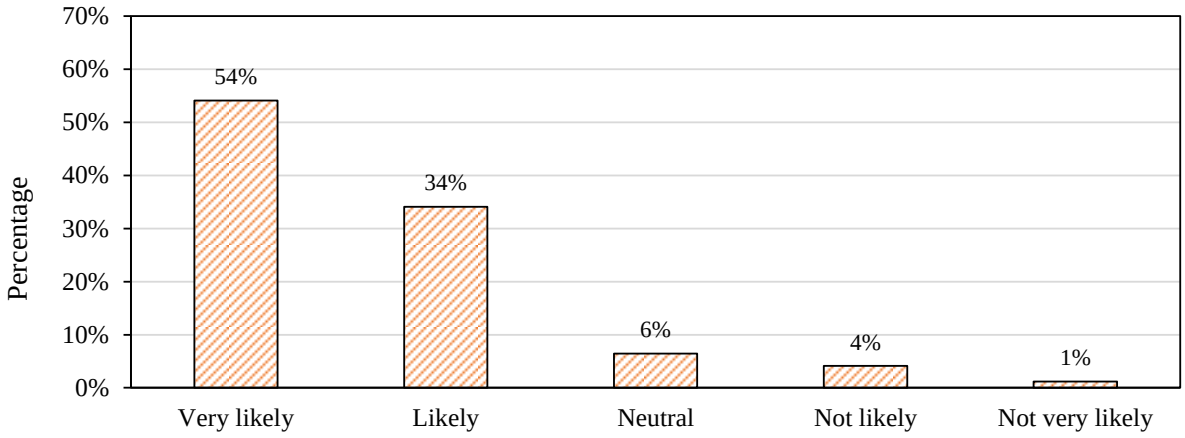
How likely would your walking behavior be impacted by encountering an **individual with a disability** at a narrow doorway?



How likely would your walking behavior be impacted by encountering an **individual with a disability** at a wide corner?



How likely would your walking behavior be impacted by encountering an **individual with a disability** at a narrow corner?



APPENDIX C: Post-survey form

1. For the last lap I completed, I had enough room to maneuver/walk.
   - ☐ Strongly Agree
   - ☐ Agree
   - ☐ Neither disagree or agree
   - ☐ Disagree
   - ☐ Strongly disagree
2. For the last lap I completed, I was able to maintain my desired walking speed.
   - ☐ Strongly Agree
   - ☐ Agree
   - ☐ Neither disagree or agree
   - ☐ Disagree
   - ☐ Strongly disagree
3. For the last lap I completed, my ability to maneuver/walk along the corridors was affected by other people in the environment.
   - ☐ Strongly Agree
   - ☐ Agree
   - ☐ Neither disagree or agree
   - ☐ Disagree
   - ☐ Strongly disagree

   If you strongly agree or agree, what affected your ability to maneuver?

   _____
4. For the last lap I completed, my ability to pass through the doorway was affected by other people in the environment.
   - ☐ Strongly Agree
   - ☐ Agree
   - ☐ Neither disagree or agree
   - ☐ Disagree

- ☐ Strongly disagree

If you strongly agree or agree, what affected your ability to pass through the doorway?

_____

5. For the last lap I completed, my ability to maneuver/walk around the corners was affected by other people in the environment.
   - ☐ Strongly Agree
   - ☐ Agree
   - ☐ Neither disagree or agree
   - ☐ Disagree
   - ☐ Strongly disagree

   If you strongly agree or agree, what affected your ability to maneuver around the corners?

   _____

6. For the last lap I completed, my ability to maneuver/walk when the corridor changed width was affected by other people in the environment.
   - ☐ Strongly Agree
   - ☐ Agree
   - ☐ Neither disagree or agree
   - ☐ Disagree
   - ☐ Strongly disagree

   If you strongly agree or agree, what affected your ability to maneuver when the corridor width changed?

   _____

7. My ability to maneuver/walk was affected by obstacles in the environment?
   - ☐ Strongly Agree
   - ☐ Agree
   - ☐ Neither disagree or agree

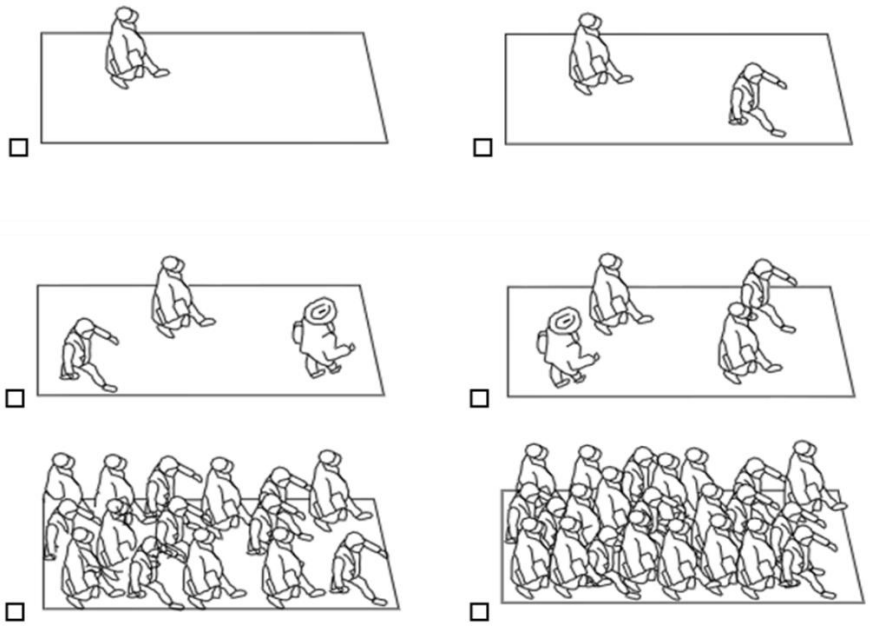
- ☐ Disagree
- ☐ Strongly disagree

If you strongly agree or agree, what affected your ability to maneuver?

_____

8. For the last lap I completed, my ability to maneuver/walk freely was affected by the presence of an **individual with a disability** in the following areas?
   - ☐ Narrow corridor
   - ☐ Wide corridor
   - ☐ Where the corridor width changed
   - ☐ Corner
   - ☐ Doorway

9. Please select the image representing the conditions of the last lap you completed.



10. Please make any comments or suggestions you feel would be beneficial.