New York City
Pedestrian Level of Service Study
Phase I

APRIL 2006

Michael R. Bloomberg, Mayor
City of New York

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EXECUTIVE SUMMARY

The Highway Capacity Manual (HCM), published by the Transportation Research Board, is the definitive document for the measurement of level of service (LOS) on American transportation facilities. The pedestrian LOS as defined and calculated in the HCM has advantages in providing a standardized method for pedestrian analysis in the United States. The HCM provides clear instruction as to what kinds of data need to be collected and how it is to be collected, and LOS is straightforward to calculate.

However, New York City is unique in the United States with regard to its heterogeneity of transportation modes, particularly in its relatively large proportion of walking trips. Although the HCM's methodology may be perfectly adequate for measuring pedestrian LOS in much of the United States, it appears to be underdeveloped for the analysis of New York City's sidewalks, as it does not accurately reflect the complex pedestrian experience in this city. This conclusion has been supplemented by a review of current and historical literature and by the experience of using the HCM in pedestrian studies within this department.

The objectives of this study are to evaluate the HCM pedestrian LOS methodology in terms of its suitability for pedestrian planning in New York City, to compile a pedestrian characteristics database, and to make recommendations for changes in pedestrian LOS analysis in New York City.

After surveying relevant literature and collecting and analyzing pedestrian data, the New York City Department of City Planning, Transportation Division (TD) identified the strengths and weaknesses of the HCM methodology, and outlined possible solutions for the shortcomings. One inadequacy of the HCM is the lack of location specific pedestrian and environmental characteristics. Furthermore, the HCM lacks a clear definition of "shy distance," which used in the determination of the effective width of sidewalks, an important measurement in LOS calculation. Fruin, Pushkarev, Zupan, and others discuss the space that pedestrians tend to keep between themselves and obstacles on the edges of the sidewalk—the so-called shy distance. But few empirical studies that the TD has found have been undertaken to determine what this shy distance is for different types of obstacles and how it changes with different levels of sidewalk density. In addition, the frictional force induced by opposing pedestrian flow is not addressed in the HCM's methodology. There are studies that have demonstrated the influence of this frictional force on pedestrian flow and speed.

The TD designed and tested several new methods of collecting pedestrian data to develop a pedestrian characteristics database. These included a speed and delay walk, video analysis of pedestrian behavior around obstacles, and a pedestrian speed and characteristics survey in the field. The TD's data collection efforts included 50 speed and delay walks over a 1.66 mile route in Lower Manhattan; pedestrian surveys of over sixty locations in Lower Manhattan;

the collection of the characteristics of approximately 9,000 pedestrians; and 30 hours of pedestrian counts. The TD also conducted 7-day pedestrian and vehicle counts to study their relationship, and gathered video footage at various locations for pedestrian behavior analysis.

As the data the TD collected was summarized and analyzed, the TD created a database that would catalog Lower Manhattan pedestrian characteristics, such as speed versus gender, age, trip purpose and size, among others. One important finding the TD reached while conducting this study was that the proportion of pedestrians observed to be impeded (by obstacles or by other pedestrians) at a location is an excellent predictor of overall pedestrian speed and of the TD's subjective interpretation of the sidewalk's level of service. The TD also found that the concept of pedestrian delay is useful as a method of evaluating LOS.

The TD believes that the HCM pedestrian LOS methodology could be improved for New York City with an enhanced focus on the characteristics of pedestrians, and on a more accurate quantification of the physical makeup of the city's sidewalks. This report does not attempt to address the qualitative side of sidewalk design, such as attractiveness, comfort, convenience, safety, security, system coherence, and system continuity, as some researchers have done. This report concentrates on the quantitative aspects of pedestrians, like HCM, to present a tool for planners and engineers to analyze pedestrian facilities' effectiveness through mathematical modeling.

This report serves as the first step in recommending an improved HCM pedestrian LOS methodology. With the preliminary data compiled and analyzed, the document was reviewed by a Technical Advisory Committee consisting of interested transportation academics and professionals. Subsequently, the TD will seek academic and industry partnerships in carrying out the next phase of the project, which will include further data collection and analysis. The final report will then be presented to the Transportation Research Board for review.

CHAPTER 1.

INTRODUCTION

Joe is a 35-year-old financial analyst who lives in the West Village and works at the Federal Reserve Bank in Lower Manhattan. He is also a long time resident of New York City. Every day Joe climbs out of the 1/9 subway station at Rector Street, a briefcase and a Wall Street Journal in his hands, strides east on Rector, then north on Broadway, and takes a right onto Maiden Lane, toward his office. Joe's total walking distance from the subway to work is around 1,950 feet. Along the way, he likes to stop at his favorite coffee stand, buying a coffee and a bagel with cream cheese at a coffee cart at the intersection of Broadway and Liberty Streets. Over the years, Joe has determined that it takes him approximately eleven minutes to get from the subway stop to his office, including waiting in line at the coffee stand and buying his breakfast. He likes to arrive at the office just before 9am, which is when his boss comes in. He has always wished that there was a fruit stand next to the coffee vendor, as he would like to buy a piece of fruit with his coffee and bagel. Sometimes he is frustrated by people talking on their cell phones while walking; they tend to weave and slow down abruptly, and Joe finds that they impede him in his 11-minute walk-time goal to the office. The area around where Joe works is highly interesting to New York's visitors. Joe thinks tourists are even worse than cell phone talkers in their walking habits. They travel in large groups and occupy too much sidewalk space; they take pictures, slow down and point often. Today as Joe leaves the coffee stand, he almost spills his coffee on Mildred.

Mildred is a 70-year-old enthusiastic visitor to New York. She retired a few years ago and is coming with two friends to see the Big Apple for the first time. They are eager to enjoy the museums, Broadway shows, and shopping in Manhattan. The density of skyscrapers, traffic, and people in the city are amazing to Mildred and her friends. Because they have so much to do in a day, Mildred and her friends wake up early on the second day of their trip to visit the World Trade Center site. After seeing Ground Zero, they stroll over to Dey Street then turn on Broadway, heading south toward Wall Street, where they hope to see the Stock Exchange. Total distance: 1,950 feet. Even though Mildred's backpack is a little heavy for all the walking, she does not mind; she enjoys taking in the sights and chatting with her friends. She pauses often to take pictures, look at storefronts, and browse at souvenir vendors. Mildred often wonders why she can not make it across the street during the green signal time; she wonders if she is walking too slowly or if the pedestrian green light time is too short. She thinks that more greenery downtown, especially sidewalk planters with flowers and trees, would help to beautify this part of the city. She also thinks that a sidewalk café on Broadway or Wall Street would improve her visiting experience; she could sit and enjoy the sights without having to rush down the busy streets. Mildred pauses in front of the coffee stand on Broadway and Liberty Street where Joe gets his coffee and she puzzles over her map about which direction she should take to Wall Street. There is Joe.

Joe and Mildred, two very different pedestrians using the same sidewalk, represent a microcosm of New York City's array of walking individuals, all with different expectations of acceptable sidewalk conditions. Their story is a simplified example of the challenges and complexities of pedestrian sidewalk planning in New York City; there are so many different needs to address within such limited space. Joe is irritated by cell phone users and tourists, who are potential roadblocks to his 11 minute walking timeframe. However, he patronizes a busy coffee cart, whose morning queue of like-minded professionals takes up sidewalk space and contributes to the impedance of pedestrians like him. Joe also desires an additional vendor adjacent to his favorite coffee cart, so he can buy fruit for breakfast, but does not realize the implications of pedestrian traffic impedance that this additional stand might introduce to his commute. Mildred has as much right to walk on the sidewalk as Joe, but does not realize the problems she and her tourist group, with their bulky backpacks and confused sense of direction, introduce to the sidewalk traffic flow. In addition, Mildred desires certain tourist and elderly pedestrian-related amenities like sidewalk cafes and longer crosswalk signal timing, which would introduce further complexity to sidewalks that serve a primarily business-oriented population (especially during the morning rush), but must also accommodate those who visit the area for its considerable number of important civic attractions.

For these reasons, the personal characteristics of pedestrians are important to study in detail, because who is walking on sidewalks greatly affects the performance of the sidewalk and its traffic flow. If we become intimately familiar with the variety of New York City pedestrian characteristics, the information could help to make important decisions in planning for pedestrians.

A. New York City and the Pedestrian

New York City is the largest city in the United States in terms of population. According to the census, 7,322,564 people lived in the city in year 1990, a number that increased to 8,008,278 people in year 2000 – a 9.4% increase.

New York is also by far the city with the highest population density in the country: in 2000, the city's density was 26,403 people per square mile, as opposed to the 16,634 people/sq.mi. of San Francisco (second highest population density in the country) or the 12,750 people/sq.mi. of Chicago (third highest population density).

In the year 2000, 88% of workers over 16 years old in the U.S. used a car, truck or van to commute to work, while approximately 5% used public transportation and 3% walked to work. However, New York City represented a very different journey-to-work scenario: 34% of workers went to their workplace by car, truck or van, while 55% used public transportation and 9% walked.

The city of New York is composed of five different boroughs, each with a very different urban fabric and character. In Manhattan, the borough with the highest population density (66,940 people/sq.mi. in year 2000; 1,564,798 inhabitants) and concentration of business and tourist destinations, only 18% of the working population drove to work in 2000, while 72% used public transportation and 8% walked. When we look at the commuting characteristics of Manhattan central business districts (CBD) in comparison to those of the rest of the country, these numbers are even more striking. One good example is that of the Lower Manhattan CBD. According to Census data from 2000, in Community District 1 (the area south of Canal Street), 77.4% of workers used public transportation to get to their workplace, while 3.4% walked and 18.1% drove. In the Midtown CBD– the area lying between 42nd and 59th streets, and 3rd and 8th avenues – only 12.1% of workers drove to work, while 80.7% used public transportation and 6.4% walked.

Another characteristic of New York City, and particularly Manhattan, is a high concentration of civic activities and destinations, which translates into high volumes of traffic, both vehicular and pedestrian. On any given afternoon in the city, workers, shoppers, and tourists share the same sidewalk space on the way to various destinations. In the CBDs and the main shopping and entertainment areas in New York, there is often sidewalk congestion and overcrowding. As a result, walking on certain sidewalk segments sometimes becomes an inefficient, uncomfortable, and even unsafe activity, with pedestrians occasionally spilling onto the roadbed. In addition, on some sidewalks, street furniture and vendors take up space, reducing the width that is actually available for pedestrians to move.

After 9/11, several government and private office buildings have placed new devices such as bollards, delta barriers, jersey barriers and planters on sidewalks for security reasons. These devices help to provide protection for the buildings, but impede pedestrians walking on adjacent sidewalks. Meanwhile, special congestion conditions occur around points of access to public transportation, such as subway entrances and/or exits and heavily used bus stops.

This is the built environment which, through informed planning, would ideally provide efficient and comfortable everyday access to work for our financial analyst Joe, while at the same time presenting a welcoming, safe and attractive strolling environment for Mildred and her tour group.

B. Measuring Pedestrian Level of Service

The Highway Capacity Manual (HCM) by the Transportation Research Board is used as the transportation engineering and planning standard in evaluating transportation facilities. According to the TRB, it is a division of the National Research Council "which serves as an independent adviser to the federal government and others on scientific and technical questions of national importance." The TRB is administered by the National Academy of Sciences, the National Academy of Engineering, and the Institute of Medicine jointly and its mission is to "promote and progress in transportation through research." In order to evaluate sidewalk facilities for pedestrians such as Joe and Mildred, engineers and planners use the HCM to calculate a pedestrian level of service (LOS). LOS may be used, for example, to evaluate the performance of a sidewalk and determine the need to redesign it (change its width, relocate, replace or remove street furniture, etc.); to analyze the efficiency of a sidewalk after a proposed sidewalk change, like the introduction of a sidewalk café or beautification/security elements; or to design new sidewalks in areas of proposed development.

Pedestrian LOS, as defined in the Highway Capacity Manual, is calculated by counting pedestrians who cross a point over a certain period of time (usually 15 minutes), reducing that figure to pedestrians per minute and then dividing by the effective width of the sidewalk. The resulting figure is called the flow rate. A planner may then look up the flow rate in a table to determine the pedestrian LOS grade, ranging from A (free flow) to F (virtually no movement possible). A detailed description of the HCM pedestrian LOS methodology is in Chapter 2 of this report.

The pedestrian LOS measurement has tremendous advantages—it is relatively easy to collect data for its calculation, and the subsequent LOS is easy to calculate. The HCM methodology strives to provide a universal measurement, with an index comparable between places and times. But there are studies in the transportation planning and engineering field that show that the current HCM method of analyzing pedestrian LOS does not accurately reflect the complex pedestrian experience under some circumstances. Most importantly, the HCM method does not take into account many physical, environmental, and psychological factors which affect the pedestrian walking experience.

In the above story about Joe and Mildred, we see that pedestrian characteristics (age, gender), trip characteristics (trip purpose, activities such as the use of a cell phone), and the walking environment (presence of obstacles and amenities, surrounding land use, time of day) work together to change pedestrians' travel expectations and needs. However, the HCM pedestrian LOS methodology does not adequately address the environmental and personal variables that make up a New York City sidewalk. As we have seen above, New York City is unique in the U.S. with regard to its density and its transportation modal distribution.

C. Goals and Objectives

Based on the review of the pedestrian literature and the Department of City Planning's experience with pedestrian studies in the past, the TD concluded that there is a need for a fresh look at the pedestrian LOS calculation and, specifically, how it is applied in New York City. Evidence suggests that the LOS methodology may need to be recalibrated to more accurately measure conditions on the city's sidewalks.

The purpose of this study is to:

- Analyze the suitability of the HCM pedestrian LOS methodology for New York City;
- Empirically measure the factors that contribute to pedestrian congestion on the sidewalks of Lower Manhattan; and
- Recommend pedestrian policy changes based on the study's findings and propose additional opportunities for pedestrian research in New York City.

D. Report Overview

In Chapter 2 of this report the current HCM methodology for pedestrian LOS analysis and vehicular analysis is discussed, and the two analyses are compared. The strengths and weaknesses of the HCM pedestrian LOS methodology are also outlined.

In Chapter 3, the existing literature on pedestrian behavior and level of service is reviewed. Pedestrian research is summarized under five topic headings: analysis of pedestrian characteristics, analysis of environmental characteristics, analysis of flow characteristics, data collection techniques, data analyses and simulation models. In each area, the current HCM LOS methodology is compared to approaches by other researchers.

In Chapter 4 the TD's data collection methodologies are explained. First of all, the methodology for collecting pedestrian characteristics and speeds in the field while also conducting pedestrian counts is described. Second, the video capture and analysis procedure, which is used to study pedestrian impedance and walking behavior, is detailed. A methodology to determine the "shy distances" which people walk away from specific sidewalk obstacles is also outlined.

In Chapter 5 the gathered data is analyzed, and a summary of findings is provided, including pedestrians' speeds by age, gender, group size, and more. Possible ways for defining pedestrian LOS other than flow rate, such as in terms of delay or impedance are also explored. Finally, the merits of each of the study's data collection methods are explored, and potential improvements for the next stage of this project are discussed.

Chapter 6 concludes the report with a summary of the report's findings based on the literature review and data analysis. Then, the TD's proposals for future study, including data collection and recommendations finalization, are introduced. A summary of the peer review comments is presented in Appendix K.

The flow chart in Figure 1.1 provides an overview of the project.

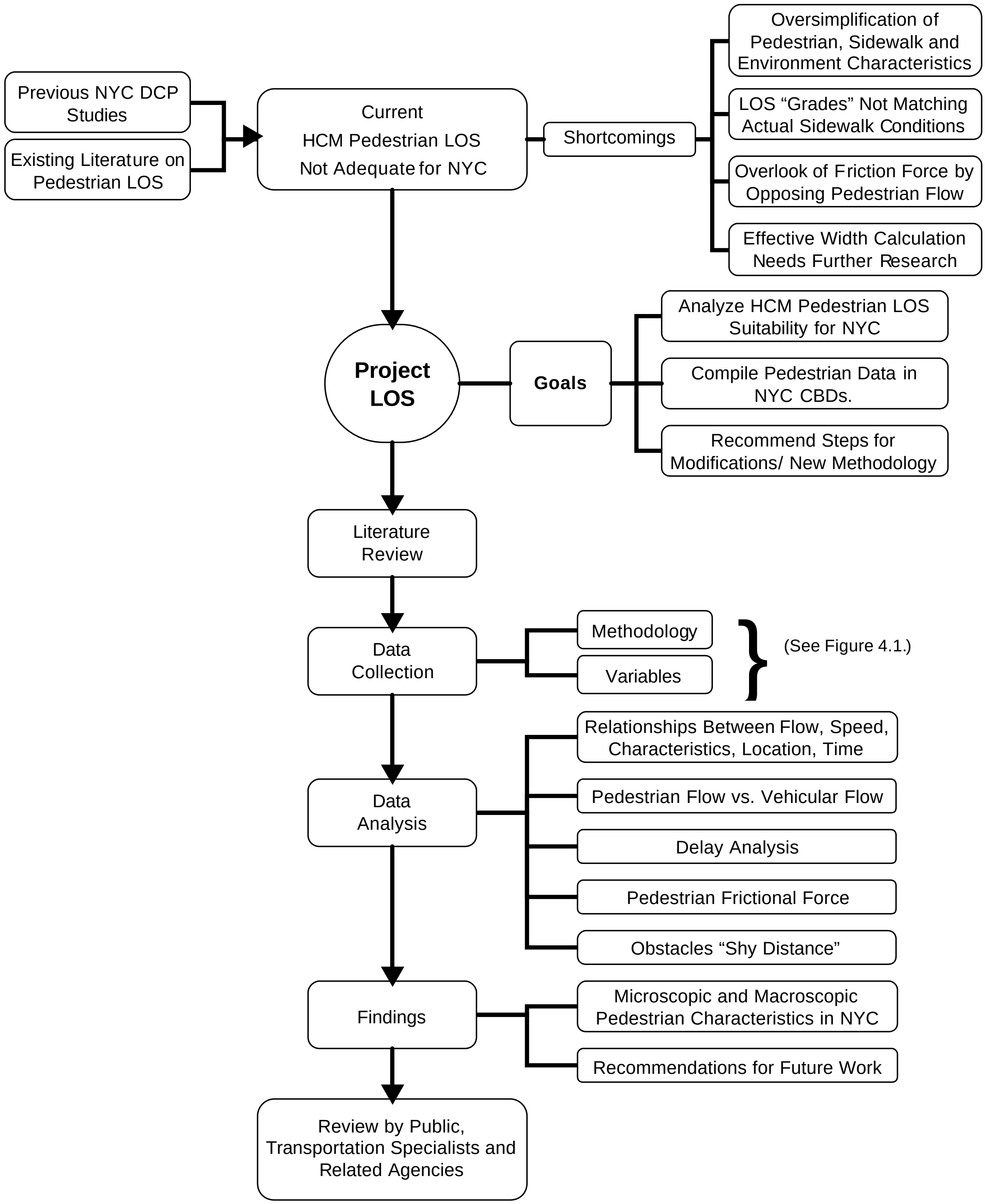

Figure 1.1. Pedestrian HCM LOS Methodology Review Overview

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CHAPTER 2.

CURRENT HCM METHODOLOGY

The Highway Capacity Manual (HCM) by the Transportation Research Board (TRB) is used as the industry standard for analyzing traffic of different transportation modes. The HCM uses the concept of level of service (LOS) as a qualitative measure to describe operational conditions of vehicular and pedestrian traffic, "based on service measures such as speed and travel time, freedom to maneuver, traffic interruptions, comfort and convenience." The section of the HCM dedicated to the level of service analysis of pedestrian flow on sidewalks, crosswalks, and street corners is mainly derived from John Fruin's research. In this chapter, the HCM's current pedestrian and vehicular methodologies will be discussed, compared and contrasted. A discussion of the strengths and weaknesses of the pedestrian level of service methodology in the HCM concludes the chapter.

A. Pedestrian LOS

The HCM's methods for analyzing pedestrian LOS are based on the measurement of pedestrian flow rate and sidewalk space. The pedestrian flow rate, which incorporates pedestrian speed, density, and volume, is equivalent to vehicular flow. According to the HCM:

> "As volume and density increase, pedestrian speed declines. As density increases and pedestrian space decreases, the degree of mobility afforded to the individual pedestrian declines, as does the average speed of the pedestrian stream."

The analysis of the sidewalk level of service for the midblock uses the calculation of pedestrians per minute per foot (ped/min/ft) as the basis for LOS classification (see Table 2.1.). According to this measurement, on a walkway with LOS A, pedestrians move freely without altering their speed in response to other pedestrians or to a decrease in the sidewalk width. On the other hand, on a walkway with LOS F, all walking speeds are severely restricted and forward progress is made only by "shuffling." See Figure 2.1. for the HCM's description for each pedestrian LOS.

The pedestrian unit flow rate (ped/min/ft) is obtained by taking the pedestrian 15-minute flow rate (ped/15-min) and dividing by the effective walkway width. The HCM suggests collecting pedestrian opposing flow volumes at 15-minute intervals. The sum of the two directional flows is used as the 15-minute flow rate. Effective width of the sidewalk is calculated by taking the total width of the sidewalk and subtracting obstacle widths and a 1 to 1.5 ft buffer width per obstacle. Obstacle widths can be measured from the field. The additional buffer width is based on an estimation provided by the HCM. The HCM cites Pushkarev and Zupan (1975) as their source for the method of buffer width calculation; however, no studies the TD has found, including the cited Pushkarev and Zupan volume, describe any method of buffer width calculation. Using the pedestrian

Table 2.1. Average Flow LOS Criteria for Walkways and Sidewalks

LOS	Space (ft²/p)	Flow Rate (p/min/ft)	Speed (ft/s)	V/C Ratio
A	> 60	≤ 5	> 4.25	≤ 0.21
B	> 40-60	> 5-7	> 4.17-4.25	> 0.21-0.31
C	> 24-40	> 7-10	> 4.00-4.17	> 0.31-0.44
D	>15-24	> 10-15	> 3.75-4.00	> 0.44-0.65
E	> 8-15	> 15-23	> 2.50-3.75	> 0.65-1.00
F	≤ 8	variable	≤ 2.50	variable

LOS A
Pedestrian Space > 60 ft²/p, Flow Rate = 5 p/min/ft

At a walkway LOS A, pedestrians move in desired paths without altering their movements in response to other pedestrians. Walking speeds are freely selected, and conflicts between pedestrians are unlikely.

LOS B
Pedestrian Space > 40-60 ft²/p, Flow Rate > 5-7 p/min/ft

At LOS B, there is sufficient area for pedestrians to select walking speeds freely to bypass other pedestrians, and to avoid crossing conflicts. At this level, pedestrians begin to be aware of other pedestrians, and to response to their presence when electing a walking path.

LOS C
Pedestrian Space > 24-40 ft²/p, Flow Rate > 7-10 p/min/ft

At LOS C, space is sufficient for normal walking speeds, and for bypassing other pedestrians in primarily unidirectional streams. Reverse-direction or crossing movements can cause minor conflicts, and speeds and flow rate are somewhat lower.

LOS D
Pedestrian Space > 15-24 ft²/p, Flow Rate > 10-15 p/min/ft

At LOS D, freedom to select individual walking speed and to bypass other pedestrians is restricted. Crossing or reverse-flow movements face a high probability of conflict, requiring frequent changes in speed and position. The LOS provides reasonably fluid flow, but friction and interaction between pedestrians is likely.

LOS E
Pedestrian Space > 8-15 ft²/p, Flow Rate > 15-23 p/min/ft

At LOS E, virtually all pedestrians restrict their normal walking speed, frequently adjusting their gait. At the lower range, forward movement is possible only by shuffling. Space is not sufficient for passing slower pedestrians. Cross- or reverse-flow movements are possible only with extreme difficulties. Design volumes approach the limit of walkway capacity, with stoppages and interruptions to flow.

LOS F
Pedestrian Space = 8 ft²/p, Flow Rate varies p/min/ft

At LOS F, all walking speeds are severely restricted, and forward progress is made only by shuffling. There is frequent unavoidable contact with other pedestrians. Cross-and reverse-flow movements are virtually impossible. Flow is sporadic and unstable. Space is more characteristic of queued pedestrians than of moving pedestrian streams.

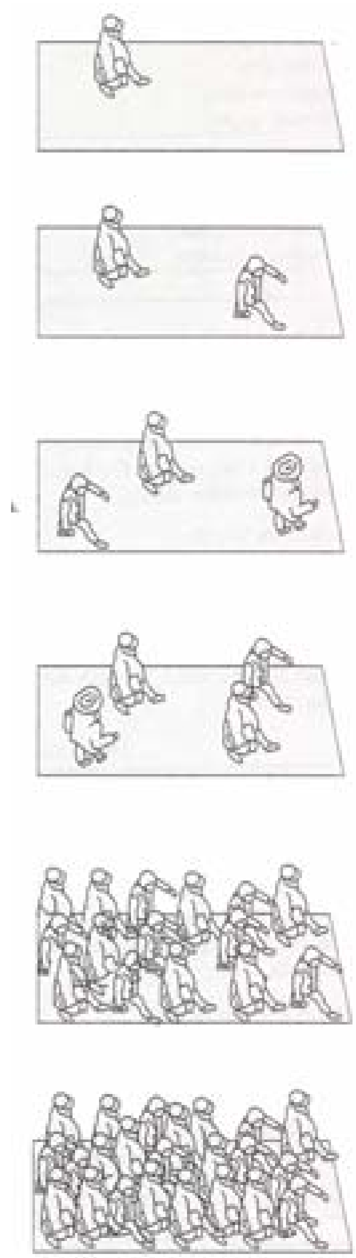


Figure 2.1. Pedestrian LOS according to HCM

unit flow rate in the "Average Flow LOS Criteria for Walkways and Sidewalks" (see Table 2.1), pedestrian LOS can be calculated. In addition to LOS grades A to F, space (ft^2/p), speed (ft/s), and the volume-to-capacity (v/c) ratio can also be derived from the table. Capacity is "the maximum number of persons that can be accommodated along a given point of a sidewalk or transit corridor, or that can be accommodated within a crosswalk, intersection, corner reservoir, transit vehicle or turnstile" (CEQR). The volume-to-capacity ratio is "the ratio of flow rate to capacity for a transportation facility" (HCM).

Pedestrians often travel together as a group, voluntarily or involuntarily, due to signal control, geometrics, or other factors. This phenomenon is called platooning and it occurs, for example, when a large number of bus or subway riders exit onto the sidewalk. To account for the impact of platooning on pedestrian travel behavior, the HCM introduces the "Platoon-Adjusted LOS Criteria for Walkways and Sidewalks," a table which can be used to obtain the platoon LOS. Using research done by Pushkarev and Zupan in *Urban Space for Pedestrians*, impeded flow in the HCM platoon LOS starts at 530 ft^2/p, 0.5 ped/min/ft (LOS A); while "jammed flow" begins at 11 ft^2/p, 18ped/min/ft (LOS F) (see Table 2.2.). The HCM states that the LOS which occurs in platoons is generally one level poorer than that determined by average flow criteria.

Table 2.2. Platoon-Adjusted LOS Criteria for Walkways and Sidewalks

LOS	Space (ft^2/p)	Flow Rate (p/min/ft)
A	> 530	≤ 0.5
B	> 90-530	> 0.5-3
C	> 40-90	> 3-6
D	> 23-40	> 6-11
E	> 11-23	> 11-18
F	≤ 11	> 18

B. Vehicular LOS

Similarly to the pedestrian HCM LOS analysis, vehicular LOS analysis is based on a scale from A through F, with A representing the best and F representing the worst traveling conditions. There are three street categories in the vehicular LOS analysis: urban streets, freeways, and highways. Within the urban street analysis, there are sub-analyses for arterial, signalized and unsignalized intersections. The main criterion for evaluating the LOS of arterial streets is travel speed (Table 2.3). The criterion for determining LOS at signalized and unsignalized intersections is control delay per vehicle, in seconds per vehicle (Tables 2.4. and 2.5). Delay is the "additional travel time experienced by a driver, passenger or pedestrian" (HCM). Control delay is defined by "initial deceleration delay, queue move-up, stopped delay, and final acceleration delay" (HCM). Signals are often put in place to handle high traffic flow at intersections. Combining higher volumes with drivers' perceptions and reaction times to traffic signals, signalized intersections often have higher delays than unsignalized intersections. A roundabout is defined by the Federal Highway Administration as "a one-way, circular intersection without traffic signal equipment in which traffic flows around a center island". Roundabout analysis in the HCM is based on gap acceptance - or "the process by which a minor-street vehicle accepts an available gap to maneuver" (HCM) – and it is evaluated in terms of capacity and v/c ratio. For vehicular traffic, capacity is defined as "the maximum numbers of vehicles that can pass a point on a street or highway during a specified time period, usually expressed as vehicles per hour" (CEQR). No formal LOS has been established for roundabouts by the HCM.

The two-lane highway LOS analysis is separated into Class I and Class II categories. The HCM explains that, on Class I highways, "efficient mobility is paramount, and LOS is defined in terms of both percent time-spent-following and average travel speed." (see Table 2.6.). On Class II highways, however, "mobility is less critical and LOS is defined only in terms of per time-spent-following, without consideration of average travel speed" (see Table 2.7.). According to

Table 2.3. Urban Street LOS by Class

Urban Street Class	I	II	III	IV
Range of free-flow speeds (FFS)	50-45 mi/h	45-35 mi/h	35-30 mi/h	35-25 mi/h
Typical FFS	50 mi/h	40 mi/h	35 mi/h	30 mi/h
LOS	Average Travel Speed (mi/h)			
A	> 42	> 35	> 30	> 25
B	> 34-42	> 28-35	> 24-30	> 19-25
C	> 27-34	> 22-28	> 18-24	> 13-19
D	> 21-27	> 17-22	> 14-18	> 9-13
E	> 16-21	> 13-17	> 10-14	> 7-9
F	≤ 16	≤ 13	≤ 10	≤ 7

Table 2.4. LOS Criteria for Signalized Intersections

LOS	Control Delay per Vehicle (s/veh)
A	≤ 10
B	> 10-20
C	> 20-35
D	> 35-55
E	> 55-80
F	>80

Table 2.5. LOS Criteria for Two-Way (TWSC) and All-Way Stop-Controlled (AWSC) Intersections

LOS	Control Delay per Vehicle (s/veh)
A	0-10
B	>10-15
C	>15-25
D	>25-35
E	>35-50
F	>50

Table 2.6. LOS Criteria for Two-Lane Highways in Class I

LOS	Percent Time-Spent-Following	Average Travel Speed (mi/h)
A	≤ 35	> 55
B	> 35-50	> 50-55
C	> 50-65	> 45-50
D	> 65-80	> 40-45
E	> 80	≤ 40

Table 2.7. LOS Criteria for Two-Lane Highways in Class II

LOS	Percent Time-Spent-Following
A	≤ 40
B	> 40-55
C	>55-70
D	> 70-85
E	> 85

the HCM, drivers usually have a higher tolerance for delay on Class II highways because Class II highways tend to serve shorter trips.

The HCM's Multilane Highway analysis focuses on uninterrupted highway flow segments. The characteristics of a multilane highway include a 12-foot minimum lane width, a 12-foot minimum total lateral clearance, facilities for passenger cars only, the absence of direct access points, a divided highway, and free-flow speeds higher than 60 mi/hr. The LOS criteria for multilane highways are based on "typical speed-flow" and "density-flow relationships" (see Table 2.8.). Since LOS F indicates that the flow rate exceeds capacity, it is not listed in the table.

Table 2.8. LOS Criteria for Multilane Highways

Free Flow Speed	Criteria	A	B	C	D	E
60 mi/h	Maximum density (pc/mi/l)	11	18	26	35	40
	Average speed (mi/h)	60.0	60.0	59.4	56.7	55.0
	Maximum v/c	0.30	0.49	0.70	0.90	1.00
	Maximum service flow rate (pc/h/ln)	660	1,080	1,550	1,980	2,200
55 mi/h	Maximum density (pc/mi/l)	11	18	26	35	41
	Average speed (mi/h)	55.0	55.0	54.9	52.9	51.2
	Maximum v/c	0.29	0.47	0.68	0.88	1.00
	Maximum service flow rate (pc/h/ln)	600	990	1,430	1,850	2,100
50 mi/h	Maximum density (pc/mi/l)	11	18	26	35	43
	Average speed (mi/h)	50.0	50.0	50.0	48.9	47.5
	Maximum v/c	0.28	0.45	0.65	0.86	1.00
	Maximum service flow rate (pc/h/ln)	550	900	1,330	1,710	2,000
45 mi/h	Maximum density (pc/mi/l)	11.0	18.0	26.0	35.0	45.0
	Average speed (mi/h)	45	45	45	44.4	42.2
	Maximum v/c	0.26	0.43	0.62	0.82	1.00
	Maximum service flow rate (pc/h/ln)	490	810	1,170	1,550	1,900

The HCM LOS analysis methodology for freeway facilities is separated into three categories: basic freeway segments, ramp segments, and weaving segments. The HCM assumes that the performance of each of the freeway components does not affect the performance of the others. The freeway segment methodology treats each segment in terms of an individual scenario, with no impact on adjacent segments. Therefore, there is no one general LOS designation for freeway facilities; instead there are basic freeway, ramp, and weaving LOS ratings. Basic freeway LOS analysis is defined by density (vehicle per mile per lane), speed, and the volume to capacity ratio for passenger cars (see Table 2.9.). In the weaving analysis, LOS is defined by the weaving segment density (vehicle per mile per lane) (Table 2.10.). In the ramp segments analysis, the HCM focuses on the merging and diverging areas of ramps to freeways. LOS is denoted from A to E only, as LOS F represents a demand over capacity conditions (see Table 2.11.).

C. Pedestrian LOS and Vehicular LOS Comparison

The HCM's pedestrian LOS analysis criteria are based on space, average speed, flow rate, and the ratio of volume to capacity. There are some similarities in the pedestrian analysis to the determination of vehicular LOS. For example, pedestrian space (ft^2/ped) is equivalent to vehicular density on multi-lane highway and freeway facilities, including basic freeway, ramp, and weaving segments. Pedestrian average speed (ft/min) is equivalent to vehicular average travel speed (mi/hr) for urban streets, Class I two-lane and multilane highways, and basic freeways. The pedestrian flow rate (ped/min/ft) is equivalent to vehicular flow rate (passenger car/hr/lane) on multilane highways and basic freeways. In addition, the pedestrian's volume to capacity ratio is the equivalent of the volume to capacity ratio on multilane highways and basic freeway segments.

In contrast to pedestrian LOS calculations, vehicular LOS analysis includes a "control delay per vehicle" component in the analysis of signalized and unsignalized intersections. Control delay is the travel

Table 2.9. LOS Criteria for Basic Freeway Sections

Level of Service	Maximum Density (pc/mi/ln)	Maximum Speed (mph)	Max Service Flow Rate (PCPHPL)	Maximum v/c ratio
Free-flow Speed = 70 mph				
A	10.0	70.0	700	0.318/0.304
B	16.0	70.0	1,120	0.509/0.487
C	24.0	68.5	1,644	0.747/0.715
D	32.0	63.0	2,015	0.916/0.876
E	36.7/39.7	60.0/58.0	2,200/2,300	1.000
F	var	var	var	Var
Free-flow Speed = 65 mph				
A	10.0	65.0	650	0.295/0.283
B	16.0	65.0	1,040	0.473/0.452
C	24.0	64.5	1,548	0.704/0.673
D	32.0	61.0	1,952	0.887/0.849
E	39.3/43.4	56.0/53.0	2,200/2,300	1.000
F	var	var	var	var
Free-flow Speed = 60 mph				
A	10.0	60.0	600	0.272/0.261
B	16.0	60.0	960	0.436/0.417
C	24.0	60.0	1,440	0.655/0.626
D	32.0	57.0	1,824	0.829/0.793
E	41.5/46.0	53.0/50.0	2,200/2,300	1.000
F	var	var	var	var
Free-flow Speed = 55 mph				
A	10.0	55.0	550	0.250/0.239
B	16.0	55.0	880	0.400/0.383
C	24.0	55.0	1,320	0.600/0.574
D	32.0	54.8	1,760	0.800/0.765
E	44.0/47.9	50.0/48.0	2,200/2,300	1.000
F	var	var	var	var

Table 2.10. LOS Criteria for Weaving Segments

LOS	Density (pc/mi/ln)	
	Freeway Weaving Segment	Multilane and Collector-Distributor Weaving Segments
A	≤ 10.0	≤ 12.0
B	> 10.0-20.0	>12.0-24.0
C	> 20.0-28.0	>24.0-32.0
D	> 29.0-35.0	>32.0-36.0
E	> 35.0-43.0	>36.0-40.0
F	> 43.0	> 40.0

Table 2.11. LOS Criteria for Merge and Diverge Areas

LOS	Density (pc/mi/ln)
A	≤ 10
B	> 10-20
C	> 20-28
D	> 28-35
E	> 35
F	Demand exceeds capacity

time vehicles waste due to signal timing, queuing and stop and start time; it is the travel time that one would incur on stop controlled street facilities in excess of the time it would take to traverse the same distance with no control devices. In addition, the pedestrian LOS analysis lacks percent time-spent-following criteria, a measurement found in analyses of Class I and Class 2 two-lane highways. Percent time-spent-following is defined by the HCM as "…the average percentage of travel time that vehicles must travel in platoons behind slower vehicles due to the inability to pass."

D. Pedestrian HCM LOS Strengths and Weaknesses

The HCM pedestrian LOS methodology's foremost advantage is its simplicity. It is relatively easy to collect data and calculate the pedestrian LOS for a location. For the midblock pedestrian LOS, the only data necessary is a pedestrian count, the effective width of the sidewalk, and an indication whether or not platooning was occurring.

Second, the pedestrian LOS methodology attempts to create a universal standard in pedestrian analysis regardless of the size of the city, the type of pedestrians, or various environmental factors. This allows planners to easily compare the LOS derived across locations and time.

Third, although the standard LOS calculation is fixed, the HCM's pedestrian LOS methodology allows for local flexibility based on actual conditions. For example, the HCM encourages planners to consider their own LOS methodologies in areas with significant elderly populations or with a dominant trip purpose.

Finally, the pedestrian LOS methodology is not static—it evolves as researchers discover new relationships between factors or as they discover new ways to collect and model data. In fact, the TRB made significant changes to the pedestrian LOS chapters as recently as 2000.

However, the pedestrian LOS methodology does have shortcomings. Pedestrian flow rate is used to assign LOS in the HCM. For example, from the sum of two directional counts, a count of 800 pedestrians on a 12-foot effective sidewalk width yields a flow rate of 4.44 ped/ft/min. Looking up the flow rate on the "Average Flow LOS Criteria for Walkways and Sidewalks" tables (Tables 2.1. and 2.2.), an LOS of A and C for normal and platoon conditions are identified respectively. From the tables, one can also get the values of speed, space, and the V/C ratio based on the flow rates from previous research. Using the HCM methodology, the flow rate calculation does not account for possible bi-directional or multi-directional effects. Flow rate is calculated using the sum of the two directional counts. Therefore, friction introduced by the opposing pedestrian flow is not accounted for.

The HCM methodology also generalizes the makeup of the study population without much consideration for individual pedestrian characteristics. For example, pedestrians' gender, age, and trip purpose could have significant impact on their speed and comfort level on different sidewalk segments. Different times of a day, surrounding land uses, and weather could also affect the sidewalk LOS.

The sidewalk effective width is calculated in the HCM's methodology by taking the total width and subtracting sidewalk obstacle widths and a "shy distance", which is the buffer distance that pedestrians typically walk from obstacles. The shy distance is estimated in the HCM to be 1 to 1.5 feet. No detailed studies the TD has come across, including the Pushkarev and Zupan (1975) book which the HCM cited as the source of the shy distance measurement, have described how to calculate a shy distance. It would seem that the shy distance of pedestrians on an individual sidewalk could be affected by the number of pedestrians on the sidewalk, the time of day, and by the surrounding land use. It is important to find out what the real effective width is for each sidewalk if flow rate is to be used as the determining factor for LOS; this would involve developing a repeatable methodology for calculating a sidewalk's shy distance.

The HCM's pedestrian LOS methodology appears to be too insensitive to changes in pedestrian volume and sidewalk width. For example, a case study was done by the Department of City Planning, Transportation Division to examine whether the reduction of sidewalk space by sidewalk café's would induce a significant impact on the pedestrian LOS. A series of tests were done using the HCM's LOS methodology. The tests revealed that the number of pedestrians that would need to be added to a sidewalk to degrade the sidewalk's LOS was insensitive (see Table 2.12.). For example, on a sidewalk with twelve-foot effective width, with 1,300 pedestrians in a fifteen-minute period, the LOS was C; it would take an additional 600 pedestrians for the LOS to change to D. This translates into an hourly volume of 7,600 pedestrians

Table 2.12. Sidewalk Width, Pedestrian Volume and Level of Service

The following chart shows the pedestrian level of service for sidewalks with varying clear paths.
- The top portion of the chart shows café width alternatives for various sidewalk widths. (Café widths that would be unavailable under current zoning restrictions are italicized.)
- The bottom portion of the chart shows the clear path for adjacent sidewalks along the top. On the vertical axis, possible pedestrian volumes are shown. The center of the chart shows the pedestrian Level of Service (LOS), based on those two inputs.

Café Widths	**Sidewalk Width (ft)**								
8' Sidewalk Café	*12*			*15*			18		20
7' Sidewalk Café		*12*			15			18	
6' Sidewalk Café			*12*			15			18
5' Sidewalk Café				*12*			15		
4' Sidewalk Café					12			15	
	Clear Path*								
15 Min Peak Flow Rate (ped/15 min)	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
200	A	A	A	A	A	A	A	A	A
300	B	A	A	A	A	A	A	A	A
400	B	B	A	A	A	A	A	A	A
500	C	B	B	A	A	A	A	A	A
600	C	C	B	B	B	A	A	A	A
700	D	C	C	B	B	B	A	A	A
800	D	D	C	C	B	B	B	A	A
900	D	D	C	C	C	B	B	B	B
1000	E	D	D	C	C	C	B	B	B
1100	E	D	D	D	C	C	C	B	B
1200	E	E	D	D	C	C	C	C	B
1300	E	E	D	D	D	C	C	C	C
1400	F	E	E	D	D	D	C	C	C
1500	F	E	E	D	D	D	C	C	C
1600	F	E	E	E	D	D	D	C	C
1700	F	E	E	E	D	D	D	D	C
1800	F	F	E	E	D	D	D	D	C
1900	F	F	E	E	E	D	D	D	D
2000	F	F	E	E	E	D	D	D	D
2100	F	F	F	E	E	E	D	D	D

* For the purposes of this chart, Clear Path is defined as the perpendicular distance from the edge of the sidewalk café to the curb. LOS is typically calculated using the effective sidewalk width, which deducts sidewalk width for street furniture and other obstructions. However, the LOS figures shown on this chart are calculated with the clear path and are intended for illustrative purposes.

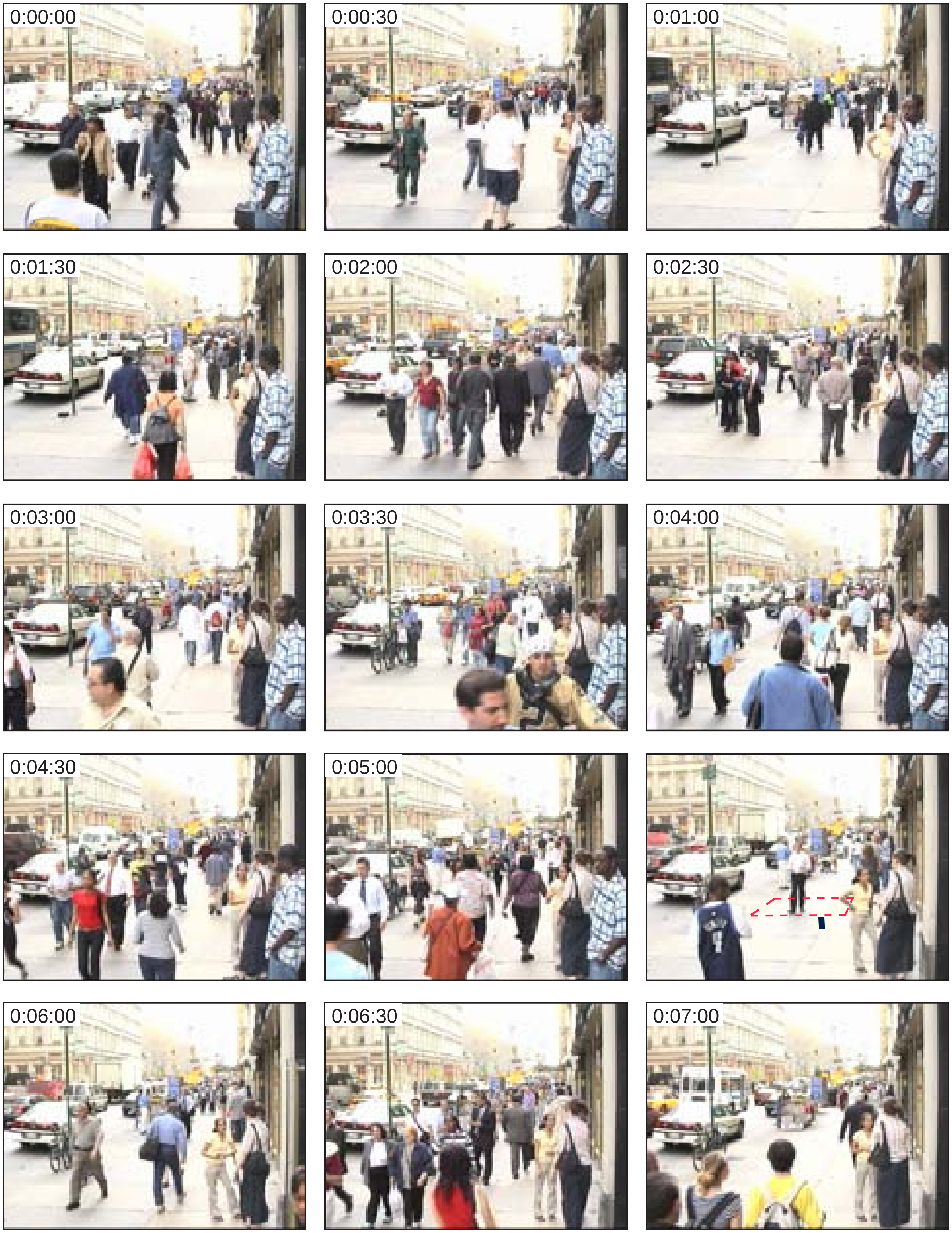
NYC Department of City Planning, Transportation Division, 25 June 2002 on a 12-foot wide sidewalk in order to have a LOS D. During odata collection, the highest pedestrian traffic during the AM peak was on the north sidewalk (12.4 feet wide) of Wall Street between William and Hanover, the volume was just over 3,000 pedestrians per hour. During the midday peak, on the east sidewalk (11.5 feet wide) of Broadway between Wall and Pine Street, there were 4,200 pedestrians hourly. Therefore, it seems almost impossible for a sidewalk to get an LOS D.

In order to help conceptualize the HCM's measurement of LOS, two series of thirty still images from a 15-minute video of a sidewalk's pedestrian traffic were captured in Lower Manhattan. These images were part of the data collection effort for this project (see Chapters 4 and 5 for further explanation of the methodology and the data analysis). One frame was exported from the 15-minute video clip every thirty seconds. In Figure 2.2, these frames are shown in sequence by time from left to right and top to bottom.

The first location, chosen to illustrate a LOS A and platoon LOS C, is this project's control location, the west sidewalk of Broadway between Duane Street and Reade Street (see Figure 2.2.). The control location is where the TD goes back repeatedly to collect data to study for daily, monthly, or seasonal variation. The fifteen-minute video for this location was filmed on April 19, 2004, at 3:15 pm. A total of 562 pedestrians were counted on the sidewalk during this fifteen-minute period. The total sidewalk width is 16.2 ft and the effective width is 14.2 ft, based on the HCM's effective width calculation methodology. According to the HCM, this section has an LOS A for overall conditions, and an LOS C for platoon conditions. A square with an approximate area of 60 ft^2 was drawn in frame 0:05:30. Using this square space, it is possible to compare a real life street condition in a 60 ft^2 space to the HCM's illustration in Figure 2.1., and consider what LOS ratings means in terms of space. 60 ft^2/pedestrian is the minimum space that has to be available for each pedestrian for a sidewalk to achieve LOS A. However, based on the observation of the image sequence, pedestrians seem to have less than 60 ft^2 of available space on average. Using the platoon condition LOS C (24-40 ft^2/pedestrian) to describe the location maybe closer to reality.

The second location is the south sidewalk of John Street between Cliff Street and Pearl Street (see Figure 2.3.). The video at this location was filmed on April 20, 2004, at 1:20 pm. A total of 471 pedestrians were counted on the sidewalk during the fifteen minute filming time. The total sidewalk width is 12 ft, and the HCM-calculated effective width is 5 ft. According to the HCM, this section has LOS B for overall conditions and LOS D for platoon conditions. Frame 0:08:00 shows the 60 ft^2 area. As in the previous location, the images show a sidewalk that, on average, seems more congested than a sidewalk should if it corresponded to the HCM's criteria and diagrams of LOS B. The platoon condition of LOS D (15-24 ft^2/pedestrian) may be better in describing this sidewalk's crowdedness.

Figure 2.2. Pedestrian LOS at Control Location on a Weekday, 3:15 p.m.



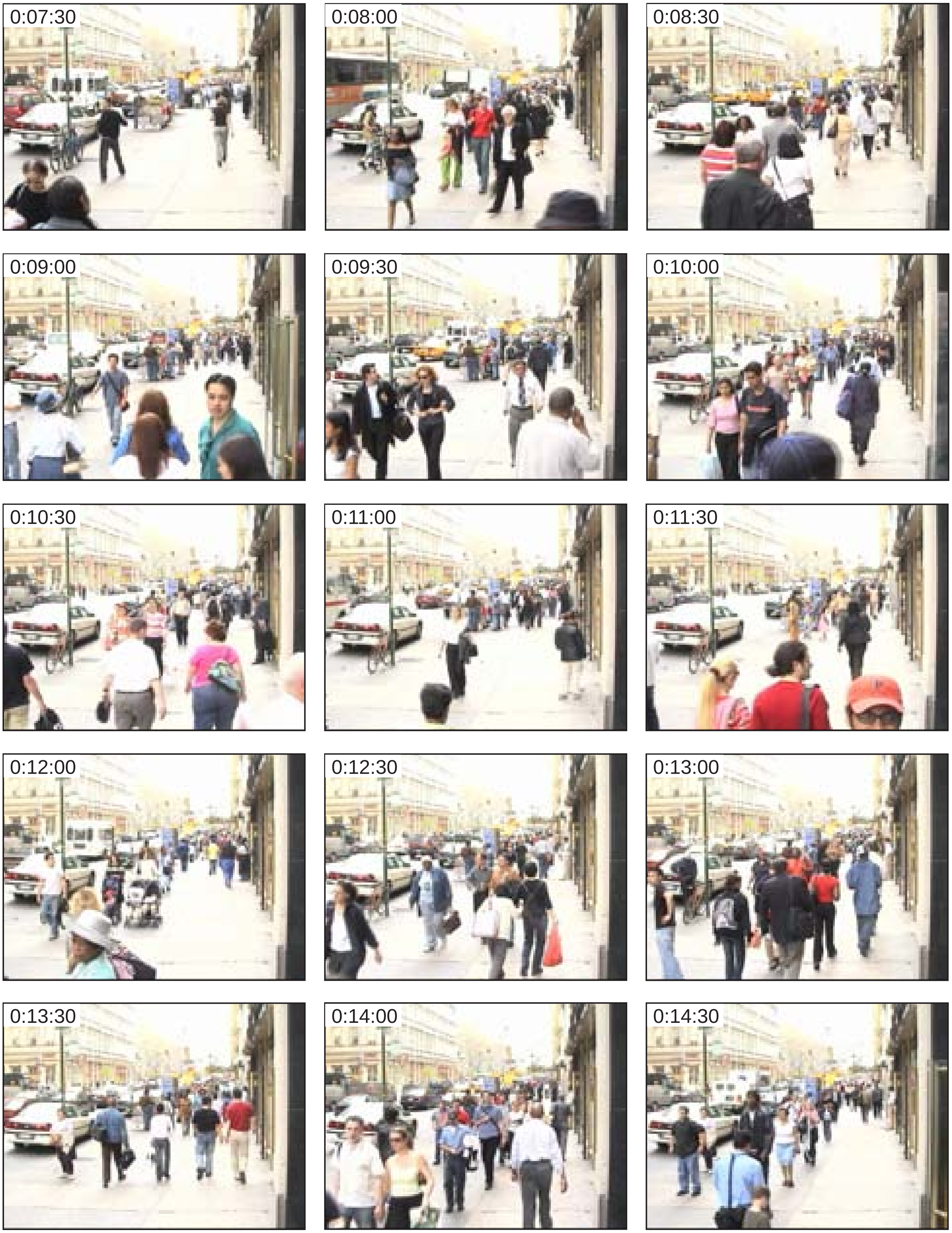
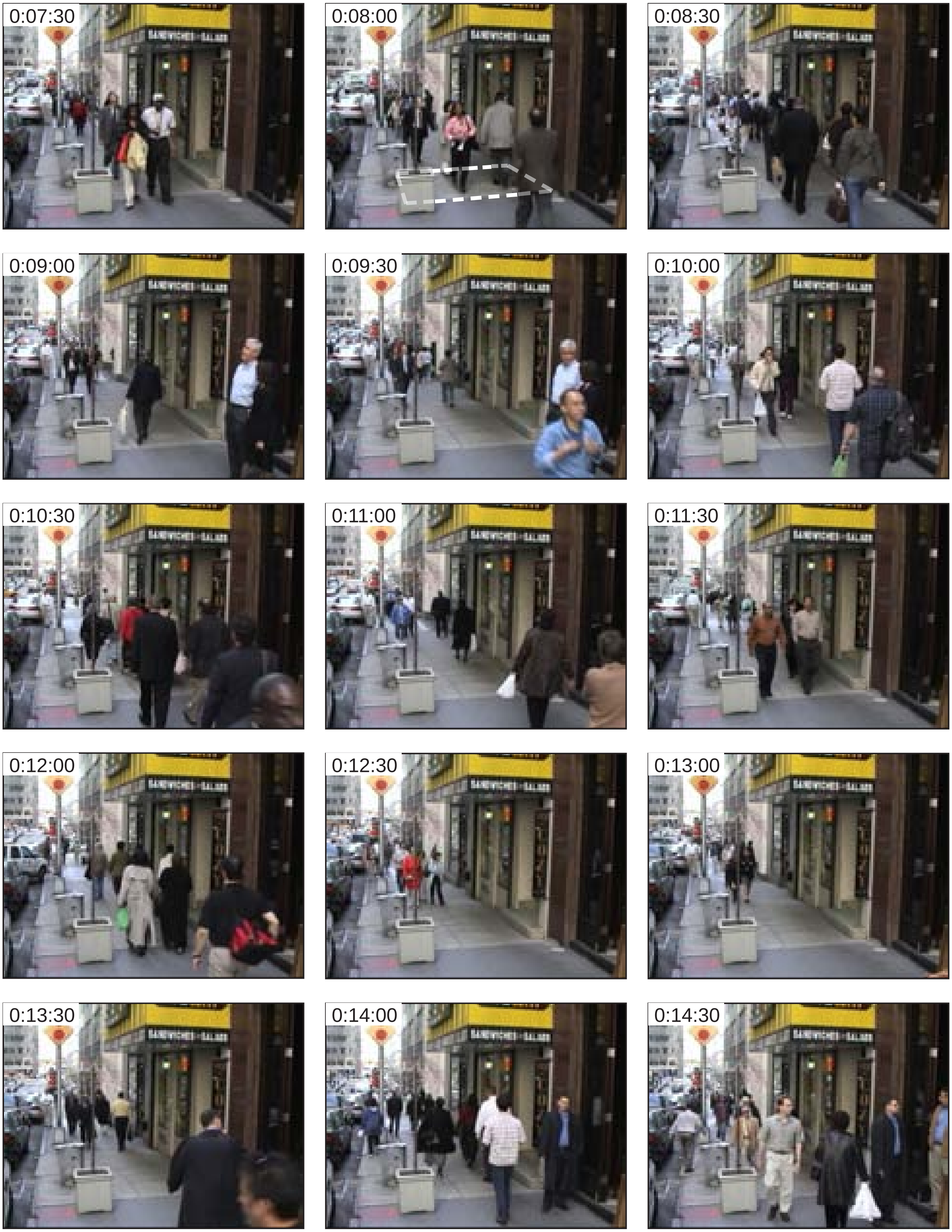

0:07:30
0:08:00
0:08:30
0:09:00
0:09:30
0:10:00
0:10:30
0:11:00
0:11:30
0:12:00
0:12:30
0:13:00
0:13:30
0:14:00
0:14:30

Figure 2.3. Pedestrian LOS at John St. between Cliff St. and Pearl St. on a Weekday, 1:20 p.m.


0:07:30
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0:08:30
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CHAPTER 3.

LITERATURE REVIEW

The Highway Capacity Manual (HCM) is the traffic engineering and planning industry standard in conducting pedestrian level of service (LOS) analysis. The HCM pedestrian LOS analysis has many advantages. It provides a standardized methodology for data collection and for quantifying congestion in pedestrian facilities. However, there are many studies which recommend various amendments to the HCM methodology or propose new methods of pedestrian LOS analysis altogether.

The purpose of this chapter is to explore existing pedestrian literature in order to identify best practices in pedestrian data collection, analysis, and measurement as well as areas where additional research is warranted.

A. Introduction

The measurement of pedestrian level of service is a tool which ensures that pedestrian facilities are balanced with vehicular facilities and other land uses. As discussed earlier, the HCM provides two components in its level of service calculation: a quantitative measure of pedestrian flow rate and a table that helps planners derive an LOS grade from that flow rate. The HCM's pedestrian LOS grade is designed to be an objective measure of congestion on a pedestrian facility. It also provides a set of empirical data that highlights the limitations of this basic method and suggests ways to localize the LOS calculation based on various factors: pedestrian trip purpose, age, and group size, for example.

Since the HCM pedestrian LOS methodology was published, researchers inside and outside the United States have published studies on ways to better measure pedestrian LOS in their regions, given local conditions. They have focused on three primary areas: the sidewalk environment, pedestrian characteristics and flow characteristics. Relationships among these categories have emerged in pedestrian literature. For example, researchers have explained how elements in the sidewalk environment – such as land use and proximity to transit – influence pedestrian and flow characteristics. They have also sought to explain how pedestrian characteristics shape the speed and density characteristics of flow. These relationships are illustrated in Figure 3.1. below.

While a great deal of research has been published to describe how the pedestrian LOS calculation may be tailored to local environments, the HCM has remained consistent in its generic, location-independent approach. The limitations of this approach in its applicability to New York City, as defined in the HCM, are discussed below.

In the following sections existing literature is reviewed to understand how planners and researchers in other regions are collecting, analyzing, and applying pedestrian data in order to develop better LOS measurement tools. A detailed summary of each publication cited in the literature review is included in Appendix A.

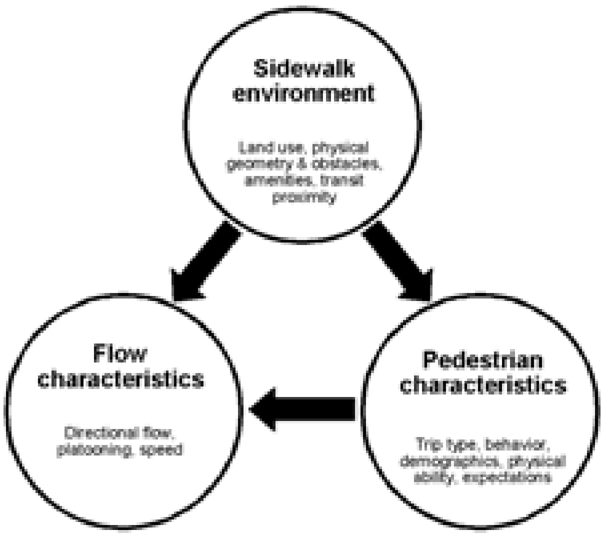

Figure 3.1. Relationship between the Sidewalk, Pedestrians, and Flow

B. Analysis of Pedestrian Characteristics

1. Personal Characteristics

Researchers have documented that normal pedestrian speeds are a function of a large number of factors: age, gender, and group size are frequently cited (Bowman, 1994; Knoblauch, 1996; Fruin, 1971; Whyte, 1988; Puskharev, 1995). While the HCM refers to these differences and recommends taking them into account when, for example, a large number of elderly pedestrians are expected on a facility, these differences are not incorporated into the standard LOS calculation.

Person size is a factor that has been widely discussed in pedestrian literature as it relates to personal space requirements (Fruin, 1971). But sidewalk widths have not kept pace with American waistlines over the last decade. Because personal space requirements are tightly coupled with the speed-space relationships used to interpret the HCM LOS from the flow rate calculation, it may be necessary to revisit these assumptions.

2. Trip Purpose and Expectations

Varying pedestrian expectations—especially as a function of a pedestrian's trip purpose—are also ignored by the HCM. At lunchtime, many sidewalks in Lower Manhattan have a diverse mix of users, from financial sector executives to tourists. Even if these pedestrians have everything else in common, their expectations of sidewalk crowding may vary widely. A pedestrian on his way to lunch may not mind the same delay faced by the person behind him, on her way to a meeting. Other pedestrian perceptions such as comfort, safety and convenience are not addressed by the HCM.

The HCM uses a single LOS scale for all pedestrians, but recommends that planners take the predominant trip purpose into account when evaluating local facilities. However, researchers have found that pedestrians' perceptions of the walking environment can affect pedestrian behavior significantly (Sarkar, 1993; Khisty, 1994; Miler, 1993). Hoogendoorn found that pedestrians predict the "cost" of each sidewalk facility in terms of the convenience and speed to reach a destination and that the cost is based on their personal expectations (2004a).

In Benz's time-space level of service methodology, trip purpose plays a key role. He uses it to identify the preferred walking speed of a pedestrian subgroup (commuters, for example), determine the mix of subgroups on a sidewalk, and prioritize the subgroups with the greatest speed expectations (1986).

3. Behavior

Devices such as mobile phones and portable music players have become ubiquitous in urban areas. Writers in the popular press have lampooned the ability of people to walk and use cell phones at the same time (Belson, 2004). But researchers have nothing more than anecdotal evidence to suggest the impact these devices have on pedestrians in the aggregate.

C. Analysis of Environmental Characteristics

1. Usable Sidewalk Space and Obstacles

The only characteristic of a midblock location that the Highway Capacity Manual's pedestrian LOS takes into account is the effective width of the walkway. This measurement is determined by reducing the total walkway width by the width of obstacles in the amenity strip and along the building line.

The HCM reiterates a recommendation made by AASHTO that the effective sidewalk width should not be under 5 feet on any facility (2000). Even 5 feet may be a conservative minimum width. After observing groups of pedestrians trying to get past one another in Midtown Manhattan, Pushkarev and Zupan (1975) suggest that 7.5 feet is a better minimum width when a large number of groups are expected on a pedestrian facility.

A simple example illustrates the wisdom of a 5 foot or 7.5 foot minimum width. Using the standard pedestrian LOS calculation, a moderately traveled 3-foot-wide sidewalk (1,080 people/hour with platooning) will achieve an acceptable LOS of C according to the HCM. In Fruin's (1971) work, upon which the HCM methodology was based, it states that the average male pedestrian would occupy an area of approximately 1.5 ft^2 . By this measure, a sidewalk with a 3-foot effective width would likely require passing pedestrians to slow down and twist their bodies to get around each other. And with 1,080 people/hour, there will be up to 9 passing events (18 impeded pedestrians) per minute.

The Highway Capacity Manual also recommends decreasing the effective sidewalk width by 12-18 inches on each side to account for the buffer space between pedestrians and obstacles. The empirical origin of this distance is difficult to confirm, but many researchers also advocate a so-called "shy distance", "buffer zone", or "cushion" and have attempted to measure what those distances should be. Pushkarev and Zupan, while cited by the HCM as the origin of "shy distance" did not, in fact, invent the term or the distance. Based on their observation of Midtown Manhattan pedestrians, they state that, "the exact effect of the various obstacles on pedestrian capacity and flow is a good subject for further study." The closest the authors come to providing a "shy distance" (a term used by HCM, not Pushkarev and Zupan) is by suggesting a standard distance of 2.5 feet between the curb next to an obstacle and a pedestrian walking adjacent to the obstacle (1975).

How pedestrians negotiate obstacles on New York City sidewalks, whether they are transit entrances, vendor stands, bus shelters, newspaper boxes, or security devices, is still not understood. The HCM classifies walkway obstructions in the following categories: street furniture, public underground access, landscaping, commercial uses and building protrusions. And, according to the HCM, these obstructions (and the shy distance alongside them) should be taken into account when calculating a walkway's effective width.

Literature on the distance that people walk away from obstacles is scarce. Weidmann synthesized data from a number of other studies and then used that data into determining average distance values for different obstacles (1993). Mauron compiled data on the distances people walk from a curb on a straight sidewalk in order to calibrate his simulation methods (2002). More recently, Hoogendoorn conducted an experiment in an indoor pedestrian space and found that pedestrians require about 10 cm (≈ 4 inches) of lateral spacing (2004b). For obvious reasons, these results cannot be assumed to be valid on New York City sidewalks without confirmation.

While Benz does not address the question of shy distance, he proposes a completely different unit of space for level of service analysis—the entire length and width of a sidewalk segment minus obstacles and a "cushion" near obstacles and the edges of buildings and curbs (1986).

In order to determine when pedestrians choose to walk on narrow street beds in Japan, Kwon et al. (1989) created overhead video recordings of a walkway marked in a 10cm. X 20cm. grid. They used the video to record the location of each pedestrian over time. However, they did not create a general shy distance based on these findings.

Thambiah et al. (2004) predicted that obstacles are important to pedestrians' perception of a sidewalk level of service and used conjoint analysis to attempt to show this. They did find the number of obstacles on a sidewalk influences pedestrian perceptions, but did not seek to observe how pedestrians actually behave around these obstacles.

Stucki et al. (2003) synthesized the work of Ulrich Weidmann (1993) to come up with shy distances for different types of obstacles. For example, pedestrians walk 0.45m (~1.5 ft.) from walls, 0.35m (~1.14ft.) from fences, and 0.30m (~1 ft.) from small obstacles such as street lights, trees, and benches.

These studies indicate that there is consensus about the fact that a shy distance exists and that a good measure of these shy distances is needed. But there is no consensus on what those distances should be.

2. Land Use / Amenities

In addition to the need for a better understanding of the relationship between a sidewalk's capacity and its obstacles, researchers have found that pedestrians tend to judge the LOS of a sidewalk based on additional, qualitative factors. For example, some researchers have found that the sidewalk's separation from vehicular travel lanes, the speed of traffic, and the attractiveness of the location are more important to pedestrians than pedestrian congestion (Dixon, 1996; Khisty, 1994). While it is unlikely New York City pedestrians have exactly the same set of preferences given differences in land use and intensity, these environmental factors are not considered in the HCM's LOS methodology.

Phillips et al. (2001) push this concept the farthest. They surveyed pedestrians at segments of a predetermined route through Pensacola, FL, asking them, "How safe / comfortable they felt as they traveled each segment." They used the pedestrian ratings along with measurements of each segment to create a regression model incorporating everything from the percent of on-street parking to the average speed of traffic to the width of the sidewalk. While this is an innovative approach in a suburban location with low to moderate pedestrian volumes, wide and fast commercial streets, and frequent curb cuts, it is not particularly applicable to New York City CBDs. But there are sidewalk amenities in New York City that may warrant attention: bus stops, vendor carts, newsstands, subway entrances, security devices, and sidewalk cafes.

D. Analysis of Flow Characteristics

1. Platooning

The HCM's pedestrian LOS calculation accounts for pedestrian platooning by assigning worse LOS grades at lower flow rates on facilities where platooning is expected. This is an important consideration as Pushkarev and Zupan observed that most pedestrian traffic in New York City travels in platoons (1975). In fact, researchers find that pedestrian platooning – rather than random, even flow – may be a general characteristic of urban life due to density, rates of transit use, and signalized intersections (Virkler, 1998; Chilukuri, 2000).

2. Directional Flow

A second flow characteristic that researchers have sought to understand in its relation to pedestrian level of service is friction created as a result of bi- and multi-directional pedestrian flows. In other words, holding all other variables constant, do differences in the ratio of flow in opposing directions result in different levels of service depending on the direction of travel?

Several researchers have attempted to answer this question. John Fruin (1971) found that when neither opposing flow dominates, the speed in both directions tends to be equal, but a strong flow tends to impede weaker flow. William Whyte (1988) and Pushkarev and Zupan (1975) observed the same phenomenon. Researchers studying pedestrian behavior in transit stations also found discrepancies in directional flow under different circumstances (Blue & Adler, 2000).

The HCM includes Fruin's finding that highly lopsided bi-directional flow may result in a lower level of service for flow in the weaker direction. However, the standard LOS calculation does not take these differences into account: a single LOS is calculated for the entire facility based on the sum of pedestrians walking in both directions.

E. Data Collection Techniques

Three predominant methodologies for collecting pedestrian data were identified: direct observation, video observation, and surveys. For a more comprehensive review of pedestrian and bicycle data collection techniques in the United States, Schneider et al. have published an excellent guide (2005).

1. Direct Observation Methodologies
Virtually all pedestrian studies and models, including the HCM LOS methodology, rely on direct observation of pedestrians for data collection. Direct observation has been applied indoors (Hoogendoorn, 2004b) and outdoors (Whyte, 1971), with experimental (Phillips, 2001) and non-experimental studies (Chilukuri, 2000).

2. Video Techniques
Increasingly, researchers are using video to observe and collect data about pedestrians. Video has plenty of advantages over direct observation: you can collect data from the video carefully back in the office or lab, you can easily share video with others to illustrate a point, and there are tools available to automate data collection. On the other hand, it is difficult to collect video data in an unobtrusive way and identifying pedestrian characteristics—even gender—can be difficult on a video monitor.

Whyte (1988) pioneered the use of film to record pedestrian behavior in urban environments, using a combination of ground level and overhead cameras to collect data. He and his team analyzed some of the video methodically to create objective, quantitative comparisons between locations (the number of people using each location by time of day, for example). They also used video for more qualitative—almost ethnographic—analysis.

Birrel et al. (2001) did not use video to capture pedestrians, but used techniques that may be useful to pedestrian researchers. They filmed in-line skaters at grade level and devised a methodology to measure their lateral motion.

Mauron (2002) and Kwon et al. (1989) placed video cameras directly overhead in order to get a clear picture of pedestrian movement and lateral spacing on the two-dimensional plane of the sidewalk.

As part of their PEDFLOW simulation model, Willis et al. created an computer-based application that improved the ability to collect video data (2001).

3. Survey Methodologies
Transportation planners face a difficult task in assigning levels of service grades because perceptions vary widely among drivers, cyclists, and walkers.

Surveys are sometimes used to help establish a level of service scale. Thambiah et al. (2004) used an entirely survey-based methodology, simply having participants rate pictures of sidewalks with varying conditions. The results of these surveys were processed through a conjoint analysis, a statistical modeling method available in SPSS (a statistical software), to determine what sidewalk "features" resulted in the high and low scores. This method has a high degree of internal validity, but its external validity is limited.

Phillips et al. (2001) used a combination of field observation and survey. During their FunWalk for Science, they set up checkpoints along the route where they asked participants to rate the segment they had just walked. Unlike the method used by Thambiah et al., this has the advantage of testing real conditions rather than those imagined based on a picture. On the other hand, there are some minor external validity problems due to self-selection of participants and the uniformity of trip purposes.

Although Willis et al. (2001) used computer-aided video analysis for their PEDFLOW simulation model, they conducted interviews in order to understand how individual pedestrians make decisions as they walk.

4. Experimental vs. Non-Experimental Design

Most pedestrian studies are non-experimental. Researchers simply visit a location, observe pedestrian behavior and collect data, and analyze that data without interfering in the pedestrian environment. While this ensures that studies are externally valid, it becomes nearly impossible to draw definitive causal conclusions since a typical sidewalk is a complex system, with dozens of interrelated factors that change level of service perceptions.

Hoogendoorn's (2004b) study of pedestrian bottlenecks is among the few pedestrian studies with an experimental design. Hoogendoorn set up three different bottleneck conditions in order to determine how pedestrians behave in each one. By reducing the number of uncontrolled variables, he was able to draw causal conclusions that are not possible in most pedestrian studies.

F. Data Analysis and Simulation Models

If the HCM's LOS model is to be critiqued, it is critical that the alternatives and the general techniques that may be used to create a modified pedestrian LOS model are understood. The HCM LOS model is a macroscopic pedestrian model based on the relationship between space, walking speed, and flow. The input is a pedestrian count, a time period, and sidewalk's effective width. The output is the flow rate and a corresponding grade.

The broadest discussion of pedestrian modeling can be found in Bierlaire et al. (2003). They provide a survey of microscopic and macroscopic models and discuss their applicability to different types of problems.

1. Regression Analysis / Modeling

After conducting their FunWalk for Science survey, Phillips et al. created a regression model to explain what sidewalk characteristics result in a higher survey score by participants (2001). This allows transportation planners to easily assess their own pedestrian facilities based on the factors in the regression model.

Thambiah et al. (2004) used conjoint analysis, a statistical method by SPSS in "how individual product attributes affect consumer and citizen preferences," to come up with a pedestrian LOS. Basically, they propose that every sidewalk has a set of features. The conjoint analysis process allows researchers to assess the value of these features to pedestrians based on a survey.

2. Microscopic Pedestrian Models

The conjoint analysis and regression models above—and the HCM pedestrian calculation, in fact—are applied to an entire location based on the results of many pedestrians taken together. Other researchers—especially those optimizing evacuation planning and procedures—have focused on microscopic pedestrian models in which each pedestrian's behavior is considered independently of all other pedestrians. The advantage of this type of model is that it is potentially more realistic and fine-grained than the macroscopic models. On the other hand, the model is only as good as the data collected (which can be intensive) and may actually be overkill when then question to be answered is simply: what is the LOS for this sidewalk segment? Bierlaire et al. discuss microscopic modeling, its advantages and disadvantages in much greater detail (2003).

Researchers have used microscopic pedestrian models to attempt to answer LOS-related questions. For example, Stucki et al. have applied a microscopic model to try to determine how individual pedestrians behave around obstacles (2003). Blue and Adler use a microscopic model to predict complex, multi-directional pedestrian flows in Grand Central Station (2000).

Other researchers use microscopic models to predict how pedestrians make larger decisions about the routes they take. Mauron proposes a model in which each pedestrian chooses the fastest— though not necessarily the shortest—route (2002). Similarly, Hoogendoorn suggests a simulation model in which individual pedestrians predict the relative "cost" of each route based on their preferences and choose the one with the lowest cost (2004a).

G. Conclusion

As the TD has seen, there is a significant body of research featuring new ways of evaluating pedestrian service levels on urban sidewalks. These studies recommend everything from small amendments to the HCM's LOS calculation to completely new LOS methodologies, depending on local needs and characteristics.

The studies cited in this Chapter suggest that the current tool for measuring pedestrian LOS prescribed by the Highway Capacity Manual may not take into account important differences in pedestrian characteristics, location characteristics, and flow characteristics when evaluating New York City sidewalks. If that is the case, the LOS used to evaluate New York City's sidewalks does not serve the city's pedestrians.

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CHAPTER 4.

METHODOLOGY DESIGN

There is a need to conduct a comprehensive collection of pedestrian characteristics data in New York City. The current HCM LOS methodology has shortcomings which have been made apparent by the Department of City Planning Transportation Division's experience and by studies undertaken by other organizations and individuals. Different sidewalk locations in central business districts (CBD) are characterized by unique pedestrian characteristics, a fact which has a significant impact on walkway performance. Because of this, a New York City CBD database of pedestrian characteristics could be useful in current and future pedestrian planning.

Developing a data collection methodology involved trial and error. It was desired to collect as much detailed pedestrian data as possible, but the limited resources available also had to be considered. In the following section, the goals, objectives and data collection methodologies of this study are outlined.

A. Goals and Objectives

Based on the review of the pedestrian literature and experience with pedestrian studies in the past, the TD has concluded that there is sufficient need for a fresh look at the pedestrian LOS process in New York City. Specifically, evidence suggests that the LOS methodology may need to be recalibrated to more accurately measure conditions on the city's sidewalks.

Why does it matter? First, the population of New York City is growing. As the rate of walking trips is high in New York City relative to the rest of the United States, the number of pedestrians can also be expected to increase. Second, transit use is increasing in the city. Because most transit trips involve walking segments, there are more pedestrians on the sidewalk than ever. Third, Lower Manhattan is undergoing physical changes that will alter the pedestrian environment. Replacing millions of square feet of office space, thousands of residential units, hundreds of retail stores, several large-scale cultural institutions and a major memorial will change the fabric of Lower Manhattan. These developments will certainly alter the pedestrian environment and an accurate LOS helps ensure that adequate space is allocated to pedestrian needs.

The purpose of this study is to:

1. Analyze the suitability of the HCM pedestrian LOS methodology for New York City;
2. Empirically measure the factors that contribute to pedestrian congestion on the sidewalks of Lower Manhattan; and
3. Recommend pedestrian policy changes based on this study's findings and propose additional opportunities for pedestrian research in New York City.

The TD has defined the methodology of this study with these three objectives in mind and has decided to use several quantitative observational studies to achieve them. While an experimental approach would allow us to draw decisive causal conclusions, it would require significant interference with the sidewalk conditions, including pedestrian behavior and flow rate. Because of the harmful effect on the external validity of the study, it was unadvisable to use an experimental approach. The data collection methodologies were designed to minimize the impact on pedestrian behavior and the sidewalk environment.

Two types of studies were conducted:

1. Pedestrian Speeds, Counts, and Characteristics
Pedestrian counts were done to study the pedestrian flow rates at different times and days of the week. Vehicular counts were also collected to study the relationship between pedestrian and vehicular volumes.

Observations of the characteristics and walking speeds of pedestrians were collected on sidewalks. A survey was used to build a pedestrian database, to aid in understanding the relationship between pedestrian characteristics and New York City sidewalks.

Using a speed and delay walk, the TD collected sidewalk pedestrian speeds and crosswalk pedestrian speeds at various times of the day.

2. Impedance and Pedestrian Behavior
Using a digital video camera, the TD recorded sidewalks at various locations in 15-minute segments. The videos were then used to observe pedestrian walking behavior, including pedestrian interactions with street furniture or with other pedestrians.

In the process of sharpening the specific data gathering methodology, the TD undertook extensive observations of pedestrians on sidewalks. The TD

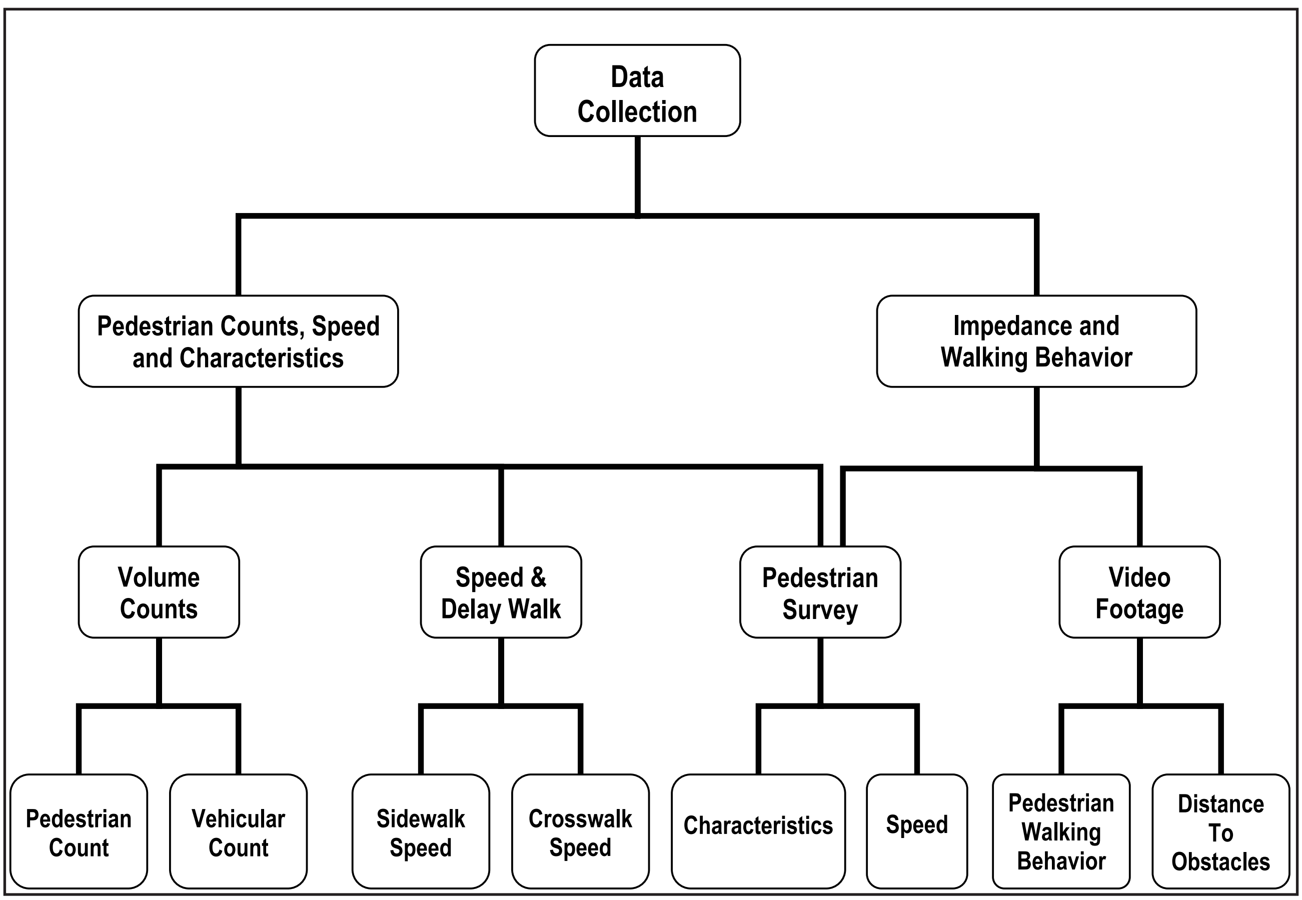


Figure 4.1. Data Collection Methodology

subsequently learned how some data gathering methods may work better than others, and it was learned how to ensure the quality and consistency of the data collection process. A considerable amount of pedestrian and sidewalk data from the Lower Manhattan CBD that is analyzable has been gathered; much of this data might be valuable in future research. Figure 4.1 summarizes the data collection methodology.

B. Pedestrian Speeds, Counts, and Characteristics

Pedestrians were counted and their walking speeds and relevant characteristics were recorded at different sidewalk locations in Lower Manhattan. These data were used to build a pedestrian database, which is the core data source for this project. The survey data helped in finding out how pedestrian characteristics are affecting, and are affected by, the sidewalk environment.

1. Survey Design

A survey form was designed, on which individual pedestrian speeds and characteristics were collected. Table 4.1 shows the form used for recording pedestrian characteristics. Sidewalk conditions, such as width, existing furniture, and building entrances and exits, were documented before the start of the survey. Using ground references such as pavement lines or fire hydrants, two lines were designated to mark pedestrians' entrance into and exit from the designated study zone on each sidewalk segment. The study zone was usually between twenty to forty-five feet in length, based on available sidewalks' identifiers, like street furniture or pavement markings. The pedestrians' speeds were measured by using a stopwatch to time them walking between the two lines on the sidewalk delineating each study zone (see Appendix C, table C.1 for completed sample survey).

In order to obtain a statistically valid sample of pedestrian speeds in each location, the randomization of the sampling process was sought. By doing this, a representative sample of pedestrian speeds and characteristics could be gathered that could subsequently be generalized to represent the population of all pedestrians in that location (at each given time).

Table 4.1. Pedestrian Characteristics Data Collection Form

Location:
Speed Timing Length on Sidewalk (ft): **Weather:**
Name **Date:** **Time:**

PED #	Travel Time (s)	DIRECTION	GENDER	AGE	PERSON SIZE	GROUP	TRIP PURPOSE	BAG(S)	PERSONAL ITEMS					PUSHING	WALKING AIDE	IMPEDED	COMMENT
		N = north S = south E = east W = west	F = Female M = Male	1 = under 14 2 = 14-65 3 = over 65	0 = Average 1 = Large (well over average space req'd)	# = people in group 1 = 1 person 2 = 2 people etc.	0 = Not sure 1 = Tourist 2 = Non-Work 3 = Work	0 = None 1 = Yes, no effect 2 = Yes, affects speed	Phone	Headphone	Drink/Food	PDA	Cigarette	0 = Nothing 1 = Stroller 2 = Service cart 3 = Wheelchair 4 = Rolling suitcase	0 = No 1 = Crutches 2 = Wheelchair 3 = Cane/Walker 4 = Stroller	0 = No 1 = Yes	
1																	
2																	
3																	
4																	
5																	
6																	
7																	
8																	
9																	
10																	

Based on the literature review and field observations, it was determined that the following were important pedestrian characteristics which should be considered:

- Gender
- Age
- Person size
- Group size, if pedestrian is walking in a group
- Trip Purpose (business, non-business, tourist, etc.)
- Personal Items: bag, phone, headphone, food or drink, PDA (Personal Digital Assistant), or cigarette
- Pushing: stroller, service cart, wheelchair, or rolling suitcase
- Walking aide: crutches, wheelchair, cane, or stroller
- Impedance (if the pedestrian is being impeded by other pedestrians or obstacles)

In addition to pedestrian characteristics, pedestrian volume, in both primary flow and counter-flow directions was counted. In addition, it was determined that street and environmental characteristics could also affect the mobility of pedestrians. The following street and environmental characteristics were noted:

- Adjacent sidewalk usage: parking, bus stop, or moving lanes
- Land use (office, retail, or residential)
- Presence of street furniture
- Number of building entrances and exits
- Queue Attractors (bus stops, vendors, etc.)
- Street geometry (sidewalk width, etc.)
- Sidewalk conditions (smooth, cracked, even, uneven, or broken)
- Time of day
- Day of the week
- Weather

The speed observation process began by selecting the first pedestrian who walked by in the direction being monitored, and then noting his/her speed and relevant characteristics. If that pedestrian was walking in a group, the number of pedestrians in the group was noted, and each group members' characteristics were noted as well. When each pedestrian's data had been entered onto a form, the process was repeated for the next pedestrian observed, who would be the very next person to walk by in the observer's direction.

This randomized process helped to ensure that there was no selection bias on the part of the observers. Pedestrians were not selected by their characteristics, but were selected by their being the first who happened to walk by the observer when the observer was ready to record speeds and characteristics.

An internal validity test was conducted to ensure that the team was consistent in gathering pedestrian speeds and characteristics. The test was conducted at three different times and at two different locations. A total of one hundred pedestrians, two sample sizes of thirty-six pedestrians and one of twenty-eight pedestrians, were sampled. All team members sampled the same pedestrians during the test, and the pedestrians being sampled were randomly chosen by one of the team members.

The data was compared to see how consistent the observations were within the team. Overall, speeds, gender, age, group size, pushing and walking aide characteristics were consistent within the team. There were some differences in the size, use of bag and use of personal item categories. It was noticed that not all team members paid the same amount of attention to the impeded attribute. In addition, trip purpose was the characteristic with the most inconsistencies among the team members.

After this analysis, it was concluded that to ensure the quality and consistency of the data collected it was needed to better define each characteristic value, and analyze and standardize some specific cases. As a result, a set of rules for recording pedestrian characteristics (see Appendix B – Pedestrian Survey Rules) was produced. One of the main rules was that when in doubt, leave the column blank or use the "not sure" category. The survey was not designed to confirm the pedestrians' characteristics through interviews; because it was desired not to interrupt the flow on the sidewalks. The idea was to get a large amount of data to obtain trends. Only pedestrians who were obviously over 65 years old were marked down as elderly. If the pedestrians' trip purpose was unclear, it was marked as unsure. Based on the literature reviewed, there were other researchers who used the non-experimental, observational approach in categorizing pedestrians. To make the observation as accurate as possible, it was necessary to collect the pedestrian characteristics data in the field instead of using videos; because it was much more difficult to distinguish pedestrians' gender, age or trip purpose in videos. The possibility of errors in the methodology was understood; however, because of the large quantity of data collected, the margin of error from the few instances of uncertainty of pedestrian characteristics was minimized.

2. Pedestrian Characteristics and Speed Data Collection

Pedestrian counts, speeds, and characteristics at about sixty-two Lower Manhattan locations in the morning, midday, and afternoon peak periods were gathered using the pedestrian survey described above. A control location 7-day 12-hour count, speed, and characteristics data collection was also conducted (see Figure 4.2.).

a. Lower Manhattan 62 Sites

The study locations were selected on the basis of several factors. Most pedestrians arrive in and leave Lower Manhattan by public transit, so attention was focused on locations near subway stations. About fifty sites around subway stations that accounted for the majority of pedestrian access locations to Lower Manhattan streets were identified. The data collection was concentrated at locations near subway entrances and exits, and additional locations that would perhaps yield high pedestrian volume or unique travel patterns were selected (see Appendix C, table C.2. for a list of locations).

Pedestrian counts at each location during peak 15-minute periods of the day between the times of 8:30 – 9:30 AM, 12:30-1:30 PM, and 4:30-5:30 PM (see Table 4.2) were conducted. In addition, the speeds of randomly selected pedestrians during these periods of time were tracked. One person counted pedestrians walking in both directions on the sidewalk, taking note of their walking direction. Two people tracked pedestrian speeds—one in each sidewalk direction.

Table 4.2. Pedestrian Volume Count Form

Name: Date:

Location:

Start Time: Weather:

	5 min	10 min	15 min
Eastbound/Northbound			
Westbound/Southbound			

b. Seven-Day Vehicular and Pedestrian Count

Vehicular counts, pedestrian counts, and pedestrian speed and characteristic data were collected at the study's control location, Broadway between Duane Street and Reade Street. At the same time, a 24-hour vehicular count was collected using an Automatic Traffic Recorder (ATR) for seven days. Pedestrian counts were collected on the west sidewalk of the control location, during the same week of the ATR count, between 7am and 7pm from Monday to Friday, and between 10am and 3pm on Saturday and Sunday (see Table 4.3). Sample pedestrian characteristics and speeds were collected on the weekdays during the count hours. The same pedestrian characteristics and speed collection methods were used here as mentioned in the earlier section.

The objectives of this data collection effort were to:

- Establish a pedestrian flow profile, determining pedestrian traffic peak times and off-peak times;
- Determine the relationships between the time of day and pedestrian volumes and speeds; and
- Determine any correlation between vehicular volumes, pedestrian volumes and pedestrian speeds.

See Appendix C, Table C.3. for a sample data collection form.

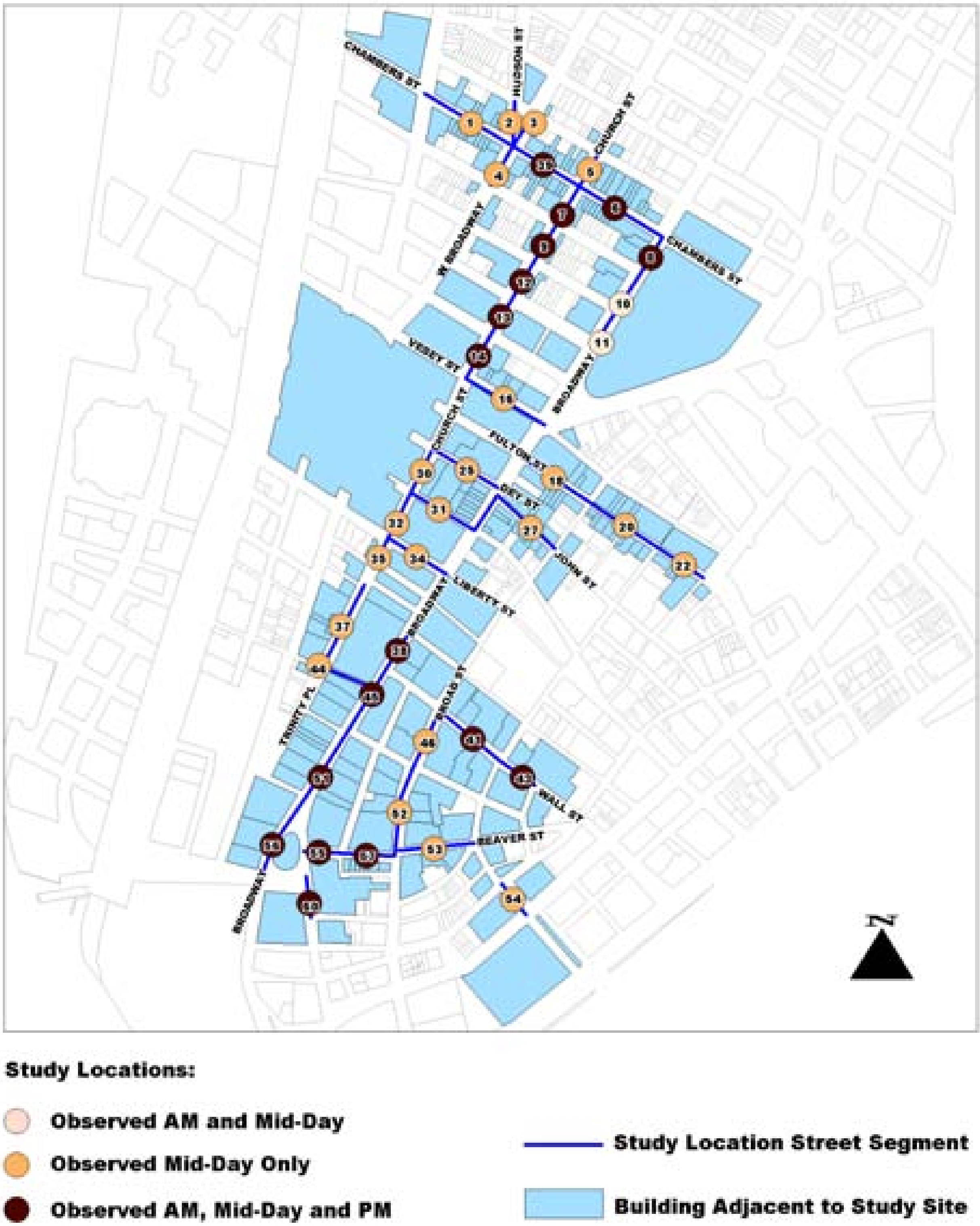


Figure 4.2. Lower Manhattan Study Locations

Table 4.3. Seven Day Pedestrian Count Form

Broadway between Duane and Reade, West Sidewalk

Name: Date:
Start Time: Weather:

	5 min	10 min	15 min	20 min
Northbound				
Southbound				

	25 min	30 min	35 min	40 min
Northbound				
Southbound				

	45 min	50 min	55 min	60 min
Northbound				
Southbound				

3. Speed Walk

During the course of designing this study, it was decided to re-create vehicular speed and delay run survey techniques for sidewalk traffic. The purpose was to determine the average speed and delay experienced by pedestrians at crosswalks on a designated route at specific times of day, and the sidewalk speeds of different walkers at different times of day. This could be used to study sidewalk density in relation to speed.

a. Background

Vehicular speed and delay runs involve a vehicle driving on a road while a surveyor in the car marks down distance and time traveled. During the run, the vehicle's time is marked at each predetermined distance interval. For example, the test driver will record a start up time of 1:30pm as the beginning time; then every 0.2 miles the driver will record the time traveled, such as 45 seconds for 0.2 miles, 1 minute and 10 seconds for 0.4 miles, and so on. With repeated runs during different hours of the day, a profile of travel speed of the corridor is established.

From the data gathered as described above, the degree of vehicular delay on the test route can be determined. For example, on a ten-mile stretch of road with a sixty-five mile per hour speed limit, a driver should ideally take less than 10 minutes to travel the segment. During the peak hour, according to the speed and delay run results, each run might take fifteen to twenty minutes. In these cases, one could draw the conclusion that the delay on the road is five to ten minutes for a ten mile distance during peak hours. Also, one could compare the seriousness of congestion for different hours. For example, if the data shows 15 minutes travel time in the morning peak and 20 minutes travel time in the evening peak for the same stretch of road, the study segment can be said to be more congested in the evening than in the morning. Engineers and planners can then compare the speed and delay run data for AM and PM vehicle counts and see if the two data sets agree. Vehicular speed and delay run analysis provides useful information for understanding how the streets function, contributing to an overall illustration that enhances volume and flow rate measurements.

b. Methodology

With the vehicle speed and delay analysis in mind, a pedestrian speed and delay walk survey was designed. The Lower Manhattan CBD walk used for this survey covers an eighteen-block, 1-mile route starting from the southwest corner of Broadway and Duane Street to the northwest corner of Wall Street and William Street, and then back to the point of origin (see Figure. 4.3.). Each of the members of this project team was assigned a certain time slot during the day to carry out the walk. After two weeks, team members exchanged time slots. A tape recorder or a digital recorder was used to document locations and times of reaching each intersection. During each walk, the starting and ending times were recorded. Between the starting time and ending time, the time of arrival at each side of each crosswalk was recorded, as were the times of any instances of stopping at crosswalks, which would have their corresponding start-up times recorded, as well. Team members then transcribed their recordings onto a data transcription form. See Table 4.4 for the data collection form. See Appendix C, table C.4. for a filled out sample.

c. Data Summary

The transcribed data was input into a spreadsheet to calculate overall route speed, speed over specific street segments, and stop times. Using measurements of street segment lengths from the DCP's LION street centerline Geographic Information Systems (GIS) files and then field verifications in some locations, the recorded travel times were manipulated into:

- Average sidewalk speed
- Sidewalk speed with stop
- Sidewalk speed with no stop
- Average crosswalk speed
- Crosswalk speed with no stop
- Crosswalk speed after stop

The observations above were then summarized as:

- Team member individual walks
- Comparisons between team members' walks
- Walks between specific intersections by team members

4. Other Pedestrian Counts – Expository Database

In addition to the data that collected by the TD, pedestrian data from outside sources was also gathered. The purpose was to cross reference the data collected against established data sources, to make sure this study's data is accurate. Also, one of the criteria that was used to select filming and count locations was the number of pedestrians that use a specific sidewalk. In general, sidewalks with the highest pedestrian use were the ones selected for conducting field work. As many pedestrian counts from recent years as possible were consulted in order to determine the busiest sidewalks in Manhattan CBDs.

One source for pedestrian surveys were Manhattan's Business Improvement Districts (BIDs). BIDs serve the businesses in their areas by promoting retail and tourism, and by providing services such as security and beautification. In addition, one of the services that BIDs provide to businesses is information on the economic market and on retail opportunities in

Figure 4.3. Speed and Delay Walk Route

the area. Pedestrian counts are usually conducted to study potential retail attraction within the BID. Counts are useful for both existing and potential retailers, property owners and real estate companies. Pedestrian traffic numbers inform decisions such as business hours of operation, timing of promotions, and locations for new businesses.

For this study, the following were contacted:

- Lincoln Square BID
- Downtown Alliance
- Grand Central Partnership
- Fashion Center BID
- Union Square Partnership
- Lower East Side BID
- Noho NY BID
- 34th Street Partnership
- Times Square BID
- Village Alliance

Table 4.4. Speed Walk Data Collection Form

PEDESTRIAN LOS SPEED WALK SHEET

ROUTE CHARACTERISTICS

Route:	Broadway to Wall Street to William & back		Date:	
Walker:		Timer:	Time of Day:	
Weather:			Route time:	

	Name	Arrive	Depart	Comments
Intersection 1:	Bway/Duane South			
Intersection 2:	Bway/Reade North			
Intersection 3:	Bway/Reade South			
Intersection 4:	Bway/Chambers North			
Intersection 5:	Bway/Chambers South			
Intersection 6:	Bway/Warren North			
Intersection 7:	Bway/Warren South			
Intersection 8:	Bway/Murray North			
Intersection 9:	Bway/Murray South			
Intersection 10:	Bway/Park North			
Intersection 11:	Bway/Park South			
Intersection 12:	Bway/Barclay North			
Intersection 13:	Bway/Barclay South			
Intersection 14:	Bway/Vesey North			
Intersection 15:	Bway/Vesey South			
Intersection 16:	Bway/Fulton North			
Intersection 17:	Bway/Fulton South			
Intersection 18:	Bway/Dey North			
Intersection 19:	Bway/Dey South			
Intersection 20:	Bway/Cortlandt North			
Intersection 21:	Bway/Cortlandt South			
Intersection 22:	Bway/Liberty North			
Intersection 23:	Bway/Liberty South			
Intersection 24:	Bway/Cedar North			
Intersection 25:	Bway/Cedar South			
Intersection 26:	Bway/Thames North			
Intersection 27:	Bway/Thames South			
Intersection 28:	Bway/Rector North			
Intersection 29:	Bway/Rector South			
Intersection 30:	Bway/Exchange Northwest			
Intersection 31:	Bway/Exchange Northeast			
Intersection 32:	Bway/Wall South			
Intersection 33:	Bway/Wall North			
Intersection 34:	Wall/Nassau West			
Intersection 35:	Wall/Nassau East			
Intersection 36:	Wall/Willam West			
Northbound				
Intersection 1:	Wall/Willam West			
Intersection 2:	Wall/Nassau East			
Intersection 3:	Wall/Nassau West			
Intersection 4:	Bway/Wall North			
Intersection 5:	Bway/Pine South			
Intersection 6:	Bway/Pine North			
Intersection 7:	Bway/Cedar South			
Intersection 8:	Bway/Cedar North			
Intersection 9:	Bway/Liberty South			
Intersection 10:	Bway/Liberty North			
Intersection 11:	Bway/Maiden South			
Intersection 12:	Bway/Maiden North			
Intersection 13:	Bway/John South			
Intersection 14:	Bway/John North			
Intersection 15:	Bway/Fulton South			
Intersection 16:	Bway/Fulton North			
Intersection 17:	Bway/Ann South			
Intersection 18:	Bway/Traffic Island South			
Intersection 19:	Bway/Traffic Island North			
Intersection 20:	Bway/City Hall Park South			
Intersection 21:	Bway/Chambers South			
Intersection 22:	Bway/Chambers North			
Intersection 23:	Bway/Reade South			
Intersection 24:	Bway/Reade North			
Intersection 25:	Bway/Duane South			

Pedestrian count data was obtained from the Downtown Alliance, the Grand Central Partnership, the Fashion Center BID, the Union Square Partnership and the Times Square BID. Even thought this study is concentrated in Lower Manhattan BIDs outside the area were also consulted, so a pedestrian count database could be built for future reference in site selection and trend observation.

C. Impedance and Walking Behavior

The video camera has proven useful to researchers of pedestrian facilities in the past (see Chapter 3). The videotaping procedure enables one to capture a large volume of pedestrian data for an extended period of time, freeing researchers to conduct less data intense surveys on-site and to analyze video captured data later. Depending on the site being filmed, the video camera can be set up in an unobtrusive space to the side of the sidewalk, and can capture facility characteristics as well as pedestrian characteristics which might not have been caught by the researcher's eye during the on-site data capturing process. In this study, extensive video footage of sidewalk traffic has been collected, primarily in an effort to analyze pedestrian walking behavior and how it is affected by sidewalk obstacles.

1. Site Selection

For the videotaping undertaken in this study, the video camera was placed atop an 80-inch high tripod, which created an elevated view. This view afforded the recognition of pedestrian characteristics and sidewalk traffic patterns in a clearer manner than would a less elevated, or "straight-on" view. Previous studies have placed cameras on scaffoldings or filmed from windows of buildings adjacent to the sidewalk, in order to create a similar – though more pronounced – overhead view. Capturing the sidewalk from above minimizes perspective distortion and allows a researcher to assimilate the study area to a planar geometry on which to project Cartesian coordinates and draw imaginary measurement lines or grids for detailed analysis. The ideal setting would include two cameras filming simultaneously: one overhead camera to facilitate the analysis of trajectories and measurements of distances to obstacles, and an eye-level camera to capture pedestrian characteristics. In this study, a completely vertical vantage point was considered but decided to be unfeasible, because of the needs of flexibility in site selection. The elevated tripod would be the closest available approximation to a completely vertical vantage point, and it would allow us to observe pedestrian characteristics as well.

In order to select New York City sidewalk sites to film for this study, several factors were taken into account. First of all, pedestrian volumes on sidewalk facilities in Lower Manhattan were derived from all day 15-minute counts undertaken by the Department of City Planning and the Downtown Alliance (Lower Manhattan BID) and from the measured widths of the sidewalks in question. On heavily trafficked sidewalks, such factors as platooning and variation in pedestrian walking speed can make for a large diversity of flows, more so than on sidewalks with relatively little traffic. Therefore, in the site selection process, it was decided to focus on high-volume facilities. In addition, potential sites were visited and evaluated for possible filming spots (out of the way, sufficient viewing angle, etc.), as well as for the extent of possible flow-affecting factors on the sidewalk, such as street furniture (phone booths, signs, newspaper boxes, etc.) and queuing sites (bus stops, vendors, etc.), which might add to the diversity of the data gathered.

Some additional criteria used for the selection of sidewalks in this study were:

– The section of sidewalk should have had a moderate to high pedestrian flow rate at the time it was recorded.
– The section of sidewalk should have had one or more active front doors (offices, retail stores, restaurants, etc.) adjacent to it.
– Pedestrians on the sidewalk should have appeared to have a diverse mix of purposes: office workers, shoppers, delivery people, tourists, etc.
– If possible, the sidewalk should have been a fairly static color to make the computer grid overlay easier (see below).

– While interesting sidewalk obstructions should have been sought out, they should not have significantly obstructed the viewing angle of the camera.

2. Filming Preparation

Prior to the actual filming of each sidewalk, the geometry of the sidewalk facility and its surroundings were noted. The sidewalk width, distance between recognizable features (such as pavement joints), width of street furniture and their distance from curbs, and related sidewalk features were measured. An "analysis zone" or study area, a rectangular zone within the sidewalk facility, was measured using a 30-foot string ruler with attached reflective domes at 5 foot intervals, and was photographed on the sidewalk for later use in the computer analysis phase (see Figure 4.4.). The analysis zone was typically 30 feet long and as wide as the width of the sidewalk. The 5-foot intervals between reflective domes were used in the computer analysis phase to measure and draw horizontal lines for the analysis of pedestrian flow patterns.

In addition, initially a large, custom made sidewalk ruler was used to measure 6-inch intervals along the width of the sidewalk. The ruler was stretched out along the width of the sidewalk and was photographed for use in the computer analysis phase. This ruler device consisted of a twenty foot wide black vinyl sheet with white vertical lines spaced 6 inches apart, and was unfurled when sidewalk traffic was light or non-existent (see Figure 4.4.). If there was sidewalk traffic, pedestrians were told to wait to proceed until the ruler was photographed, in order to avoid possible accidents. The image taken of the unfurled ruler was used in a computer program to draw a ground-truthed series of lines, 6-inches apart and parallel to the curb line, for the analysis of lateral pedestrian movements. The ruler was black and wide in order to block out the color of the sidewalk on which it was unfurled (enhancing its visibility), and its measurement lines were white in order to contrast with their black background, for easy identification in the line drawing process.

Figure 4.4. Sidewalk Ruler and Reflective Domes Demonstrations

After developing this measurement tool, it wsa realized that there was also a geometry measurement-based technique for drawing the 6-inch spaced sidewalk lines which could be accomplished in AutoCad without the use of the sidewalk ruler (see computer techniques discussion below and in the Appendix D). The AutoCad method of line drawing has primarily been used in the computer analysis of sidewalk videos. However, this technique requires visible sidewalk reference lines. If these lines were not visible on the sidewalk video, the sidewalk measurement tool was used as a standby for the longitudinal line drawing technique.

3. Counts

Once the sidewalk geometry had been noted and the appropriate photographs for computer analysis had been taken, the filming of sidewalk traffic began. In order to ensure the accuracy of film-based counts and to consider aspects of sidewalk traffic which may not have been apparent in the film (see Table 4.5), the following counts were performed during each 15-minute sidewalk filming:

– Pedestrian traffic entering or exiting buildings whose doors are adjacent to the study zone, in five minute increments
– Vehicular traffic adjacent to the study zone (taking note of the existence or non-existence of a buffer space between the sidewalk and the street, usually consisting of planters or a parking lane) for the 15-minute total
– Queues which may exist within the study zone, for vendors, bus stops, etc. The number of people in the queues per minute of filming and the distance to which the queues invade

Table 4.5. Video Filming Pedestrian Count Form

PEDESTRIAN LOS FIELD COUNT SHEET

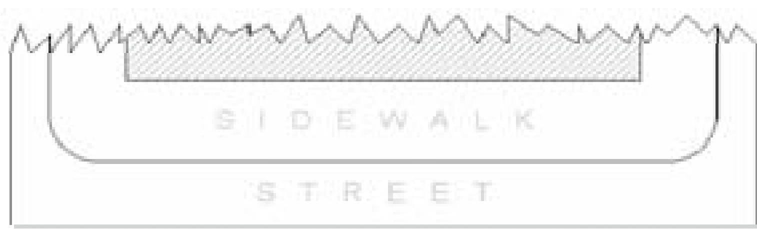
STREET / ENVIRONMENT CHARACTERISTICS

Street / intersection: ____ Date: ____ Weather: ____
Adjacent sidewalk usage: parking / bus stop / moving cars Time: ____ Sidewalk quality: 1 - 2 - 3 - 4 - 5

Direction 1: → (N / S / E / W) Total width: ____ Timed length: ____
Direction 2: ← (N / S / E / W) Effective width: ____ Land uses:

Vendor / queue 1: ____
Vendor / queue 2: ____
Vendor / queue 3: ____
Vendor / queue 4: ____

Building entrance 1: ____
Building entrance 2: ____
Building entrance 3: ____
Building entrance 4: ____



COUNTS

PEDESTRIAN COUNT BY MINUTE

	1:00	2:00	3:00	4:00	5:00	6:00	7:00	8:00	9:00	10:00	11:00	12:00	13:00	14:00	15:00
Pedestrian count (Dir. 1):															
Pedestrian count (Dir. 2):															
Vendor / queue 1 count:															
Vendor / queue 2 count:															
Vendor / queue 3 count:															
Vendor / queue 4 count:															
Entrance 1 count (IN):															
Entrance 1 count (OUT):															
Entrance 2 count (IN):															
Entrance 2 count (OUT):															
Entrance 3 count (IN):															
Entrance 3 count (OUT):															
Entrance 4 count (IN):															
Entrance 4 count (OUT):															

Vehicle count (Dir. 1): ____
Vehicle count (Dir. 2): ____

the effective walking space were noted
- Pedestrian flow by direction in one minute intervals

In addition, the walking speeds of randomly selected pedestrians wee noted throughout the 15 minute site visit by measuring a length on the sidewalk (approximately 30 to 40 feet long, depending on the location) and timing how long it took the pedestrians to traverse the measured length. Selected characteristics of the speed-tested pedestrians were also noted.

4. Control Location

A control filming location was chosen on the West sidewalk on Broadway between Duane and Reade Street. This was a site whose variations in traffic, pedestrian characteristics and environmental characteristics were used to measure against those of the "experimental" study sites. The control location was filmed for 15 minutes each day on which a study site was filmed. The control location was on a relatively busy sidewalk, and filming was chosen for a time (around 3 pm) when the TD was not likely to be filming at a study site. The filming of the control location served as a regulatory device, allowing for the observation of any non site-specific anomalies due to attributes of the particular filming day which might also affect the study area visited on the same day. The control film could show inter-site variations in traffic which might not necessarily have been unique to the study site filmed. If the traffic at the control location was significantly different on one day than it was on others because of reasons not specific to the site, some related inferences might be made about any similar anomalies in the traffic at the study site for that day.

5. Video Processing

When a day's filming was complete for the control location and the study site, the video was exported into a computer using the Adobe Premiere editing program. Still pictures of the string ruler with reflective domes, stretched out on the sidewalk (see description above), and the large sidewalk ruler (if it is being used) were also exported from the camera into the computer for grid-line rendering. These stills were brought into AutoCad, where images of the string ruler with domes (which had been stretched out at two parallel lengths on the sidewalk) were used to draw horizontal lines across the sidewalk (see Figure 4.4.). These horizontal lines measured an initial reference line in front of the camera and parallel lines 15 and 30 feet away from the reference line, which represented the beginning, middle and end of the study zone, used for pedestrian analysis. If the large sidewalk ruler was being used for grid line drawing, two stills of the ruler stretched across the sidewalk at parallel widths were used for reference measurements, as each ruler line pair represented a measurement of 6 inches. The stills were used in AutoCad to draw several 6-inch separated longitudinal lines – parallel to the curb line – on the sidewalk in the video, stretching from the curb to the adjacent building line. If the sidewalk ruler was not being used, a geometry-based process was employed, using measured reference lines from the sidewalk to draw the longitudinal measurement lines. In this procedure, a one-point perspective drawing was used to represent the screen image and draw 6-inch-apart longitudinal lines on the sidewalk with AutoCad (see Appendix D for a detailed explanation).

In both cases, once the 6-inch longitudinal lines had been drawn in AutoCad, they had to be superimposed onto the video using the "blue screen" option was used in Adobe Premiere (see Figure 4.5.). This feature allowed us to composite a blue background with the 6-inch lines in bright color and the video with the moving pedestrians; blue was the standard color for this transparency overlay because it is relatively absent from human skin tones. As a result, the timeline output had a slight blue tint from the underlying "blue screen."

6. Data Collection – Pedestrian Characteristics and Speed

The pedestrian characteristics to be observed from the captured video were: walking direction; start time and end time of the pedestrian walking through the study area; gender; age (under 14, 14 to 65, or over 65 years old); size (average or significantly larger than average); group size (number of people walking with the pedestrian being studied); estimated trip

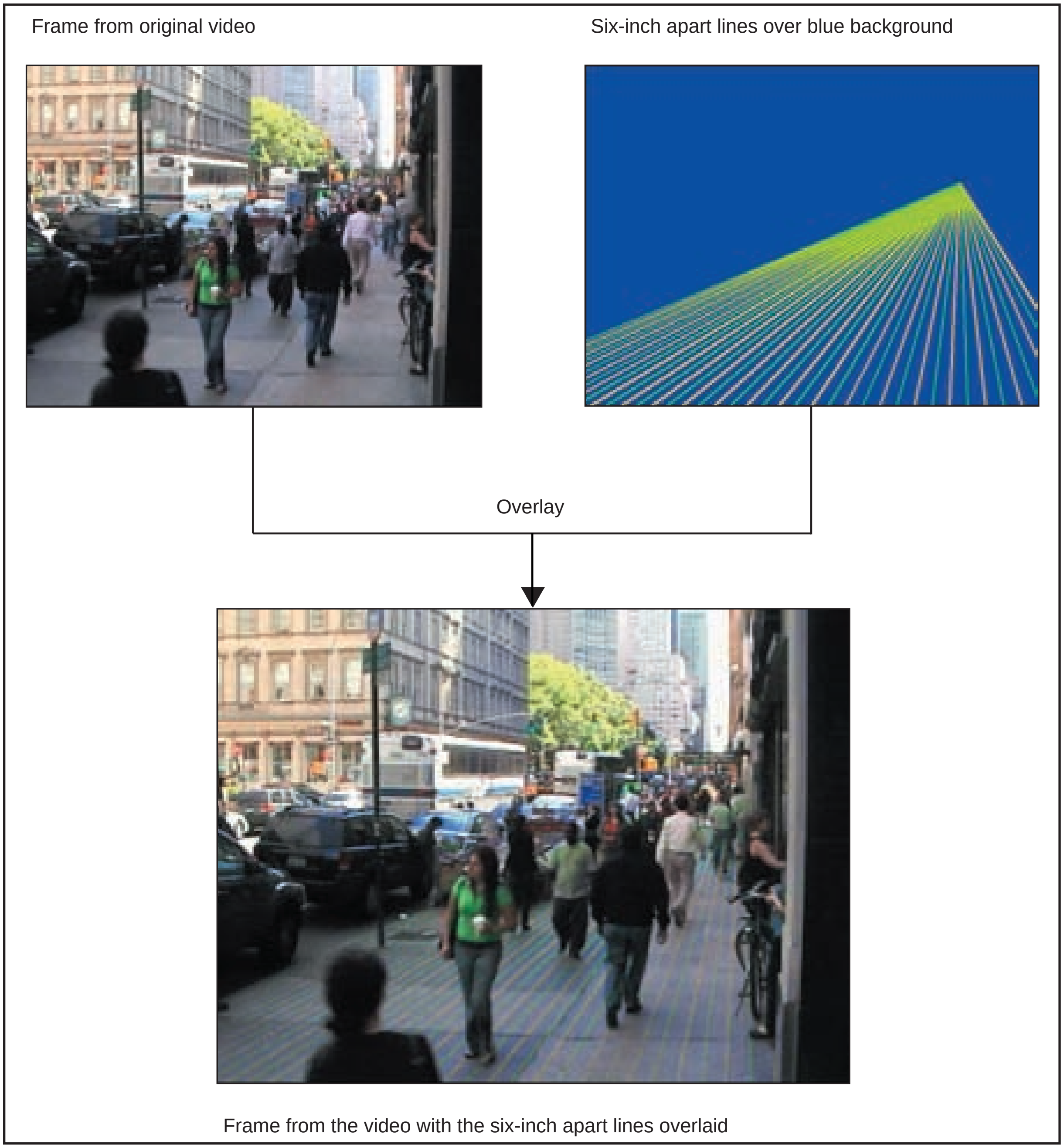


Figure 4.5. Video Overlay of Lines with 6-inch Apart

purpose; carrying bags (yes/no, if yes, did bag affect walking speed or not); holding a phone; using headphones; drinking or eating; using a PDA; smoking a cigarette; pushing a stroller, service cart, wheelchair or rolling suitcase; using walking aides such as crutches, a wheelchair, a cane or a stroller; if the pedestrian stopped, the time at which they stopped, the time at which they resumed walking, and the observed reason for their stopping; and the pedestrians' walking distance ("shy distance") from sidewalk borders, obstacles and each other (measured using lines derived from the 6-inch wide stripes or AutoCad process discussed above). The methodology for determining peoples' "shy distance" from obstacles, an important component of this study, is described below.

7. Obstacle Study

The TD is interested in determining the distance that pedestrians walk away from obstacles on the

Lower Manhattan CBD sidewalks. Videotaping of pedestrian traffic is essential in the process of determining this "shy distance," the measurement of which is itself essential in determining the effective width of sidewalks. The obstacles that can be studied in these videos are: bus stops, bicycles attached to bus stops, vendors, store displays, doors, street lights, stairs, bollards, subway entrances/exits, planters, trash cans, bus shelters, phone booths, cones and news stands.

While establishing a methodology for analyzing pedestrians' relationships to obstacles, the main question was whether all of the pedestrians in a video should be studied, or only those in platoons. In addition, it was asked if this study should look at pedestrians walking on "empty" sidewalks, or at pedestrians on crowded sidewalks; pedestrians walking within a specific distance from the obstacle and what this distance is; and the impacts of obstacles have on pedestrians.

It was decided to account for all pedestrians that were seen on the screen. By studying all of them, it was attempted to compile information for two main scenarios: first, when the sidewalk was empty and a pedestrian could follow his or her "desired path"; and second, when there were other people on the same sidewalk section and the pedestrian's available path choices were therefore reduced. To distinguish between these scenarios, it was necessary to record the number of people walking close to each individual pedestrian being studied. Based on observations and the literature review, it was learned that in the United States pedestrians tend to form lanes, walking on the right hand side of the sidewalks when the sidewalks are busy or where there are obstacles. The TD believed it was also important to note the pedestrian's walking direction.

The video analysis methodology that the TD has developed to analyze "shy distance" consists of the following steps:

a. Determine the obstacle to be studied. Typically there will be a building wall or border on the side of the sidewalk opposite the curb. The TD is also interested in determining the distance that people walk away from this border.
b. On an auxiliary transparency overlaid on the computer screen, draw a horizontal line perpendicular to the curb from the center and the inner most edge of the obstacle to the building wall. Calculate the length of this segment.
c. Draw a line belonging to the same beam as the 6 inch lines going through the middle point of the segment above. This line is named the middle line.
d. Mark the intersections of the horizontal line with every two six inch lines. Number the intersections starting both on the obstacle side and on the border side, increasing towards the middle line.
e. Draw a rectangular buffer zone centered on the horizontal line. The total width of the buffer zone is approximately twice a person's stride. See Figure 4.6.
f. Every pedestrian whose feet can be seen when he/she is crossing the horizontal line will be studied – due to the camera position, not all pedestrians' feet are visible because other people might block the view. If there is more than one pedestrian in the same cross section as the obstacle, the pedestrian closer to the obstacle will be observed. For every pedestrian considered, information will be noted regarding the person's:
   - Distance from the obstacle to the outmost edge of the foot that is closer to the obstacle;
   - Gender;
   - Walking direction;
   - Impediment (whether they are impeded or not); and
   - Number of pedestrians walking in both directions on both sides of the middle line and within the buffer zone.

As a result the TD intends to develop a database with a measurement of the distance that people walk away from each different obstacle. This database will be analyzed to obtain an average "shy distance" for each obstacle and to establish the potential relationship between this distance and gender, sidewalk impediment and sidewalk crowdedness. Also, it might be possible to develop an index of precise "buffer zone" distances from specific obstacles (mentioned above), based on pedestrian "shy distances" from those obstacles (see Table 4.6. for sample data collection form).

At the time of writing this report, the TD has just tested the proposed methodology with one of the videos. Future work will include an exhaustive collection of data for every observable obstacle from the corresponding video(s) and their analyses (see Appendix C, Table C.6. for a filled out sample form).

8. Street Furniture

Several physical components on sidewalks may be classified into different categories while others belong to more than one category. Some elements are part of the infrastructure that provides basic urban services, such as street lights, fire hydrants and manhole covers. Others provide different services, such as mail boxes, telephones, trash cans and informational signs. Examples of transportation related features are bus stops, bus shelters, parking meters, bicycle racks, traffic signals and subway entrances and exits. Some sidewalk elements have mainly an aesthetic function, such as trees, planters, benches and artwork, while others serve mainly security purposes, like bollards, barriers and fences. Finally, some are retail oriented, such as vendors, news stands and news boxes.

Sidewalk elements may be classified as permanent or temporary. Except for sidewalk vendors, most street furniture is permanent. In terms of space, surface elements can be distinguished from elements with volume. Surface elements include grates, manhole covers, metal plates and ventilation shafts. These do not occupy vertical space above the sidewalk, but may affect pedestrian behavior just the same. Table 4.7 contains a list of obstacles that are found on New York City sidewalks.

It is important to document the existing street

Figure 4.6. Obstacle Analysis Video Grid

Table 4.6. Obstacle Data Collection Form

Location: ____
Date: ____ **Time:** ____ **Observer:** ____

Ped #	Gender	Pedestrian Direction	Left of Screen				Right of Screen			
			Obstacle: / Distance (ft)	Impeded? (Y/N)	# of Pedestrians		Obstacle: / Distance (ft)	Impeded? (Y/N)	# of Pedestrians	
					NB	SB			NB	SB
1										
2										
3										
4										
5										
6										
7										
8										
9										
10										
11										
12										
13										

furniture and other elements on sidewalks because they are impediments that affect pedestrian movement and behavior, and, thus, may affect that sidewalk's level of service. Surface features such as grates tend to affect pedestrian movement; indeed, it appears that people avoid them if they have the choice to walk next to them instead of on top of them – particularly people wearing pointy heels. The elements which occupy vertical and horizontal space on the sidewalk are also obstacles to pedestrian movement, reducing the space available for walking. Some street furniture, like mail boxes, telephones, news stands and vendors might affect pedestrians' behavior by making them stop momentarily.

Maps have been created for filmed locations, to store the approximate locations of existing street furniture, building entrances and other significant elements. Figure 4.7. shows the legend of sidewalk elements with the symbols used to represent these elements and the street furniture map for the control location (Broadway between Duane St and Reade St, west sidewalk). For other data collection locations, street furniture placements are recorded on hard copies.

Table 4.7. Obstacle Categories

Street Furniture
Alarm Box
Art Work
Barrier/Fence
Bench
Bike Rack
Bollard
Bus Shelter
Bus Stop
Fire Hydrant
Flag Pole
Information Sign
Mailbox
Metal Plate
News Box
Parking Meter
Sign Pole
Street Light
Telephone
Trash Can
Ventilation Shaft

Public Underground Access
Elevator Box
Subway Entrance/Exit

Landscaping
Planter
Street Tree

Commercial Uses
Advertising Display
News Stand
Sidewalk Café
Vendor

Building Protrusions
Cellar Door
Stairs
Standpipe

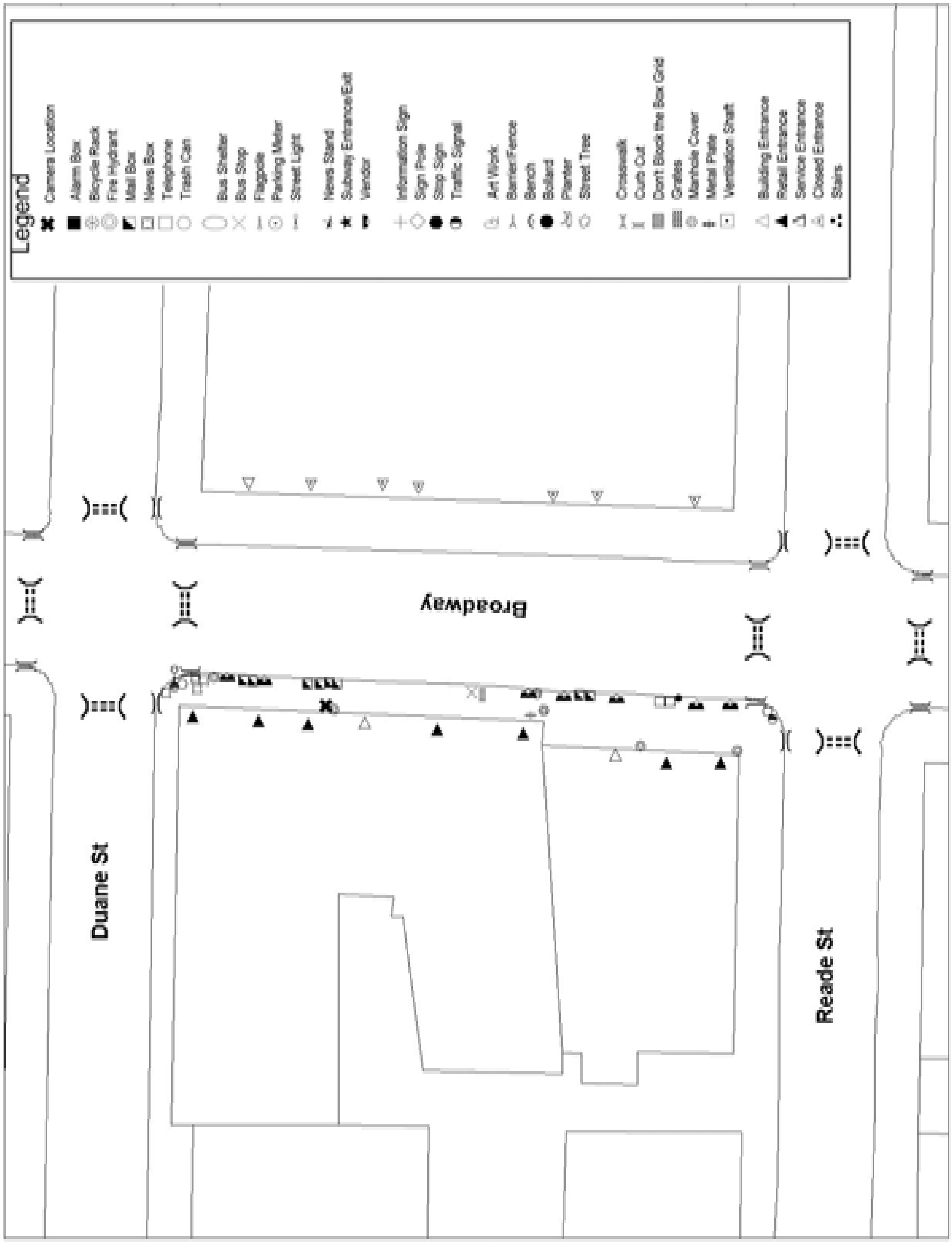


Figure 4.7. Street Furniture Map Sample: Broadway between Duane and Reade Street

CHAPTER 5.

DATA SUMMARY AND ANALYSIS

The following chapter describes in detail the data that the TD has collected, summarized, and analyzed. Below are four main concepts which represent the key findings for this study.

1. Pedestrian Characteristics
   Pedestrians in Lower Manhattan are diverse in personal characteristics and trip purpose. This diversity is correlated with significant differences in individual walking speeds. The characteristics that are associated with the greatest differences in walking speed are gender, group size, headphone use, and trip purpose.

2. Location Characteristics
   a. Land Use
   Different land uses attract different pedestrian trips; and pedestrians trips are made up by different pedestrian characteristics. The trip purpose variations between sidewalks are affected by the proportions of land use within the lots surrounding the sidewalks; therefore, it is valuable to examine variations in land use proportions. The results suggest that land use is related to trip purpose in expected ways (i.e., the more office space, the more work trips), and trip purpose can be used as a proxy for land use while studying speed in our overall data analysis.
   b. Time of Day
   There is a relationship between the time of day and the proportion of each trip purpose on a sidewalk. The TD observed that the majority of pedestrians during the AM peak have a work trip purpose. Tourists and pedestrians with non-work trip purposes were observed more often at the midday and the afternoon peaks.

3. Impedance
   Impedance is defined as the pedestrian being involuntarily slowed by conditions on the sidewalk. There was significant variation in the extent of pedestrian impedance across different times-of-day. Impedance is negatively correlated with mean speed and positively correlated with flow rate. In other words, when a location's overall mean speed increases, the proportion of impeded pedestrians at that location decreases. Time of day appears in itself to be a strong predictor of the proportion of impedance.

4. Pedestrian Delay Analysis
   This study has found that pedestrian characteristics, land use, and time of day have a strong influence on impedance; and that impedance has a strong influence on midblock sidewalk speed. It was decided that measuring pedestrian delay based on

impeded and unimpeded speed would be a good quantitative method to add to the pedestrian LOS methodology, so the TD derived a pedestrian delay analysis.

In this study, pedestrian delay is the difference between the "ideal" speed and "actual" speed at a location. The result is the delay, in seconds, in excess of the "ideal" walking time which would be experienced at each location if each location were a uniform representative walking length (i.e. 1,070 feet).

Sidewalk Delay = [(1,070 feet / median unimpeded speed) – (1,070 feet / median actual speed)]

As discussed in Chapter 4, the TD has developed several pedestrian data collection methodologies to observe walking habits and to determine the effects of the New York City walking environment on pedestrian behavior. These methodologies include speed and delay walks (See Chapter 4), filming on sidewalks, surveying pedestrian characteristics, and pedestrian counts. The objective was to compile a New York City pedestrian characteristics database. From the data collected, some conclusions about pedestrian characteristics in New York City and their interaction with sidewalk factors will be drawn. The TD is interested in laying the groundwork for making recommendations to improve the current HCM pedestrian LOS methodology.

At the end of August 2004, the preliminary stage of data collection was concluded. The following tasks were completed during this stage:

- In March and April 2004, 50 speed and delay walk tests were conducted, over a 1.66 mile route from Broadway and Duane Street to Wall Street and William Street in Lower Manhattan.
- In May 2004, a 7-day pedestrian count was undertaken, in which pedestrian speed samples and Automated Traffic Recorder (ATR) counts were collected on Broadway between Duane Street and Reade Street.
- In July and August of 2004, sixty locations in Lower Manhattan were surveyed during the AM, Mid-Day, and PM peak periods. Over 9,000 pedestrian characteristics, a sample of pedestrian speeds and 30 hours of pedestrian counts were collected.
- Since November, 2003, 15-minute videos were filmed in various locations in midtown and downtown Manhattan. Sixteen locations have been documented. Some locations have been filmed more than once in order to show hourly variations, seasonal variations, or daily variations.
- Previous pedestrian counts collected by the Department of City Planning and by Business Improvement Districts (BIDs) have also been compiled as part of the study.

At the current stage of data summary and analysis, the TD is concentrating on acquiring basic pedestrian characteristics in New York City. The focus is in finding out which critical factors affect pedestrians in order to plan for the next stage of this study. The TD is also concentrating on determining which of the methodologies developed is best for this study's purposes.

A. Pedestrian Characteristics and Speed Data Collection

A sample speed and count collection was conducted in Lower Manhattan in order to:

- Compare Lower Manhattan speed/flow relationships with studies that have been conducted in the past;
- Gather data on the personal attributes of pedestrians that have not been studied in detail in the past in order to make generalizations about their relationship (or lack of relationship) with walking speed;
- Test the methodology for rapidly observing pedestrian attributes and speeds in the field; and
- Evaluate the data collection methodology as well as the results of the summarized data in order to: 1) improve the methodology in the future, 2) focus on the most meaningful factors in determining pedestrian speed and flow.

In this section of the report, the count and speed data gathered are summarized. The chapter focuses on four areas: pedestrian characteristics, location characteristics, delay analysis, and flow analysis.

1. General Information

Speed and attribute data was collected on a sample of 8,978 pedestrians observed at various sidewalk locations in Lower Manhattan over about four weeks. In the same locations, over the same time period, all 23,739 pedestrians were counted in order to determine sidewalk flow rates, and basic information about each of the 62 locations was recorded. Based on these sets of data, two databases were built: a database containing each sample pedestrian's attributes and speed and an aggregate database of each of the study locations. This aggregated locational database includes the calculated flow rate based on the count at the location, the effective width of the sidewalk, and land use proportions based on the New York City Primary Land Use Tax Lot Output (PLUTO) data set. It also includes the mean and median speeds of all sampled pedestrians at each location, in addition to the proportion of sampled pedestrians at the location exhibiting particular attributes.

All subsequent analyses were based on these databases.

a. Data cleansing

Before the data analysis began, a data cleansing was undertaken to correct for potential inconsistencies introduced in the data gathering process. A detailed discussion of the data cleansing can be found in Appendix E.

b. Exploratory Data Analysis (EDA)

An exploratory data analysis (EDA) was also undertaken as the first step of the data analysis process. The purpose of the EDA was to familiarize ourselves with the distribution of the data, and to determine the statistical validity of the data distribution. The EDA is a crucial first step in determining the possibility of specific methods of statistical analysis. A detailed discussion of the EDA can be found in Appendix F.

2. Analysis of Pedestrian Characteristic Frequencies

In general, the frequencies of pedestrian characteristics identified are in line with expectations. The ratio of men to women is skewed slightly toward men more than in the city as a whole (where men make up only 47% of the population according to Census 2000 data). The age distribution is definitely skewed toward those aged 14-65, but that is expected in a central business district with a small residential population.

About 13.5% of all pedestrians observed were engaged in some activity: talking on the phone, listening to headphones, using a PDA, smoking, or eating/drinking. 16% of all pedestriansobserved were visibly impeded by street furniture or by other pedestrians.

The predominant trip purpose observed was 'work' at 49% of all observed pedestrian trips. However, the 'not sure' category was not far behind, accounting for 37% of pedestrian trips. This high proportion of 'not sure' trips is a result of a decision to be cautious about assigning trip purposes to pedestrians via observation.

About 66% of pedestrians observed were walking alone, with most of the remainder walking in pairs. The time of day influenced whether or not pedestrians were observed walking in groups. In the morning, with most pedestrians making their morning commute, relatively few groups were observed. At midday, about 42% of all observed pedestrians were part of a group of 2 or more, compared with 16% in the morning and 33% in the afternoon. These findings are in line with other researchers' findings in midtown Manhattan.

It was found that most observed pedestrians (67%) carry some sort of bag while they walk. A very small number of all pedestrians (1%) were visibly impeded by a heavy or awkward bag.

Very few observed pedestrians used walking aides (0.9%) or pushed devices such as strollers or wheelchairs (1.7%). See Figure 5.1. for Pedestrian Characteristics Frequencies.

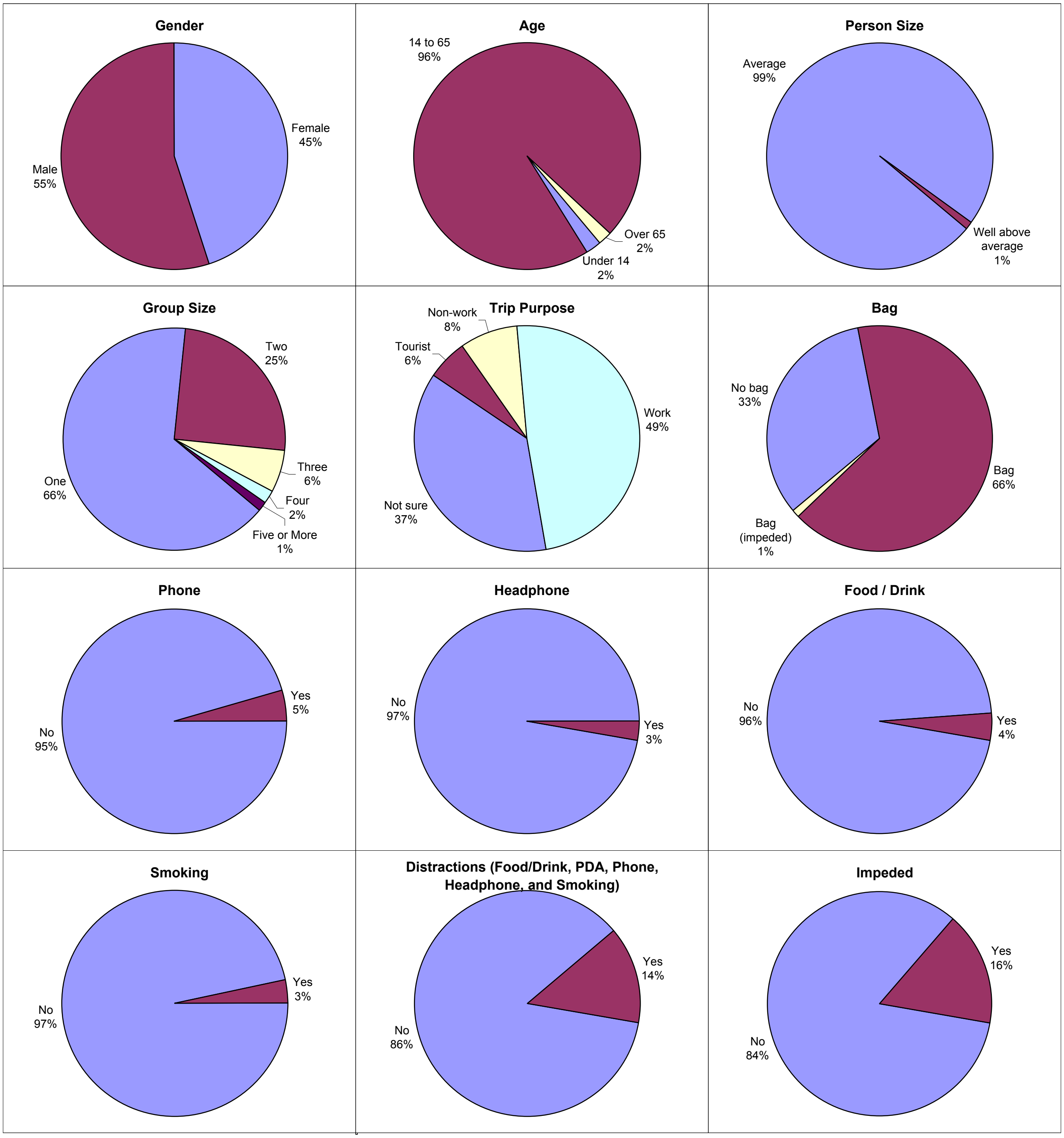


Figure 5.1. Pedestrian Characteristics Frequencies

3. Analysis of Pedestrian Characteristics & Speed

The TD also sought to quantify the relationship between pedestrian characteristics and pedestrian walking speeds—independent of location characteristics. Prior research has suggested some probable findings—that age, group size, gender, and trip purpose influence walking speed; and that carrying a bag does not.

a. All pedestrians

The speed of all observed pedestrians was distributed normally, as shown in Figure 5.2, with a mean speed of 4.27 ft/s and a median speed of 4.26 ft/s. This is a little lower than Fruin's average speed of 4.5 ft/s and Weidmann's average speed of 4.40 ft/s (Fruin, 1971; Weidmann, 1991), but this could be due to the fact that most of the observations were mid day. The indirect influence of time of day on walking speed is discussed later in this chapter.

b. Gender

It was observed that men's walking speeds (mean = 4.42 ft/s) are faster than women's speeds (mean = 4.10 ft/s).

This result is complicated by the fact that, according to the observations, women are more likely to walk in groups than men and are less likely to have a work trip purpose. But, even holding those factors constant and comparing men and women walking alone with a work trip purpose, it was still found that women walk slightly slower than men (see Figure 5.3, Table 5.1, and Table 5.2).

c. Age

As shown in Figure 5.4., pedestrians between 14-65 years old walk faster (median = 4.29 ft/s) than those under 14 years old (median = 3.64 ft/s) and over 65 years old (median = 3.63 ft/s). A relatively small

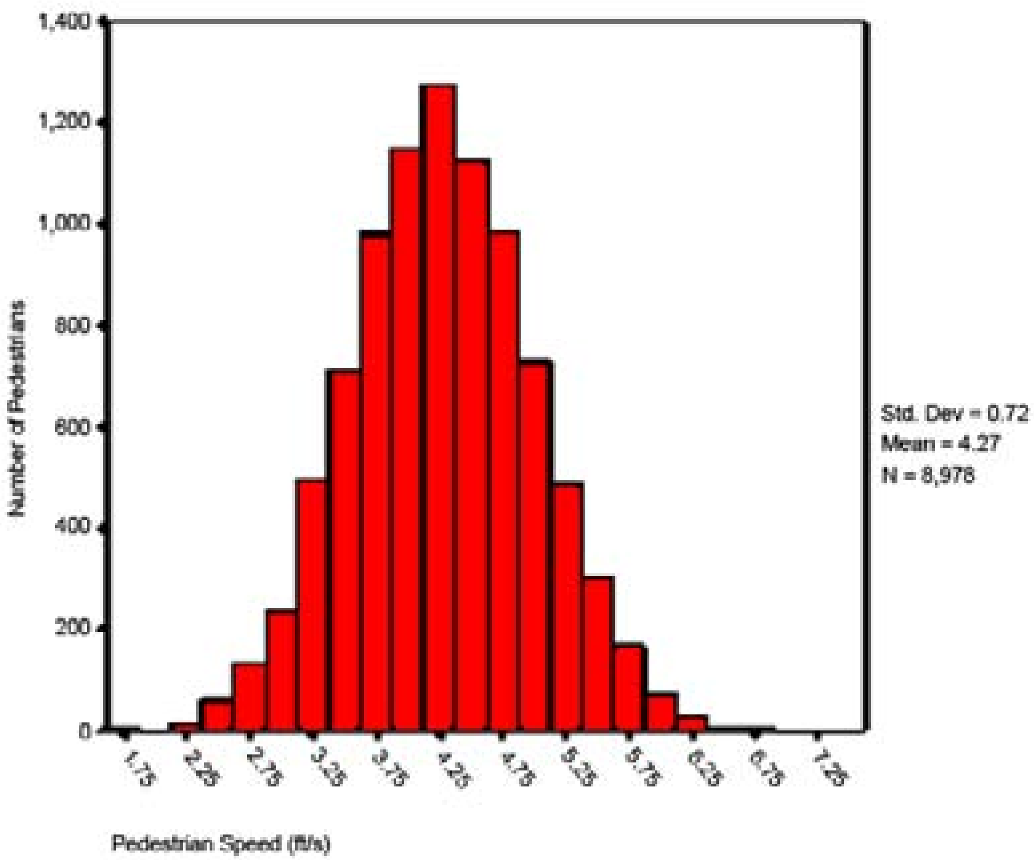


Figure 5.2. Pedestrian Speed Distribution

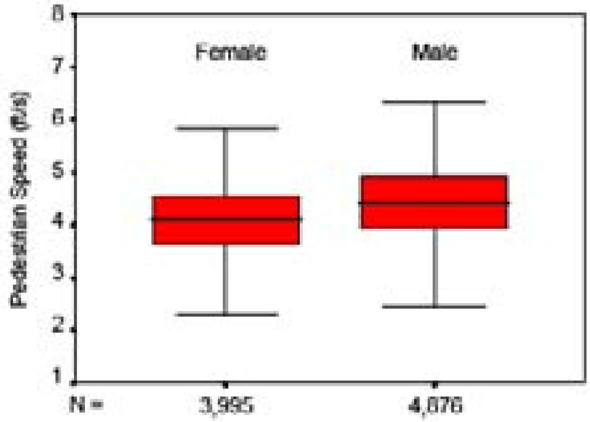


Figure 5.3. Pedestrian Speed by Gender

*A note regarding the interpretation of our box plot figures:

- The box plot represents the distribution of values in a data set. In this case (Figure 5.3), the box plots are illustrating the distribution of pedestrian speeds (in feet per second) observed by gender.
- "N" is the number of cases we observed for each variable. In this case, N is 3,996 female pedestrians and 4,876 male pedestrians.
- The median value of the data distribution is represented by the black line at the center of each red box. 50% of values in the data distribution for each variable are greater than the median and 50% are less than the median.
- The top line of each box is the 75^{th} percentile (upper quartile) and the bottom line of each box is the 25^{th} percentile (lower quartile). 75% of the values in the data distribution for each variable are less than the 75^{th} percentile value, and 25% are less than the 25^{th} percentile value. The space between the 75^{th} percentile and 25^{th} percentile values is called the "inter-quartile range."
- The line below the box plot parallel to the 25^{th} percentile line is drawn according to a formula in which the inter-quartile range value (75^{th} percentile value – 25^{th} percentile value) is multiplied by 1.5; the product is then subtracted from the 25^{th} percentile value. The resultant value is named L1. The line parallel to the 25^{th} percentile line is drawn at the smallest value which is greater than L1.
- Similarly, the line above the box plot parallel to the 75^{th} percentile line is drawn according to a formula in which the inter-quartile range is multiplied by 1.5. The product is then added to the 75^{th} percentile value. The resultant value is named U1. The line parallel to the 75^{th} percentile line is drawn at the greatest value which is smaller than U1.

Some of the figures and tables in this chapter which refer to individual characteristics have different total number of cases ("N"). For example, Figure 5.2 refers to a total pedestrian sample size N of 8,978 while the sum of N in Figure 5.3 is only 8,871. This discrepancy is due to the fact that a number of the pedestrians we observed were walking in large groups from which it was not possible to record the individual characteristics of each group member. In these cases, the pedestrians were counted, but their individual characteristics were not recorded. In addition, babies in strollers were considered "pedestrians," but it was difficult to discern their individual characteristics (such as gender), so they were also counted but some of their characteristics were not recorded. Overall, however, the number of individuals with missing characteristics was relatively small ("person size" was not recorded for 111 individuals; it was the characteristic left blank the most).

Table 5.1. Group Size Distribution by Gender

Gender		Group size					Total
		1	2	3	4	>4	
Female	Count	2,528	1,071	281	84	31	3,995
	Percentage	63.3%	26.8%	7.0%	2.1%	0.8%	100.0%
Male	Count	3,366	1,150	243	94	23	4,876
	Percentage	69.0%	23.6%	5.0%	1.9%	0.5%	100.0%
Total	Count	5,894	2,221	524	178	54	8,871
	Percentage	66.5%	25.0%	5.9%	2.0%	0.6%	100.0%

Table 5.2. Trip Purpose Distribution by Gender

Gender		Trip Purpose				Total
		Not Sure	Tourist	Non-Work	Work	
Female	Count	1,693	261	440	1,601	3,995
	Percentage	42.4%	6.5%	11.0%	40.1%	100.0%
Male	Count	1,600	262	290	2,724	4,876
	Percentage	32.8%	5.4%	5.9%	55.9%	100.0%
Total	Count	3,293	523	730	4,325	8,871
	Percentage	37.1%	5.9%	8.2%	48.8%	100.0%

number of pedestrians were observed in the outlying age ranges (under 14 and over 65), though, and as evidenced by the irregular distribution of speeds in those cases, it may not be possible to draw conclusions about those populations. In addition, many of the pedestrians under age 14 were in a stroller and unable to control their own speed.

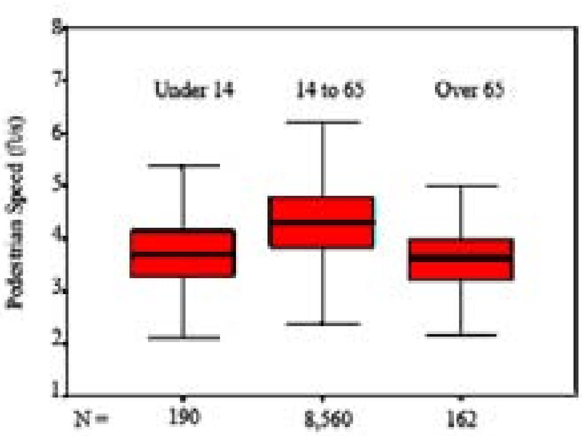


Figure 5.4. Pedestrian Speed by Age

d. Person size

Early in the study, it was hypothesized that pedestrians may be physically larger in 2004 than they had been in the mid-1970s when many of the landmark pedestrian studies had been completed. This could lead to slower walking speeds and larger body ellipses—changing the fundamental relationships between flow rate, speed, and density.

It was observed that pedestrians who were well above average size (according to the observations) walked slower than all other pedestrians (median speed = 3.74 ft/s vs. 4.26 ft/s). However, large pedestrians make up a very small proportion of the overall sample (about 1.1%) so they probably had only a limited impact on the overall flow of traffic (see Figure 5.5).

e. Group size

It was observed that groups of pedestrians have lower speeds overall than pedestrians walking alone. And, as the size of groups increases in number, the median speed decreases. It is not clear whether the difference in group size speeds is due to pedestrians choosing

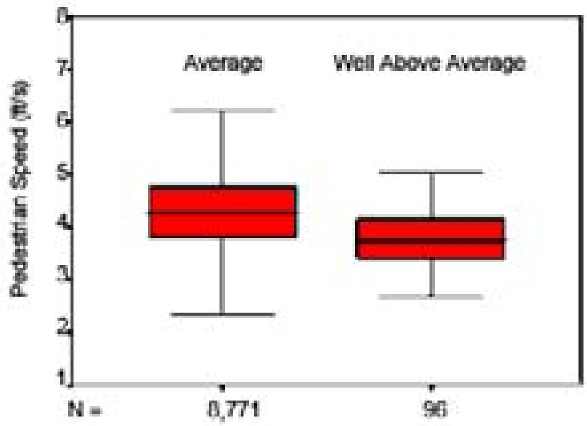


Figure 5.5. Pedestrian Speed by Person Size

the speed of the slowest member, walking slower to be able to talk, or due to the fact that pedestrians tend to walk in groups for less urgent trip purposes (going to lunch, for example).

In this sample, over 30% of all pedestrians were walking with at least one other person. The data may be skewed toward more groups because the TD counted at mid-day more often than it counted in the morning (when most pedestrians walk alone), but this is still an important finding. Does the HCM properly account for the tendency of people to walk in groups? It might be argued that this is just a specific type of platooning, but a platoon of strangers probably behaves differently than a group of friends when confronted with an opposing pedestrian flow.

It was found that tourists and pedestrians with non-work trip purposes tend to walk in groups (see Table 5.3. and Figure 5.6.)

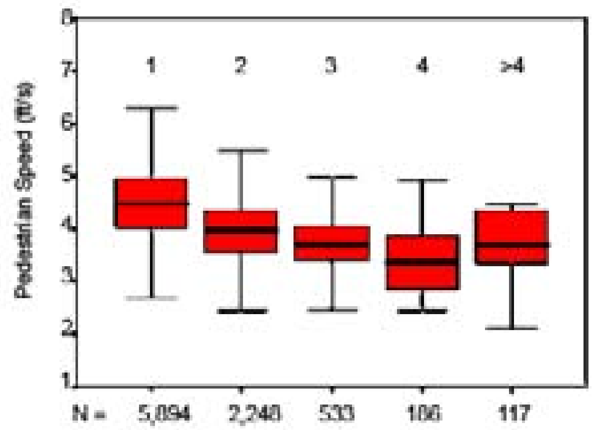


Figure 5.6. Pedestrian Speed by Group Size

f. Trip Purpose

Generally, the relationship observed between a pedestrian's trip purpose and his or her walking speed is in line with past studies and common sense. As shown in Figure 5.7, it was observed that pedestrians whose trip purpose is work tend to walk the fastest, with a median speed of 4.41 ft/s. Tourists tend to walk the slowest (median speed = 3.79 ft/s) and non-tourists with a recreational or casual trip purpose

Table 5.3. Group Size Distribution by Trip Purpose

Trip Purpose		Group Size					Total
		1	2	3	4	>4	
Not Sure	Count	2,428	727	113	20	5	3,293
	Percentage	73.7%	22.1%	3.4%	0.6%	0.2%	100.0%
Tourist	Count	64	224	115	75	45	523
	Percentage	12.2%	42.8%	22.0%	14.3%	8.6%	100.0%
Non-work	Count	248	332	109	39	3	731
	Percentage	33.9%	45.4%	14.9%	5.3%	0.4%	100.0%
Work	Count	3,154	938	188	44	1	4,325
	Percentage	72.9%	21.7%	4.3%	1.0%	0.0%	100.0%
Total	Count	5,894	2,221	525	178	54	8,872
	Percentage	66.4%	25.0%	5.9%	2.0%	0.6%	100.0%

walk just slightly faster (median speed = 3.90 ft/s). The large group of pedestrians whose trip purpose was unclear to us walked at a median speed in line with the overall sample (4.25 ft/s).

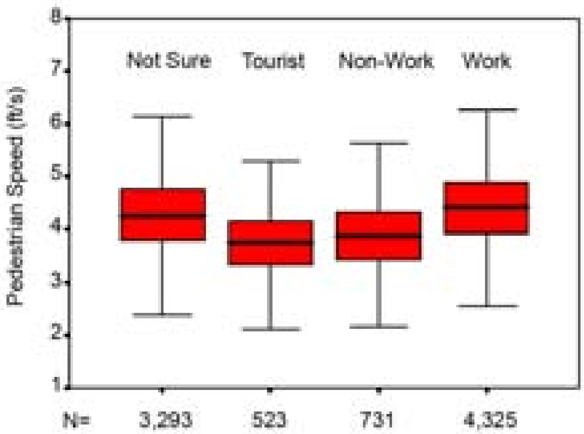


Figure 5.7. Pedestrian Speed by Trip Purpose

g. Bag

Fruin and Whyte found that the walking speed of pedestrians does not change if they are carrying bags or not. The observations validate their findings. The median speed of all pedestrians carrying bags (including those observed as being impeded by the weight or size of their bag) was 4.27 ft/s while the median speed of pedestrians without bags was 4.25 ft/s—not a significant difference (see Figure 5.8).

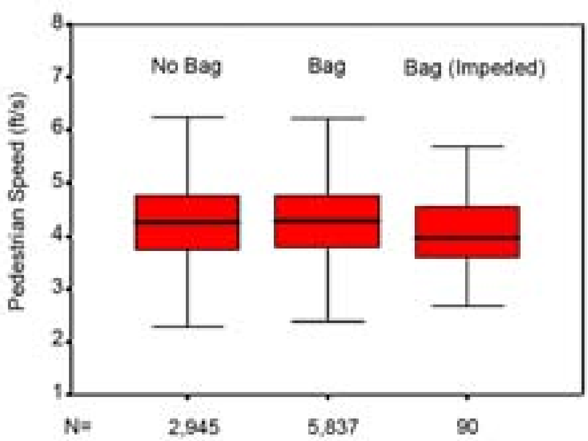


Figure 5.8. Pedestrian Speed by Use of a Bag

h. Distractions

It was also hypothesized that the use of devices such as cell phones and portable stereos (portable cassette, CD, and MP3 players) might change the speed at which individual pedestrians walk on the sidewalk. It was observed that 13.8% of all pedestrians are engaged in one (or more) of the five activities the TD decided to monitor—using a cell phone, listening to headphones, using a PDA, smoking a cigarette, or consuming food and drink.

As shown in Figure 5.9, when analyzed in aggregate, there appears to be no significant difference in walking speed between pedestrians engaged in one or more of these activities vs. pedestrians who are not. However, pedestrians who engage in specific activities do have different walking speeds than those who do not.

The mean walking speeds for pedestrians listening to headphones, talking on cellular phones, and smoking are significantly different than the mean walking speed of pedestrians who are not. Remarkably, pedestrians wearing headphones have slightly faster walking speeds (mean = 4.64 ft/s) than those without (mean = 4.27 ft/s). This could indicate that pedestrians who wear headphones are focused on reaching their destination without being distracted by activity on the sidewalk. It could also indicate that another variable influences both a pedestrian's likelihood of wearing headphones and his or her walking speed (e.g. youthful physical fitness). Gender may be one of those factors: according to the sample, men are more likely to be wearing headphones than women (see Table 5.4).

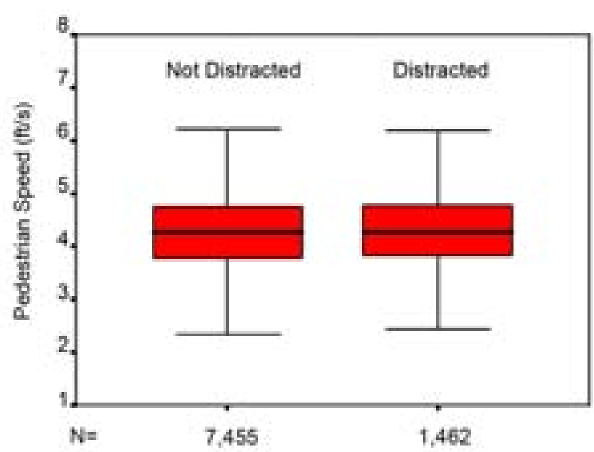


Figure 5.9. Pedestrian Speed by Distraction

Table 5.4. Headphone Use Distribution by Gender

Gender		Headphone		Total
		No	Yes	
Female	Count	3,915	80	3,995
	Percentage	98.0%	2.0%	100.0%
Male	Count	4,714	162	4,876
	Percentage	96.7%	3.3%	100.0%
Total	Count	8,629	242	8,871
	Percentage	97.3%	2.7%	100.0%

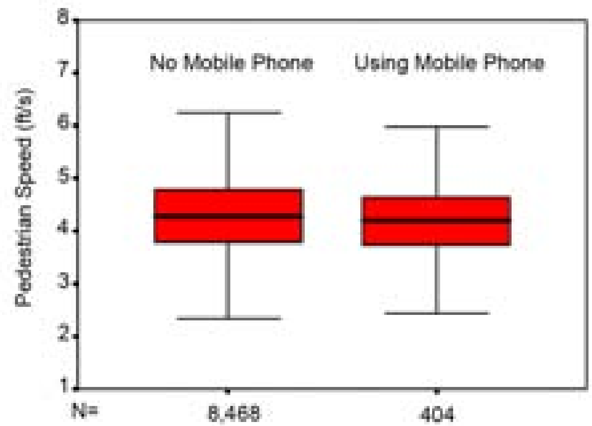


Figure 5.10. Pedestrian Speed by Use of a Phone

Pedestrians talking on cell phones and smoking have lower walking speeds than those who are not engaged in those activities. Smokers' mean walking speed is 4.17 ft/s while cell phone users' walking speed is 4.20 ft/s. In both cases, the mean walking speed of all others is 4.28 ft/s. These are small differences and, given that only 5% of pedestrians are talking on cell phones and 3% are smoking in the sample, these factors probably have little impact on the overall flow on the sidewalk.

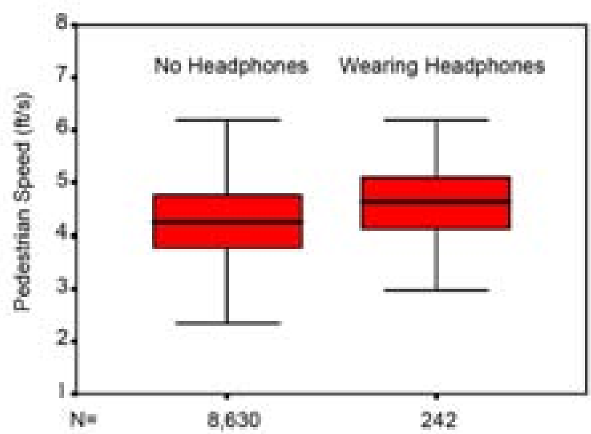


Figure 5.11. Pedestrian Speed by Use of Headphones

Because of small sample sizes, food & drink and PDA use were not analyzed individually. See Figures 5.9, 5.10, 5.11, and 5.12 for pedestrian speed by distractions.

i. Impeded

As defined in Appendix B, a pedestrian is impeded if he/she is involuntarily slowed by conditions on the sidewalk. Perhaps unsurprisingly, it was found that pedestrians who were observed as being impeded have a significantly slower walking speed than pedestrians who are not impeded. As shown in Figure 5.13, impeded pedestrians have a mean walking speed of 3.96 ft/s while unimpeded pedestrians have a mean speed of 4.34 ft/s.

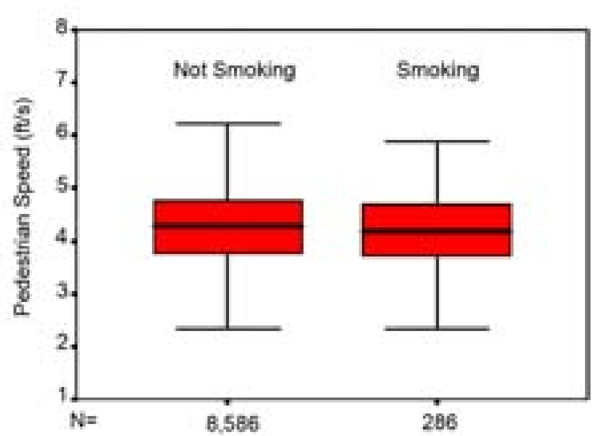


Figure 5.12. Pedestrian Speed by Use of a Cigarette

It was found that women are more likely to be impeded than men, pedestrians are more likely to be impeded at midday than morning or afternoon, and that groups of 2 and 3 are more likely to be impeded than larger groups or single pedestrians. An unusual finding is that tourists tend to be impeded more often than pedestrians with other trip purposes. This is

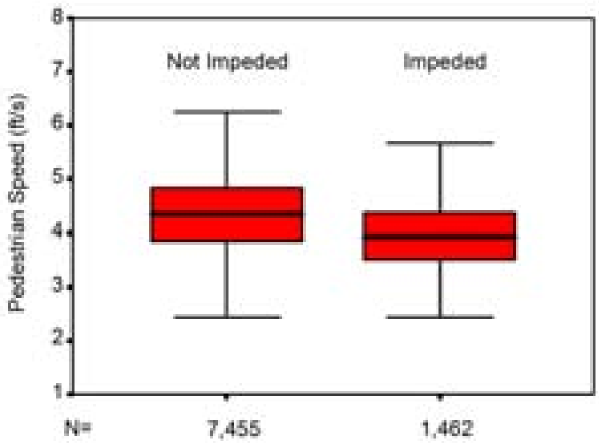


Figure 5.13. Pedestrian Speed by Impedance

surprising because one might expect that tourists, with slower walking speeds, might not be held up very often by other pedestrians. Whyte observed that, in his experience, New York pedestrians are particularly skilled at navigating city sidewalks efficiently. Perhaps out-of-towners are just not as used to the crowds as residents. In addition, it seems that tourists would be most attracted to sidewalks which typically exhibit high activity, as they are probably primarily interested in well-known and therefore highly traveled sites. See Tables 5.5, 5.6, 5.7, and 5.8 for a summary of gender, time and day, trip purpose, group size crosstabulation with impedance.

j. Summary of Pedestrian Characteristics

Based on this analysis a few general conclusions were drawn:

- Pedestrians in Lower Manhattan are diverse in personal characteristics and trip purpose. This diversity is correlated with significant differences in individual walking speeds.

Table 5.5. Impedance Distribution by Gender

Gender		Impeded		Total
		No	Yes	
Female	Count	3,288	707	3,995
	Percentage	82.3%	17.7%	100.0%
Male	Count	4,129	747	4,876
	Percentage	84.7%	15.3%	100.0%
Total	Count	7,417	1,454	8,871
	Percentage	83.6%	16.4%	100.0%

Table 5.6. Impedance Distribution by Time of Day

Time of Day		Impeded		Total
		No	Yes	
AM	Count	1,882	159	2,041
	Percentage	92.2%	7.8%	100.0%
MD	Count	3,909	1,012	4,921
	Percentage	79.4%	20.6%	100.0%
PM	Count	1,664	291	1,955
	Percentage	85.1%	14.9%	100.0%
Total	Count	7,455	1,462	8,917
	Percentage	83.6%	16.4%	100.0%

Table 5.7. Impedance Distribution by Trip Purpose

Trip Purpose		Impeded		Total
		No	Yes	
Not Sure	Count	2,714	579	3,293
	Percentage	82.4%	17.6%	100.0%
Tourist	Count	414	109	523
	Percentage	79.2%	20.8%	100.0%
Non-work	Count	633	98	731
	Percentage	86.6%	13.4%	100.0%
Work	Count	3,657	668	4,325
	Percentage	84.6%	15.4%	100.0%
Total	Count	7,418	1,454	8,872
	Percentage	83.6%	16.4%	100.0%

Table 5.8. Impedance Distribution by Group Size

Group Size		Impeded		Total
		No	Yes	
1	Count	5,050	844	5,894
	Percentage	85.7%	14.3%	100.0%
2	Count	1,778	470	2,248
	Percentage	79.1%	20.9%	100.0%
3	Count	418	115	533
	Percentage	78.4%	21.6%	100.0%
4	Count	158	28	186
	Percentage	84.9%	15.1%	100.0%
More than 4	Count	51	5	56
	Percentage	91.1%	8.9%	100.0%
Total	Count	7,455	1,462	8,917
	Percentage	83.6%	16.4%	100.0%

The characteristics that are associated with the greatest differences in walking speed are gender, group size, headphone use, and trip purpose.

– Pedestrians are being impeded on Lower Manhattan sidewalks, primarily by other pedestrians, bus stop and vendor queues, bus shelters, and subway entrances. In all, 16% of all pedestrians in the sample were impeded. Pedestrian impediments will be analyzed further in the discussion of a methodology to measure pedestrian delay.

This analysis leaves out some important factors which might affect pedestrians, such as: how do the locations themselves impact the speed of pedestrians? Do these pedestrian characteristics, when taken at an aggregate level at a location, influence the overall walking speed and flow characteristics of a location? Finally, are pedestrian speeds and rates of impediment distributed evenly across all locations or were some locations more likely to influence these outcomes than others? What are the characteristics of those locations? These factors are discussed in the next section.

B. Location Characteristics

1. Land Use

One of the most basic characteristics of space in a CBD like lower Manhattan is its land use. The office and retail-oriented nature of Lower Manhattan is what defines it as a CBD. However, different streets within the CBD have different proportions of primary land use classifications (residential, office, retail, etc.). These proportional differences have an impact on the makeup of each street's pedestrian traffic, as different land uses attract different kinds of pedestrian trips. As is discussed above, differences in pedestrian trip purposes (work, tourism, etc.) yield variations in walking speeds. The trip purpose variations between sidewalks are affected by the proportions of land use within the lots surrounding the sidewalks (see correlation discussion below). Therefore, it is valuable to examine variations in land use proportions, to get a better sense of the interaction between location characteristics and pedestrian characteristics, which have an impact on overall sidewalk conditions and, eventually, the calculation of LOS.

In order to determine the proportions of primary land use types surrounding the study locations, the Primary Land Use Tax Lot Output (PLUTO), the Department of City Planning's database of land use based on tax lots, was consulted. The PLUTO database includes such information as the zoning district of each tax lot, each tax lot's owner's name, the area of the lot, and the floor area of buildings on the lot by land use. Land use types include commercial and residential, with the designation of commercial land use encompassing office, retail, garage, storage and factory. By isolating the lots surrounding each study location and dividing the lots' total building area into the area of each land use type, the proportion of primary land use types at each individual study location was determined. Although pedestrian data was collected on specific sides of streets (i.e. east or west, north or south), the land uses were aggregated for both sides of the street for each location, and the proportions of land use types reflect the land use areas for both sides of the street for each location. It was assumed that pedestrians on study sidewalks could have buildings on either side of the street as their trip origin or destination, so aggregating the land use areas on both sides makes sense.

Most of the locations in the study have office space as their primary surrounding land use. The average proportion of office space for all study locations is 66.3%. The average residential land use for all study locations is 16.7%, and the average retail land use is 9.2%. Of course, there are locations that are primarily residential or retail in character. For instance, West Broadway between Reade Street and Chambers Street has residential space comprising 73.6% of its surrounding land use; it is the location with the greatest proportion of residential land use among the study spots. Church Street between Chambers Street and Warren Street is the location with the greatest proportion of retail land use, with 53.6% of its surrounding land use comprised of retail space. See Figures 5.14., 5.15. and 5.16.

In the interest of testing the relationship between the mean speed of pedestrians at study locations and the proportions of different land uses surrounding the sites, a backward stepwise regression in SPSS was performed, with the mean speed as the dependent variable, and the proportions of retail, office and residential land use as the independent (predictor) variables. These three land use types were chosen to be analyzed because, as is apparent in the land use maps (see below), they are the predominant land use types around the lower Manhattan sidewalks on which data was gathered. None of the resultant regression models had predictor coefficients that were significant at the 95% confidence level. In addition, the coefficient of determination (r^2), which is the proportion of the variation in mean speed that can be explained by the predictors in the regression equation, was just 0.032.

These regression results indicate that, in this study, differences in the proportions of the three land use types surrounding the study locations did not have a significant impact on the mean speed measured at the locations. This may be because most of the study locations have surrounding land uses that are over 50% office oriented; several sites have land use proportions approaching 100% office. Because this analysis zone (lower Manhattan) is a CBD, the primacy of office space is not surprising. The near homogeneity of land use surrounding the study sites renders land use proportions, as predictive variables, quite unrevealing. However, as mentioned in the Pedestrian Characteristics section above, trip purpose has a direct influence on walking speed. Because land use appears to have an influence on trip purpose variations on sidewalks, it can be said to have an indirect influence on sidewalk speed. Therefore, it is important to illustrate the connection between land use and trip purpose as it applies to this study.

Pushkarev and Zupan (1975) suggest that the use and size of buildings on Manhattan streets can be predictive of the amount of traffic experienced on their bordering sidewalks. By extension, building use and size might also be predictive of primary sidewalk trip purpose. It seems intuitive that a sidewalk whose surrounding buildings are primarily office oriented would be populated by primarily work oriented traffic; the same can be said for primarily residential and retail oriented buildings, which would bound sidewalks with primarily non-work traffic. In Table 5.9., generated from an SPSS correlation analysis, there appears to be a moderate positive correlation between the proportion of pedestrians whose trip purpose was recorded as "non-work" on this study's sidewalks and the total surrounding building area dedicated to a retail land use. In addition, there is also:

- a moderate negative correlation between the "non-work" proportion and the surrounding office area;
- a moderate positive correlation between the "work" proportion and the surrounding office area;
- a moderate negative correlation between the "work" proportion and the surrounding retail area;
- a moderate negative correlation between the "unknown" proportion and the surrounding office area; and
- a moderate positive correlation between the "unknown" proportion and the surrounding retail area.

These results suggest that land use is related to trip purpose in expected ways (i.e., the more office space, the more work trips), and trip purpose can be used as a proxy for land use while studying speed in the overall data analysis.

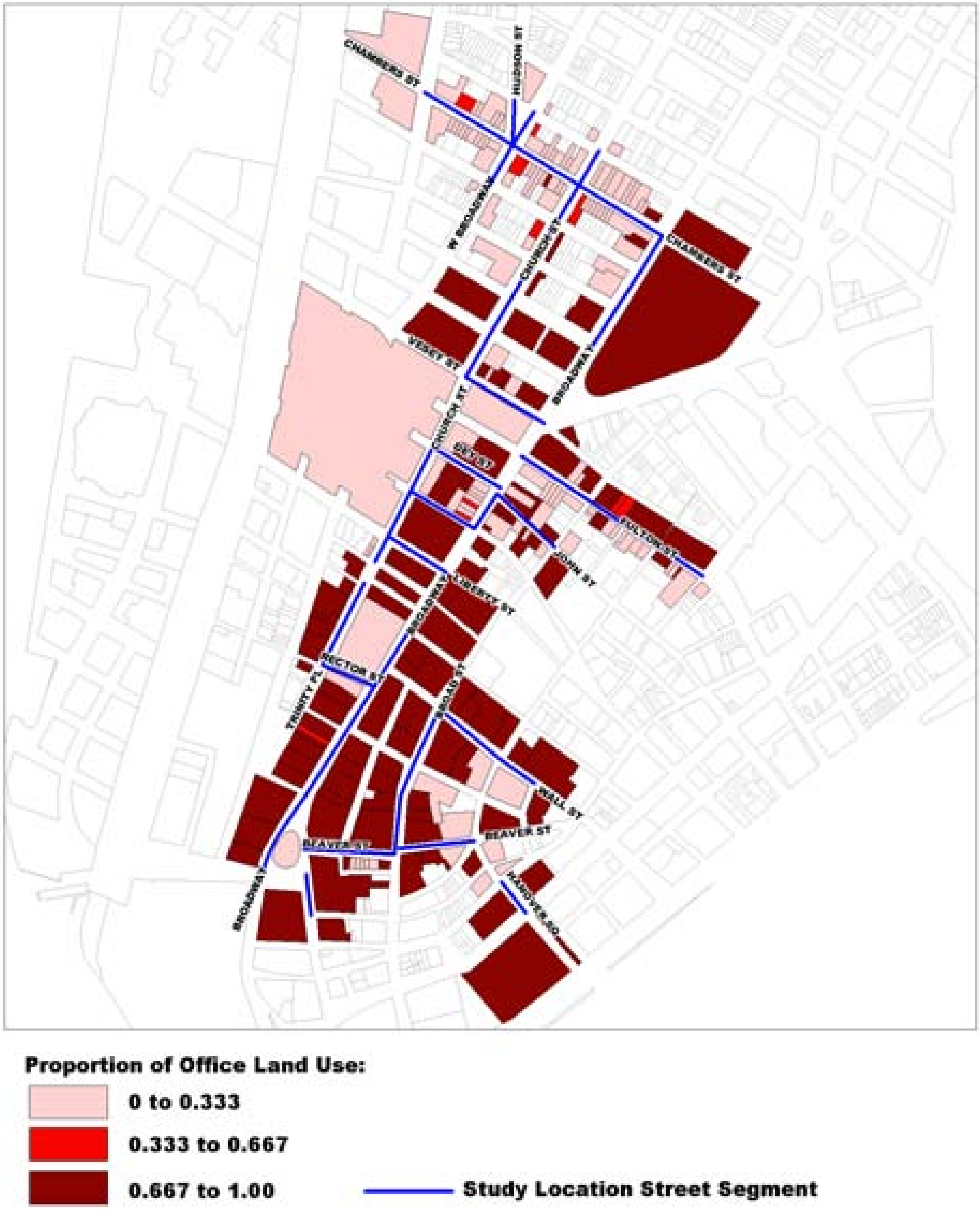


Figure 5.14. Proportion of Office-Oriented Land Use at Study Sites

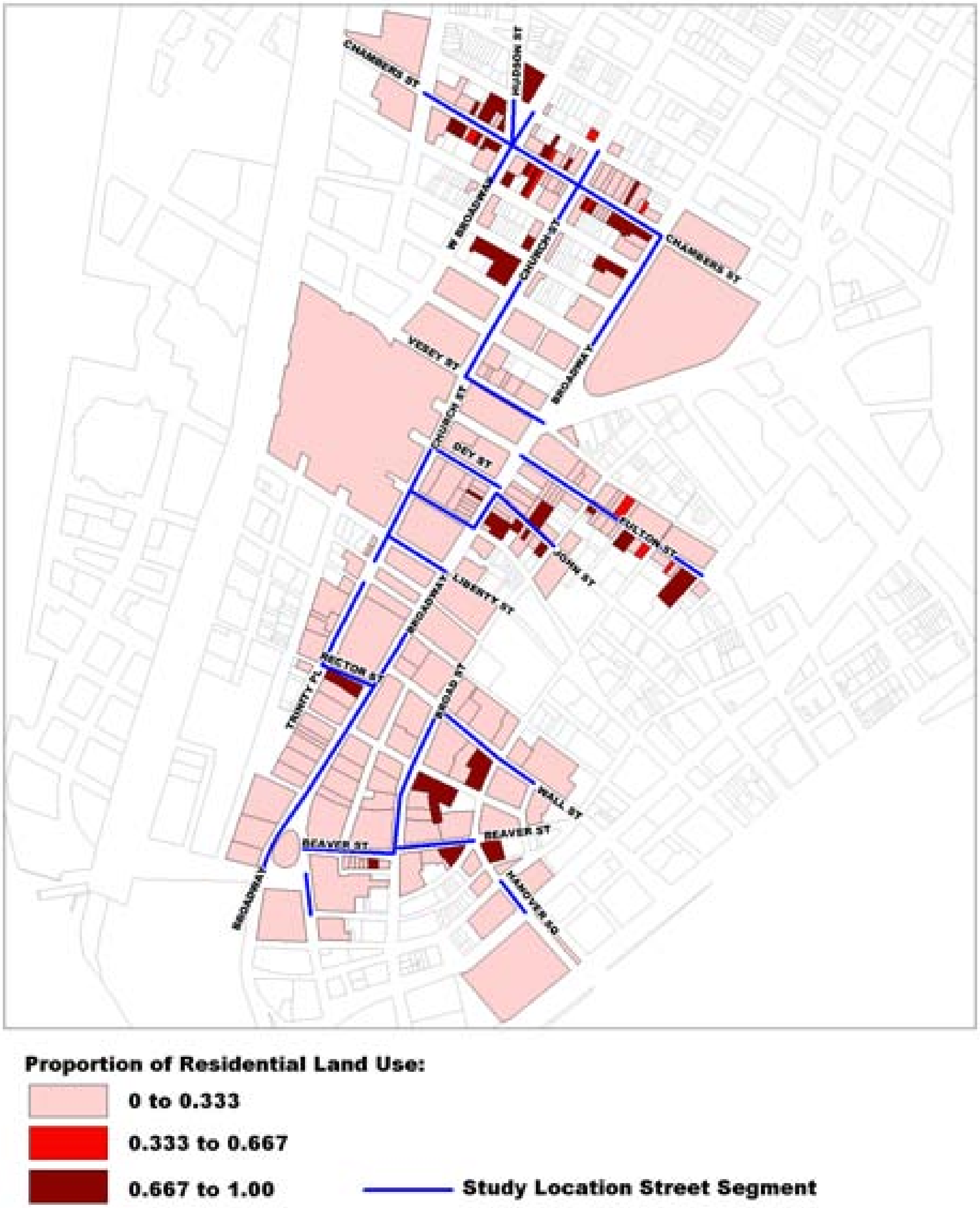


Figure 5.15. Proportion of Residential Land Use at Study Sites

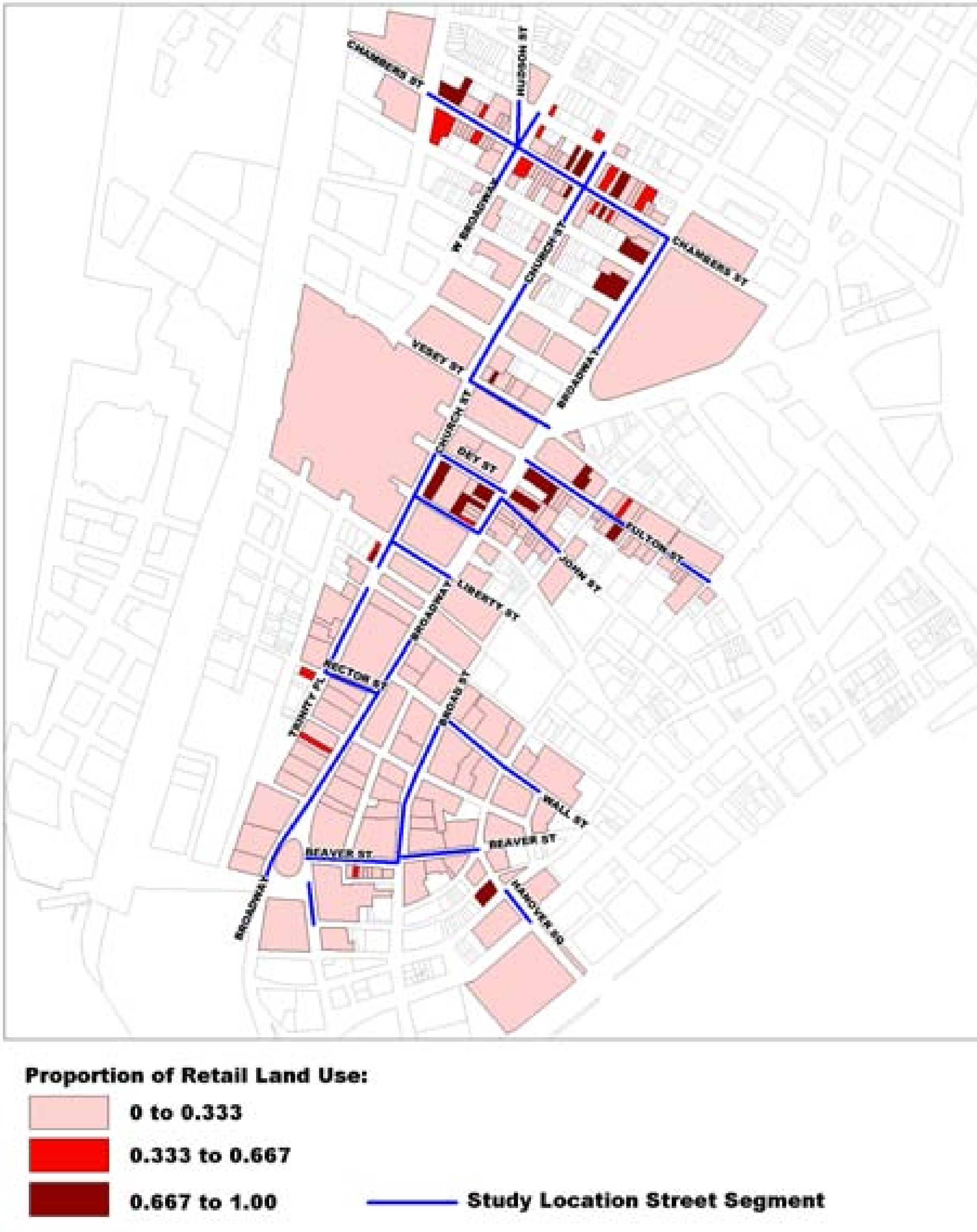


Figure 5.16. Proportion of Retail-Oriented Land Use at Study Sites

Table 5.9. Correlation between Land Use Area and Pedestrian Trip Purpose at Study Locations

		Trip: Unknown	Trip: Tourist	Trip: Non-work	Trip: Work	Area of Land Use: Residential	Area of Land Use: Office	Area of Land Use: Retail
Trip: Unknown	Correlation Coefficient	1.000	0.035	0.043	-0.800**	-0.149	-0.442**	0.387**
	Sig. (2-tailed)		0.707	0.639	0.000	0.107	0.000	0.000
Trip: Tourist	Correlation Coefficient	0.035	1.000	0.095	-0.333**	-0.108	0.190*	-0.155
	Sig. (2-tailed)	0.707		0.303	0.000	0.241	0.038	0.092
Trip: Non-work	Correlation Coefficient	0.043	0.095	1.000	-0.450**	0.013	-0.320**	0.201*
	Sig. (2-tailed)	0.639	0.303		0.000	0.891	0.000	0.029
Trip: Work	Correlation Coefficient	-0.800**	-0.333**	-0.450**	1.000	0.216*	0.431**	-0.368**
	Sig. (2-tailed)	0.000	0.000	0.000		0.019	0.000	0.000
Area of Land Use: Residential	Correlation Coefficient	-0.149	-0.108	0.013	0.216*	1.000	-0.067	-0.513**
	Sig. (2-tailed)	0.107	0.241	0.891	0.019		0.469	0.000
Area of Land Use: Office	Correlation Coefficient	-0.442**	0.190*	-0.320**	0.431**	-0.067	1.000	-0.366**
	Sig. (2-tailed)	0.000	0.038	0.000	0.000	0.469		0.000
Area of Land Use: Retail	Correlation Coefficient	0.387**	-0.155	0.201*	-0.368**	-0.513**	-0.366**	1.000
	Sig. (2-tailed)	0.000	0.092	0.029	0.000	0.000	0.000	

Note: N = 119

**Correlation is significant at the 0.01 level (2-tailed).

*Correlation is significant at the 0.05 level (2-tailed).

2. Location Characteristics and Speed

Analyzing pedestrian characteristics alone leads us to conclusions about how individuals' speeds relate to different factors. This level of analysis does not address a simple fact about pedestrian level of service: pedestrian LOS is assigned to locations rather than pedestrians. Questions about how locations—with their confluence of diverse pedestrian characteristics and speeds—impact the flow of pedestrians themselves still need to be addressed.

In this section, several key factors are analyzed:

- Which pedestrian characteristics, in aggregate within a location, explain the most variation in the speed and flow rate at that location?
- How do location characteristics, such as the land use and width of the sidewalk, help explain variation in pedestrian speed?

In order to determine what proportions of pedestrian characteristics at a location best explain variations in its walking speed, a stepwise regression analysis was carried out. The regression shows that a small number of factors contribute to most of the variation in the mean walking speed: the flow rate at the location, the proportion of pedestrians carrying a bag, walking alone, walking with a 'work' trip purpose, impeded, and the proportion of pedestrians of each gender. The coefficient of determination (r^2) is a fairly high 0.659, indicating that nearly two-thirds of the variation in mean speed by location can be explained by these factors. See Appendix G for Location Characteristics and Speed Regression Summary.

NOTE: When two cases from the regression analysis, 60E in the morning peak and 8W in the afternoon peak, are excluded, an r^2 of 0.741 is achieved—a very high coefficient of determination.

An unusual finding is the model's fairly strong negative coefficient for pedestrians who do not carry a bag. In other words, sidewalk locations with a higher proportion of people carrying bags tend to have higher walking speeds. Intuitively, this result appears suspect—especially because no significant relationship between individuals carrying bags and their own walking speed was found.

Several explanations for this anomaly were considered, given what was learned about the relationship between pedestrian characteristics and speed. Particularly, it was considered that some other factor—trip purpose or gender, for example—may be influencing whether people carry bags in addition to explaining differences in walking speed. The single most important factor appears to be the time of day. During the morning peak, the vast majority of pedestrians are carrying bags and walking quickly. At midday, fewer pedestrians carry bags and the average walking speed is much lower across locations.

The proportion of pedestrians exhibiting certain characteristics at each location and time of day was plotted in Figure 5.17. For example, at the majority of locations, the proportion of pedestrians without bags changes from between 20-30% in the morning to 40-50% at midday and back down to 20-35% in the evening.

Whether or not pedestrians are carrying bags is not the only factor explained by the time of day. Based on an analysis of variance of all the factors in the regression model, time of day explains variance in all of them except gender at a significant level ($\alpha = 0.05$).

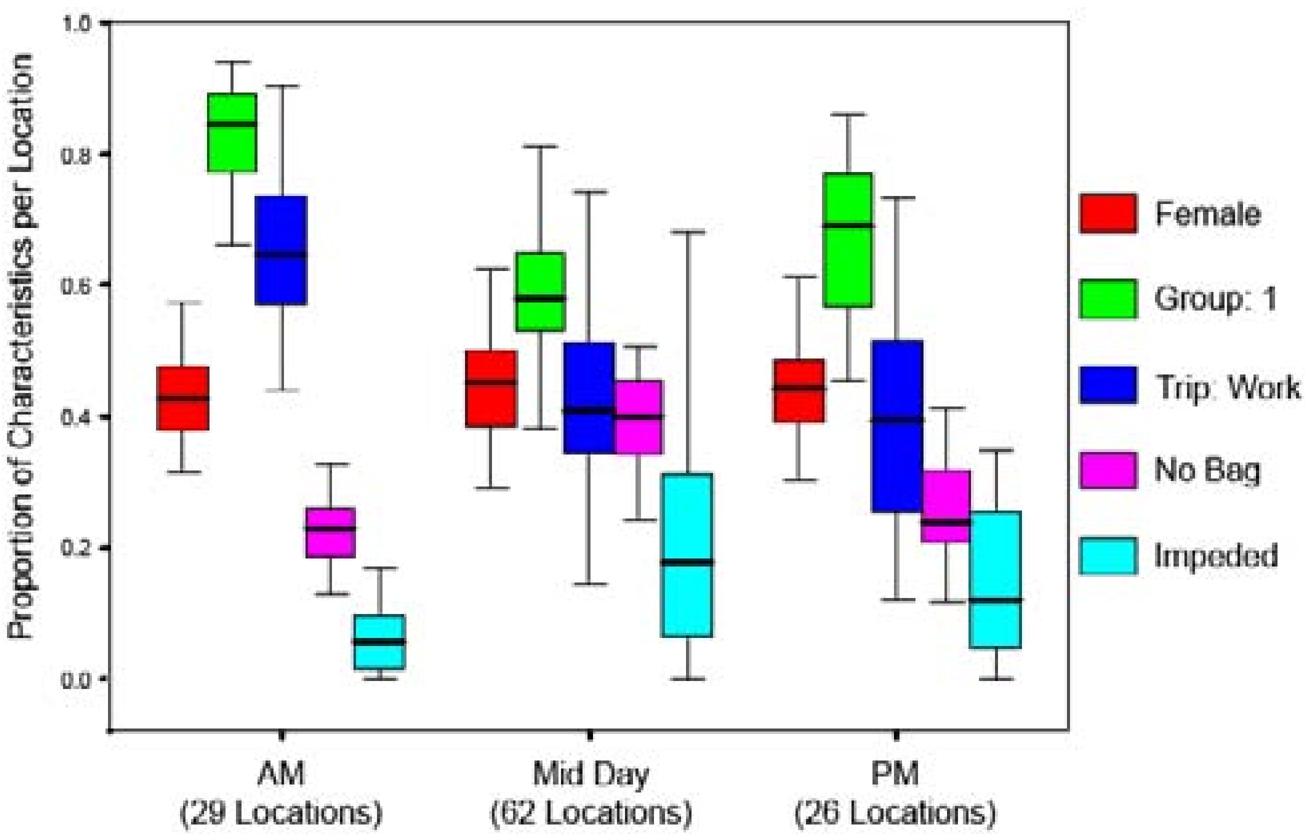


Figure 5.17. Pedestrian Characteristics by Time of Day

This example illustrates the difficulty in isolating variables to explain pedestrian speed at a location. It is also a reminder that, while this regression model helps predict a location's mean walking speed given these factors, assigning causation to any factor is not possible given the nature of this non-experimental study.

3. Speed by Time of Day

Intuitively, there is a relationship between the time of day and the proportion of each trip purpose on a sidewalk. It was observed that the majority of pedestrians during the AM peak have a work trip purpose, for example. Also, tourists and pedestrians with non-work trip purposes were observed more often at the midday and the afternoon peaks.

Time of day also explains directional flow on the sidewalk. The ratio between counts in each direction (eastbound/northbound count divided by the westbound/southbound count) was plotted in Figure 5.18. A ratio of 1.0 at a location would indicate that there were exactly the same number of eastbound and northbound trips as westbound and southbound trips. A ratio greater than 1.0 at a location would indicate a higher volume of northbound or eastbound pedestrians. A ratio less than 1.0 at a location would indicate a higher volume of southbound or westbound pedestrians.

During the AM peak the ratio is skewed slightly toward northbound and eastbound pedestrians, during the midday peak the ratio is centered around 1.0, and during the PM peak the ratio is skewed slightly to the opposite direction of the AM peak. Lower Manhattan is a CBD with a relatively small residential population of its own, so most workers in the area arrive by subway. They typically arrive in the subway station nearest their office building in the morning and leave by the same station in the evening. This accounts for the slightly unequal directional flow in the morning and afternoon. At midday, workers are already distributed among the downtown office buildings and make short round trips for lunch and errands. This accounts for the symmetry in flow during this time.

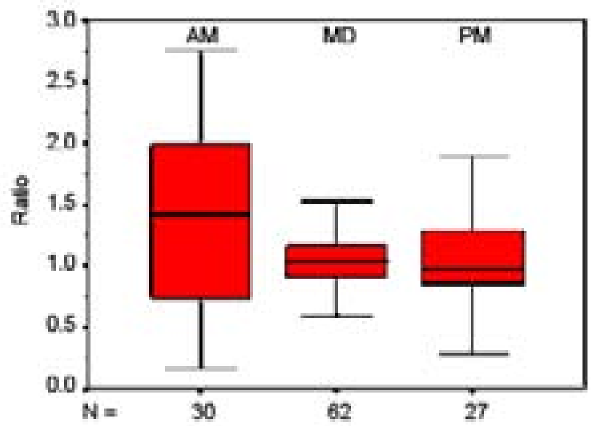


Figure 5.18. Pedestrian Directional Ratio by Time of Day

To produce Figure 5.18, locations were simply grouped by time of day. If locations had been plotted just north or east of a subway station separately from locations just south or west of a subway station, the directional differences would be even more striking.

There is also a relationship between time of day and the number of pedestrians walking alone. During the morning and, to a lesser extent, the evening peak, pedestrians tend to walk alone. This is because commuters tend to walk alone from their subway stop to the office and vice versa. At midday, workers frequently take lunch in groups and mingle with groups of tourists and non-workers who are shopping or sight-seeing.

Because time of day explains so much about the proportion of pedestrian characteristics and the mean pedestrian speed at a location, regression analyses were run to determine the factors that explained the most variance in pedestrian speed, proportion of impeded pedestrians, and flow rate for each time of day (see Table 5.10. for summary of AM, Mid-day and PM mean speed regression factors).

a. Regression – Speed AM

According to a stepwise regression, the most important set of factors in explaining the mean speed of a location in the morning peak period are the flow rate, the proportion of pedestrians whose trip purpose is work, the proportion of pedestrians engaged in some activity like talking on the phone or carrying

Table 5.10. Speed by Time of Day – Mean Speed Factors

	AM	MD	PM
r^2	0.743	0.429	0.803
Mean Speed Factors	Flow Rate	Flow Rate	Impeded
	Trip Purpose: Work	Impeded	Walking Alone
	Activity: Talking on phone or carrying food or drink		Carrying a bag
	Group Size: Three		Trip Purpose: Work

food/drink, and the proportion of pedestrians walking in groups of three ($r^2 = 0.743$).

Flow rate and work trip purpose were also important in explaining speeds for all times of the day, but the other factors were not. By itself, the proportion of distracted pedestrians by time of day explains 0.060 of the variance in speed. Groups of three explain 0.050 of the variance in speed. The distribution of pedestrians who have these characteristics is similar to pedestrians at other times of day (see Appendix H for Speed by Time of Day Regression Summary).

b. Regression – Speed Mid-Day

According to a stepwise regression, the most important set of factors in explaining the mean speed of a location in the midday peak period are the flow rate and the proportion of pedestrians who are impeded ($r^2 = 0.429$). The coefficient of determination is comparatively low at midday. This is because the mean speed at each location varies much more at midday than it does in the morning and afternoon peaks. In addition, midday flow is more complex. There are more (and larger) groups, more trip purpose diversity, and higher pedestrian volumes than at any other time of the day (see Appendix H for Speed by Time of Day Regression Summary).

c. Regression – Speed PM

According to a stepwise regression, the most important set of factors in explaining the mean speed of a location in the afternoon peak period are the proportion of pedestrians who are impeded, walking alone, carrying a bag, and whose trip purpose is work ($r^2 = 0.803$) (see Appendix H for Speed by Time of Day Regression Summary).

4. Location Characteristics and Impedance

A series of backward stepwise regression analyses were undertaken to determine the effect that variations in pedestrian characteristics had on the proportion of impeded pedestrians at each study site. The dependent variable in this analysis was the observed proportion of pedestrians at each study site who were impeded, and the independent (predictor) variables were the pedestrian characteristics described above in the pedestrian characteristics section. There were four backward stepwise regression analyses undertaken in this series: one for the morning (AM) observations, one for the mid-day (MD) observations, one for the evening (PM) observations and one for all observations regardless of the time of day. The reason that the analysis was divided into different times of day was because, in a preliminary examination of the impedance data, it appeared that there was significant variation in the extent of pedestrian impedance across different times-of-day. Therefore, time of day appears in itself to be a strong predictor of the proportion of impedance, so it is important to determine the effect of pedestrian variables while controlling for effect of the time of day.

In the overall (all times of day) analysis:

- The coefficient of determination (r^2) is a moderate 0.416;
- The pedestrian variables determined to be significant in the regression model are flow rate and mean speed; and
- Mean speed has a coefficient of -0.239, while flow rate has a coefficient of 0.033.

These coefficients indicate that impedance is negatively correlated with mean speed and positively correlated with flow rate. In other words, when a location's overall mean speed increases, the proportion of impeded pedestrians at that location decreases. This result seems intuitive. Also, when the flow rate (ped/min/ft) increases, the proportion of impeded pedestrians increases. This would seem to make sense too (when the density of people increases over a certain number of minutes, more people will likely be impeded by others). Recalling that the r^2 in this model is 0.416, the regression results state that 41.6% of the variation of impedance on the study sidewalks can be explained by the mean speed and flow rate of the pedestrians observed on the sidewalk.

The results of the AM analysis are more striking than those of the other three:

- The r^2 in the AM regression is 0.647, which is significantly higher than that of the overall model, described above;
- The significant predictor variables are flow rate, proportion of female pedestrians, and proportion of pedestrians without bags; and
- The female variable has a coefficient of -0.256, while the no bag variable has a coefficient of -0.249 and the flow rate variable has a coefficient of 0.046.

These coefficients indicate that, in the morning, impedance is negatively correlated with the proportion of females on the sidewalk, is negatively correlated with the proportion of pedestrians who are not carrying a bag, and is positively correlated with flow rate. In other words, in the morning, impedance on a sidewalk decreases when the sidewalk's proportion of female pedestrians and the proportion of pedestrians without bags increases. It could be because female pedestrians and pedestrians with bags walk slower than the overall population, they become obstacles to others which leads to impedance. Also, as in the previous model, impedance increases when the flow rate increases. The r^2 value indicates that 64.7% of the variation of sidewalk impedance in the morning can be explained by the proportion of women, the proportion of pedestrians without bags and the flow rate of pedestrians on the sidewalk.

In the MD analysis:

- The r^2 value is 0.424, also a moderate value;
- The significant predictor variables are flow rate, mean speed, and the proportion of pedestrians walking in groups of 4 or more; and
- The flow rate variable has a coefficient of 0.022, while the mean speed variable has a coefficient of -0.462 and the group of 4+ variable has a coefficient of -0.548.

As in the morning, the mid-day sidewalk impedance increases as the flow rate increases and decreases as the mean speed increases. In addition, the mid-day impedance decreases as the proportion of pedestrians in groups of 4 or more increases. This does not seem to make intuitive sense. The mid-day model's r^2 value indicates that 42.4% of the variation of sidewalk impedance can be explained by the proportion of pedestrians walking in groups of 4 or more, the flow rate and pedestrian mean speed on the sidewalk.

Finally, in the PM analysis, the r^2 value is the lowest, at 0.037. In this analysis, however, there are no predictor variables significant at the 95% level. Therefore, it does not appear that the impedance of sidewalks in the analysis during the evening hours can be explained

Table 5.11. Location Characteristics and Impedance Summary – Significant Variables

r^2	Overall		AM		MD		PM	
	0.416		0.647		0.424		0.037	
Significant Variables	**Variables**	**Coefficient**	**Variables**	**Coefficient**	**Variables**	**Coefficient**	**Variables**	**Coefficient**
	Flow Rate	0.033	Flow Rate	0.046	Flow Rate	0.022	None	
	Mean Speed	-0.239	Female	-0.256	Mean Speed	-0.462		
			No Bags	-0.249	Group Size >4	-0.548		

by the variation in any of the individual pedestrian variables (see Table 5.11. Location Characteristics and Impedance – Significant Variables).

5. Location Data and Pedestrian LOS

The pedestrian level of service was calculated for all locations using the HCM methodology and using the methodology derived by Pushkarev and Zupan. For every location, platoon conditions based on observations were assumed. In both cases, there were three locations with LOS 'D' based on the HCM methodology and 'CROWDED' based on the Pushkarev-Zupan methodology. The distribution between locations with higher scores differed, however. The HCM was a little more forgiving, assigning a LOS of 'B' to 89 locations and a LOS of 'C' to 27 locations. Pushkarev-Zupan's methodology resulted in 56 locations at the 'IMPEDED' level and 60 locations at the 'CONSTRAINED' level. In other words, Pushkarev-Zupan's methodology resulted in worse locations ratings than the HCM methodology (see Tables 5.12., 5.13. and 5.14.).

These HCM LOS categories were compared to variables with which the TD was more familiar: mean walking speed and the proportion of impeded pedestrians. As shown in boxplots 5.19., 5.20., 5.21., and 5.22. below illustrate the relationship between LOS and these variables. As the LOS categories at each location worsens, the mean speed decreases and the proportion of impeded pedestrians increases.

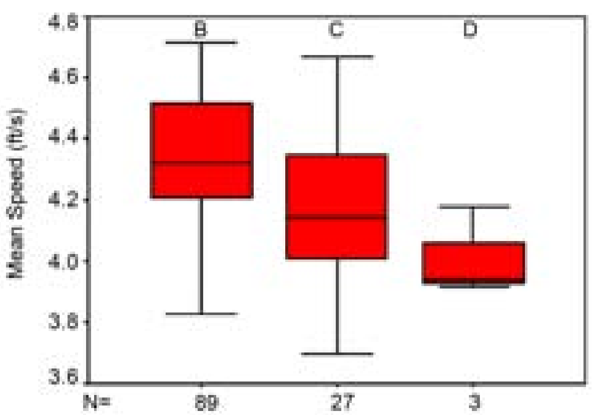


Figure 5.19. HCM LOS Platooning and Impedance

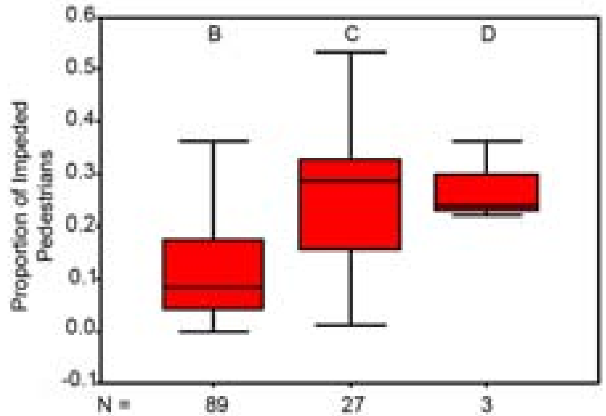


Figure 5.21. HCM LOS Platooning and Mean Speed

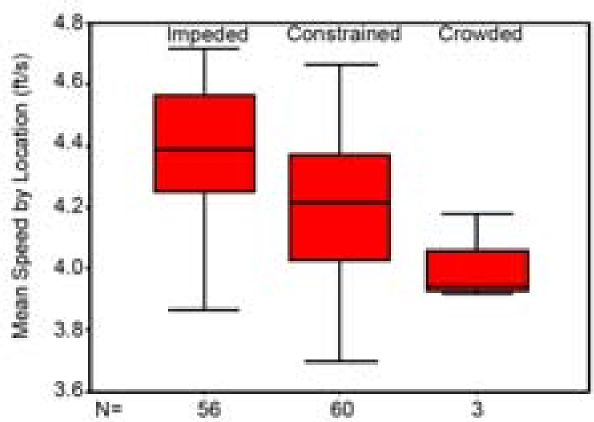


Figure 5.20. Zupan's LOS Platooning and Impedance

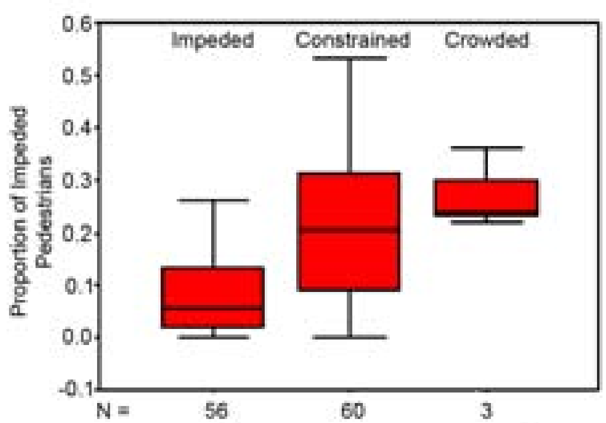


Figure 5.22. Zupan's LOS Platooning and Mean Speed

This indicates that level of service does appear to measure factors that pedestrians perceive on the sidewalk—changes in walking speed and rates of impediment. One question is still open: where should the lines between LOS grades be drawn? Should they be based on factors like walking speed and rate of impediment or should they be derived based on a delay calculation similar to the one discussed above? That the HCM and Pushkarev-Zupan methodologies do not agree on this point makes it even less clear that New York City pedestrians' preferences are incorporated in the pedestrian LOS calculation.

Table 5.12. HCM LOS, Zupan's LOS, and Pedestrian Delay Analysis, AM

LOC	HCM LOS		Zupan		Median Speed (ft/s)		% Delay*	Seconds** Lost (Gained) @1,070 ft***
	Average	Platoon	Average	Platoon	Unimpeded	All		
06N	A	B	Impeded	Constrained	4.36	4.30	1.23%	-3.05
06S	A	B	Unimpeded	Impeded	4.74	4.73	0.16%	-0.36
07E	A	B	Unimpeded	Impeded	4.74	4.69	1.07%	-2.43
07W	A	B	Unimpeded	Impeded	4.62	4.62	0.00%	0.00
08E	A	B	Unimpeded	Impeded	4.52	4.52	0.00%	0.00
08W	A	B	Unimpeded	Impeded	4.76	4.76	0.00%	0.00
09E	A	B	Unimpeded	Impeded	4.70	4.69	0.23%	-0.53
09W	A	B	Unimpeded	Impeded	4.55	4.55	0.00%	0.00
10E	A	B	Unimpeded	Impeded	4.48	4.48	0.00%	0.00
10W	A	B	Unimpeded	Impeded	4.35	4.36	-0.21%	(0.517)
11E	A	B	Unimpeded	Impeded	4.79	4.79	0.00%	0.00
11W	A	B	Unimpeded	Impeded	4.69	4.69	0.00%	0.00
12E	A	B	Unimpeded	Impeded	4.66	4.62	0.82%	-1.89
12W	A	B	Unimpeded	Impeded	4.48	4.49	-0.17%	(0.411)
13E	A	B	Unimpeded	Impeded	4.61	4.60	0.25%	-0.57
13W	A	B	Impeded	Constrained	4.62	4.57	1.01%	-2.36
14E	A	B	Unimpeded	Impeded	4.74	4.74	0.00%	0.00
38E	A	C	Impeded	Constrained	4.41	4.39	0.26%	-0.63
38W	A	B	Impeded	Constrained	4.54	4.53	0.30%	-0.72
39S	A	B	Unimpeded	Impeded	4.43	4.43	0.00%	0.00
41N	A	B	Impeded	Constrained	4.66	4.66	0.10%	-0.22
43N	A	C	Impeded	Constrained	4.60	4.59	0.34%	-0.80
43S	A	B	Unimpeded	Impeded	4.61	4.62	-0.16%	(0.373)
45E	A	B	Impeded	Constrained	4.58	4.57	0.41%	-0.97
45W	A	C	Impeded	Constrained	4.22	4.20	0.55%	-1.40
51E	A	B	Unimpeded	Impeded	4.78	4.72	1.22%	-2.77
55S	A	B	Unimpeded	Impeded	4.45	4.45	0.00%	0.00
56W	A	B	Unimpeded	Impeded	4.41	4.41	-0.07%	(0.181)
57S	A	B	Unimpeded	Impeded	4.68	4.54	2.96%	-6.98
60E	A	B	Impeded	Constrained	3.89	3.89	0.00%	0.00

* % Delay = (median unimpeded speed - median all speed) \ median unimpeded speed
** Seconds Lost/Gain = (1,070 feet / median unimpeded speed) – (1,070 feet / median actual speed)
*** 1,070 ft derived from Fruin's research.

Table 5.13. HCM LOS, Zupan's LOS, and Pedestrian Delay Analysis, MD

LOC	HCM LOS		Zupan		Median Speed (ft/s)		% Delay*	Seconds** Lost (Gained) @1,070 ft***
	Average	Platoon	Average	Platoon	Unimpeded	All		
01N	A	B	Unimpeded	Impeded	4.09	4.04	1.11%	-2.95
01S	A	B	Unimpeded	Impeded	4.46	4.30	3.47%	-8.63
02W	A	B	Unimpeded	Impeded	4.32	4.31	0.19%	-0.46
03E	A	B	Impeded	Constrained	4.34	4.26	1.66%	-4.17
04E	A	B	Unimpeded	Impeded	4.33	4.31	0.42%	-1.04
04W	A	B	Unimpeded	Impeded	4.16	4.16	0.00%	0.00
05E	A	C	Impeded	Constrained	4.11	4.06	1.15%	-3.03
05W	A	B	Impeded	Constrained	4.05	4.04	0.39%	-1.03
06N	A	B	Impeded	Constrained	4.08	3.88	4.88%	-13.46
06S	A	B	Unimpeded	Impeded	4.28	4.22	1.38%	-3.49
07E	A	C	Impeded	Constrained	4.24	4.18	1.42%	-3.65
07W	A	B	Impeded	Constrained	4.09	4.08	0.31%	-0.82
08E	A	B	Impeded	Constrained	4.35	4.35	0.13%	-0.32
08W	A	B	Impeded	Constrained	4.26	4.27	-0.28%	(0.71)
09E	A	B	Unimpeded	Impeded	4.30	4.27	0.64%	-1.62
09W	A	B	Unimpeded	Impeded	4.20	4.18	0.58%	-1.50
10E	A	B	Unimpeded	Impeded	4.38	4.38	0.00%	0.00
10W	A	C	Impeded	Constrained	4.28	4.14	3.14%	-8.10
11E	A	B	Unimpeded	Impeded	4.36	4.22	3.31%	-8.40
11W	C	D	Constrained	Crowded	4.23	4.17	1.48%	-3.80
12E	A	B	Impeded	Constrained	4.17	4.16	0.23%	-0.58
12W	A	B	Impeded	Constrained	4.27	4.24	0.65%	-1.65
13E	A	B	Unimpeded	Impeded	4.35	4.27	1.90%	-4.76
13W	A	C	Impeded	Constrained	4.00	4.04	-0.83%	(2.20)
14E	A	C	Impeded	Constrained	4.28	4.07	4.91%	-12.90
16N	A	B	Impeded	Constrained	4.41	4.19	4.89%	-12.49
18N	A	C	Impeded	Constrained	3.97	3.92	1.31%	-3.57
18S	A	C	Impeded	Constrained	3.66	3.33	8.98%	-28.85
20N	A	C	Impeded	Constrained	4.02	3.57	11.09%	-33.22
20S	A	B	Impeded	Constrained	4.17	3.68	11.77%	-34.26
22N	A	B	Impeded	Constrained	4.10	3.78	7.79%	-22.07
22S	A	C	Impeded	Constrained	3.89	3.76	3.35%	-9.55
25N	A	B	Unimpeded	Impeded	4.00	4.18	-4.47%	(11.44)
25S	A	B	Impeded	Constrained	4.52	4.42	2.14%	-5.17
27N	A	C	Impeded	Constrained	4.21	4.17	0.95%	-2.45
30E	A	B	Impeded	Constrained	4.24	4.24	0.00%	0.00
31N	A	C	Impeded	Constrained	3.90	3.77	3.28%	-9.31
32E	A	B	Unimpeded	Impeded	4.22	4.20	0.37%	-0.94
34N	A	B	Unimpeded	Impeded	4.37	4.39	-0.50%	(1.21)
35W	A	B	Impeded	Constrained	3.86	3.69	4.34%	-12.59
37W	A	B	Impeded	Constrained	4.17	4.14	0.68%	-1.76
38E	B	D	Constrained	Crowded	3.96	3.90	1.53%	-4.20
38W	A	C	Impeded	Constrained	3.99	3.99	0.04%	-0.12
39N	A	B	Unimpeded	Impeded	4.32	4.33	-0.22%	(0.54)
39S	A	B	Unimpeded	Impeded	4.13	4.13	0.00%	0.00
41N	A	C	Impeded	Constrained	4.37	4.28	1.95%	-4.86
41S	A	C	Impeded	Constrained	4.08	4.23	-3.72%	(9.41)
43N	A	B	Impeded	Constrained	4.37	4.35	0.49%	-1.20
43S	A	B	Unimpeded	Impeded	4.36	4.36	0.00%	0.00
44S	A	B	Unimpeded	Impeded	4.38	4.30	1.82%	-4.54
45E	C	D	Constrained	Crowded	3.99	3.84	3.77%	-10.51
45W	B	C	Impeded	Constrained	3.91	3.82	2.35%	-6.57
46E	A	C	Impeded	Constrained	4.33	4.24	2.06%	-5.20
51E	A	B	Impeded	Constrained	3.97	3.99	-0.59%	(1.58)
52E	A	B	Impeded	Constrained	4.16	4.16	0.08%	-0.21
52W	A	B	Unimpeded	Impeded	3.97	3.83	3.45%	-9.62
53S	A	B	Unimpeded	Impeded	4.21	4.11	2.57%	-6.70
54N	A	B	Unimpeded	Impeded	4.38	4.34	0.88%	-2.16
55S	A	B	Impeded	Constrained	4.17	3.98	4.55%	-12.23
56W	A	B	Impeded	Constrained	4.52	4.37	3.26%	-7.98
57S	A	B	Impeded	Constrained	4.20	3.95	5.92%	-16.02
60E	B	C	Impeded	Constrained	4.06	3.97	2.23%	-6.01

* % Delay = (median unimpeded speed - median all speed) \ median unimpeded speed
** Seconds Lost/Gain = (1,070 feet / median unimpeded speed) – (1,070 feet / median actual speed)
*** 1,070 ft derived from Fruin's research.

Table 5.14. HCM LOS, Zupan's LOS, and Pedestrian Delay Analysis, PM

LOC	HCM LOS		Zupan		Median Speed (ft/s)		% Delay*	Seconds** Lost (Gained) @1,070 ft***
	Average	Platoon	Average	Platoon	Unimpeded	All		
06N	A	B	Impeded	Constrained	4.14	3.99	3.81%	-10.24
06S	A	B	Impeded	Constrained	4.45	4.37	1.86%	-4.57
07E	A	B	Unimpeded	Impeded	4.86	4.80	1.24%	-2.77
07W	A	B	Unimpeded	Impeded	4.54	4.53	0.23%	-0.54
08E	A	B	Unimpeded	Impeded	4.42	4.42	0.00%	0.00
08W	A	B	Unimpeded	Impeded	3.95	3.94	0.39%	-1.06
09E	A	B	Unimpeded	Impeded	4.21	4.18	0.63%	-1.60
09W	A	B	Unimpeded	Impeded	4.46	4.40	1.33%	-3.24
10E	A	B	Unimpeded	Impeded	4.35	4.27	1.79%	-4.49
12E	A	B	Unimpeded	Impeded	4.10	4.10	0.00%	0.00
12W	A	B	Unimpeded	Impeded	4.69	4.66	0.72%	-1.66
13E	A	B	Unimpeded	Impeded	4.22	4.12	2.42%	-6.28
13W	A	C	Impeded	Constrained	4.46	4.32	3.13%	-7.77
14E	A	B	Impeded	Constrained	4.34	4.23	2.37%	-5.98
38E	A	C	Impeded	Constrained	4.43	4.43	0.00%	0.00
38W	A	C	Impeded	Constrained	4.72	4.70	0.31%	-0.72
39S	A	B	Unimpeded	Impeded	4.52	4.31	4.59%	-11.40
41N	A	C	Impeded	Constrained	4.73	4.62	2.15%	-4.97
43N	A	B	Impeded	Constrained	4.55	4.51	0.85%	-2.01
43S	A	C	Impeded	Constrained	4.50	4.45	1.19%	-2.86
45E	A	C	Impeded	Constrained	4.38	4.38	0.00%	0.00
45W	A	C	Impeded	Constrained	4.09	4.09	0.00%	0.00
51E	A	B	Impeded	Constrained	4.47	4.46	0.22%	-0.53
55S	A	B	Unimpeded	Impeded	4.63	4.46	3.65%	-8.76
56W	A	B	Unimpeded	Impeded	4.01	4.00	0.20%	-0.55
57S	A	B	Unimpeded	Impeded	4.23	4.23	0.00%	0.00
60E	A	B	Impeded	Constrained	4.56	4.36	4.25%	-10.42

* % Delay = (median unimpeded speed - median all speed) \ median unimpeded speed
** Seconds Lost/Gain = (1,070 feet / median unimpeded speed) – (1,070 feet / median actual speed)
*** 1,070 ft derived from Fruin's research.

C. Others

1. Pedestrian Delay

The HCM's measurement of delay for the vehicular LOS calculation does not have an equivalent in its pedestrian LOS analysis. As discussed in Chapter 2, control delay per vehicle is a crucial measurement in determining vehicular LOS for signalized and unsignalized intersections. According to HCM, "the average control delay per vehicle is estimated for each lane group and aggregated for each approach and for the intersection as a whole. LOS is directly related to the control delay value" (HCM). As mentioned in Chapter 2, control delay is a summation of "initial deceleration delay, queue move-up, stopped delay, and final acceleration delay" at vehicular intersections. Control delay is measured in seconds per vehicle, and at signalized intersections, an LOS of A corresponds with less than or equal to 10 seconds of delay per vehicle; an LOS of C corresponds with 20 to 35 seconds of delay per vehicle and an LOS of F corresponds with greater than 80 seconds of delay per vehicle.

In this study, the walking speeds of pedestrians who are both impeded and unimpeded by sidewalk obstacles and by other pedestrians have been measured. Assuming that, on any given sidewalk segment, the median unimpeded speed for all measured pedestrians is close to the "ideal" speed, then a measurement of the difference between the median unimpeded speed and the "actual" median speed (including unimpeded and impeded speeds) would represent the overall pedestrian delay for that segment.

The overall mean speed in this study, including all locations and pedestrian characteristics, is about 4.27 ft/sec. However, field work was undertaken at numerous sites at different times of day. The land use and pedestrian characteristics of sites varied widely, and because of this, mean speeds at each location also varied. In addition, the time of day had a profound influence on the median speeds of pedestrians throughout the study sites. Because 4.27 ft/sec. represents the overall mean speed, it is a measurement which lumps the speeds of unimpeded walkers in with impeded walkers, as well as speeds at different times of day on characteristically different sidewalk segments.

In order to more closely represent the actual differences in pedestrian conditions for individual sidewalk segments and to arrive at a more accurate LOS measurement, a delay component, representing the difference between the "ideal" speed and "actual" speed at a location, would be useful. It might also be beneficial to include a "time of day" factor in the LOS calculation, as median speeds vary widely at different locations by time of day, but perhaps it is more realistic in terms of data gathering to focus the analysis on planning for the time of day with the worst delay, which appears to be mid-day.

To compute delay in Table 5.15., the following formula was used for each location:

[(1,070 feet / median unimpeded speed) –
(1,070 feet / median actual speed)]

The result is the delay, in seconds, in excess of the "ideal" walking time which would be experienced at each location if each location were a uniform representative walking length (1,070 feet). In order to represent delay in a conceptually meaningful way, for the delay computation the TD has used John Fruin's (1971) determination that the median walking distance for pedestrians in Manhattan is 1,070 feet. It is assumed this distance has not changed significantly since the 1970s. If this length has changed significantly, it is not extremely important to this analysis, as the formula is only using Fruin's measurement as an aid in illustrating delay over a uniform walking distance. The distance can be changed to any deemed more accurate.

As is apparent in the table below (Table 5.15.), several locations (though a small proportion of all locations) show a "delay" of zero, or show a positive "delay," in which the median actual speed is faster than the median unimpeded (ideal) speed. Locations with zero delay are locations where the median actual speed exactly matched the median unimpeded speed; this most likely came about because the locations did not have any impeded pedestrians. Zero delay was observed in greatest proportion at locations studied in the morning hours. This may be due to the fact that many of the AM pedestrians were single, relatively fast walkers on their way to work.

Locations with positive delay are locations where, although pedestrians may have been impeded, overall the impeded pedestrians walked *faster* than the unimpeded pedestrians, and the median speed of the impeded and unimpeded pedestrians combined outpaced that of the unimpeded pedestrians alone. This was a phenomenon noticed primarily on sidewalks where heavy business-oriented traffic mixed with heavy non-business traffic, where those who tended to walk significantly faster than the median (male business pedestrians walking alone)

Table 5.15. Pedestrian Delay Analysis, All Time Periods

LOC	Median Speed (ft/s)		% Delay*	Seconds** Lost (Gained) @1,070 ft***
	Unimpeded	All		
01N	4.09	4.04	1.11%	-2.95
01S	4.46	4.30	3.47%	-8.63
02W	4.32	4.31	0.19%	-0.46
03E	4.34	4.26	1.66%	-4.17
04E	4.33	4.31	0.42%	-1.04
04W	4.16	4.16	0.00%	0.00
05E	4.11	4.06	1.15%	-3.03
05W	4.05	4.04	0.39%	-1.03
06N	4.20	4.07	3.21%	-8.44
06S	4.45	4.33	2.54%	-6.28
07E	4.55	4.51	0.87%	-2.07
07W	4.36	4.33	0.50%	-1.23
08E	4.46	4.40	1.32%	-3.20
08W	4.24	4.23	0.28%	-0.71
09E	4.32	4.30	0.43%	-1.07
09W	4.43	4.39	0.97%	-2.37
10E	4.44	4.36	1.99%	-4.90
10W	4.31	4.27	0.95%	-2.38
11E	4.61	4.48	2.72%	-6.50
11W	4.45	4.38	1.56%	-3.81
12E	4.30	4.19	2.67%	-6.81
12W	4.44	4.44	0.00%	0.00
13E	4.40	4.35	1.16%	-2.85
13W	4.42	4.34	2.02%	-4.99
14E	4.54	4.26	6.26%	-15.74
16N	4.41	4.19	4.89%	-12.49
18N	3.97	3.92	1.31%	-3.57
18S	3.66	3.33	8.98%	-28.85
20N	4.02	3.57	11.09%	-33.22
20S	4.17	3.68	11.77%	-34.26
22N	4.10	3.78	7.79%	-22.07
22S	3.89	3.76	3.35%	-9.55
25N	4.00	4.18	-4.47%	(11.444)
25S	4.52	4.42	2.14%	-5.17
27N	4.21	4.17	0.95%	-2.45
30E	4.24	4.24	0.00%	0.00
31N	3.90	3.77	3.28%	-9.31
32E	4.22	4.20	0.37%	-0.94
34N	4.37	4.39	-0.50%	(1.208)
35W	3.86	3.69	4.34%	-12.59
37W	4.17	4.14	0.68%	-1.76
38E	4.31	4.24	1.51%	-3.80
38W	4.49	4.37	2.65%	-6.48
39N	4.32	4.33	-0.22%	(0.536)
39S	4.30	4.28	0.41%	-1.04
41N	4.57	4.49	1.76%	-4.20
41S	4.08	4.23	-3.72%	(9.412)
43N	4.49	4.44	1.00%	-2.41
43S	4.51	4.48	0.62%	-1.49
44S	4.38	4.30	1.82%	-4.54
45E	4.40	4.30	2.25%	-5.60
45W	4.09	4.07	0.58%	-1.54
46E	4.33	4.24	2.06%	-5.20
51E	4.47	4.42	1.14%	-2.75
52E	4.16	4.16	0.08%	-0.21
52W	3.97	3.83	3.45%	-9.62
53S	4.21	4.11	2.57%	-6.70
54N	4.38	4.34	0.88%	-2.16
55S	4.39	4.27	2.77%	-6.93
56W	4.35	4.33	0.51%	-1.27
57S	4.29	4.21	1.99%	-5.05
60E	4.12	4.09	0.74%	-1.94

* % Delay = (median unimpeded speed - median all speed) \ median unimpeded speed
** Seconds Lost/Gain = (1,070 feet / median unimpeded speed) – (1,070 feet / median actual speed)
*** 1,070 ft derived from Fruin's research.

were impeded by those who tended to walk slower (tourists, non-business, etc.), creating a situation in which the median speed of those who were not impeded (but were naturally slower) was less than the median speed overall (including the impeded business walkers, who were naturally fast).

The inadequacy of the current HCM methodology can be illustrated by an analysis of the location which, using the above formula, provided pedestrians with the greatest delay of all the study locations. In a mid-day count, the conditions at location 20S (on the south side of Fulton Street between Nassau Street and William Street) would provide a pedestrian with 34.26 seconds of delay in excess of the amount of time it would take him or her to walk the sidewalk's median "ideal" speed for Fruin's typical Manhattan walking distance of 1,070 feet. Using the site's median "ideal" (unimpeded) speed of 4.167 ft/sec., the time it would take to walk 1,070 feet would be 256.779 seconds (4.28 minutes). Obviously, 34.26 seconds of delay, a 13% lost time, would represent a significant amount of lost time for the typical pedestrian "expecting" to walk a distance in 4.28 minutes. Although the high delay may indicate a poor perceived LOS at this location, the LOS calculated using the HCM methodology was "A" for the average and "B" for platoon conditions. There were 466 pedestrians counted over 15 minutes at this site, which is close to the 15-minute count average of 455 pedestrians for all sites. However, those present at this location's mid-day count agree that the sidewalk traffic conditions were relatively poor, and probably did not warrant an LOS A or B (by HCM, a LOS A is defined as "walking speeds are freely selected, and conflicts between pedestrians are unlikely" and a LOS B is defined as "sufficient area for pedestrians to select walking speeds freely to bypass other pedestrians, and to avoid crossing conflicts). In situations such as this, the inclusion of a measure of delay in the calculation of LOS could help to bring the grading system closer to a reflection of actual, observed sidewalk conditions.

One of the flaws of the current HCM methodology for determining average pedestrian LOS is that it focuses on the average overall conditions of sidewalk traffic for a set period of time. Because of things like pedestrian signal timing and subway egress, much of the pedestrian traffic encountered in the study sites in Lower Manhattan was in platoons. As Pushkarev and Zupan (1975) point out, "conditions in the platoons, not average conditions in a traffic stream, determine its perceived quality." Because of platooning, "more than half, and up to 73 percent of the people walk during minutes when flow exceeds the 15-minute average…the time period truly relevant for design appears to be not 15 minutes, 1 minute, or any other arbitrary time span, but rather that period during which flow in platoons occurs." In other words, one can not argue that pedestrian perception of sidewalk conditions is affected by the times when the sidewalk is empty (i.e. most of the time between platoons), so why are these times included in the determination of a sidewalk's level of service? This is partially addressed by the HCM calculation of a "platoon" LOS on sidewalks. However, because platooning may occur to differing degrees on different sidewalks, it would not be wise to advocate disposing of the average LOS measurement altogether.

The addition of a measurement of delay within both the "average" and "platoon" LOS calculations may bring their determined grades closer to a more descriptive illustration of realistic sidewalk traffic conditions. The consideration of delay-oriented LOS measurements, both average and platoon, may allow for a more coherent understanding of the range of pedestrian perceptions of sidewalks, which naturally encounter a range of crowding conditions over 15 minutes.

See Table 5.12., Table 5.13., and Table 5.14. for the result of the pedestrian delay analysis in the AM, MD, and PM periods.

2. Pedestrian Frictional Force

The HCM pedestrian LOS process does not include a measurement of effects from opposing pedestrian flows. In this section, it is measured whether variations in the proportions of opposing flow influence the speed of pedestrians.

Using the count data, pedestrian volumes were separated by direction. Then pedestrian speeds were analyzed according to their corresponding volumes. The ratio of the volume in the predominant flow direction to the volume in the counter-flow direction was calculated. The ratio of walking speed in the predominant flow direction to speed in the counter-flow direction was also calculated. It was then determined how many locations have higher speeds in their predominant flow direction than in their counter-flow direction, and how many locations have lower speeds in their predominant flow direction. It was assumed that a higher flow in a specific direction would either present a higher speed than the lower volume direction or higher volume direction would have a lower speed than the lower volume direction due to conflicting pedestrian flow (see Tables 5.16., 5.17., and 5.18 for volume, speed, and dominant ratio by direction, AM, MD, and PM respectively).

In other words, A and B are opposing directions at each locations and VolumeA > VolumeB:

- Volume Ratio AB = Volume A/Volume B
- Speed Ratio AB = Speed A/ Speed B

By comparing Volume Ratio AB to Speed Ratio AB, it can be determined whether there is a relationship between the direction of dominant flow and the speed in either direction.

During the AM period, 16 out of 30 locations showed that a higher volume in one direction corresponded with a higher average speed in that direction. For the midday, 27 out of 62 locations showed higher volumes in one direction corresponding with higher speeds and for the PM period, 14 out of 27 locations showed higher volumes in one direction corresponding with higher speeds. As we can see, the numbers show that almost half the time higher volumes in a particular direction are accompanied by higher speeds and

Table 5.16. Volume, Speed and Dominant Ratio by Direction, AM

Loc ID	Northbound/Eastbound		Southbound/Westbound		Dominant/Non-Dominant Ratio	
	Ped Count	Avg Speed	Ped Count	Avg Speed	Volume	Speed
06N	216	4.375	154	4.324	1.403	1.012
06S	143	4.658	72	4.613	1.986	1.010
07E	102	4.680	53	4.589	1.925	1.020
07W	112	4.656	51	4.608	2.196	1.010
08E	254	4.386	92	4.460	2.761	0.983
08W	154	4.595	110	4.718	1.400	0.974
09E	70	4.502	42	4.770	1.667	0.944
09W	118	4.578	57	4.806	2.070	0.953
10E	103	4.213	71	4.602	1.451	0.915
10W	123	4.427	132	4.540	1.073	1.026
11E	101	4.622	132	4.819	1.307	1.043
11W	118	4.647	210	4.535	1.780	0.976
12E	110	4.402	52	4.761	2.115	0.925
12W	96	4.457	51	4.515	1.882	0.987
13E	98	4.678	151	4.475	1.541	0.957
13W	186	4.618	284	4.382	1.527	0.949
14E	60	4.644	64	4.517	1.067	0.973
38E	329	4.215	377	4.464	1.146	1.059
38W	261	4.527	235	4.525	1.111	1.000
39S	76	4.393	37	4.789	2.054	0.917
41N	260	4.765	133	4.462	1.955	1.068
43N	623	4.481	129	4.590	4.829	0.976
43S	256	4.775	57	4.403	4.491	1.085
45E	117	4.452	213	4.559	1.821	1.024
45W	81	4.355	482	4.083	5.951	0.938
51E	116	4.622	262	4.745	2.259	1.027
55S	151	4.634	82	4.415	1.841	1.050
56W	115	4.481	155	4.637	1.348	1.035
57S	112	4.673	77	4.487	1.455	1.041
60E	163	3.890	330	4.107	2.025	1.056

almost half the time, higher volumes in one direction yield lower speeds. It appears that the impact of friction from opposing pedestrian volumes cannot be concluded with any statistical certainty from the initial data gathered at the study sites. A more detailed analysis of the impact of opposing volume frictional force might be advantageous. The frictional force of opposing pedestrian volumes could actually have an effect on sidewalk speeds, but that effect has not been comprehensively illustrated in the initial analysis.

Table 5.17. Volume, Speed and Dominant Ratio by Direction, MD

Loc ID	Northbound/Eastbound		Southbound/Westbound		Dominant/Non-Dominant Ratio	
	Ped Count	Avg Speed	Ped Count	Avg Speed	Volume	Speed
01N	221	4.127	145	4.249	1.524	0.971
01S	126	4.488	109	4.136	1.156	1.085
02W	117	4.513	94	4.053	1.245	1.113
03E	144	4.344	147	4.233	1.021	0.974
04E	79	4.102	106	4.390	1.342	1.070
04W	71	4.548	107	4.103	1.507	0.902
05E	229	3.939	239	4.329	1.044	1.099
05W	162	4.086	155	4.305	1.045	0.949
06N	231	4.033	270	3.923	1.169	0.973
06S	206	4.162	210	4.204	1.019	1.010
07E	199	4.140	155	4.449	1.284	0.930
07W	179	4.213	130	4.119	1.377	1.023
08E	289	4.212	256	4.357	1.129	0.967
08W	440	4.181	413	4.421	1.065	0.946
09E	206	4.221	160	4.388	1.288	0.962
09W	139	4.261	93	4.199	1.495	1.015
10E	277	4.334	272	4.404	1.018	0.984
10W	459	3.900	379	4.287	1.211	0.910
11E	352	4.160	336	4.271	1.048	0.974
11W	546	3.979	521	4.360	1.048	0.913
12E	245	4.228	220	4.059	1.114	1.042
12W	176	4.205	144	4.204	1.222	1.000
13E	148	4.553	126	4.156	1.175	1.096
13W	306	4.110	271	4.116	1.129	0.999
14E	205	4.080	216	4.079	1.054	1.000
16N	127	4.436	170	4.104	1.339	0.925
18N	213	3.782	256	4.039	1.202	1.068
18S	279	3.650	174	3.833	1.603	0.952
20N	161	3.708	223	3.681	1.385	0.993
20S	257	3.930	209	4.107	1.230	0.957
22N	210	3.966	200	3.905	1.050	1.016
22S	270	3.869	278	3.596	1.030	0.930
25N	89	4.098	96	4.076	1.079	0.995
25S	143	4.325	152	4.426	1.063	1.023
27N	230	4.169	209	3.999	1.100	1.043
30E	297	4.026	208	4.539	1.428	0.887
31N	326	3.746	337	3.893	1.034	1.039
32E	161	4.178	270	4.036	1.677	0.966
34N	81	4.513	94	4.165	1.160	0.923
35W	143	3.909	194	3.707	1.357	0.949
37W	214	4.209	209	4.261	1.024	0.988
38E	556	3.883	494	4.030	1.126	0.963
38W	391	4.099	312	3.952	1.253	1.037
39N	171	4.265	143	4.347	1.196	0.981
39S	166	4.310	170	4.080	1.024	0.947
41N	346	4.135	417	4.393	1.205	1.062
41S	140	4.212	111	4.436	1.261	0.950
43N	276	4.420	338	4.218	1.225	0.954
43S	146	4.266	161	4.554	1.103	1.068
44S	98	4.226	102	4.374	1.041	1.035
45E	484	3.824	529	4.045	1.093	1.058
45W	324	3.874	364	3.894	1.123	1.005
46E	333	4.209	319	4.233	1.044	0.994
51E	350	4.004	333	4.280	1.051	0.936
52E	225	4.207	195	4.208	1.154	1.000
52W	174	3.852	166	4.274	1.048	0.901
53S	78	4.046	95	4.092	1.218	1.011
54N	69	4.295	85	4.394	1.232	1.023
55S	240	3.705	242	4.124	1.008	1.113
56W	273	4.364	264	4.463	1.034	0.978
57S	227	4.093	177	3.940	1.282	1.039
60E	319	3.895	315	4.118	1.013	0.946

Table 5.18. Volume, Speed and Dominant Ratio by Direction, PM

Loc ID	Northbound/Eastbound		Southbound/Westbound		Dominant/Non-Dominant Ratio	
	Ped Count	Avg Speed	Ped Count	Avg Speed	Volume	Speed
06N	91	3.797	226	4.179	2.484	1.101
06S	150	4.168	169	4.506	1.127	1.081
07E	72	4.503	87	4.826	1.208	1.072
07W	111	4.422	104	4.650	1.067	0.951
08E	143	4.453	266	4.405	1.860	0.989
08W	213	3.812	238	3.954	1.117	1.037
09E	83	4.217	72	4.094	1.153	1.030
09W	108	4.666	102	4.435	1.059	1.052
10E	198	4.256	123	4.266	1.610	0.998
12E	117	4.579	132	4.189	1.128	0.915
12W	122	4.674	130	4.350	1.066	0.931
13E	120	4.339	100	4.122	1.200	1.053
13W	349	4.362	260	4.659	1.342	0.936
14E	128	4.202	131	4.337	1.023	1.032
38E	345	4.239	223	4.345	1.547	0.976
38W	396	4.727	209	4.614	1.895	1.024
39S	140	4.165	108	4.621	1.296	0.901
41N	199	4.805	477	4.562	2.397	0.950
43N	180	4.449	353	4.499	1.961	1.011
43S	105	4.354	372	4.494	3.543	1.032
45E	258	4.420	189	4.320	1.365	1.023
45W	253	3.852	157	4.196	1.611	0.918
51E	360	4.553	218	4.515	1.651	1.008
55S	83	4.612	163	4.356	1.964	0.945
56W	137	3.905	117	4.065	1.171	0.961
57S	76	4.031	84	4.427	1.105	1.098
60E	238	4.474	246	4.320	1.034	0.965

3. Seven-Day Vehicular and Pedestrian Count

During a seven day count, pedestrian characteristics data were collected in 5-minute intervals at the study's control location, on the west sidewalk of Broadway between Duane Street and Reade Street. The data was then aggregated and the hourly pedestrian volumes at the site for the seven days was determined. Looking at the weekday pedestrian volumes, similar trends were found Monday through Friday (see Appendix I for Seven Day Pedestrian and Vehicular Count Summary). From the graph, we can see that the pedestrian peak volume occurs between 1pm and 2pm. In contrast to vehicular flow, pedestrian volume in the morning period is relatively low, while late afternoon shows a second peak volume after the midday period peak (see Figure 5.23.). Weekend pedestrian volumes at this location are relatively low. This could be due to the land use of the area, which is primarily office oriented. See Appendix I for summarized weekend pedestrian volumes.

In Figure 5.23., there is an apparent trend: when pedestrian volume is high, pedestrian speed is low. In other words, there appears to be a negative correlation between speed and volume. Pedestrian characteristics such as trip purpose or impedance may be the causes of this negative correlation. The relationship between flow and speed will be discussed more in-depth in later sections.

The 7-day 24-hour ATR counts were summarized by the hour and the Tuesday to Thursday (vehicular analyses' standard in obtaining average weekday volume) volumes were averaged to obtain the average weekday vehicular volume. The average of the pedestrian volumes from Tuesday to Thursday was taken to determine the average weekday pedestrian volume. To understand the relationship

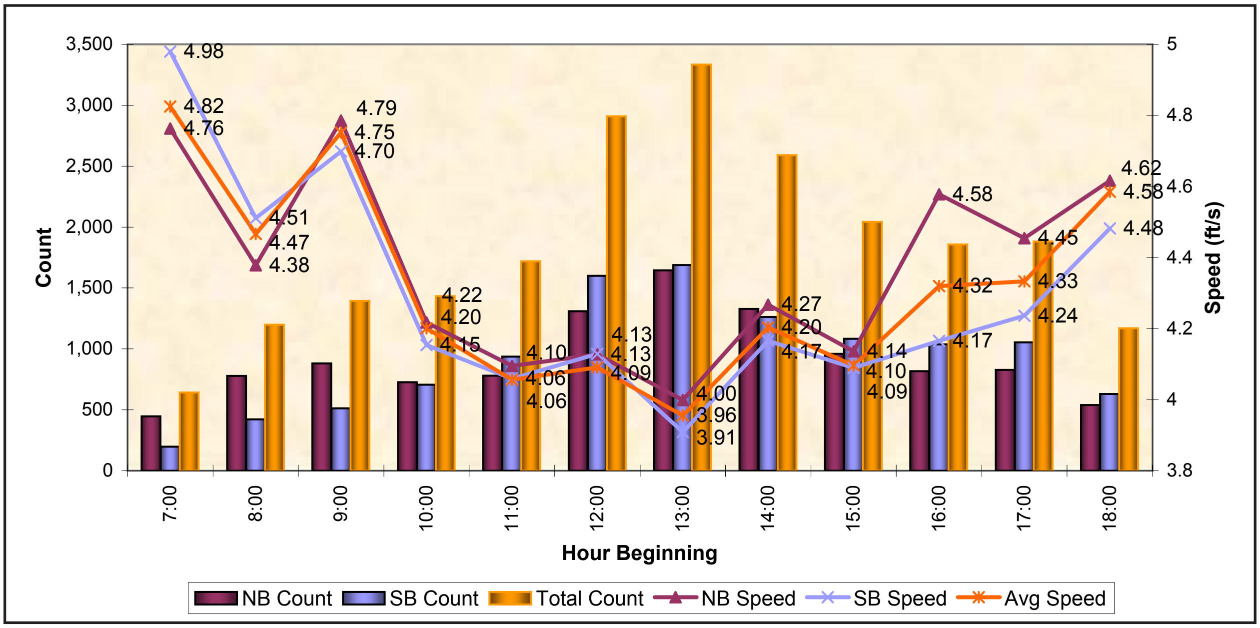


Figure 5.23. Seven-day Count: Pedestrian Count and Speed, Weekday Average

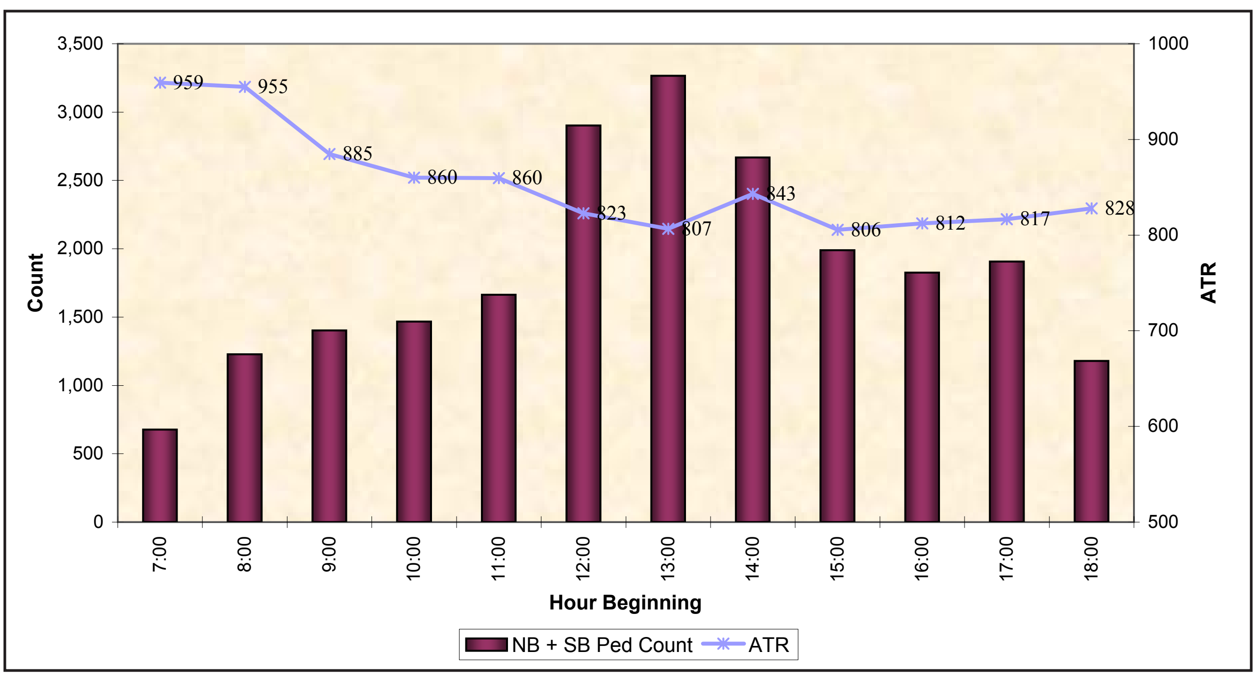


Figure 5.24. Seven-day Count: Pedestrian and Vehicular Count, Tuesday to Thursday Average

between vehicular and pedestrian flow, the two data sets were overlaid (see Figure 5.24.). The vehicular flow does not have the typical peak pattern in the morning between 7 to 9 am and afternoon peak pattern between 4 to 7 pm. Figure 5.24. shows that there was one peak during the morning, 7 to 9 am, around 960 vehicles per hour, then the traffic volume remained steady for the rest of the day, between 800 to 885 vehicles per hour. There is no evening peak, which is contrary to what one would expect in a CBD. This may be due to the fact that Broadway is a one way street running toward the downtown financial area; in the evening commuters are more likely to be driving uptown on a parallel street. Based on Figure 5.24., there is no direct correlation between pedestrian volume and vehicular volume.

4. Speed and Delay Walk

For the speed and delay walk, four team members walked the same route during specific time of day. The average walking speeds from each team member for this walk were generally higher than the HCM average of 4.00 to 4.25ft/s (see Appendix J for Speed and Delay Walk Summary by Walker and Time). One reason for the higher than average speed could be that the "speed walk" did not have a specific trip purpose (tourist, work, non-work,etc.) other than to walk on a prescribed route at the walker's desired speed, and the walker was trying to avoid interruptions. The team members' familiarity with the route could be another explanation for the higher than average speeds. Within the team, the speeds also varied due to individual physical differences.

Between March to May 2004, 50 walks were completed by four team members. Observations made during the walks include:

- On late afternoon walks, at around 3 pm to 4 pm, there were fewer pedestrians on sidewalks than at noontime walks. Because of the relative lack of impedance presented by other pedestrians, it was easier for team members to maneuver during late afternoon walks.
- Street construction on Wall Street between Broadway and Nassau created pedestrian bottleneck congestion, which reduced available sidewalk space and lowered pedestrian speed.

Figures 5.25. and 5.26. show the travel time versus distance during a typical "speed walk." From the figures, we can see the speed curves for each walker are almost a straight line, which indicates that there was no large variation in walking speed from one intersection to another. The graphs also confirm that the 3:30pm walk has the lowest travel time for walkers A, C, and D. Team walkers were able to walk faster partially due to there being fewer pedestrians on the sidewalk at these hours. Walker A has a much higher walking speed than the rest of the team because walker A has a much longer stride, which increases his walking speed.

Pedestrian speed and delay walk data are difficult to analyze because of the numerous anomalies in each walk. Unlike the vehicle speed and delay runs as described in Chapter 4, any vehicles would be adequate in performing the data collection; but with pedestrian speed and delay walks, different surveyors yield different results. If the instrument for collecting the data was constant as one tried to collect information about walking speed on sidewalks at different times of day, one would expect to acquire the same or close to the same results on every walk. However, with different walkers participating in the walk, personal characteristics allowed for different possibilities in the study outcomes. For example, from Figure 5.25., the Walker A 12:30pm walk was significantly different than the Walker D 12:45pm walk; Walker A had a much faster speed than Walker D. Therefore, it could not be concluded that in general a 12:30pm run takes approximately 800s to complete.

In addition, sidewalk and environmental conditions are difficult to control. For example, street or sidewalk construction, street closures, traffic breakdowns, weather, and other conditions can affect the speed and delay walk's outcome. When there are so many factors other than time of day, number of pedestrians on sidewalk, or signal timing can contribute to delay, quantitative conclusions in pedestrian delay can not be drawn as from vehicular speed and delay runs.

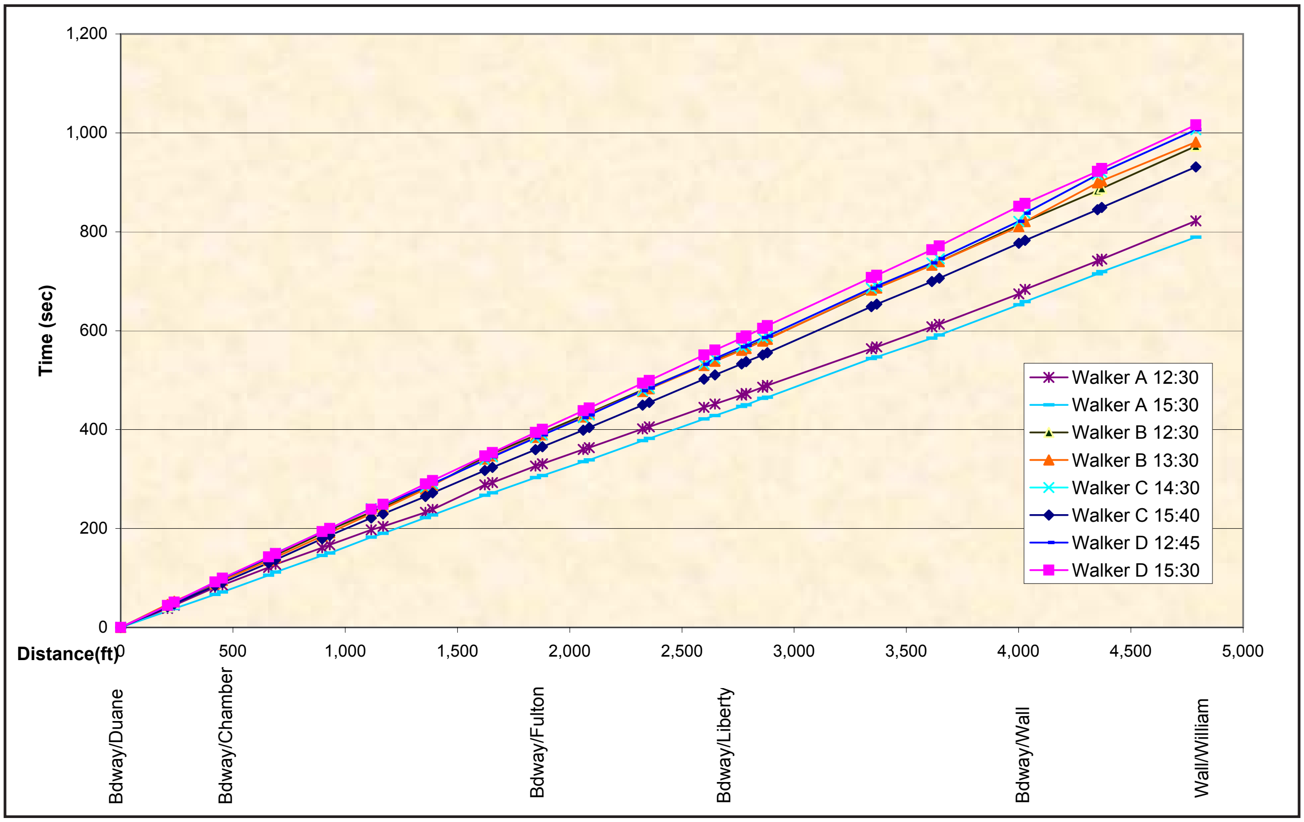


Figure 5.25. Travel Time and Delay Walk Typical Runs: Northbound

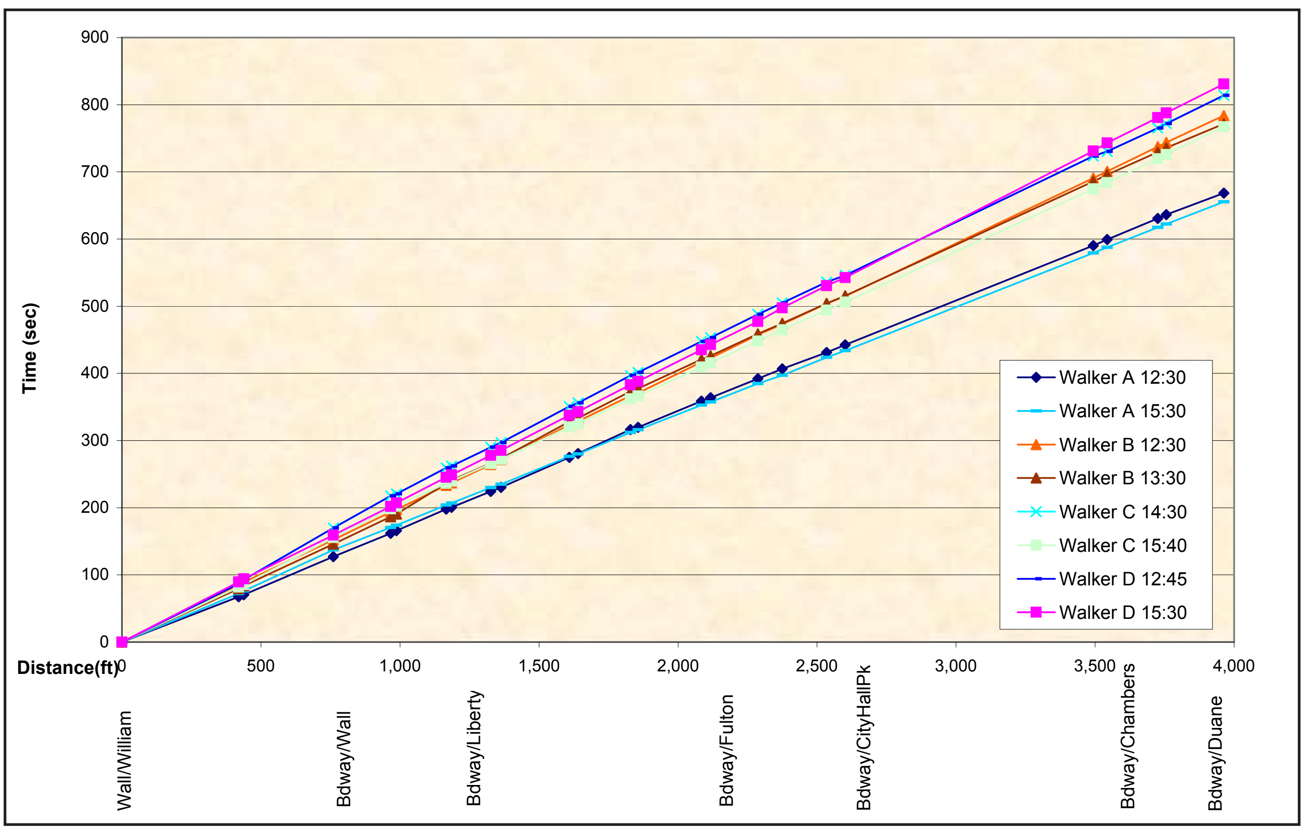


Figure 5.26. Travel Time and Delay Walk Typical Runs: Southbound

CHAPTER 6.

FINDINGS AND FUTURE RESEARCH

The objective of this study is to develop recommendations to make the pedestrian LOS calculation more sensitive to pedestrian characteristics and environmental conditions and to establish new methodologies for urban pedestrian analysis in New York City. In Chapter 3, the comprehensive literature review, which serves as the backbone of this project, was presented. It allows the TD to understand where the HCM methodology originates, what others have done in the field, and how to collect pedestrian data. Lower Manhattan was subsequently used as the laboratory for this study, to test the theories developed from reading the various relevant literature. A large amount of pedestrian data was collected to validate some of the theories and assumptions of pedestrian analysis developed from experience and from the literature review. The analyzed data also serves as a guidepost for the next phase of this study, and will aid in reaching the objective of recommending modifications for the pedestrian LOS methodology for New York City.

In this section, the findings are presented as a result of the data analysis, valuable methodology developments that may be useful to other researchers studying pedestrian behavior in dense urban areas, and the recommendations for further research opportunities—including plans for the next phase of the project.

A. Findings and Methodology Developments

1. Findings Based on the Literature Review

The Highway Capacity Manual establishes the technical criteria for evaluating pedestrian LOS using the flow rate concept. The methodology provides relatively simple and easy to understand data collection and analysis techniques for users. Even though HCM suggests parameter adjustments considering unique local characteristics; those data are lacking in New York City. Based on the literature review, many researchers recommend a LOS that would be more sensitive to pedestrian, environmental and flow characteristics – factors that influence pedestrians' walking experience and performances. Therefore, the first step of this study was to collect New York City pedestrian characteristics data.

In addition, many researchers have studied the lateral space or obstacles' "shy distance" required by pedestrians in determining effective walkway widths to use as a basis for LOS evaluations (Pushkarev and Zupan; Fruin; Hoogendoorn). However, none of them have produced results that can be adopted for New York City. In this study, a methodology that can be used in collecting "shy distance" data is tested and recommended.

Also based on the literature review, it was considered how other researchers have collected their pedestrian data; this information was incorporated into this study's methodology.

2. Pedestrian Impedance and Delay Findings

It was found that the number of impeded pedestrians observed at a location was an excellent predictor of pedestrian speed and subjective interpretations of the sidewalk's level of service. During midday (MD) peak periods, the proportion of impeded pedestrians at a location was a better predictor of speed than the flow rate at that location. In the AM peak periods, the flow rate and pedestrian speed are high while the number of impeded pedestrians is low. In the MD peak periods, flow rates are still high, but the speeds are significantly lower. This suggests that flow rate alone may not be the most reliable predictor of pedestrian speed. A difference is that a higher proportion of pedestrians are impeded at the mid-day peak. This may be a result of other factors—trip purpose, and proportion of pedestrians walking in groups, for example—but it is still a single variable that explains pedestrian speed under all circumstances.

It was also found that the concept of pedestrian delay is useful as a method of evaluating LOS. This study's rather simple delay calculation (average unimpeded speed – average speed), was an effective way of comparing the actual speed vs. the ideal speed or "speed limit" of a section of sidewalk independent of the time of day or predominant trip purpose. In some ways this is similar to the vehicular LOS concept of percent-time spent following other vehicles discussed in Chapter 2.

Finally, the delay impacts faced by pedestrians in midblock sections of the sidewalk due to crowding are small relative to delays at signalized intersections and transit terminals. For example, it was found that a median of 5% of all the time on speed and delay walks was spent waiting at traffic signals—that is 5% of the time going 0 ft/s. What is more, in some of the speed walk trials, some walkers crossed against the traffic light—reducing overall delay by violating traffic rules.

The worst case from the midblock delay methodology was found at location 20S (Fulton Street between Nassau Street and William Street) during one mid-day visit. Here, based on the data, one would lose 34.26 seconds over 1,070 feet, assuming an unimpeded walking speed of 4.17 ft/s (the median unimpeded walking speed for this location). This results in the equivalent of 13.34% of time going 0 ft/s. That is a very significant delay. But the median loss for this location for all visits (losing 4.17 seconds over 1,070 feet and assuming the unimpeded walking speed above) results in only 1.7% of time going 0 ft/s. In addition, research indicates that commuters overestimate wait times in their trips. That suggests that a small reduction in these signalized intersection delays would have a significant effect on pedestrians' perception of trip length. In order to evaluate these delays, a more comprehensive commute trip delay study considering midblock and intersection delays is warranted.

3. Shy Distance Findings

Fruin, Pushkarev, Zupan, and others discuss the space that pedestrians tend to keep between themselves and obstacles on the edges of the sidewalk—the so-called shy distance. But, except for Hoogendoorn's hallway experiments, no empirical studies that the TD has found have been done to determine what this shy distance is for different types of obstacles and how it changes with different levels of sidewalk density.

Although data collection has not been completed, the TD's video-based methodology for measuring shy distance in the field is promising. Based on several trials, the distance pedestrians walk from obstacles while also controlling for variables such as the direction of travel, the number of other pedestrians on the sidewalk, and pedestrian characteristics are able to be measured. Based on the review of literature, this is a superior method of obstacle analysis because it meets the following criteria:

a. It is relatively easy to collect data. There are automated methods that seem easier, but they have reliability drawbacks and require expensive equipment.
b. It is reliable. A person collects the data so it is more reliable than the state of the art in computer vision.

c. It is robust. This method takes into account many other factors that contribute to shy distance: direction traveled, pedestrian characteristics, and pedestrian density on the sidewalk.
d. It is externally valid. Some studies of shy distance have controlled the environment in which pedestrians are analyzed and the pedestrian subjects themselves. These studies allow for causal inferences, but may not be transferable to chaotic New York City streets. This study's methodology requires minimal environmental intrusion.

B. Future Research

In the next phase of the pedestrian LOS project, the TD plans to focus on the following:

1. Developing an Opposing Flow Methodology
Weidmann found that opposing pedestrian flows reduce pedestrian flow capacity by up to 14.5% depending on the conditions (1993). In the pedestrian study, a simple method of evaluating the impact of opposing flows on pedestrian LOS was used. Given the differences in speed and impedance between AM peaks (when flows are predominantly unidirectional) and midday peaks (when flows are balanced), there is reason to believe similar reductions in capacity may be observed. Additional data collection and analysis are necessary.

2. Street Furniture Data Collection and Analysis
The TD will analyze the video collected so far, using the shy distance methodology to build a database of street furniture types and distances. This database will be useful for other pedestrian researchers and in the next pedestrian characteristic, speed, and count analysis.

3. Conduct Additional Pedestrian Characteristics, Speeds, and Counts
Another set of pedestrian characteristic, speed, and count data will be collected. Based on what has been learned in this study, the approach will be changed in several ways.

First, high flow locations will be the focus of data gathering. When the speed-flow curve was plotted, it was found that very few locations had flow rates at the upper end of the scale (> 5 ped/ft/min). As these are the most interesting data points in terms of pedestrian behavior, more of them need to be collected.

Second, the focus will be on collecting data during the AM and midday peak periods. It was found that the AM peak period is characterized by high speeds, low impedance, and homogeneous trip purposes. In contrast, midday peaks have mixed speeds and higher levels of impedance. PM peaks had fewer distinguishing characteristics and tended to have lower volumes than AM and midday peaks—perhaps because workers leave the office in the evening over a greater range of time.

Third, it is planned to reduce the number of pedestrian characteristics collected. It was found that some characteristics (PDA, pushing, and walking aide, for example) occur too infrequently to be consequential. A study in a more residential or retail-oriented location may be more appropriate for collecting some of these characteristics.

An additional variable for each location will be collected—the LOS perceived by the field research team at the time of data collection. When the TD returned to the office and calculated the LOS for each location according to the HCM, it was sometimes felt that the LOS did not reflect the sidewalk conditions remembered. This will allow us to compare the observed LOS of three independent judges against the actual calculated LOS at each location and against factors such as the speed, proportion of impeded pedestrians, and flow rate.

Finally, the TD's database of shy distances will be used as an additional factor in the analysis of pedestrian LOS at each location.

4. Comprehensive Pedestrian Delay Evaluation
In this study, the TD focused on delays faced by pedestrians in the middle of urban blocks. Although some significant impedance in these locations was

observed, these delays are relatively short and transient. Of more concern are delays faced by pedestrians at traffic signals. In New York, where north-south blocks are relatively short, a pedestrian may face a number of these intersections in a single walking commute. In addition, delays at signalized intersections lead to additional pedestrian platooning which, in turn, leads to midblock pedestrian delays. Quantifying the impacts of these delays on commute times and on platooning is a high priority.

One way to study pedestrian trip delays is by using an enhanced version of the speed and delay walk methodology. There were some problems with this methodology that may need to be resolved. First, and most importantly, the TD is not able to control for conditions at each sidewalk on each speed run, so it is not known if differences in speed were due to crowding or some other factor. Second, by conducting its own speed walks, the TD influences a significant factor associated with walking speed—the trip purpose. Third, following and timing anonymous pedestrians on their routes may be a valid approach, but gives us no control over the route. On the other hand, the speed and delay walk methodology allows us to study the exact delays faced by pedestrians at signalized intersections and to compute the average pedestrian walking speed on each sidewalk segment.

The TD may continue to perform speed and delay walks using a slightly different methodology. In particular, the speed and delay study may be a useful way to conduct a comprehensive evaluation of total delays faced by commuting pedestrians at the midblock and at intersections given standard walking speeds. While this may not allow us to associate certain midblock conditions with pedestrian delays, delay which may be due to conditions at intersections can precisely be determined.

5. Develop Pedestrian Impedance and Delay-based LOS

Pedestrian impedance and delay were found to be excellent predictors of pedestrian speed at a location. However, the TD still needs to do further analysis to validate these findings under different conditions and determine the cut-off points between different levels of service based on the delay.

In addition, the TD needs to consider midblock pedestrian delay as a subset of all pedestrian delay, including signalized intersection delays.

C. Phase II of Pedestrian LOS

Here are the steps for Phase II of the pedestrian LOS project:

1. The pedestrian LOS team will commence with Phase II of the data gathering and analysis effort, which will consist of:
    a. Seeking partnerships with academic or research institutions for collaboration in data analysis and LOS recommendations.
    b. Gathering more Lower Manhattan pedestrian characteristic, speed, and count data, based on the revised approach detailed in section B.3 above.
    c. Developing an opposing flow methodology to account for the “friction factor” of counter-flow traffic on the study sidewalks.
    d. Developing a modified version of the speed and delay walk methodology to gather data on intersection delay. The data from this effort will be combined with data derived from the midblock delay methodology (see Chapter 4) and the impedance data to help develop a pedestrian impedance and delay based LOS.
    e. Collecting more video data and using existing videos to gather and analyze street furniture and “shy distance” data.

2. In collaboration with partnered institutions, analyze all data gathered and develop possible recommendations for changes in LOS calculation, taking into account suggestions and concerns raised in internal review and technical advisory review.

3. Present findings and recommendations to the Transportation Research Board. With the accepted findings and recommendations from transportation professionals and academics, propose modifications in pedestrian LOS analysis in New York.

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APPENDIX A.

LITERATURE REVIEW SUMMARY

A. HCM Pedestrian LOS Design and Impact

Pedestrian Planning & Design - John Fruin

Pedestrian Planning & Design is the basis of the current pedestrian LOS methodology. Many of the LOS tenets-the idea of speed/density relationships, personal body shape and dimensions, and the very idea of a pedestrian level of service and how to distinguish between levels-originate from this book. Fruin is in favor of taking a combined quantitative/qualitative approach to evaluating sidewalks. The LOS measurement is to be used to ensure that pedestrian facilities are adequate for peak periods, while other criteria that may worsen the LOS (street vendors, sidewalk cafes, retail stores with nice windows) are important to maintain a quality of pedestrian life.

Fruin cites studies of bi-directional pedestrian flow, stating that flows of equal strength will not have much of an effect on one another, but that a strong flow will slow a weaker opposing flow somewhat. This is an observation that we should be able to confirm based on our field work and analysis. Fruin also notes that the measured effective widths of sidewalks should be automatically decreased by 12-18" on each side to account for the buffer space required by pedestrians as they try to avoid sidewalk obstacles.

Fruin indicates that "pedestrian service standards should be based on the freedom to select normal locomotion speed, the ability to bypass slow-moving pedestrians, and the relative ease of cross- and reverse-flow movements at various pedestrian traffic concentrations." He also indicates that design standards are not universal across all environments and that his level of service guidelines are, ultimately, subjective, though based on a great deal of observed evidence.

Some useful figures included by Fruin are: "the fully clothed dimensions of the 95th percentile of the population (95% are less than this) are 13 inches body depth and 23 inches shoulder breadth…the plan view of the average male human body occupies an area of approximately 1.5 ft^2." These figures could be helpful in determining the "buffer zone" between pedestrians required for comfortable use of walkways to be applied in our study. In addition, "behavioral experiments involving personal space preferences have shown minimum desirable occupancies ranging between 5 and 10 ft^2/person, where physical contact with others is avoidable."

More interestingly for the purposes of this study, Fruin has found that "people require a lateral space of 28 to 30 inches…for comfortable movement. The longitudinal spacing for walking…would be 8 to 10 feet. This results in a minimum personal area of 20 to 30 ft^2/person for relatively unimpeded walking in groups on level surfaces." Later, Fruin writes that "photographic studies of pedestrian traffic flow on walkways have shown that individual area occupancies of at least 35 ft^2/person are required for pedestrians to attain normal walking speeds and to avoid conflicts with others."

In addition, Fruin has found that unimpeded walking speed varies between 150 and 350 feet per minute, and the average is 270 feet per minute. Also, "healthy older adults are capable of increasing their walking speed by 40% for short distances." Fruin writes later that "average walking distances in Manhattan were found to be 1,720 feet, with a median at 1,070 feet. Higher average walking distances were found for passengers at the New York Port Authority Bus Terminal."

Fruin defines two types of queues, the "linear or ordered queue, in which pedestrians line up and are served in their order of arrival, and the undisciplined or bulk queue, where there is more general, less ordered crowding." He then states that spacing between people in linear queues is generally 19 to 20 inches; the "recommended lateral single-file width for railings or other dividers is 30 inches." He also provides a chart which includes "queuing LOSs based on pedestrian area occupancies and relative degrees of mobility within the waiting space" on page 229 of his book.

Urban Space for Pedestrians - Boris S. Pushkarev and Jeffrey M. Zupan

Pushkarev and Zupan's *Urban Space for Pedestrians* is often quoted in the HCM methodology. The authors advocate "mandatory minimum" standards for pedestrian space on New York City streets based on proportionate volumes of building floor space. At the time of their study, pedestrian space was allocated on a case-by-case basis, using "special zoning districts." The authors state that the purpose of their study is "to develop a quantitative relationship between building floor space and pedestrian circulation space". They acknowledge the importance of setting "firm factual basis" in pedestrian facilities planning. One of the authors' innovations is a new definition of service levels. Their new scale includes the levels Open Flow, Unimpeded, Impeded and Constrained to replace the A to F scale. They determine that New York City pedestrian flow is often gathered in platoons because of intersection signal control.

The authors state that the "average flow rates in excess of 10 people per foot per minute…are generally not found on outdoor walkways and cannot be handled by signalized intersections". Note that a flow rate of 10.0 is the lowest end of LOS D, so it would be very unusual to see an LOS D anywhere outside a train station or special event. This explains why a LOS D is rarely seen in pedestrian LOS analysis as opposed to vehicular LOS analysis.

There are several interesting findings in the Pushkarev and Zupan book. The first is that flow rate and speed are closely related. Pushkarev and Zupan find that "people, or vehicles, tend to move at a faster speed if the flow rate is low." One by-product of the measurement of flow rate and speed which the authors put forth is the calculation of space per person. According to the authors, "…if the flow rate is 60 persons per hour, or one person passing a point every minute, and the people are walking at a speed of 260 ft per minute, then the average distance between them is 260 ft. Multiplying that by the width of the path will give us the space allocation per person at that flow rate and that speed."

The authors also propose that the true perception of a sidewalk's quality has its root in platoon conditions rather than an overall "average" condition. This is because the sidewalk could be perceptibly empty during one minute, but relatively crowded during the next because of platooning due to crosswalk signal timing, subway egress, etc. The average of these conditions would not represent the perception of walking on the sidewalk, rather a combination of walking conditions and emptiness. The true representation of walking conditions would be determined from times when there were actually people walking on the sidewalk, which occurs primarily in platoons. The authors highly emphasize the importance of platooning as a focus of analysis, writing that "the time period truly relevant for design appears to be not 15 minutes, 1 minute, or any other arbitrary time span, but rather that period during which flow in platoons occurs."

Pushkarev and Zupan assert that building size and use can be used to estimate the volume of pedestrian travel on perimeter sidewalks. In terms of the flow rate at different times of day, Pushkarev and Zupan find that the highest flow in their study is attained from 12:30 to 1:30 PM, "if an area is shopping oriented," and from 5:00 to 5:30 PM, "if an area is office-building oriented."

In reference to the issue of counter-flow, Pushkarev and Zupan find that "two thirds to three quarters of the peak flow occur in the predominant direction. The greatest imbalances occur during the morning peak and are followed by the evening peak. Midday, by contrast, is split rather evenly by direction," and "directional distribution in pedestrian design is generally less important than in the design of mechanical systems: a walkway has more flexibility in accommodating varying directional flows than a reversible lane or a reversible track can ever achieve," however, "…the capacity of a walkway is about the same whether 100 percent of the flow is moving in one direction or whether the movement is split 50-50. The only troublesome condition that can arise is when there is a significant minor flow against the predominant direction of movement. The resulting turbulence can reduce capacity and speed and be psychologically unpleasant for both the minority and majority."

Pushkarev and Zupan suggest studying pedestrian behavior in the presence of street furniture and other obstacles. They write that the "dead space" (building walls, grates, etc.) of walkways must be calculated in order to achieve a true effective width on a sidewalk. Also, it is necessary to exclude "strips preempted by physical obstructions, such as light poles, mail boxes, and parking meters, though their exact effect on pedestrian flow has not been sufficiently investigated." And "the exact effect of the various obstacles on pedestrian capacity and flow is a good subject for further study; paths could be traced with time-lapse photography…each obstacle leaves an unused sidewalk area in its 'wake' in the pedestrian stream."

B. Studies Recommending Changes in LOS Calculation

There are many studies which recommend changes in pedestrian LOS calculation. Some of them propose new methodologies in evaluating pedestrian flow on facilities while others propose adjustments in the current HCM scale. This section includes some of the most relevant studies that helped to shape our methodological approach.

Pedestrian Time-Space Concept: A New Approach to the Planning and Design of Pedestrian Facilities - Gregory Benz.

Gregory Benz has a slightly different way of determining the pedestrian LOS than using Fruin's flow rate method. Benz's method is probably best suited for transportation terminals and other complex pedestrian spaces, could be applied to sidewalks, as well. His methodology is called the time-space approach.

In the time-space approach, pedestrian activities generate time-space needs. The areas where these activities take place are time-space zones. They have limited capacity to meet pedestrian time-space needs. Mathematically, the time-space concept can be described as:

$$T\text{-}S_{req.} = \sum P_i M_i T_i$$

Where

$T\text{-}S_{req.}$ = time-space required

P_i = number of people involved in activity i

M_i = space required per person for activity i

T_i = time required for activity i

$T\text{-}S_{req.}$ is then compared with the time-space available. The time-space available ($T\text{-}S_{avail.}$) is simply the product of the area available ($A_{avail.}$) and the time it is available ($T_{avail.}$).

Number of people involved in an activity is based from counting at peak period. The determination of what type of activity the person is involved in, such as commuter or shopper, is from observation. Space required for a person in the activity is found using published space-speed guidelines, such as Fruin and some of the tables in this particular report. The time required for an activity is based on observation and based on the speed a person is moving when they are engaged in that activity. Activity could be another word for 'trip purpose' or even for 'sub-trip purpose' (buying a coffee from a vendor on the way to work where the trip purpose is commuting, but the sub-trip purpose for that specific time-space zone is buying a coffee).

Note that Benz's approach focuses on area (sq. ft.) and not simply the effective width at an imaginary point. In calculating the $A_{avail.}$, Benz also recommends taking into account "cushions" around obstacles that represent unused space. But, he doesn't clearly identify how big those cushions ought to be.

Multi-Modal Quality of Service Project - Rhonda Philips, John Karachepone, and Bruce Landis

The Florida DOT commissioned this study to determine the best way to evaluate multi-modal linkages (bicycle, pedestrian, transit). The purpose is to improve the design of facilities in order to encourage use of non-automobile transportation.

This study includes a comprehensive literature review of various pedestrian quality of service methodologies. In contrast to the HCM LOS methodology, the methods cited in the document are based on factors that contribute to a pedestrian's perceived level of comfort rather than the expected density of the facility given its width and pedestrian volume.

The investigators outlined a pedestrian route in Pensacola, Florida, with varying conditions and advertised a "FunWalk for Science" to the community to attract participants. These participants walked around the course in reverse directions (to create friction). Along the way, investigators observed the participants while the participants ranked each segment of the course on a scale from "A" to "F" as "how safe / comfortable they felt as they traveled each segments", level A as the most safe or comfortable and Level F as the worst.

Using regression analysis, a pedestrian LOS model was developed, the model considers factors including width of outside lanes, width of shoulder or bike lane, on-street parking effect coefficient, percent of segment with on-street parking, buffer area barrier coefficient, buffer width, sidewalk presence coefficient, width of sidewalk, average traffic during a fifteen minute period, total number of lanes, and average running speed of motor vehicle traffic. The report suggests that the Pedestrian LOS Model "coupled with the capacity (Fruin) measure and a quality performance measure (i.e., "Walkability Audit" to asses the enjoyment and convenience of the walking experience…) 'completes the picture' of the roadside walking environment."

Calculating Multi-Modal Levels of Service (Abridged) - David Mozer

Mozer presents interesting ideas about the calculation of LOS for all transportation modes (including bicycle and pedestrian). The LOS levels are tailored to each mode, using a "stress level" measurement based on several transportation facility measurements.

Mozer introduces a measurement called the "walkarea width volume" (WWV) for pedestrians. The WWV is determined using an equation which includes measures of peak hour pedestrian volumes, mode split that is not pedestrian (wheelchairs, bicyclists, skaters, runners, etc.), usable width of the walk area, and a "travel pattern factor" representing the one way or bi-directional nature of the facility's pedestrian traffic.

Capacity Analysis of Pedestrian and Bicycle Facilities: Recommended Procedures for the "Pedestrians" Chapter of the Highway Capacity Manual (no author) - The www.tthrc.gov website.

The Turner-Fairbank Highway Research Center report (TFHRC, which is the home of the Federal Highway Administration's (FHWA's) Office of Research, Development and Technology) contains a useful measure of a seemingly subjective term. In calculating walking speed for crosswalks, the report suggests, the speed should be expected to be lower where "large numbers of older pedestrians" are present. In defining "large numbers," the report suggests that "large numbers of older pedestrians exist when the elderly proportion begins to materially affect the *overall* speed distribution at the facility." In this case, a material effect on the overall speed distribution occurs when the percentage of elderly using a crosswalk facility exceeds 20 percent.

This overview of the current (when it was written) literature seeks to advance the thesis that the HCM "procedures rely on incomplete and outdated information." Although this is in reference to the 1994 HCM, some of the insights outlined in this report have current relevance. In addition, the report puts forth the idea that pedestrian considerations need to have a higher priority in the HCM analysis.

Some of the recommendations outlined are related to pedestrian space requirements, pedestrian walking speeds, pedestrian start-up times and pedestrian traffic flow relationships.

In reference to space requirements, specific body ellipse sizes and body buffer zone sizes are recommended for analyzing the maintenance of walking speeds. This information might help in developing criteria for analyzing pedestrians' preferred distance from other pedestrians and in fine-tuning buffer zone and body ellipse criteria to specific conditions and pedestrian attributes on New York City sidewalks.

Pedestrian Arrivals at Signalized Intersections in Central Business Districts - Venkata Chilukuri

This study challenges the current (in 2000) equation used by the HCM to calculate pedestrian delay at signalized intersections. According to the author, the HCM equation assumes that pedestrian arrival at intersections is random. The study tests this assumption by observing pedestrian progression between upstream and downstream signals on seven St. Louis sidewalks. Chilukuri's statistical analysis of high and low flow rates on sidewalks between signalized intersections indicates that the arrival of pedestrians at those intersections had a significantly non-random pattern. In addition, it is found that, in a coordinated signal network (such as those which exist in large urban areas), "pedestrians arriving randomly at an intersection will move in a group after the signal turns green and might continue as a significant group towards the downstream signal."

Quality of Service for Uninterrupted Pedestrian Facilities in the 2000 Highway Capacity Manual - Joseph S. Milazzo, et al.

The most important concept in the Milazzo *et al.* article in terms of this study is the authors' suggestion that platooning in specific locations such as airport terminals is more common and thus more expected than it is on normal everyday walkways. They introduce the idea of "transportation terminals," in which LOS calculations for platooning are adjusted to reflect the special nature of certain walkway facilities. The LOS rating is relative to the expectation of platooning on particular walkways.

There is also some useful information in the literature review of the Milazzo article. The authors cite a study of crossflow by Khisty in which a "major flow" is defined as the predominant flow of pedestrian traffic and a "minor flow," or crossflow, is the opposing, less predominant flow. According to Khisty (paraphrased by Milazzo *et al.*), "the major flow did not undergo a significant change up to a pedestrian density of about 0.8 to 1.0 peds/ m^2. The minor flow begins to change when densities approach 0.7 to 0.8 peds/m^2." In addition, "Khisty hypothesized that minor flow speeds are actually higher than major flow speeds because pedestrians in the former group must act aggressively to cross the major flow."

Evaluation of Pedestrian Level-of-Service on Sidewalks and Crosswalks Using Conjoint Analysis - Muraleetharan Thambiah, Takeo Adachi, Toru Hagiwara, Seiichi Kagaya, and Ken'etsu Uchida

The authors intend to re-configure the calculation of pedestrian levels of service using a statistical method named "conjoint analysis." They are interested in updating the Highway Capacity Manual 2000 method of calculating level of service, which they describe as being primarily dependent upon capacity and space requirement measurements (in the form of flow-speed-density relationships). They cite several studies which have found that pedestrians perceived LOS depends upon factors other than flow, speed and density, including separation from moving traffic and the number of obstructions on the sidewalk. They contend that a new method of LOS computation should be developed to directly include these factors.

The conjoint analysis technique, which is undertaken in this study via an SPSS extension, is intended as a tool to determine what people value in particular services or products. In this study, the conjoint analysis technique is used to determine how pedestrians prioritize the attributes of sidewalks and how different levels of the above factors (or attributes) affect their perceived level of service on a sidewalk. According to the authors, the conjoint analysis tool "estimates an individual's 'value system,' which specifies how much value a user puts on each level of the attributes… we can determine what attributes are important or unimportant to the pedestrians…"

The "levels" to which the authors refer are similar to the LOS A-F rating levels, but are simplified for surveying purposes "because too many levels can greatly increase the burden on respondents and affect the quality of data." There are three levels (Levels 1-3) in this study, and each level is applied to a specific sidewalk condition for each of the above factors. In the pedestrian survey, the respondents are asked to rate the probability of their using a sidewalk facility based on the conditions of sidewalk factors represented by levels 1-3. 1,000 pedestrians were surveyed as to which factor was the most important and how willing they would be to use a facility based on each factor's particular service level. Using the conjoint analysis function, the authors find that differences in levels of flow rate on sidewalks effect pedestrian perceived LOS more than differences in levels of any other sidewalk attributes.

C. Pedestrian Case Studies

In the following section, pedestrian case studies are reviewed. They are primarily studies that do not use the traditional HCM pedestrian LOS analysis methodology. They provide an insight into the ways pedestrian studies can be undertaken without following a pre-existing set of guidelines.

City. Rediscovering the Center - William H. Whyte

This book is the result of an extensive study of street life in New York City in the 1980s. The author and his research team observed pedestrians in several locations in New York, as well as in other cities, during three years. They were interested in the design and management of public spaces, how these spaces were used by pedestrians and the relationship between the design and pedestrians' behavior. The study was also very concerned with density, which was the main quantitative variable used to determine whether the design of a street or an open space was adequate to satisfy the pedestrians' demands for space.

The basic methodology for Whyte's study was observation. However, the research team occasionally did some interviews and experiments. After several tests in the field, the methodology evolved into filming only from scaffolding placed at a certain height and distance from the study area, to obtain some perspective.

The author notes how time-consuming it is to analyze a time-lapse photography video for the peak hour. It is a tedious task, and that is why few time-lapse study programs are undertaken.

The author enumerates the chief characteristics of pedestrians:

- Pedestrians usually walk on the right.
- A large proportion of pedestrians walk in pairs or threesomes.
- "Men walk a little faster than women."
- "Younger people walk a little faster than older people."
- "People in groups walk a little slower than people walking alone."
- Carrying bags or suitcases does not slow people significantly.
- Pedestrians usually take the shortest path possible.
- "Pedestrians form up in platoons at traffic

lights and they move in platoons for a block or more" after crossing the street.

– "Pedestrians often function most efficiently at the peak of rush-hour flows."

Whyte notes how speeds and pace vary according to the time of day and the trip purpose. People walk progressively slower as the day wears on. He found that the morning rush hour is the fastest time of the day in terms of pedestrian speed. The evening rush hour is also fast, but more sociable. Pedestrian observation led the author to conclude that when there is a dominant flow in one direction, pedestrians in that flow walk at higher speeds than pedestrians walking in the opposite direction.

The author indicates that pedestrian behavior is very similar in every city. The main difference which affects people's walking speed is the city size and pedestrian density. According to Whyte, people in big cities walk faster than people in small cities.

Whyte mentions the cluttering of sidewalks by several different types of street furniture, placed without any logic or uniformity. He asserts that such obstacles reduce the effective walkway width considerably.

In conclusion, Whyte observes that "there is no one all-purpose optimum sidewalk width." However, he believes that sidewalks should always accommodate pedestrian flow comfortably, even in the most congested situations, but with a certain degree of crowdedness at the same time. Whyte also thinks that it is better to provide more than less space for pedestrians, but without giving them too much room, in order to keep the street lively and vibrant.

Field Studies of Pedestrian Walking Speed and Start-Up Time - Richard L. Knoblauch, Martin T. Pietrucha, and Marsha Nitzburg

This article finds that age, gender, and site environment have significant impacts on pedestrian walking speed and start-up time at crosswalks. The researchers use a stopwatch to time the speed of pedestrians between the time they step off a curb and the time they step on the opposite curb. The study's population includes two age groups, under 65 years old and 65 years old and over. The population was further divided into groups of males and females, and groups of those walking with others or walking alone. Data was collected during dry, rainy, and snowy conditions.

The study concludes that walking speeds have statistically significant variations across a variety of site and environmental conditions. The mean speed for pedestrians 65 years old and younger was 4.95ft/sec. The mean speed for pedestrians older than 65 was 4.11 ft/sec. Meanwhile, females 65 years old and under walked 0.32 ft/sec slower than males, while 65 and above females walk 0.4ft/sec slower than males. Weather conditions also had a significant effect on walking speed. Site and environmental conditions did not have as significant an impact on start-up time as walking speed. Overall, the study indicates that aggregated times and speeds for pedestrians should be used in designing crosswalks.

Comparison of CBD pedestrian characteristics in Canada and Sri Lanka - John F. Morrall, L.L. Ratnayake, and P.N. Seneviratne

Walking speed data was collected in Calgary, Canada and Colombo, Sri Lanka by researchers who manually timed pedestrians over a test section. In Colombo, the average walking speed for male pedestrians was 4.43ft/s, 0.16 ft/s faster than that of females. In Calgary, the average walking speed for male pedestrians was 4.70 ft/s, 0.27 ft/s faster than that of females. The elderly were observed to walk slower than the general population. The study also compared average walking speeds observed in other studies from other Asian countries. Concluding that different geographic areas yield different walking speeds, the study recommends that pedestrian planning should be based on local pedestrian characteristics rather than on pedestrian characteristics from cities with dissimilar cultures.

Analysis of Pedestrian Behavior and Planning Guidelines with Mixed Traffic for Narrow Urban Streets - Young-In Kwon, Shigeru Morichi, and Tetsuo Yai

The authors test HCM measures for sidewalk level of service on the primarily narrow and busy streets around a railway station in Tokyo, Japan. They aim to develop modifications of HCM methods to build LOS measurements that reflect the atypical geometry and pedestrian density of narrow Tokyo sidewalks and streets, considering that many people walk on the actual streets rather than the sidewalks (because of the narrowness of the entire roadbed and consequent narrowness of the sidewalk) and need to negotiate street obstacles and opposing travel modes.

The data collection for this study was undertaken using video recording at elevated vantage points such as the tops of buildings and railway station platforms. The authors marked the streets they recorded in 10 cm lateral intervals and 50 cm longitudinal intervals using a vaguely described method of "marking the distance points on a TV screen based on the markings on the screen during survey." An elevated, relatively distant vantage point makes it relatively easy for Kwon *et al.* to mark the streets at shorter lateral distances (they mark every 10 cm = approx. 4 inches) and longitudinal distances (they mark every 50 cm = approx. 20 inches).

Kwon *et al.* also develop equations and models for determining the distance pedestrians walk from street obstacles, based on the "distance to keep personal space" and "the distance caused by the pedestrian's forward movement." They also analyze the decision of pedestrians to walk on the sidewalk or on the roadbed, trying to "find any trends or parameters that reflect these behavioral characteristics." They found this decision to be based on car speed on the adjacent street, car flow on the street and pedestrian flow on the sidewalk.

The authors go on to outline models for analyzing time and space occupancy rates for different modes of transportation based on the speed of the mode, traffic volume of the mode and the geometry of the transportation facility on which the mode is traveling. These rates are used to build an "occupancy index" in order to determine how much space on a street is needed for each mode of travel. Space occupancy is related to the size of pedestrians or cars, etc., and time occupancy is related to their speed. According to the authors, "the new index…could be applied for the design of planned streets and the evaluation of street space improvements…considering not only traffic flow but also the physical size of traffic modes and the time needed to traverse the street." The authors suggest that the occupancy concept be applied to the LOS measurement procedure for streets with "mixed traffic" modes, i.e. streets which are so narrow that pedestrians sometimes walk in automobile and bicycle lanes. This seems to be a useful measure for planning particularly narrow, busy streets with limited roadbed (such as those in Lower Manhattan).

Walking Behavior in Bottlenecks and its Implications for Capacity - Serge P. Hoogendoorn

The author conducted walking experiments in a controlled environment (hallway surrounded by "soft" material walls) to determine how pedestrians behave when confronted with three different bottlenecks: no bottleneck, a wide bottleneck and a narrow bottleneck. The pedestrians walked in one direction only; the study does not consider bi-directional flow. It was noticed that when the bottleneck created congestion, pedestrians formed two distinct travel lanes. According to Hoogendoorn, "upstream of the bottleneck…pedestrians will use more of the available space…Inside the bottleneck, lanes are formed as soon as the bottleneck becomes over-saturated." It was also noted that the lateral distance required between pedestrians walking in a bottleneck is less than the lateral distance between the lanes, as peoples' shoulders are wider than their legs. The lateral space required by pedestrians between other pedestrians and the wall (obstacle similar to a building wall, but softer) equals the shoulder width of the pedestrian plus the amount of space required to move side to side while walking. It is found that this additional lateral space amounts to 10 centimeters in 95% of all Hoogendoorn's cases.

In addition, the speed of a pedestrian in one lane is independent of the speed of pedestrians in an adjacent lane, but is mostly reliant on the speed of the pedestrian in the front of the pedestrian in question's platoon. Hoogendoorn writes that "the leader - i.e. the pedestrian which is effectively being followed - is thus the pedestrian in front that is impairing the ability of the follower to make a step, and not necessarily the pedestrian in front who is closest in terms of distance." The experiment also showed that the surface of the obstacles which made up the bottleneck, which were soft, resulted in the pedestrians' needing "only a few centimeters distance between themselves and the obstruction." This indicates that the "buffer" distance required between pedestrians and obstacles might vary with the obstacle material and its physical make-up.

The author concludes that the capacity of a bottleneck does not have a linear relationship with the effective width of the bottleneck. The capacity per unit width of a bottleneck depends on the composition of the pedestrian flow – walking direction, gender, age, trip purpose, infrastructure characteristics – grade of ramp, stairs, and external conditions – weather, ambient conditions. The unused sidewalk width in a bottleneck depends on the type of obstruction – the material, the cleanness, the bulk, etc., of the obstacle. The author proposes a method to calculate the effective width of a bottleneck.

Obstacles in Pedestrian Simulations - Pascal Stucki, Christian Gloor and Kai Nagel

This thesis develops two new pedestrian simulation models that incorporate the influence of obstacles and other pedestrians in walking behavior.

To calibrate these models, the author uses empirical pedestrian data collected by Weidmann in his report "Transporttechnik der Fussgänger".

In the models, the walking speed of a pedestrian depends on:

- Attributes of the agent itself, such as gender, age, size, health, mood, stress and baggage.
- Attributes of the agent's environment, such as trip purpose, time of the day and the year, weather, trip length, steepness, attractiveness, safety of the route and shelter.
- The pedestrian density in the area.
- The distance to obstacles.

Weidmann obtained a normally distributed average speed of 1.34 m/s (4.83 km/h or 4.40 ft/s) and a standard deviation of 0.26 (19.3%) for pedestrians walking on the street. This value decreased for pedestrians walking on stairs and escalators. (Our team spoke with Weidmann about his methodology. Weidmann stated that his data was based on publications he collected, and he did not conduct the field work. He built a synthesis upon all the information compiled.)

Weidmann measured an average (maximal) body diameter of 0.46 m (1.51 ft) and a body depth of 0.23 m (0.75 ft). This equals a rectangular area of 0.11 m^2 (1.18 ft^2), although he chose to work with a more conservative value of 0.15 m^2 (1.61 ft^2). This translates into a maximum density of 6.6 persons/m^2. For densities above 3.0 persons/m^2 physical contact is inevitable.

According to the authors, when a person is walking, he/she needs an extra lateral space of around 0.30 m on each side, plus an extra longitudinal space which depends on the speed, and increases with speed. According to field measurements done by Mauron, pedestrians normally keep a distance of 1.03 m when crossing each other.

The measured distances to obstacles for pedestrians walking on sidewalks are:

- To walls: 0.45m.
- To fences: 0.35 m.
- To the roadway: 0.35 m.
- To small obstacles, like street lights, signals, trees or benches: 0.30 m.
- In curves, pedestrians keep an extra distance of 0.15 m.

According to the author, if an obstacle is more than half meter away from a pedestrian, it does not affect that pedestrian's walking behavior.

Experimental Research of Pedestrian Walking Behavior - Winnie Daamen and Serge P. Hoogendoorn

The authors recognize the lack of microscopic pedestrian data to describe pedestrian flow in detail. They find this data necessary to evaluate and calibrate simulation models used to design pedestrian infrastructure. Therefore, to overcome this problem, the authors develop a series of pedestrian experiments to collect microscopic pedestrian data.

According to the authors, walking speeds of pedestrians depend on the pedestrian density and on the following exogenous factors:

- Personal characteristics of pedestrians, such as age, gender, size, health, etc.
- Characteristics of the trip, such as walking purpose, route familiarity, luggage, trip length, etc.
- Properties of the infrastructure, such as type, grade, attractiveness of environment, shelter, etc.
- Environmental characteristics, such as weather and ambient conditions.

They also find that the necessary width for an adequate walkway depends on each pedestrian's speed. The longitudinal space use increases with speed exponentially. A relationship between the elliptical area needed by a pedestrian and his/her speed has been established.

In addition, "dynamic lane formation" or "streaming" in bidirectional pedestrian flows is a well-known phenomenon, in which pedestrians walking in opposite directions tend to separate and form lanes when they are walking in crowds. This lane formation is responsible for capacity loss – between 4% and 14.5% - that occurs in a bidirectional pedestrian flows.

D. Pedestrian Simulation Models

Pedestrian simulation studies evaluate the advantage of projecting and forecasting pedestrian flow using computer simulations. There are a few pedestrian simulation packages being used in the field, such as PEDFLOW, which simulates pedestrian interaction with obstacles found on walking facilities (Kukla, 2001). Researchers such as Hoogendoorn have come up with innovations in pedestrian modeling like using a gas-kinetic modeling technique to simulate pedestrian flows (2000). Regardless of which model one chooses to use, we have determined that pedestrian simulation often requires extensive data input and complicated parameters to build and calibrate. The following section deals with pedestrian simulation related literature. It presents some of the simulation options for pedestrian LOS analysis. It also outlines some of the difficulties in designing, building and implementing a simulation model.

Modeling for Four-Directional Pedestrian Flows - Victor Blue and Jeffrey Adler

The authors of this study state that the standard pedestrian LOS methodology does not adequately address bi-directional pedestrian flows that are not "directionally separated," cross-flows, or other n-directional flows.

The authors distinguish between traffic flows in the model they develop by identifying them as: 1) directionally separated flows (flows that, like vehicle traffic lanes, are stable and well-defined); 2) dynamic multi-lane flows (flows that grow or shrink based on demand and, in some cases, may split into multiple flows in a single direction); and 3) interspersed flows (flows without lanes that last a short period of time). The authors focus primarily on dynamic multi-lane flows. They also argue that the existing LOS methodology takes directionally separated flows into account already while interspersed flows are too random to model and calibrate against actual data with certainty.

Using their modeling technique, the authors find that directional pedestrian flows exhibit unique characteristics depending on the number and the type of flows. In particular, the authors focus on pedestrian behavior in conflict situations, i.e. how pedestrians react when confronted by another pedestrian moving toward them or perpendicular to them. In general, the researchers find that two pedestrians that perceive impending conflict will first attempt to find a path that allows them both to move forward, then to find a path that allows one to move forward while the other side-steps or pauses.

One important finding in this study is that the standard LOS bi-directional flow method is incomplete and can be better modeled using their simulation. Unfortunately, the authors do not attempt to qualify how pedestrians perceive resolving these directional conflicts in level of service terms.

Behavioral Dynamics for Pedestrians - Michel Bierlaire, Gianluca Antonini and Mats Weber

The authors propose the best combination of modeling techniques based on criteria such as ease of data collection, realism, ability to calibrate against actual data, and the ability to generate simulation data given a few parameters (volume of pedestrians and the physical characteristics of pedestrians and the space being modeled).

The authors found that microscopic, agent-based pedestrian behavior models best met their criteria and should be used for future pedestrian simulations.

The paper is interesting for the following reasons:

- The authors indirectly questioned a key tenet of the standard pedestrian LOS calculation: the relationship between walking speed and pedestrian density. They cited a study by AlGhadhi entitled, "A Speed-Concentration Relation for Bi-directional Crowd Movements", that deems the relationship to be unreliable. We investigated this; however the study is specific to large religious festivals and events in India only.
- The authors presented a good survey of microscopic pedestrian modeling techniques. Macroscopic techniques are briefly discussed, but only long enough to discount them for serious simulation. The authors argued that an agent-based approach taking into account each individual's line-of-sight is best because it is the most realistic.

Modeling the behavior of individual pedestrians may be useful theoretically, but may not be practical. In the introduction, the authors mentioned that this technique is most useful for simulating panic situations.

The models described in this paper require extensive, detailed data collection, much more than could be compiled manually. The authors disclose that, although automated video analysis is necessary for this model development, it "does not cover all aspects of data collection and focuses mainly on short-range behavior." This data collection is also expensive given the equipment requirements and error-prone due to the problems of automatically identifying pedestrians via video data.

Pedestrian Flow Modeling by Adaptive Control - Serge P. Hoogendoorn

The author proposes a theory and a model to describe pedestrian walking behavior. He reviews some literature concerning pedestrian behavior and the factors that influence it. According to his theory, pedestrians are driven by cost minimization. Pedestrians behave according to predictions on other pedestrians' behavior, but they have a limited predictive ability. Walking too close to other pedestrians and obstacles has a cost for a pedestrian: the "proximity discomfort" or "proximity cost". Accelerating and deviating from the planned path have also a cost for a pedestrian.

Another hypothesis of this model is that walkers avoid proximity to groups of pedestrians more than to a single pedestrian, because it is assumed that proximity costs are additive. The author concludes that this model is able to predict pedestrian walking behavior quite accurately, based on several application examples.

E. Data Collection Methodology

In order to design an effective data collection methodology, studies were reviewed based on their video surveying techniques and uses of pedestrian surveys. In seeking ideas related to motion sensing and detection of pedestrians, we expanded our review of literature beyond pedestrian and traffic studies, and found ideas from the realms of reinforced soil design (Arriaga, 2000), coastal science (Black, 1999; Hume, 1998) and biometric technologies (Bolle, 2001). However, automating the process of data collection may be too expensive and labor intensive for the scope of this study. The purpose of this section is to summarize some of the literature we studied, and to outline which data collection procedures others used and which might inform the development of data collection methodologies for this project.

Laying the Foundations: the Use of Video Footage to Explore Pedestrian Dynamics in PEDFLOW - Alexandra Willis, Robert Kukla, Jon Kerridge, and Julian Hine

According to the authors, the best way to obtain a comprehensive and complete knowledge of pedestrian behavior is with a combination of observational and interview methodologies. Observation allows us to determine quantitative values of pedestrian movement – such as number of pedestrians, speeds, distance to obstacles – as well as moving patterns. Interviews help us to understand the decision-making process underlying pedestrian movement, and to estimate the actual demand for pedestrian facilities.

Pedestrian observation can be done with a video camera. The main advantage of using a video camera instead of other visual techniques is that it provides a permanent record that can be observed and analyzed as often as needed, thus considerably reducing the amount of on-site field work. However, there are two main problems with the use of a video camera. First of all, the videotapes need to be calibrated for the foreshortening that occurs when the camera is not positioned perpendicular to the ground. Second, manual analysis of every pedestrian in every tape is extremely laborious and time-consuming. Recent developments in image and motion analysis software can help overcome these problems in the future and make systematic exploration of pedestrian movement at a microscopic level a reality.

Pedestrian Simulation Methods - Laurent Mauron

In his thesis, the author develops two simulation methods to model pedestrian flow in large infrastructures.

Mauron states that pedestrians tend to walk with a desired speed which depends on the age, gender, time of the day, trip purpose, environmental conditions, etc.; previous field measurement found that desired speeds in crowds are usually normally distributed with a mean value of 1.34 m/s approximately; pedestrians choose the fastest route, not the shortest; pedestrians avoid other pedestrians, and they also try to keep a certain distance from obstacles and walls; it has been shown that pedestrians walk further away from a dirty wall than from a clean one; when the walkway is sufficiently crowded, pedestrians tend to form directional lanes.

In chapter 5, Mauron performs some field measurements to calibrate and test his models. The location chosen by the author is a sidewalk at the Tannenstrasse in the ETH campus in Zurich. The author chose this block to observe bidirectional flow because it is devoid of elements that interfere in pedestrian behavior, such as shopping windows and zebra crossings. The methodology consists of the following steps:

1. A video camera is placed above the study location, fixed to a tripod in a window, to reduce image deformation due to perspective for shortening as much as possible.
2. A planar Cartesian coordinate system is defined on the field; the x axis is the curb. Four reference points are marked on the sidewalk with bright tape, and their relative locations are measured. These points are used as a calibration of the field coordinate system.
3. Videos are filmed at different times of the day to observe different travel characteristics.
4. The videos are captured and compressed in a computer with Adobe Premiere.
5. The pedestrians' trajectories are tracked with an image analysis software. The author decided to create his own tracking software because none of the commercially available programs were adequate of affordable. Since the experiment was done on a real sidewalk with real people not knowing that they were being observed, the software could not automatically track pedestrians – this would have been possible if all pedestrians were wearing a bright hat. Therefore, pedestrians had to be tracked manually, one by one, in a very time-consuming task. The camera coordinates were calibrated with the four reference points. Errors are estimated by measuring in the video a one meter stick that was placed in the study area.
6. For every pedestrian, his/her position on the

sidewalk relative to the curb is measured. The author distinguishes two groups: pedestrians walking alone and -not interacting with other pedestrians, and two pedestrians walking alone but crossing each other.

MauronThe author found that non-interacting pedestrians tend to walk in a straight line at a constant distance from the curb side. These distances are statistically distributed around a peak value of 1.611 m, with a standard deviation of 0.412. In the case of crossing pedestrians, the peak values for the distances are 0.852 m with a standard deviation of 0.264, and 1.8795 m with a standard deviation of 0.21. The author uses these values to test and compare the proposed simulation models.

Operational Characteristics of Inline Skaters - Elizabeth Birriel, Juan C. Pernia, Juan John Lu, and Theodore A. Petritsch

The Florida Department of Transportation (FDOT) sponsored this study of the operational characteristics, speed, sweep width (lateral distance), stopping technique, stopping distance, and stopping width of inline skaters. After, placing orange cones at 40 feet apart, a video camera was set up to film skaters as they passed the cones. The 50th and 85th percentile speeds were estimated.

The sweep width (lateral distance) was measured by drawing twenty feet longitudinal lines one foot apart on the sidewalk. The number of lines that the skaters crossed, using their skates or hands, were captured by video cameras. Three cameras, one facing skaters, one set up on the side of the first 60 feet of the skaters stopping distances, and the last one of the last 40 feet, were used to capture the stopping technique, distance and width. Horizontal lines of five feet apart within a distance of 100 feet before the stopping sign were drawn to study the stopping distance. Then the stopping width was measured by two feet apart longitudinal lines. The study also divided up the sample group into male, female, learner, and advanced skaters.

This study is relevant to pedestrian level of service study because it shows how data could be collected using video camera and lines on the ground. Using relatively simple methodology, data of speed, lateral spacing, stopping technique and distance of in-line skaters could be collected.

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APPENDIX B.

PEDESTRIAN SURVEY RULES

A. General Rules

- The pedestrian characteristics survey was designed to be completed quickly based on visible pedestrian features. It is best to try not to overanalyze characteristics.
- Conservatism is the rule. If you have a lengthy internal debate about whether someone is sufficiently larger than average or is slowed by a bag, indicate they are not. If you have a lengthy internal debate about someone's trip purpose, indicate that you don't know what it is.

B. Person Size

- One study = 99th percentile (men) = 20.7" shoulder width + 1.5" clothing
- Another study 95th percentile (men) = 22.8" width, 13" deep
- Standard, according to Fruin: 24" wide and 18" deep which accounts for body sway, personal articles, and space buffer
- Extra large people are about 30" X 22.5"

C. Group

- Indicate the number of people walking together in a group.
- A baby does not count as a person in a group, unless it is walking.
- In case of an extremely large group (tour/school group, for example), pick out a single group within that large group (2-3 people walking together), record their time and their characteristics. Note this sub-group's size in the Group column and the approximate size of the entire group in the Comments column.

D. Trip Purpose

- Indicate '0' if you are not sure of the pedestrian's trip purpose. This is an extremely important characteristic so never guess about someone's trip purpose, just indicate '0'. You can write something in the Comment column if you want to highlight a difficult-to-assign case.
- Indicate '1' if the person's primary purpose in the area is tourism. Some characteristics of tourists include: casual clothing, visible camera, maps/guidebooks, looking around.
- Indicate '2' if the person's primary purpose in the area is work. This includes people who are going to work, coming from work, taking a lunch/shopping break from work, or actually working. Some signals of work include: visible ID card, slightly more formal clothing or a uniform.
- Indicate '3'if the person's primary purpose in the area is non-work, but they are not a tourist. This includes people who are shopping or taking a recreational walk. It also includes people whose work entails casual activity: nannies and dog walkers, for example.

E. Bag(s)

- Indicate '1' if a person is carrying any type of bag. This includes paper lunch/deli bags, plastic bags, shopping bags, backpacks, suitcases (being carried), purses, briefcases, baby backpacks.
- Mark '2' if a person is visibly straining against a bag and appears to be slowed by it.
- Indicate '0' otherwise. Notebooks, wallets, newspapers, folders, portfolios, etc. are not considered bags.

F. Phone

- Indicate '1' if someone is actively using their cell phone: talking, dialing, fiddling, etc. Count people whether they are speaking with it up to their ear or if they are using a headset.
- Indicate '0' otherwise.

G. Headphones

- Indicate '1' if someone has headphones on their ears. Note that this characteristic should only be used for headphones attached to music/audio devices—not mobile phone headsets, which should be marked as "phone" usage (above).
- Indicate '0' otherwise.

H. Drink / Food

- Indicate '1' if someone is holding food or drink in their hand in its elemental packaging as if it could be consumed easily at any time. Examples: drink with a straw, capped bottle of water, open/closed bag of chips (because it can easily be opened an eaten while walking), fruit, pretzel, candy bar, unwrapped sandwich.
- Indicate '0' if someone is not holding food or drink or if their food/drink is inside another container or bag. For example, a fast food bag should not be counted as food/drink (but should be counted as a bag). A brown paper bag that seems to contain a bottle should not be counted as food/drink unless it is clearly drinkable – a straw poking out the top, for example.

I. PDA

- Indicate '1' if someone is actively using an electronic organizer.
- Indicate '0' otherwise.

J. Cigarette

- Indicate '1' if someone is actively using a cigarette, cigar, or pipe. Examples: removing a cigar/cigarette from a pack, lighting it, smoking.
- Indicate '0' otherwise.

K. Pushing

- Indicate '0' if someone is pushing/pulling nothing.
- Indicate '1' if someone is pushing a stroller.
- Indicate '2' if someone is pushing/pulling a service cart. This includes vendor carts, grocery carts, and hand trucks / dollies.
- Indicate '3' if someone is pushing a wheelchair.
- Indicate '4'if someone is pushing / pulling a rolling suitcase.

L. Walking Aide

- Indicate '0' if someone is not using a walking aide.
- Indicate '1' if someone is using crutches.
- Indicate '2' if someone is riding in a wheelchair (that is being pushed by someone else or self-propelled.
- Indicate '3' if someone is using a cane or a walker.

M. Impeded

- Make sure you pay attention to this column as you are watching pedestrians
- A pedestrian is impeded if he/she is involuntarily slowed by conditions on the sidewalk. Examples include: a pedestrian who slows down and changes direction abruptly due to crowded conditions or an unavoidable obstacle or a pedestrian who trips due to a sidewalk obstacle or feature.

N. Comment

– Write comments here that help explain why a pedestrian's speed is particularly slow or fast or explain behavior that might affect speed or sidewalk usage. For example, an unusual gait or disability, a person actively window shopping, someone in a big hurry, someone dribbling a basketball, etc. Also, include any comments about sidewalk conditions – physical, environmental or social – which may affect traffic flows.

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APPENDIX C.

SAMPLE FORMS

Table C.1. Sample Speed Survey

Ped Count Sample Pedestrian Speed
Location: Control Location

Speed Timing Length on Sidewalk (ft): 40
Weather: Sunny
Name Betsy
Date: 5/12/2004
Time: 11:45

PED #	Travel Time (s)	DIRECTION	GENDER	AGE	PERSON SIZE	GROUP	TRIP PURPOSE	BAG(S)	PERSONAL ITEMS					PUSHING	WALKING AIDE	COMMENT
		N = north S = south E = east W = west	F = Female M = Male	1 = under 14 2 = 14-65 3 = over 65	0 = Average 1 = Large (well over average space req'd)	# = people in group 1 = 1 person 2 = 2 people etc.	0 = Not sure 1 = Tourist 2 = Service 3 = Business 4 = Non-business	0 = None 1 = Yes, no effect 2 = Yes, affects speed	Phone	Headphone	Drink	PDA	Cigarette	0 = Nothing 1 = Stroller 2 = Service cart 3 = Wheelchair 4 = Rolling suitcase	0 = No 1 = Crutches 2 = Wheelchair 3 = Cane 4 = Stroller	
1	11.09	N	M	2	0	1	0	1						4		
2	12.37	S	F	2	0	1	4	1								
3	12.09	N	F	2	0	2	1	1								
4	12.09	N	F	2	0	2	1	1								
5	10.09	S	M	2	0	1	0	1			1					
6	10.37	N	M	2	0	1	3	0								
7	9.38	S	F	2	0	1	0	1								
8	16.16	N	F	2	0	2	4	0						1		Kids
9	16.16	N	F	2	0	2	4	0						1		Kids
10	9.7	S	F	2	0	1	4	2								
11	9.5	N	F	2	0	1	4	1								
12	8.4	S	F	2	0	2	0	1								
13	8.4	S	F	2	0	2	0	1								
14	11.25	S	F	2	0	1	0	0	1							
15	7.18	S	M	2	0	1	0	0	1							
16	11.25	S	F	2	0	1	0	2								

Table C.2. Lower Manhattan 62 Locations

Location ID	Street	Between 1	Between 2	Side
01N	Chambers	Greenwich	W. Broadway	N
01S	Chambers	Greenwich	W. Broadway	S
02W	Hudson	Reade	Chambers	W
03E	W. Broadway	Reade	Chambers	E
04E	W. Broadway	Warren	Chambers	E
04W	W. Broadway	Warren	Chambers	W
05E	Church	Reade	Chambers	E
05W	Church	Reade	Chambers	W
06N	Chambers	Church	Broadway	N
06S	Chambers	Church	Broadway	S
07E	Church	Chambers	Warren	E
07W	Church	Chambers	Warren	W
08E	Broadway	Chambers	Warren	E
08W	Broadway	Chambers	Warren	W
09E	Church	Warren	Murray	E
09W	Church	Warren	Murray	W
10E	Broadway	Warren	Murray	E
10W	Broadway	Warren	Murray	W
11W	Broadway	Murray	Park Pl	W
11E	Broadway	Murray	Park Pl	E
12E	Church	Murray	Park	E
12W	Church	Murray	Park	W
13E	Church	Park Pl	Barclay	E
13W	Church	Park Pl	Barclay	W
14E	Church	Barclay	Vesey	E
16N	Vesey	Church	Broadway	N
18N	Fulton	Broadway	Nassau	N
18S	Fulton	Broadway	Nassau	S
20N	Fulton	Nassau	William	N
20S	Fulton	Nassau	William	S
22N	Fulton	William	Gold	N
22S	Fulton	William	Gold	S
25N	Dey	Church	Broadway	N
25S	Dey	Church	Broadway	S
27N	John	Nassau	Broadway	N
30E	Church	Cortlandt	Dey	E
31N	Cortlandt	Church	Broadway	N
32E	Church	Cortlandt	Liberty	E
34N	Liberty	Church	Broadway	N
35W	Church	Liberty	Cedar	W
37W	Trinity Pl	Thames	Rector	W
38E	Broadway	Pine	Wall	E
38W	Broadway	Wall	Rector	W
39N	Chambers	W. Broadway	Church	N
39S	Chambers	W. Broadway	Church	S
41N	Wall	Nassau	William	N
41S	Wall	Nassau	William	S
43N	Wall	William	Hanover	N
43S	Wall	William	Hanover	S
44S	Rector	Trinity Pl	Broadway	S
45E	Broadway	Wall	Exchange	E
45W	Broadway	Wall	Exchange	W
46E	Nassau	Wall	Exchange	E
51E	Broadway	Exchange	Morris	E
52E	Broad	Exchange	Beaver	E
52W	Broad	Exchange	Beaver	W
53S	Beaver	Broad	William	S
54N	William	Pearl	Water	N
55S	Beaver	Whitehall	New	S
56W	Broadway	Morris	Battery Pl	W
60E	Whitehall	Battery	Stone	E
57S	Beaver	Broad	New	S

Table C.3. 7-day Sample Count

Project LOS 7-Day Pedestrian Count

Broadway between Duane and Reade, West Sidewalk

Name: Altan
Start Time: 11:00AM
Date: 5/12/2004
Weather: Sunny, hot

	5 min	10 min	15 min	20 min
Northbound	71	128	207	265
Southbound	60	129	201	254

	25 min	30 min	35 min	40 min
Northbound	338	394	445	511
Southbound	343	395	469	557

	45 min	50 min	55 min	60 min
Northbound	569	633	718	788
Southbound	605	693	798	889

Table C.4. Sample Speed Walk

PEDESTRIAN LOS SPEED WALK SHEET

ROUTE CHARACTERISTICS

Route:	Broadway to Wall Street to William & back	Date:	4/27/2004
Walker:	Monica / Timer: Monica	Time of Day:	2:35pm
Weather:	Parly sunny, a little windy, 60s	Route time:	17:30.74 / 14:28.48

	Name	Arrive	Depart	Comments
Intersection 1:	Bway/Duane South	00:00.00	00:00.00	
Intersection 2:	Bway/Reade North	00:45.08		
Intersection 3:	Bway/Reade South	00:51.36		
Intersection 4:	Bway/Chambers North	01:28.45		
Intersection 5:	Bway/Chambers South	01:35.28		
Intersection 6:	Bway/Warren North	02:17.70		
Intersection 7:	Bway/Warren South	02:24.63		
Intersection 8:	Bway/Murray North	03:07.28		
Intersection 9:	Bway/Murray South	03:14.27		
Intersection 10:	Bway/Park North	03:51.88	04:00.78	
Intersection 11:	Bway/Park South	04:09.50		
Intersection 12:	Bway/Barclay North	04:48.87		
Intersection 13:	Bway/Barclay South	04:56.11		
Intersection 14:	Bway/Vesey North	05:46.26		
Intersection 15:	Bway/Vesey South	05:52.98		
Intersection 16:	Bway/Fulton North	06:32.43		
Intersection 17:	Bway/Fulton South	06:37.44		
Intersection 18:	Bway/Dey North	07:14.52		
Intersection 19:	Bway/Dey South	07:19.54		
Intersection 20:	Bway/Cortlandt North	08:09.89		
Intersection 21:	Bway/Cortlandt South	08:15.33		
Intersection 22:	Bway/Liberty North	09:07.43		
Intersection 23:	Bway/Liberty South	09:16.28		
Intersection 24:	Bway/Cedar North	09:40.43		
Intersection 25:	Bway/Cedar South	09:44.27		
Intersection 26:	Bway/Thames North	10:00.45		
Intersection 27:	Bway/Thames South	10:03.97		
Intersection 28:	Bway/Rector North	11:43.75		
Intersection 29:	Bway/Rector South	11:48.41		
Intersection 30:	Bway/Exchange Northwest	12:40.98	13:12.99	
Intersection 31:	Bway/Exchange Northeast	13:20.65		
Intersection 32:	Bway/Wall South	14:41.42		
Intersection 33:	Bway/Wall North	14:48.35		
Intersection 34:	Wall/Nassau West	15:54.49		
Intersection 35:	Wall/Nassau East	15:59.06		
Intersection 36:	Wall/Willam West	17:30.74		

Northbound

	Name	Arrive	Depart	Comments
Intersection 1:	Wall/Willam West	00:00.00		
Intersection 2:	Wall/Nassau East	01:32.46		
Intersection 3:	Wall/Nassau West	01:36.49		
Intersection 4:	Bway/Wall North	02:44.87		
Intersection 5:	Bway/Pine South	03:29.42		
Intersection 6:	Bway/Pine North	03:33.38		
Intersection 7:	Bway/Cedar South	04:11.64		
Intersection 8:	Bway/Cedar North	04:15.28		
Intersection 9:	Bway/Liberty South	04:45.42		
Intersection 10:	Bway/Liberty North	04:52.86		
Intersection 11:	Bway/Maiden South	05:47.59		
Intersection 12:	Bway/Maiden North	05:52.56		
Intersection 13:	Bway/John South	06:33.67		
Intersection 14:	Bway/John North	06:38.52		
Intersection 15:	Bway/Fulton South	07:25.77		
Intersection 16:	Bway/Fulton North	07:32.23		
Intersection 17:	Bway/Ann South	08:09.38		
Intersection 18:	Bway/Traffic Island South	08:25.57		
Intersection 19:	Bway/Traffic Island North	08:59.11	09:27.74	
Intersection 20:	Bway/City Hall Park South	09:41.07		
Intersection 21:	Bway/Chambers South	12:47.67		
Intersection 22:	Bway/Chambers North	12:58.31		
Intersection 23:	Bway/Reade South	13:37.44		
Intersection 24:	Bway/Reade North	13:44.18		
Intersection 25:	Bway/Duane South	14:28.48		

Table C.5. Video Locations

Video Location				Day(s) Filmed	Time(s) Filmed
Street	Between 1	Between 2	Side		
Broadway	John St	Cortland St	East	9-Dec-03	10:30 AM
Beaver St	Broad St	New St	North	9-Dec-03	12:30 PM
42nd St	Park Avenue	Lexington Ave	North	12-Jan-04	11:25 AM
42nd St	Park Avenue	Lexington Ave	South	12-Jan-04	11:30 PM
Lexington	40th St	41st St	West	12-Jan-04	12:00 PM
					1:30 PM
					3:00 PM
					4:30 PM
				13-Jan-04	5:15 PM
					6:00 PM
				14-Jan-04	8:30 AM
					8:45 AM
					10:30 AM
Chambers St	Broadway	Church St	South	22-Jan-04	4:05 PM
Chambers St	Broadway	Church St	South	10-Feb-04	11:15 AM
Broadway	Thomas St	Duane St	West	10-Feb-04	3:45 PM
Broadway	Duane St	Reade St	West	11-Mar-04	3:10 PM
(Control Location)				15-Mar-04	3:05 PM
				19-Apr-04	3:15 PM
				20-Apr-04	3:17 PM
				20-May-04	3:15 PM
				10-Jun-04	3:13 PM
Broadway	Exchange Pl	Rector St	West	15-Mar-04	4:05 PM
Fulton St	Dutch St	William St	South	19-Apr-04	4:05 PM
John St	Cliff St	Pearl St	South	20-Apr-04	1:20 PM
Church	Reade	Chambers	East	10-Jun-04	12:15 PM
Fulton St	Broadway	Nassau St	South	27-Aug-04	1:15 PM
Broadway	John St	Maiden Ln	East	1-Sep-04	12:35 PM
Church	Liberty St	Cedar St	West	1-Sep-04	1:25 PM

Table C.6. Sample Obstacle Form

Location:

Date: **Time:** **Observer:**

			Left of Screen				Right of Screen			
			Obstacle:	Impeded? (Y/N)	# of Pedestrians		Obstacle:	Impeded? (Y/N)	# of Pedestrians	
Ped #	Gender	Pedestrian Direction	Distance (ft)		NB	SB	Distance (ft)		NB	SB
1	F	N	5.5	N	2	0			0	2
2	F	N	5	N	2	0			0	1
3	F	N	5.5	N	2	0			0	2
4	M	S	1.5	N	1	1			0	1
5	M	S	5	N	0	1			0	1
6	F	S	2.25	N	0	1			0	1
7	F	N	5	N	1	0			0	0
8	F	N	2.5	N	1	0			0	0
9	M	S	1.5	N	0	3			0	1
10	M	N	2.25	N	1					
11	M	N	7		1					1
12	F	N	3		2					
13	F	N	6		1					
14	M	N	5.5		1					
15	F	N	4		2					1
16	M	S	4.5			2				
17	F	S	4.5			1				1
18	F	S	3			1				
19	F	N	1.5		1					
20	M	S	0.5	Y		4				
21	M	N	2		1					
22	F	S	4.5			1				
23	M	N	4.25		1				1	
24	M	N	6.5		1					
25	M	N	2.5		2					
26	F	N	3.5		1					
27	M	N	3		3					1
28	F	N	3		3				1	2
29	F	N	5		1					1
30	M	N	0.5	Y	3					
31	F	N	6							
32	M	S	0.5		2	2				1
33	M	N	0.5	Y	3					
34	M	N	3		1					2
35	M	N	4.5		1					1
36	F	N	1		3					
37	M	N	3.5		2				1	
38	F	N	2.5	Y	3	1				
39	M	N	1.5		2					

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APPENDIX D.

PERSPECTIVE DRAWING: BLUE SCREEN VIDEO METHOD

In a one-point perspective drawing all lines which are parallel to each other converge towards a single point, the vanishing point, when the image is represented in the perspective. Since we want to draw longitudinal lines on any specific sidewalk, we need to find the vanishing point of the all the lines parallel to the curb line. Thus, a still image is captured from the video (see Figure D.1, first picture on the left column) and imported into AutoCad, where all visible lines parallel to the curb line are drawn (see Figure D.1, second picture on the left column). Because these lines are "hand-drawn" over the image and the original ones might not be accurately parallel, they don't converge at one point exactly, but they all tend to converge in a small area. One point is chosen in the approximate center of that area. This is the vanishing point of all the lines parallel to the curb line.

From this vanishing point, three lines are drawn, they are usually lines that define the concrete square blocks of the sidewalk. These three lines have been previously chosen on the field, and their distance measured with a tape measurer. The criteria to select these lines are that they have to be parallel to the curb line and to each other, and visible in the video (see Figure D.1, third picture on the left column). Now we can solve the following problem.

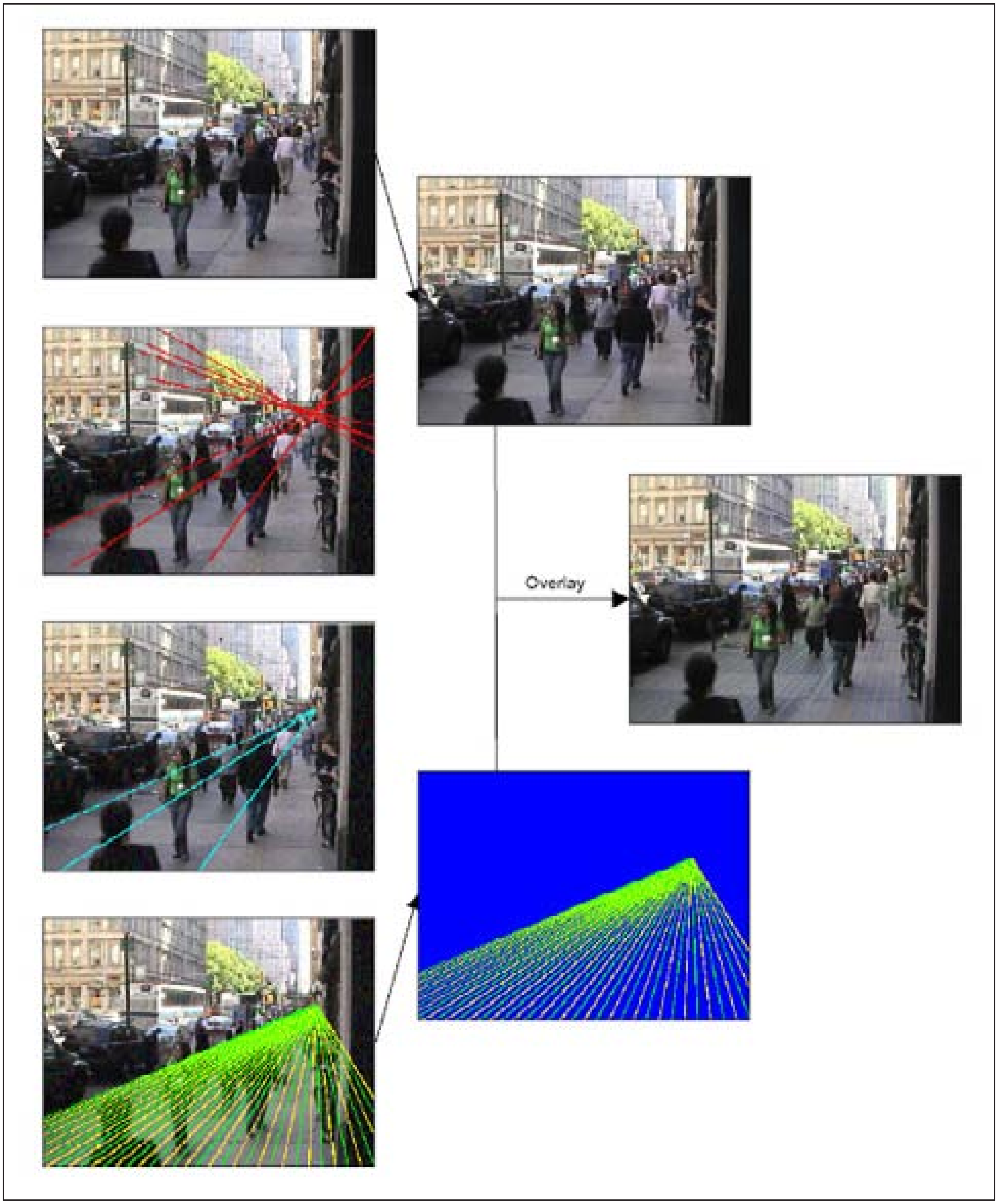

Figure D.1. Blue Screen Video Overlay

Problem: Given three lines a, b, c intersecting in O, draw a line r so that, if A, B, C are the intersection points of r with a, b, c respectively, it verifies that AB/BC = m/n, being m and n known (see Figure D.2.).

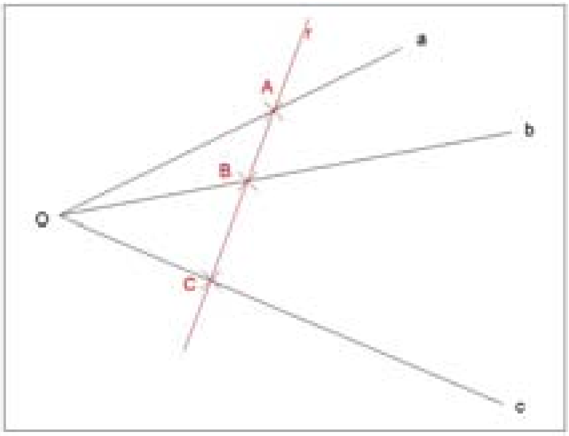

Figure D.2. Problem to Solve

Data: a, b, c, O, m, n. m/n = k (see Figures D.3. and D.4.).

g. m and n are the real distances between the lines measured in the field.
h. a, b, c have to be parallel lines in real life.
i. O is the imaginary point where perspective lines converge.

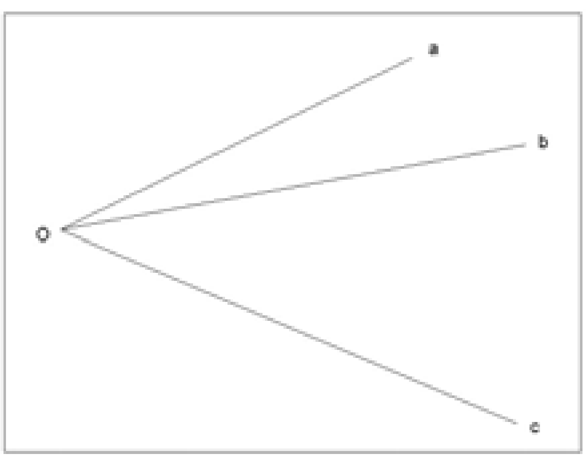

Figure D.3. Problem Data 1

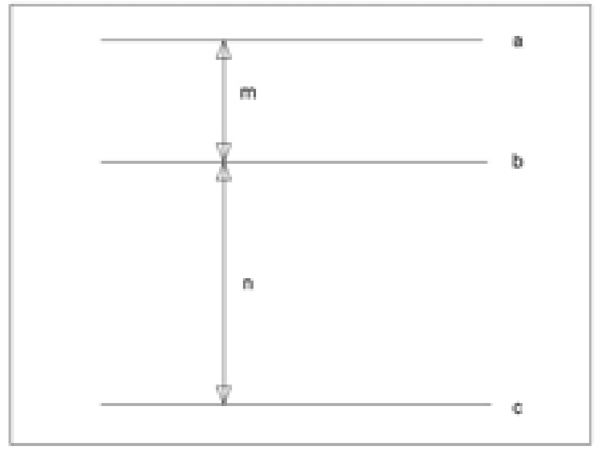

Figure D.4. Problem Data 2

Solution:

1. Draw an arbitrary line s that intersects a, b, c. The intersection points of s with a, b, c are X, Y, Z, respectively (see Figure D.5.).

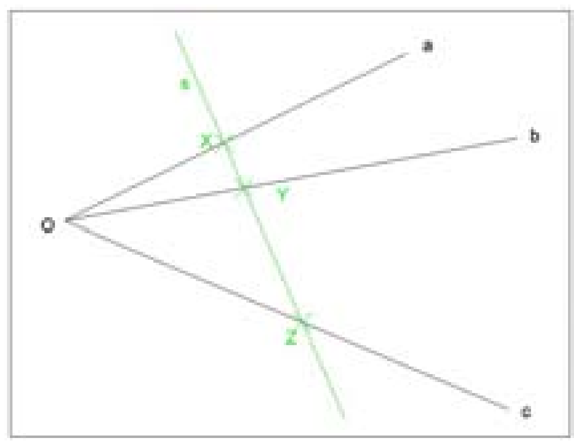

Figure D.5. Problem Solution Step 1

2. Measure the length of segment XY.
3. Divide this length by k. The result is the length of a segment YP, with P belonging to line s, so that XY/YP = k. Draw point P. For this drawing we are assuming that m/n = ½ (see Figure D.6.).

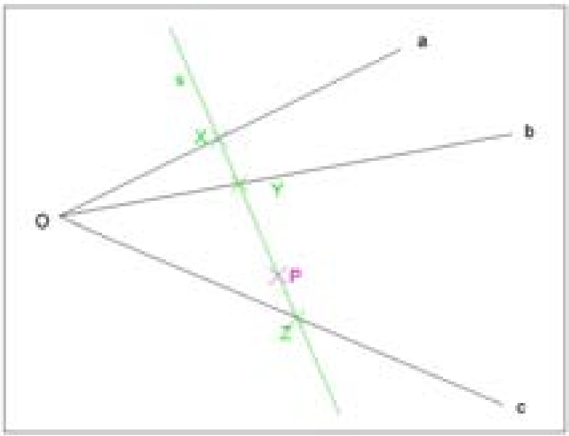

Figure D.6. Problem Solution Step 3

4. Draw a parallel line to line a through point P. This would be line a' (see Figure D.7.).

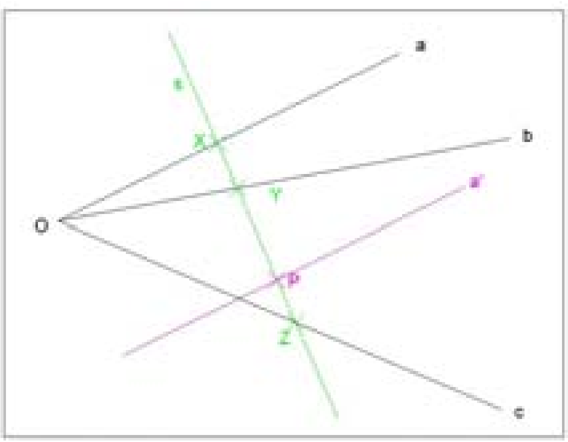

Figure D.7. Problem Solution Step 4

5. Intersection of lines a' and c is point C (see Figure D.8.).

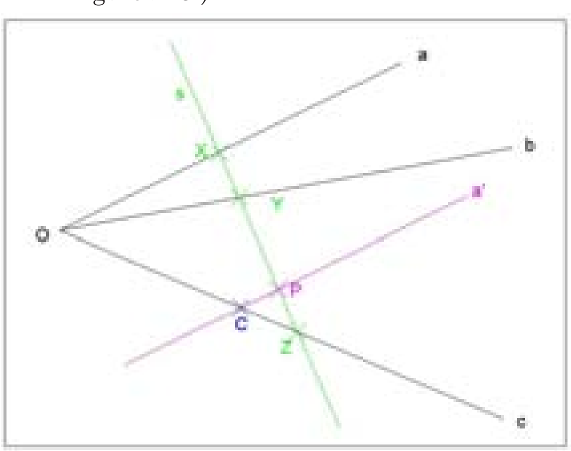

Figure D.8. Problem Solution Step 5

6. Draw a line through points Y and C. This line intersects line a at point A. This will be the line r that we are looking for, and point Y is also point B. Segments AB and BC verify the relationship AB/BC = k (see Figure D.9.).

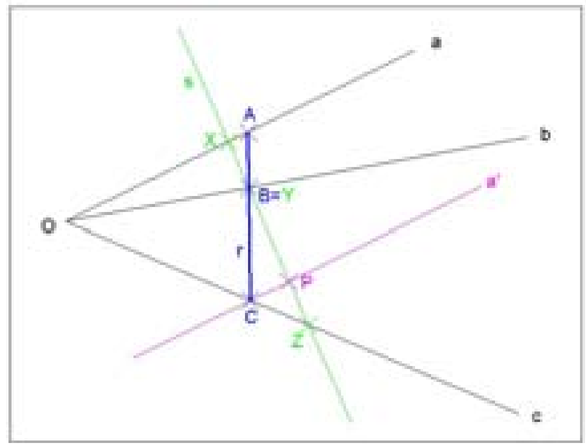

Figure D.9. Problem Solution Step 6

Let us now draw the 6 inch intervals. We will draw them on line r.

7. Multiply the length of segment AB by 6 (for the 6 inch) and divide the result by length m (in inches). This is the length of a 6 inch segment scaled to be drawn on line r.
8. Draw segments with this length on line r. These will mark the points on line r which are 6 inches apart.
9. Join these points with point O. You will obtain the 6 inch lines (see Figure D.10.).

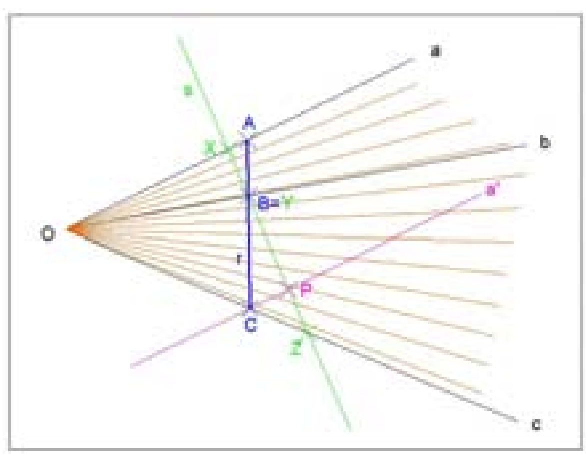

Figure D.10. Problem Solution Final Step

APPENDIX E.

DATA CLEANSING

We began the data analysis process by cleansing the data. We corrected for two potential problems: data entry mistakes and inconsistencies in our data collection methodology.

Identifying and correcting data entry mistakes required auditing the data files in SPSS and comparing them with their Excel counterparts. Specifically, we looked for pedestrian speed outliers to ensure they were exceptional cases and not data entry mistakes. We also audited the dates, times, and locations against the original data collection sheets.

When we began analyzing the data, we identified a few rules in our original methodology that seemed problematic.

A. Group Size Cleanup

In cases of large groups, we entered only one line on the pedestrian characteristic data entry form and noted the number of group members on that line. That had the effect of undercounting the cases of large (more than 5 member) groups. To resolve this problem, we added cases for all members of the group, while leaving those additional members' pedestrian characteristics as missing values. The exceptions were location characteristics and the speed of the group—we assume all members of the group are traveling at the same speed while they are walking together.

B. Strollers and Walking Aides

In cases of baby strollers, we typically entered only one line on the pedestrian characteristics form for the person pushing the stroller. In some cases we included the child in the group number. In other cases we did not. In order to resolve these inconsistencies, we reorganized this data in the following ways:

1. We located every person who was pushing a stroller.
2. If a second line already existed for a child—as part of the adult's group—we made sure the child's entry was using the stroller as a walking aide.
3. If no second line existed for the child, we added it. We left most pedestrian characteristics missing except: speed (which we adopted from the person pushing the stroller), age (to which we assigned a '1'—under 14 years old), group (which we incremented by 1 to show that the baby in the stroller is part of the group), walking aide (to which we assigned a '4'—stroller), and impeded (which we adopted from the person pushing the stroller).
4. We reconciled this data cleanup by comparing the number of people pushing strollers to the number of people riding in strollers.

C. Consolidation of Data

During the data analysis process, we realized we had collected a lot of data and needed to focus it on factors that emerged as the most important. To reduce the overall number of variables, we created a consolidated location data file with the following adjustments:

- Consider only female, assuming the opposite of female is male.
- Consider only proportion of pedestrians with no bags, assuming the opposite of this is proportion with bags + proportion with bags that affect their speed. In the individual data set, this is represented by a variable called new_bag.
- Consider only proportion of pedestrians aged 14 through 65, assuming the opposite of this is the proportion aged 14 and under + the proportion aged 65 and older.
- Consider only proportion of pedestrians who are average in size, assuming the opposite of this is the proportion who are large in size.
- Combined proportions of pedestrians in groups of 4 or more into a single group: group_4p. For group size analyses with the consolidated data set, we will consider only proportion of pedestrians in groups of 1, groups of 2, groups of 3, and groups of 4 plus (group_4p).
- Combined proportion of pedestrians with headphones, phones, drinks, PDAs, and cigarettes into a single variable called "distract". This variable indicates the proportion of people who are distracted by one or more of these items as they walk.
- Consider only proportion of pedestrians not pushing anything, assuming the opposite of this is the proportion pushing a stroller + proportion pushing a wheelchair + proportion pushing a cart + proportion pushing (or pulling) a rolling suitcase. In the individual data set, this grouping is represented by a variable called new_push.
- Consider only proportion of pedestrians with no walking aide, assuming the opposite of this is proportion of pedestrians using a cane + proportion of pedestrians using a wheelchair + proportion of pedestrians using crutches + proportion of pedestrians using a stroller. In the individual data set this grouping is represented by a variable called new_aide.
- Consider only proportion of pedestrians not impeded by street furniture or by other pedestrians, assuming the opposite of this is proportion of pedestrians impeded.

This reduces the total number of variables to be included in analysis and combines some variables with lesser proportions together.

APPENDIX F.

EXPLORATORY DATA ANALYSIS (EDA)

Prior to statistically analyzing our collected data, we performed an exploratory data analysis (EDA), using several SPSS processes, to make sure the data was statistically valid, and that it met the variable criteria required to perform linear regression analyses. The two important EDA methods employed were tests for variable collinearity and the distribution of residuals. Both of these methods are discussed below.

Collinearity in a regression model refers to a situation in which two or more of the predictor (independent) variables are related to each other in a linear fashion. In other words, collinearity (or multicollinearity) involves two or more predictor variables whose variances are related to each other, and are therefore explaining the same results in the model. Collinearity reveals redundancy in the predictor variables, and has a distorting effect on the regression equation's coefficient estimation as well as in the coefficient standard errors. One method for testing collinearity in SPSS regression models involves examining the "tolerance" and the variance inflation factor (VIF), which can be selected by the SPSS user to be displayed in a regression output. The tolerance measurement indicates the percentage of variance in each predictor variable in a regression model which can not be attributed to the other predictor variables. Therefore, a low tolerance value indicates a high collinearity between the predictor variable in question and one or more of the other predictor variables. The VIF value is essentially the reciprocal of the tolerance value, and higher VIF values are a cause for concern, as they indicate larger factors of regression model inflation due to collinearity in the predictor variables. A rule of thumb is that tolerance values of 0.20 and under are cause for concern, as are VIF values of 20 and over.

Our data analysis includes regression models with three different dependent variables: mean speed, impedance and flow rate. Prior to finalizing the three different regression models, we checked the tolerance and VIF values for the predictor variables in each, to make certain there was no significant collinearity involved in any model. We used the backward stepwise regression process in analyzing our data, so these tolerance and VIF values refer to those of the final models reached, with the most significant predictor variables. In the backward stepwise regression model with mean speed as the dependent variable, the predictor variable tolerance values ranged from 0.531 to 0.797, well above the 0.20 minimum threshold. The VIF values ranged from 1.255 to 1.884, well below the maximum threshold of 20. In the backward stepwise regression model with flow rate as the dependent variable, the predictor variable tolerance values ranged from 0.565 to 0.907, well above the 0.20 minimum threshold. The VIF values ranged from 1.103 to 1.769, well below the maximum threshold of 20. In the backward stepwise regression model with proportion impeded as the dependent variable, the predictor variable tolerance values are both 0.803, well above the 0.20 minimum threshold. The VIF values are both 1.246, well below the maximum threshold of 20. These results all indicate a lack of significant collinearity in this study's regression models.

It was also necessary to examine the residuals (the differences between observed values and expected or "predicted" values) in the regression models to determine if their distribution was normal. In order for the linear regression to have valid results, the regression residuals must have a normal distribution (values of the residuals concentrated around their mean, diminishing in frequency as residual values move away from the mean in either direction). To test for the normality of residual distribution, we performed the stepwise and backward stepwise regression analyses. There were three different analyses, with three different dependent variables: mean pedestrian speed at locations, flow rate at locations and proportion of impeded pedestrians at locations. We saved the residuals for each of these regression models, and performed a "descriptive statistics" analysis on the residuals, using the SPSS Descriptives function. Two crucial measurements of residual distribution in the descriptive statistics procedure are the skewness statistic and the kurtosis statistic. Skewness measures the degree to which a variable's distribution (in this case, residual distribution) is pulled out in the positive or negative direction by outliers. The most desirable skewness statistic would be zero, which would indicate a perfectly normal distribution. However, skewness statistics of between -1 and 1 are acceptable; with values less than two standard errors of skewness being the most desirable.

Kurtosis is a measurement which complements the skewness statistic. An in-depth discussion of Kurtosis is beyond the scope of this report, however, it also has an acceptable value of -1 to 1.

If the skewness or Kurtosis value of a residual's distribution is not within the acceptable range (-1 to 1), it is recommended to transform the dependent variable of a regression model in order to bring its outliers closer to the variable's mean value. Some typical transformation techniques are: taking the square root or $\log_{10}$ of a variable's values in order to correct for significant positive skew, and squaring or cubing a variable's values in order to correct for significant negative skew.

After we performed the three stepwise regression analyses, it was revealed that the flow rate analysis was the only one with significant residual skew. Flow rate had some seriously high skew and kurtosis values, indicating a significant positive skew in its residual distribution. We performed a Log_{10} transformation on the flow rate variable (created a new variable), re-regressed it using the new Log_{10} variable as the dependent, and noticed a change in the distribution of residuals toward normalcy (skewness and kurtosis statistics were much lower). The impeded regression did not create significantly skewed residuals. In addition, the regression analysis with speed as the dependent variable (excluding the 8W PM and 60E AM cases) resulted in skewness and kurtosis statistics which were acceptable.

APPENDIX G.

LOCATION CHARACTERISTICS AND SPEED REGRESSION SUMMARY

Regression Analysis

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Change Statistics				
					R Square Change	F Change	df1	df2	Sig. F Change
8*	0.861	0.741	0.726	0.124536	-0.001	0.357	1	109	0.551

* Model 8 Predictors: (Constant), Group:1, Impeded, Flow Rate, Bag: No, Female, Trip: Work
** Dependent Variable: Mean Speed

Table: ANOVA

Model		Sum of Squares	df	Mean Square	F	Sig.
8	Regression	4.871	6	0.812	52.346	.000(h)
	Residual	1.706	110	0.016		
	Total	6.577	116			

Predictors: (Constant), Group: 1, Impeded, Flow Rate, Bag: No, Female, Trip: Work

Table: Coefficients

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.	95% Confidence Interval for B		Correlations			Collinearity Statistics	
		B	Std. Error	Beta			Lower Bound	Upper Bound	Zero-order	Partial	Part	Tolerance	VIF
8	(Constant)	4.493	0.13		34.631	0	4.236	4.75					
	Group: 1	0.358	0.113	0.209	3.16	0.002	0.133	0.582	0.628	0.289	0.153	0.541	1.849
	Impeded	-0.48	0.104	-0.278	-4.602	0	-0.687	-0.274	-0.594	-0.402	-0.223	0.648	1.542
	Flow Rate	-0.037	0.01	-0.218	-3.772	0	-0.056	-0.018	-0.47	-0.338	-0.183	0.706	1.417
	Bag: No	-0.667	0.125	-0.321	-5.341	0	-0.915	-0.42	-0.49	-0.454	-0.259	0.653	1.531
	Female	-0.547	0.165	-0.18	-3.309	0.001	-0.875	-0.219	-0.315	-0.301	-0.161	0.798	1.253

APPENDIX H.

SPEED BY TIME OF DAY REGRESSION SUMMARY

Regression: AM

Model Summary(e)

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Change Statistics				
					R Square Change	F Change	df1	df2	Sig. F Change
1	.542(a)	0.294	0.268	0.100338	0.294	11.245	1	27	0.002
2	.787(b)	0.619	0.59	0.075112	0.325	22.182	1	26	0
3	.829(c)	0.688	0.65	0.06937	0.069	5.482	1	25	0.027
4	.862(d)	0.743	0.7	0.064252	0.055	5.141	1	24	0.033

a Predictors: (Constant), Flow Rate
b Predictors: (Constant), Flow Rate, Trip: Work
c Predictors: (Constant), Flow Rate, Trip: Work, Engaged in activity
d Predictors: (Constant), Flow Rate, Trip: Work, Engaged in activity, Group: 3
e Dependent Variable: Mean Speed

ANOVA(e)

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	0.113	1	0.113	11.245	.002(a)
	Residual	0.272	27	0.01		
	Total	0.385	28			
2	Regression	0.238	2	0.119	21.124	.000(b)
	Residual	0.147	26	0.006		
	Total	0.385	28			
3	Regression	0.265	3	0.088	18.338	.000(c)
	Residual	0.12	25	0.005		
	Total	0.385	28			
4	Regression	0.286	4	0.071	17.317	.000(d)
	Residual	0.099	24	0.004		
	Total	0.385	28			

a Predictors: (Constant), Flow Rate
b Predictors: (Constant), Flow Rate, Trip: Work
c Predictors: (Constant), Flow Rate, Trip: Work, Engaged in activity
d Predictors: (Constant), Flow Rate, Trip: Work, Engaged in activity, Group: 3
e Dependent Variable: Mean Speed

Coefficients(a)

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.	95% Confidence Interval for B	
		B	Std. Error	Beta			Lower Bound	Upper Bound
1	(Constant)	4.646	0.036		127.563	0	4.571	4.721
	Flow Rate	-0.061	0.018	-0.542	-3.353	0.002	-0.099	-0.024
2	(Constant)	4.304	0.078		55.497	0	4.145	4.464
	Flow Rate	-0.117	0.018	-1.034	-6.468	0	-0.154	-0.08
	Trip: Work	0.679	0.144	0.753	4.71	0	0.382	0.975
3	(Constant)	4.276	0.073		58.868	0	4.126	4.426
	Flow Rate	-0.115	0.017	-1.021	-6.916	0	-0.15	-0.081
	Trip: Work	0.599	0.137	0.664	4.358	0	0.316	0.882
	Engaged in activity	0.5	0.214	0.274	2.341	0.027	0.06	0.94
4	(Constant)	4.321	0.07		61.612	0	4.176	4.466
	Flow Rate	-0.118	0.015	-1.045	-7.617	0	-0.15	-0.086
	Trip: Work	0.575	0.128	0.637	4.499	0	0.311	0.838
	Engaged in activity	0.471	0.198	0.258	2.375	0.026	0.062	0.88
	Group: 3	-0.892	0.393	-0.241	-2.267	0.033	-1.704	-0.08

a Dependent Variable: Mean Speed

Residuals Statistics(a)

	Minimum	Maximum	Mean	Std. Deviation	N
Predicted Value	4.21604	4.73845	4.54128	0.101059	29
Residual	-0.10328	0.14051	0	0.059486	29
Std. Predicted Value	-3.218	1.951	0	1	29
Std. Residual	-1.607	2.187	0	0.926	29

a Dependent Variable: Mean Speed

Regression: MIDDAY

Model Summary(c)

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Change Statistics				
					R Square Change	F Change	df1	df2	Sig. F Change
1	.621(a)	0.385	0.375	0.140594	0.385	37.627	1	60	0
2	.655(b)	0.429	0.41	0.136637	0.044	4.525	1	59	0.038

a Predictors: (Constant), Impeded
b Predictors: (Constant), Impeded, Flow Rate
c Dependent Variable: Mean Speed

ANOVA(c)

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	0.744	1	0.744	37.627	.000(a)
	Residual	1.186	60	0.02		
	Total	1.93	61			
2	Regression	0.828	2	0.414	22.181	.000(b)
	Residual	1.102	59	0.019		
	Total	1.93	61			

a Predictors: (Constant), Impeded
b Predictors: (Constant), Impeded, Flow Rate
c Dependent Variable: Mean Speed

Coefficients(a)

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.	95% Confidence Interval for B	
		B	Std. Error	Beta			Lower Bound	Upper Bound
1	(Constant)	4.291	0.03		142.632	0	4.231	4.351
	Impeded	-0.732	0.119	-0.621	-6.134	0	-0.971	-0.493
2	(Constant)	4.343	0.038		114.411	0	4.267	4.419
	Impeded	-0.612	0.129	-0.519	-4.74	0	-0.87	-0.353
	Flow Rate	-0.027	0.012	-0.233	-2.127	0.038	-0.052	-0.002

a Dependent Variable: Mean Speed

Residuals Statistics(a)

	Minimum	Maximum	Mean	Std. Deviation	N
Predicted Value	3.83284	4.31229	4.14257	0.116524	62
Residual	-0.29602	0.25102	0	0.134379	62
Std. Predicted Value	-2.658	1.457	0	1	62
Std. Residual	-2.166	1.837	0	0.983	62

a Dependent Variable: Mean Speed

Regression: PM (EXCLUDE 98)

Model Summary(e)

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Change Statistics				
					R Square Change	F Change	df1	df2	Sig. F Change
1	.716(a)	0.512	0.492	0.13601	0.512	25.219	1	24	0
2	.807(b)	0.651	0.621	0.117467	0.139	9.175	1	23	0.006
3	.846(c)	0.716	0.677	0.108463	0.064	4.977	1	22	0.036
4	.896(d)	0.803	0.766	0.092375	0.087	9.33	1	21	0.006

a Predictors: (Constant), Group: 1
b Predictors: (Constant), Group: 1, Trip: Work
c Predictors: (Constant), Group: 1, Trip: Work, Bag: No
d Predictors: (Constant), Group: 1, Trip: Work, Bag: No, Impeded
e Dependent Variable: Mean Speed

ANOVA(e)

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	0.467	1	0.467	25.219	.000(a)
	Residual	0.444	24	0.018		
	Total	0.91	25			
2	Regression	0.593	2	0.297	21.492	.000(b)
	Residual	0.317	23	0.014		
	Total	0.91	25			
3	Regression	0.652	3	0.217	18.465	.000(c)
	Residual	0.259	22	0.012		
	Total	0.91	25			
4	Regression	0.731	4	0.183	21.425	.000(d)
	Residual	0.179	21	0.009		
	Total	0.91	25			

a Predictors: (Constant), Group: 1
b Predictors: (Constant), Group: 1, Trip: Work
c Predictors: (Constant), Group: 1, Trip: Work, Bag: No
d Predictors: (Constant), Group: 1, Trip: Work, Bag: No, Impeded
e Dependent Variable: Mean Speed

Coefficients(a)

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.	95% Confidence Interval for B	
		B	Std. Error	Beta			Lower Bound	Upper Bound
1	(Constant)	3.623	0.151		23.933	0	3.311	3.936
	Group: 1	1.116	0.222	0.716	5.022	0	0.657	1.575
2	(Constant)	3.602	0.131		27.504	0	3.331	3.873
	Group: 1	0.871	0.208	0.558	4.18	0	0.44	1.302
3	Trip: Work	0.465	0.153	0.405	3.029	0.006	0.147	0.782
	(Constant)	3.848	0.164		23.49	0	3.509	4.188
	Group: 1	0.781	0.197	0.501	3.973	0.001	0.373	1.188
	Trip: Work	0.435	0.142	0.379	3.062	0.006	0.141	0.73
4	Bag: No	-0.685	0.307	-0.263	-2.231	0.036	-1.322	-0.048
	(Constant)	3.98	0.146		27.248	0	3.677	4.284
	Group: 1	0.713	0.169	0.458	4.226	0	0.362	1.065
	Trip: Work	0.524	0.125	0.456	4.207	0	0.265	0.783
	Bag: No	-0.872	0.269	-0.335	-3.244	0.004	-1.43	-0.313
	Impeded	-0.528	0.173	-0.313	-3.055	0.006	-0.888	-0.169

a Dependent Variable: Mean Speed

Residuals Statistics(a)

	Minimum	Maximum	Mean	Std. Deviation	N
Predicted Value	4.04805	4.71905	4.37176	0.17103	26
Residual	-0.16514	0.1516	0	0.084663	26
Std. Predicted Value	-1.893	2.031	0	1	26
Std. Residual	-1.788	1.641	0	0.917	26

a Dependent Variable: Mean Speed

Regression: ALL

Model Summary(i)

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Change Statistics				
					R Square Change	F Change	df1	df2	Sig. F Change
1	.628(a)	0.395	0.39	0.186018	0.395	75.072	1	115	0
2	.764(b)	0.584	0.576	0.155005	0.189	51.622	1	114	0
3	.792(c)	0.628	0.618	0.147182	0.044	13.441	1	113	0
4	.817(d)	0.668	0.656	0.139635	0.04	13.544	1	112	0
5	.840(e)	0.705	0.692	0.132165	0.037	14.019	1	111	0
6	.854(f)	0.73	0.715	0.127031	0.025	10.153	1	110	0.002
7	.861(g)	0.741	0.725	0.124901	0.011	4.783	1	109	0.031
8	.861(h)	0.741	0.726	0.124536	-0.001	0.357	1	109	0.551

a Predictors: (Constant), Group: 1
b Predictors: (Constant), Group: 1, Impeded
c Predictors: (Constant), Group: 1, Impeded, Trip: Unknown
d Predictors: (Constant), Group: 1, Impeded, Trip: Unknown, Flow Rate
e Predictors: (Constant), Group: 1, Impeded, Trip: Unknown, Flow Rate, Bag: No
f Predictors: (Constant), Group: 1, Impeded, Trip: Unknown, Flow Rate, Bag: No, Female
g Predictors: (Constant), Group: 1, Impeded, Trip: Unknown, Flow Rate, Bag: No, Female, Trip: Work
h Predictors: (Constant), Group: 1, Impeded, Flow Rate, Bag: No, Female, Trip: Work
i Dependent Variable: Mean Speed

ANOVA(i)

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	2.598	1	2.598	75.072	.000(a)
	Residual	3.979	115	0.035		
	Total	6.577	116			
2	Regression	3.838	2	1.919	79.87	.000(b)
	Residual	2.739	114	0.024		
	Total	6.577	116			
3	Regression	4.129	3	1.376	63.538	.000(c)
	Residual	2.448	113	0.022		
	Total	6.577	116			
4	Regression	4.393	4	1.098	56.329	.000(d)
	Residual	2.184	112	0.019		
	Total	6.577	116			
5	Regression	4.638	5	0.928	53.106	.000(e)
	Residual	1.939	111	0.017		
	Total	6.577	116			
6	Regression	4.802	6	0.8	49.596	.000(f)
	Residual	1.775	110	0.016		
	Total	6.577	116			
7	Regression	4.877	7	0.697	44.657	.000(g)
	Residual	1.7	109	0.016		
	Total	6.577	116			
8	Regression	4.871	6	0.812	52.346	.000(h)
	Residual	1.706	110	0.016		
	Total	6.577	116			

a Predictors: (Constant), Group: 1
b Predictors: (Constant), Group: 1, Impeded
c Predictors: (Constant), Group: 1, Impeded, Trip: Unknown
d Predictors: (Constant), Group: 1, Impeded, Trip: Unknown, Flow Rate
e Predictors: (Constant), Group: 1, Impeded, Trip: Unknown, Flow Rate, Bag: No
f Predictors: (Constant), Group: 1, Impeded, Trip: Unknown, Flow Rate, Bag: No, Female
g Predictors: (Constant), Group: 1, Impeded, Trip: Unknown, Flow Rate, Bag: No, Female, Trip: Work
h Predictors: (Constant), Group: 1, Impeded, Flow Rate, Bag: No, Female, Trip: Work
i Dependent Variable: Mean Speed

Coefficients(a)

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.	95% Confidence Interval for B	
		B	Std. Error	Beta			Lower Bound	Upper Bound
1	(Constant)	3.577	0.084		42.391	0	3.41	3.744
	Group: 1	1.078	0.124	0.628	8.664	0	0.831	1.324
2	(Constant)	3.844	0.08		48.318	0	3.687	4.002
	Group: 1	0.86	0.108	0.501	7.957	0	0.646	1.074
	Impeded	-0.783	0.109	-0.453	-7.185	0	-0.999	-0.567
3	(Constant)	3.999	0.087		46.182	0	3.828	4.171
	Group: 1	0.827	0.103	0.482	8.032	0	0.623	1.031
	Impeded	-0.768	0.104	-0.443	-7.406	0	-0.973	-0.562
	Trip: Unknown	-0.362	0.099	-0.212	-3.666	0	-0.557	-0.166
4	(Constant)	4.102	0.087		47.286	0	3.93	4.274
	Group: 1	0.802	0.098	0.468	8.197	0	0.608	0.996
	Impeded	-0.554	0.114	-0.32	-4.846	0	-0.78	-0.327
	Trip: Unknown	-0.421	0.095	-0.246	-4.43	0	-0.609	-0.233
	Flow Rate	-0.041	0.011	-0.239	-3.68	0	-0.062	-0.019
5	(Constant)	4.388	0.112		39.096	0	4.166	4.611
	Group: 1	0.618	0.105	0.361	5.896	0	0.411	0.826
	Impeded	-0.52	0.108	-0.3	-4.791	0	-0.735	-0.305
	Trip: Unknown	-0.467	0.091	-0.273	-5.148	0	-0.647	-0.287
	Flow Rate	-0.04	0.01	-0.235	-3.821	0	-0.061	-0.019
	Bag: No	-0.468	0.125	-0.225	-3.744	0	-0.716	-0.22
6	(Constant)	4.647	0.135		34.434	0	4.379	4.914
	Group: 1	0.58	0.102	0.338	5.707	0	0.378	0.781
	Impeded	-0.447	0.107	-0.258	-4.188	0	-0.659	-0.236
	Trip: Unknown	-0.393	0.09	-0.23	-4.35	0	-0.572	-0.214
	Flow Rate	-0.038	0.01	-0.222	-3.742	0	-0.058	-0.018
	Bag: No	-0.583	0.125	-0.28	-4.646	0	-0.831	-0.334
	Female	-0.541	0.17	-0.178	-3.186	0.002	-0.878	-0.205
7	(Constant)	4.529	0.143		31.632	0	4.245	4.813
	Group: 1	0.396	0.13	0.231	3.038	0.003	0.138	0.655
	Impeded	-0.472	0.106	-0.273	-4.473	0	-0.682	-0.263
	Trip: Unknown	-0.097	0.162	-0.057	-0.598	0.551	-0.418	0.224
	Flow Rate	-0.038	0.01	-0.221	-3.802	0	-0.057	-0.018
	Bag: No	-0.653	0.127	-0.314	-5.125	0	-0.906	-0.401
	Female	-0.534	0.167	-0.176	-3.198	0.002	-0.866	-0.203
	Trip: Work	0.317	0.145	0.233	2.187	0.031	0.03	0.604
8	(Constant)	4.493	0.13		34.631	0	4.236	4.75
	Group: 1	0.358	0.113	0.209	3.16	0.002	0.133	0.582
	Impeded	-0.48	0.104	-0.278	-4.602	0	-0.687	-0.274
	Flow Rate	-0.037	0.01	-0.218	-3.772	0	-0.056	-0.018
	Bag: No	-0.667	0.125	-0.321	-5.341	0	-0.915	-0.42
	Female	-0.547	0.165	-0.18	-3.309	0.001	-0.875	-0.219
	Trip: Work	0.389	0.079	0.287	4.914	0	0.232	0.546

a Dependent Variable: Mean Speed

Residuals Statistics(a)

	Minimum	Maximum	Mean	Std. Deviation	N
Predicted Value	3.85126	4.71099	4.29233	0.204919	117
Residual	-0.3058	0.30367	0	0.121272	117
Std. Predicted Value	-2.152	2.043	0	1	117
Std. Residual	-2.455	2.438	0	0.974	117

a Dependent Variable: Mean Speed

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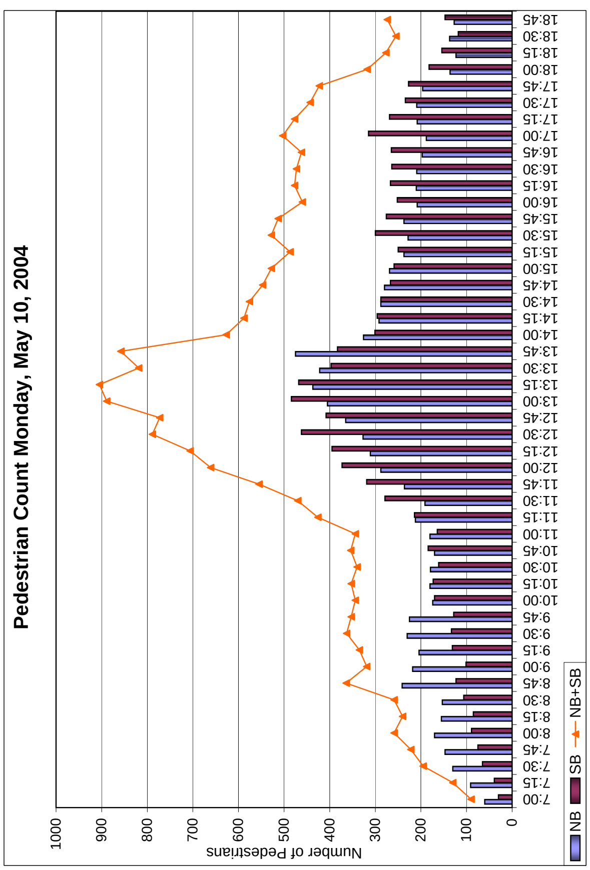
APPENDIX I.

SEVEN DAY PEDESTRIAN AND VEHICULAR COUNT SUMMARY


Pedestrian Count Monday, May 10, 2004
Number of Pedestrians
NB
SB
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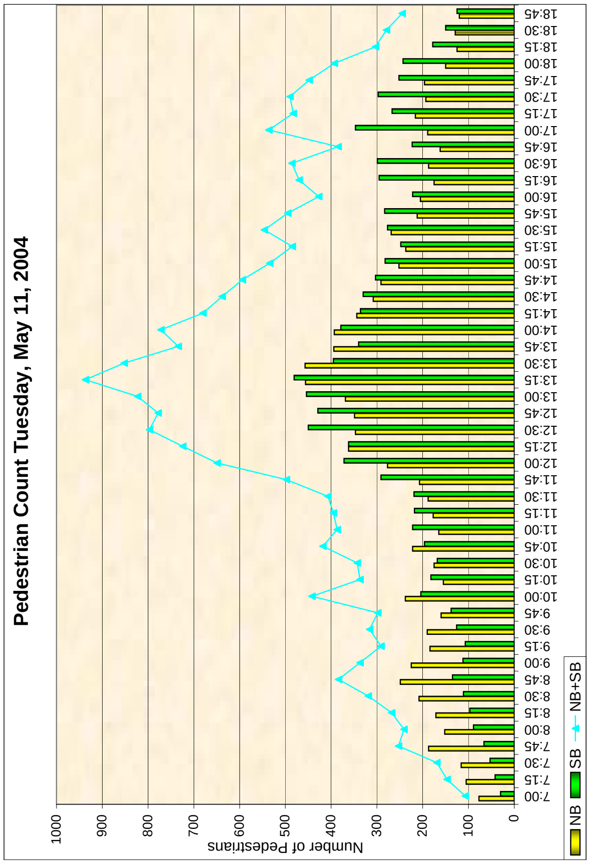
Pedestrian Count Tuesday, May 11, 2004
Number of Pedestrians
NB
SB
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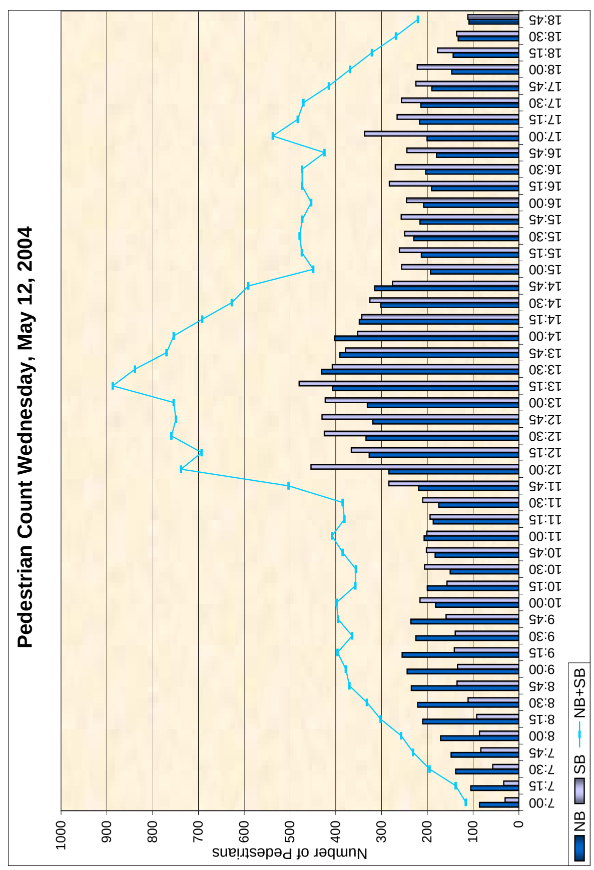
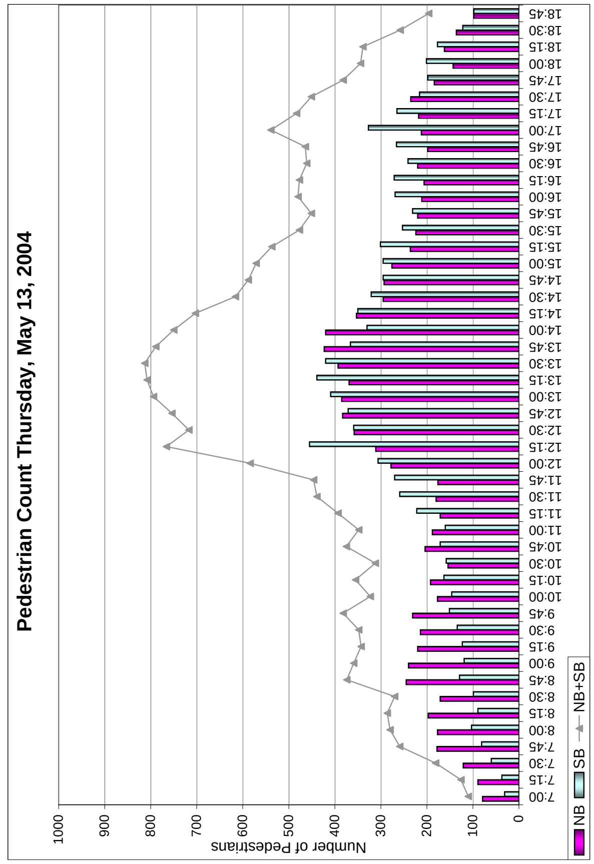
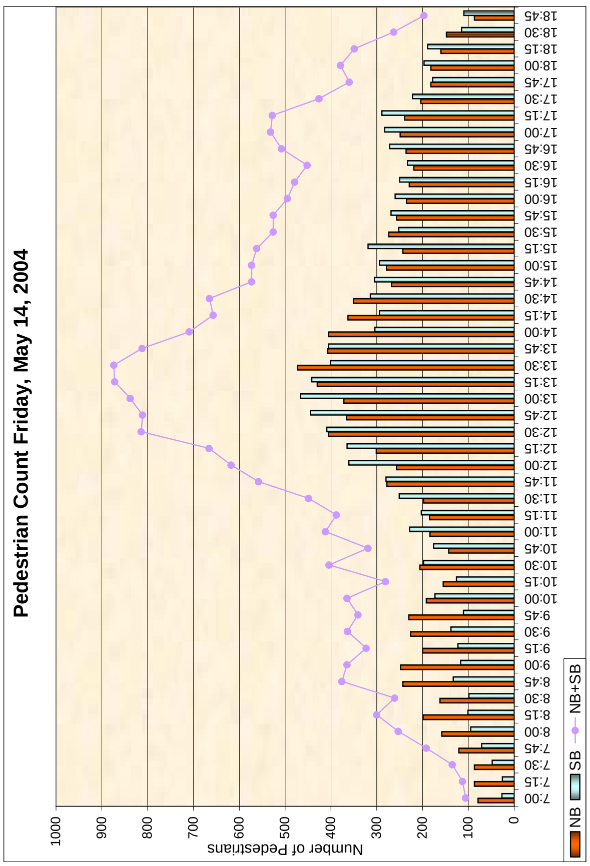
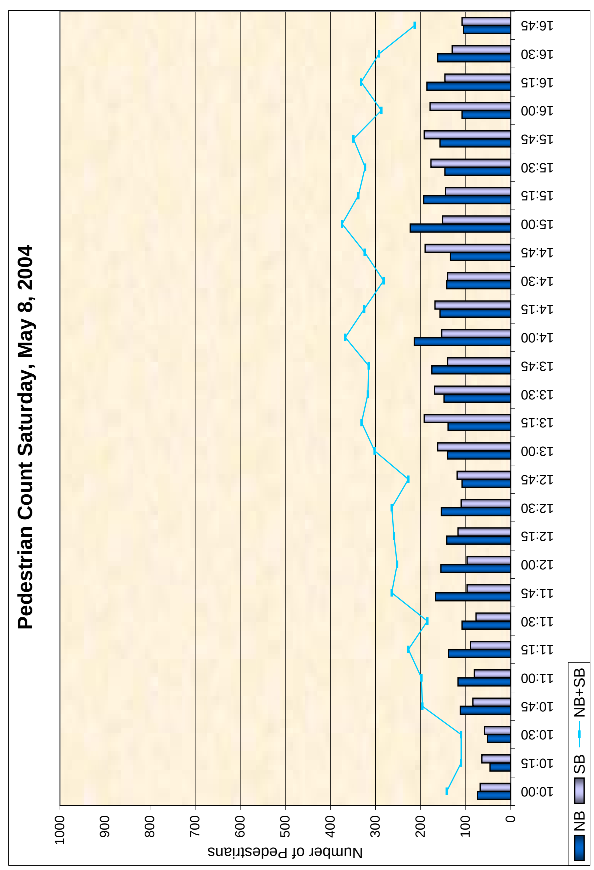
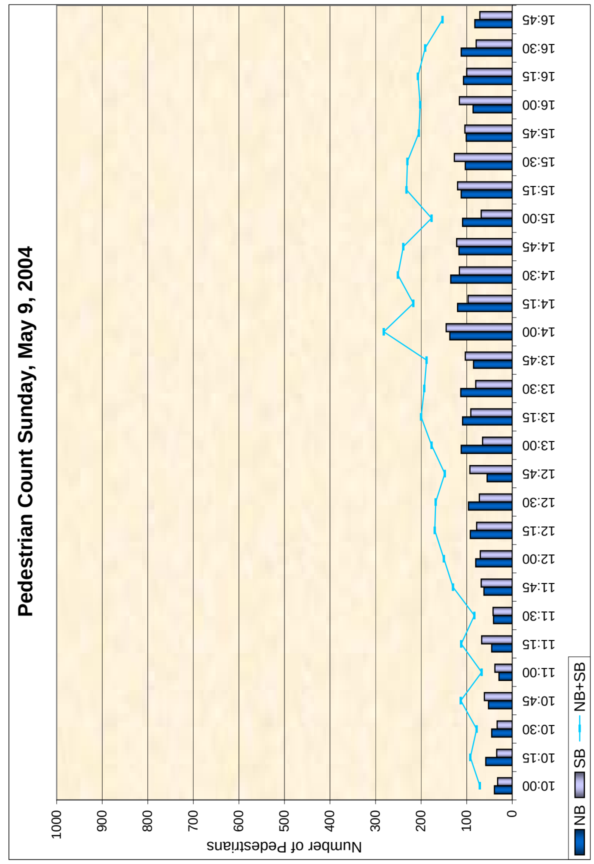
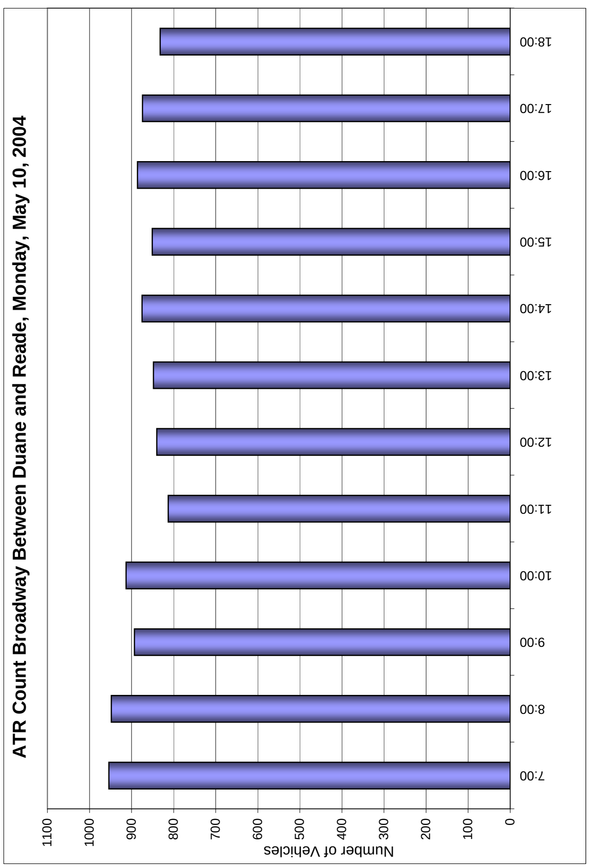

Pedestrian Count Wednesday, May 12, 2004
Number of Pedestrians
NB
SB
NB+SB


Pedestrian Count Thursday, May 13, 2004
Number of Pedestrians
NB
SB
NB+SB


Pedestrian Count Friday, May 14, 2004
Number of Pedestrians
NB
SB
NB+SB


Pedestrian Count Saturday, May 8, 2004
Number of Pedestrians
NB
SB
NB+SB


Pedestrian Count Sunday, May 9, 2004
Number of Pedestrians
NB
SB
NB+SB


ATR Count Broadway Between Duane and Reade, Monday, May 10, 2004
Number of Vehicles
0
100
200
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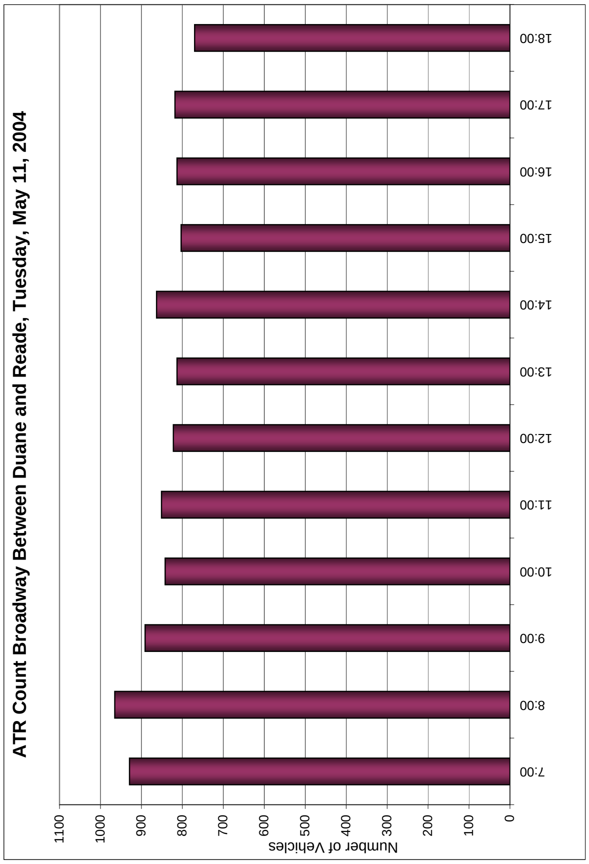
ATR Count Broadway Between Duane and Reade, Tuesday, May 11, 2004
Number of Vehicles
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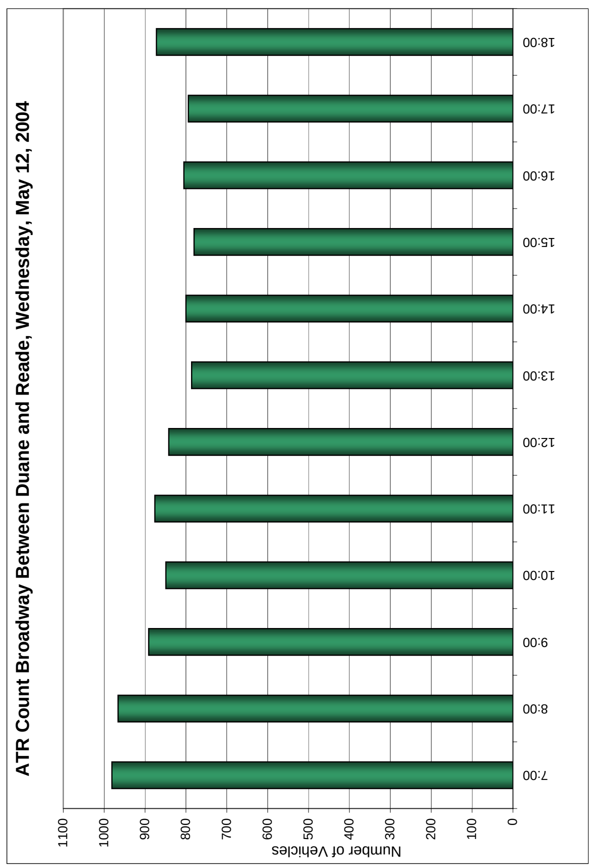
ATR Count Broadway Between Duane and Reade, Wednesday, May 12, 2004
Number of Vehicles
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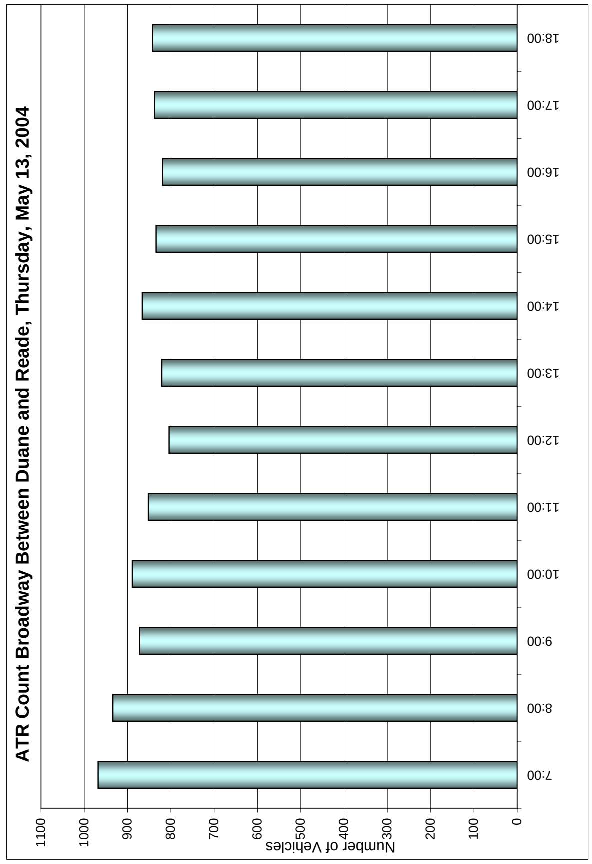
ATR Count Broadway Between Duane and Reade, Thursday, May 13, 2004
Number of Vehicles
0
100
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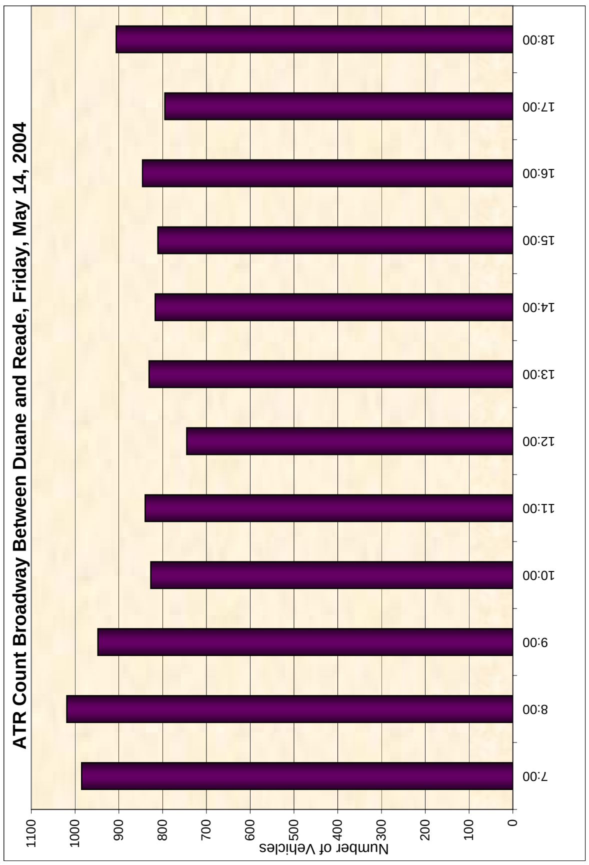
ATR Count Broadway Between Duane and Reade, Friday, May 14, 2004
Number of Vehicles
0
100
200
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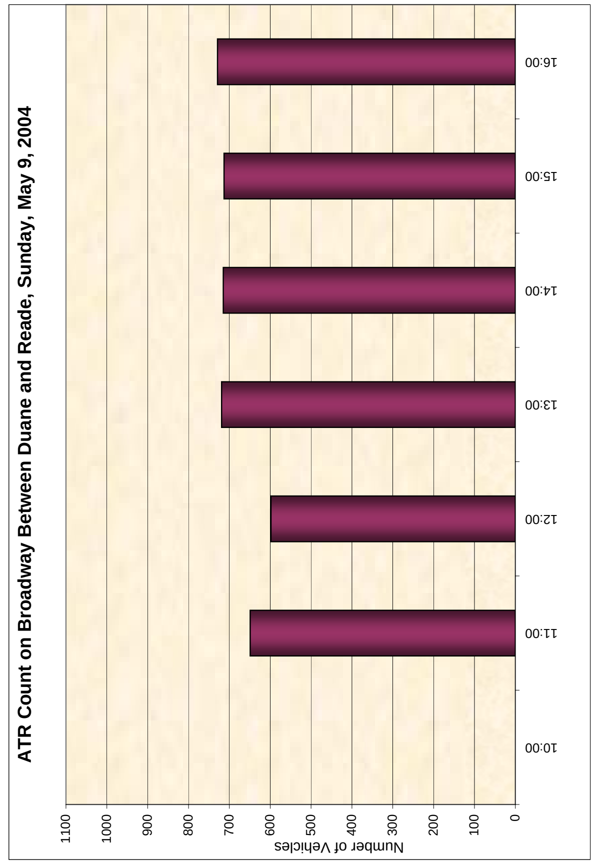
ATR Count on Broadway Between Duane and Reade, Sunday, May 9, 2004
Number of Vehicles
0
100
200
300
400
500
600
700
800
900
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1100
10:00
11:00
12:00
13:00
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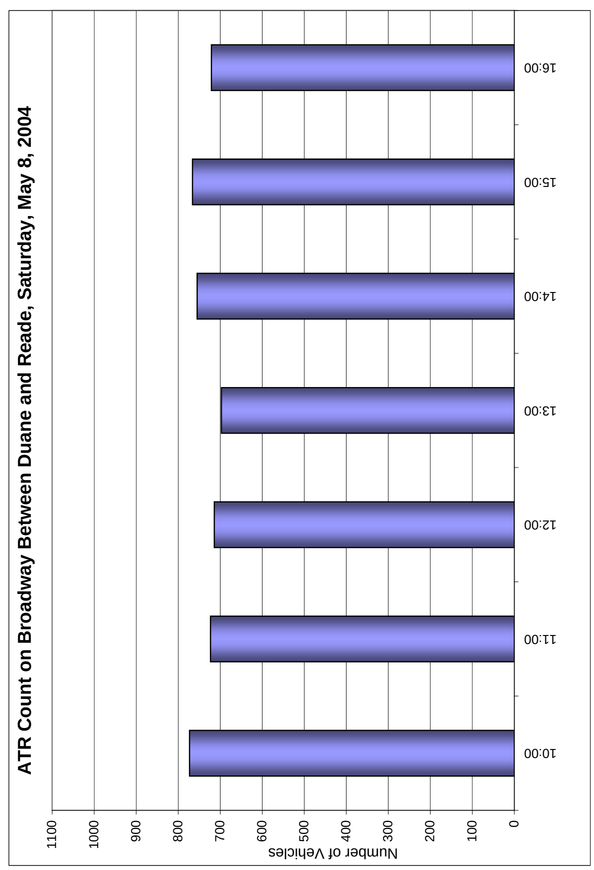
ATR Count on Broadway Between Duane and Reade, Saturday, May 8, 2004
Number of Vehicles
0
100
200
300
400
500
600
700
800
900
1000
1100
10:00
11:00
12:00
13:00
14:00
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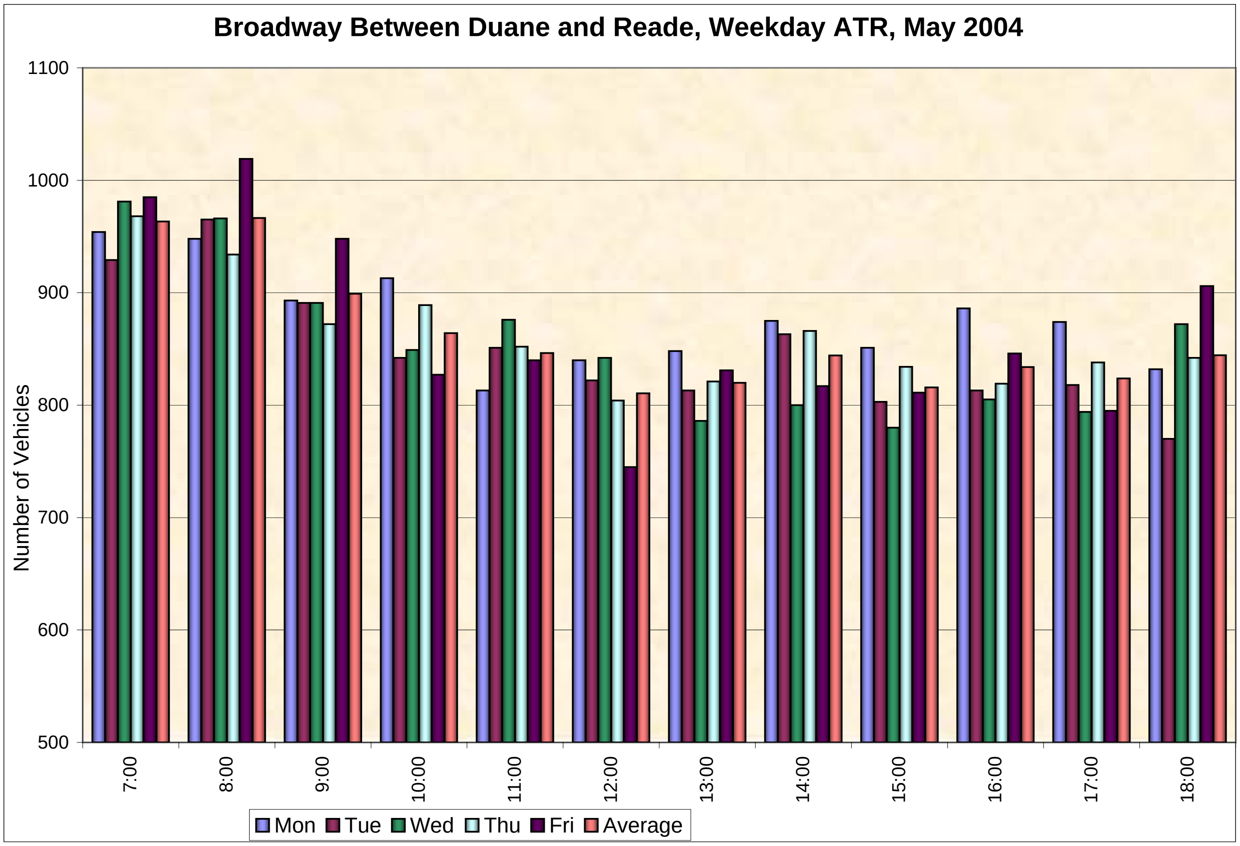
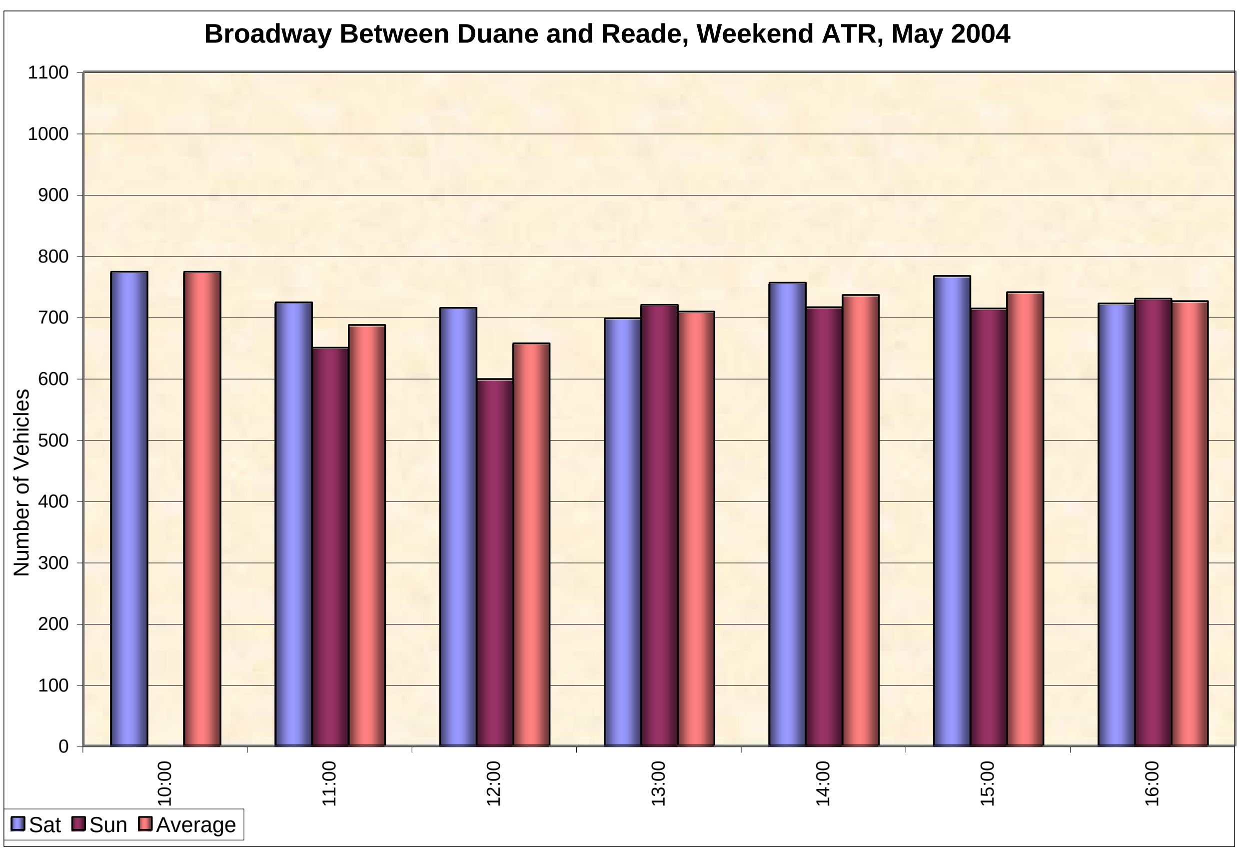

Broadway Between Duane and Reade, Weekday ATR, May 2004
Number of Vehicles
1100
1000
900
800
700
600
500
7:00
8:00
9:00
10:00
11:00
12:00
13:00
14:00
15:00
16:00
17:00
18:00
Mon
Tue
Wed
Thu
Fri
Average


Broadway Between Duane and Reade, Weekend ATR, May 2004
Number of Vehicles
1100
1000
900
800
700
600
500
400
300
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100
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10:00
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14:00
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16:00
Sat
Sun
Average

APPENDIX J.

SPEED AND DELAY WALK SUMMARY BY WALKER & TIME

Walker A						
	All		Around 12:30pm		Around 3:30pm	
	Average	Median	Average	Median	Average	Median
Time (s) (Walk Time)						
Southbound	821.03	803.64	854.60	846.20	794.17	790.72
Northbound	667.09	658.39	685.46	672.14	652.39	653.62
Total	1488.12	1452.79	1540.07	1518.34	1446.56	1442.83
Time (s) (Stop Time)						
Southbound	39.34	39.89	35.97	26.32	42.03	43.93
Northbound	35.40	35.99	36.88	35.83	34.21	35.99
Total	74.73	78.95	72.85	75.22	76.24	78.95
All Speed (ft/s)						
Southbound	6.06	6.15	5.74	5.72	6.31	6.30
Northbound	6.18	6.25	5.92	5.97	6.38	6.40
Average	6.12	6.23	5.83	5.89	6.35	6.33
All Sidewalk Speed (ft/s)						
Southbound	5.89	6.03	5.68	5.71	6.06	6.06
Northbound	5.92	5.99	5.75	5.89	6.05	6.04
Average	5.90	6.02	5.71	5.81	6.06	6.04
Sidewalk Speed, No Stop at Crosswalk (ft/s)						
Southbound	5.87	5.98	5.66	5.68	6.03	6.03
Northbound	5.87	5.93	5.69	5.77	6.02	6.03
Average	5.87	5.98	5.67	5.73	6.02	6.04
Sidewalk Speed, After Stop at Crosswalk (ft/s)						
Southbound	6.08	6.16	5.85	5.95	6.26	6.24
Northbound	6.09	6.16	5.99	6.12	6.18	6.19
Average	6.09	6.14	5.92	6.02	6.22	6.19
All Crosswalk Speed (ft/s)						
Southbound	6.23	6.41	5.80	5.74	6.57	6.54
Northbound	6.48	6.59	6.12	6.06	6.77	6.69
Average	6.36	6.52	5.96	5.93	6.67	6.62
Crosswalk Speed After Stop (ft/s)						
Southbound	6.16	6.12	6.08	6.08	6.22	6.18
Northbound	5.71	6.45	6.02	5.96	5.46	6.63
Average	5.58	6.29	6.05	5.96	5.20	6.38
Crosswalk Speed with No Stop (ft/s)						
Southbound	6.24	6.39	5.75	5.74	6.63	6.51
Northbound	6.47	6.57	6.11	6.17	6.76	6.67
Average	6.36	6.47	5.93	5.94	6.69	6.64

Walker B						
	ALL		Around 12:30pm		Around 1:30pm	
	Average	Median	Average	Median	Average	Median
Time (s) (Walk Time)						
Southbound	958.23	973.02	954.07	973.02	964.47	964.47
Northbound	791.14	783.71	812.77	814.24	758.69	758.69
Total	1749.37	1753.03	1766.84	1756.73	1723.16	1723.16
Time (s) (Stop Time)						
Southbound	45.43	51.16	50.29	54.87	38.13	38.13
Northbound	59.29	56.69	65.25	61.78	50.35	50.35
Total	104.71	93.37	115.54	93.37	88.48	88.48
All Speed (ft/s)						
Southbound	5.07	5.03	5.08	5.03	5.06	5.06
Northbound	5.09	5.21	4.95	4.85	5.31	5.31
Average	5.08	5.10	5.01	4.99	5.18	5.18
All Sidewalk Speed (ft/s)						
Southbound	5.02	4.95	4.98	4.95	5.07	5.07
Northbound	5.01	5.01	4.89	4.84	5.20	5.20
Average	5.02	4.98	4.94	4.95	5.14	5.14
Sidewalk Speed, No Stop at Crosswalk (ft/s)						
Southbound	5.00	4.96	4.98	4.96	5.04	5.04
Northbound	5.01	5.00	4.93	4.91	5.13	5.13
Average	5.01	4.97	4.95	4.96	5.09	5.09
Sidewalk Speed, After Stop at Crosswalk (ft/s)						
Southbound	4.94	4.94	4.72	4.93	5.28	5.28
Northbound	5.07	5.04	4.79	4.68	5.49	5.49
Average	5.00	4.99	4.75	4.79	5.38	5.38
All Crosswalk Speed (ft/s)						
Southbound	5.13	5.09	5.18	5.12	5.04	5.04
Northbound	5.18	5.35	5.02	4.88	5.43	5.43
Average	5.16	5.19	5.10	5.03	5.24	5.24
Crosswalk Speed After Stop (ft/s)						
Southbound	4.52	4.48	4.43	4.48	4.65	4.65
Northbound	4.97	4.89	5.03	4.81	4.89	4.89
Average	4.75	4.65	4.73	4.65	4.77	4.77
Crosswalk Speed with No Stop (ft/s)						
Southbound	5.21	5.22	5.28	5.28	5.10	5.10
Northbound	5.22	5.43	5.02	4.90	5.52	5.52
Average	5.21	5.24	5.15	5.06	5.31	5.31

Walker C						
	ALL		Around 2:30pm		Around 3:30pm	
	Average	Median	Average	Median	Average	Median
Time (s) (Walk Time)						
Southbound	1001.62	1006.70	1009.44	1007.11	931.22	931.22
Northbound	832.25	836.83	839.49	837.31	767.11	767.11
Total	1833.87	1842.95	1848.93	1849.68	1698.33	1698.33
Time (s) (Stop Time)						
Southbound	75.82	73.51	77.91	76.55	57.08	57.08
Northbound	79.47	83.99	87.31	93.59	8.94	8.94
Total	155.29	154.99	165.21	177.96	66.02	66.02
All Speed (ft/s)						
Southbound	4.88	4.88	4.86	4.87	5.11	5.11
Northbound	4.97	4.90	4.93	4.88	5.29	5.29
Average	4.93	4.88	4.89	4.87	5.20	5.20
All Sidewalk Speed (ft/s)						
Southbound	4.82	4.79	4.77	4.78	5.19	5.19
Northbound	4.74	4.72	4.70	4.71	5.15	5.15
Average	4.78	4.75	4.74	4.75	5.17	5.17
Sidewalk Speed, No Stop at Crosswalk (ft/s)						
Southbound	4.80	4.79	4.76	4.78	5.23	5.23
Northbound	4.71	4.67	4.66	4.66	5.15	5.15
Average	4.76	4.74	4.71	4.71	5.19	5.19
Sidewalk Speed, After Stop at Crosswalk (ft/s)						
Southbound	4.86	4.80	4.84	4.76	5.08	5.08
Northbound	4.79	4.77	4.76	4.76	5.13	5.13
Average	4.83	4.78	4.80	4.76	5.11	5.11
All Crosswalk Speed (ft/s)						
Southbound	4.96	4.99	4.95	4.98	5.04	5.04
Northbound	5.23	5.14	5.20	5.14	5.46	5.46
Average	5.09	5.11	5.08	5.11	5.25	5.25
Crosswalk Speed After Stop (ft/s)						
Southbound	4.68	4.60	4.61	4.55	5.31	5.31
Northbound	4.82	4.71	4.77	4.63	5.29	5.29
Average	4.75	4.70	4.69	4.63	5.30	5.30
Crosswalk Speed with No Stop (ft/s)						
Southbound	5.04	5.08	5.06	5.10	4.92	4.92
Northbound	5.36	5.32	5.35	5.30	5.48	5.48
Average	5.20	5.21	5.20	5.22	5.20	5.20

Walker D						
	ALL		Around 12:30pm		Around 3:30pm	
	Average	Median	Average	Median	Average	Median
Time (s) (Walk Time)						
Southbound	1023.85	1021.24	1033.66	1051.65	1014.05	1011.30
Northbound	830.04	834.42	825.82	850.20	834.26	831.73
Total	1853.89	1843.58	1859.48	1907.53	1848.31	1840.22
Time (s) (Stop Time)						
Southbound	58.01	62.37	39.36	38.10	76.67	74.31
Northbound	60.93	52.07	48.61	51.68	73.24	82.37
Total	118.94	108.47	87.97	89.78	149.91	154.00
All Speed (ft/s)						
Southbound	4.74	4.73	4.75	4.65	4.73	4.75
Northbound	4.82	4.78	4.87	4.78	4.76	4.77
Average	4.78	4.76	4.81	4.76	4.75	4.76
All Sidewalk Speed (ft/s)						
Southbound	4.75	4.75	4.75	4.68	4.76	4.75
Northbound	4.74	4.77	4.72	4.66	4.76	4.78
Average	4.75	4.76	4.73	4.63	4.76	4.76
Sidewalk Speed, No Stop at Crosswalk (ft/s)						
Southbound	4.76	4.77	4.75	4.70	4.77	4.81
Northbound	4.73	4.75	4.71	4.61	4.76	4.77
Average	4.75	4.77	4.73	4.64	4.76	4.78
Sidewalk Speed, After Stop at Crosswalk (ft/s)						
Southbound	4.38	4.68	4.01	4.59	4.74	4.68
Northbound	4.77	4.80	4.76	4.80	4.77	4.80
Average	4.40	4.73	4.04	4.67	4.76	4.75
All Crosswalk Speed (ft/s)						
Southbound	4.73	4.73	4.76	4.81	4.70	4.70
Northbound	4.90	4.86	5.05	4.96	4.76	4.76
Average	4.82	4.77	4.90	4.80	4.73	4.77
Crosswalk Speed After Stop (ft/s)						
Southbound	4.18	4.57	3.98	4.62	4.38	4.52
Northbound	4.82	4.80	4.82	4.92	4.82	4.62
Average	4.34	4.56	4.07	4.49	4.60	4.57
Crosswalk Speed with No Stop (ft/s)						
Southbound	4.76	4.76	4.78	4.78	4.73	4.74
Northbound	4.85	4.84	4.93	4.84	4.77	4.83
Average	4.80	4.80	4.85	4.78	4.75	4.80

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APPENDIX K.

PEER REVIEW COMMITTEE COMMENTS AND MEMBER LIST

A peer review committee received a draft of this report. The committee comprised New York City policymakers, selected experts in the field of pedestrian travel and Level of Service analysis, representatives of New York City agencies involved in the review of environmental and traffic analyses, transportation oriented citizens groups, and academics in the fields of urban planning and transportation. A list of recipients is included at the end of this section. Below is a summary of the responses received from members of the peer review committee.

Jeffrey Zupan and Michael Fishman

As part of the peer review for this project, the TD met with Jeffrey Zupan, Senior Transportation Fellow at the Regional Plan Association (RPA) and Michael Fishman, Associate Director for the Halcrow Group.

The Regional Plan Association is a private regional planning and advocacy organization that concentrates on the New York, New Jersey and Connecticut region. In addition to his work at the RPA, Jeffrey Zupan co-authored *Urban Space for Pedestrians* (1975) with Boris Pushkarev, which is cited in this report, in addition to two books and numerous published reports focused on transportation issues in the New York City region.

The Halcrow Group is a private consulting firm, which, according to its web site, "specializes in the provision of planning, design and management services for infrastructure development worldwide." Michael Fishman's consulting focus is in urban design and transportation, among other things.

Zupan and Fishman suggested that the next phase of this project should include methods of quantifying qualitative pedestrian characteristics in the interest of creating a usable street typology for the study area. The TD should apply land use, trip purpose and street typology to the developing database of sidewalk obstacles and shy distance measurements.

Fishman suggested that it might be beneficial to explore the public/private relationship on sidewalks, to develop a way of engaging the private sector in this study's purview. To achieve this, the TD might want to look at the relationship between the city and the property owner as it relates to the sidewalk. According to Fishman in a subsequent email, "(by) effectively answering the question 'What can the City do to help the property owners improve their sidewalks?' you are providing a common platform for issues to emerge and be addressed…These divergent interests are brought together for one purpose, improving the quality of experience on NYC's sidewalks."

In terms of an opposing flow methodology, Zupan pointed out that problems with opposite flows mostly occur not on sidewalks but on stairways, where flow can be highly unbalanced.

In a subsequent email correspondence, Zupan recommended that the TD focus on specific objectives such as "us(ing) your work to clean up streets of clutter, widen sidewalks and even close some streets to vehicle traffic. Your database for Lower Manhattan is critical in redesigning it for pedestrians and to turn over space now used for vehicle space for more effective use." Zupan went on to suggest that the impact of street furniture on the sidewalk is important, and with the right methodology, this study could be applied to situations in which removing street furniture would be advisable.

He also suggested that the study should focus on trip generation and its relationship with land use instead of on the relationship between pedestrian speeds and land use. Land use would then be used as a predictor of the sidewalk space required to achieve a comfortable LOS. In addition, he asserted that time of day and trip purpose determine pedestrian speed more closely than the pedestrian characteristics highlighted in the report. He suggested that the TD "work with variables you can change: land use and walking space."

Further, Zupan recommended that the TD work toward establishing platoon-oriented LOS analysis as the standard for pedestrian sections of review procedures such as ULURP or EIS. He would like to see any non-platoon analyses in these procedures replaced by platoon analyses.

Fishman, in his email comments (with input from Niels Hoffman, Halcrow "Paxport" software specialist) wrote, among other things, that:

– He agrees with Zupan regarding the importance of identifying obstacles on the sidewalk in order to recommend better sidewalk organization, and recognizes the value of the TD's obstacle study methodology outlined in the report for further analysis in Phase II.
– He supported the report's stated goal of gathering a comprehensive collection of pedestrian characteristics for New York City (page 31). Also, he saw the report as beneficial in serving as a guide to developing a comprehensive pedestrian LOS methodology for Manhattan and other urban environments. He pointed out, however, that each relevant characteristic added to the database adds complexity to the study.
– The TD survey methodology "offers a unique and site specific way of capturing critical information and analyzing patterns and conditions. However, it can also be misleading or too broad in scope to hone in on actual issues with accuracy. This appears to be the case in the Phase I study, where the survey that was undertaken gathers a fair amount of broad baseline information, but falls short in formulating accurate conclusions."
– He recommended the use of origin/destination (O/D) information for trips to the study area, as "this information can be critical in determining many aspects of pedestrian behavior." In keeping with the above recommendation to develop street typologies, Fishman noted that "within the Study Locations…residential influences are abundant and growing at the edges of the study area (Gold Street, Greenwich Street, Hudson Street)…Understanding how commercial and residential patterns compete/overlap or otherwise enhance one another over the course of the day/week is critical to improving New York City pedestrian conditions."

John J. Fruin

According to John J. Fruin's correspondence, he "is the developer of the original level of service standards (FLOS) for pedestrian traffic, and the co-developer with Mr. Gregory Benz of the times space analysis (TSA) technique." In addition, he "has organized, supervised, and analyzed pedestrian traffic surveys within virtually all of the DCP LOS study area, including most of the transit stations in it." He is the author of *Pedestrian Planning and Design* (1971), cited in this report.

Mr. Fruin thinks real problems affecting pedestrian traffic occur at corners and crosswalks, not at midblock locations. Corners have multi-directional pedestrian flow and queuing pedestrians. Crosswalks are where pedestrian flows from opposite corners mingle and interact with turning vehicles.

Mr. Fruin states that the Level of Service methodology is intended for transportation facilities and interior building space, and that "all the LOS standards represent crowded conditions, except for the unbounded ends of LOS A." As such, it has its drawbacks when it is applied to sidewalk pedestrian activity. Fruin points out that the LOS methodology has worked reasonably well for the study of busy pedestrian crosswalks and corners in New York City.

Fruin advises that any method to determine pedestrian LOS should be simple and easy to apply. It should also be tested to make sure that it is reasonable, because too much sidewalk space allocation could result in an unattractive, boring pedestrian environment.

Mr. Fruin recommends the use of digital photography, computer analysis techniques and touch screen technology to develop reliable counting techniques. He also suggests that sidewalk data in mid-block locations could be collected by having a passenger in a moving car count or photograph sidewalk occupants.

Gregory P. Benz
Senior Vice President/Operations Manager
PB Consult Inc.

Gregory P. Benz is a transportation consultant, the co-developer with John J. Fruin of the pedestrian time-space analysis (TSA) concept, and the author of *Pedestrian Time-Space Concept* (1986), which is cited in this report.

Mr. Benz notes that one of the factors affecting shy distance is the length of the obstacle being studied, and it should somehow be incorporated in the TD's obstacle study methodology (page 45).

As regards to the analysis of the Highway Capacity Manual (HCM), Mr. Benz believes that the HCM methodology needs to be applied and interpreted at each specific situation with certain judgment based on observation and circumstances, and the report should acknowledge that. Even though John Fruin's *Pedestrian Planning and Design* is included as a reference, Mr. Benz recommends that the report reviews this book more thoroughly, given its importance to the subject of study. His experience is that "there is not a very good appreciation and ability to fully understand what a particular LOS standard means," and that a particular LOS is usually perceived as being worse than what it is analytically.

According to Mr. Benz, the report should specify the intended application of the refined, New York City adjusted pedestrian analysis methodology that the TD is seeking to develop. He states that there are three main application categories: physical design, impact analysis and operational/crowd management. According to Benz, the acceptable LOS standard and its interpretation and judgment vary depending on the intended application; LOS should also be dependent on "duration of the period under consideration, nature of the activities, frequency of condition, and characteristics of the analysis population." He also points out that if this refined methodology is going to be used with projections of future conditions, it does not have to be highly precise, since the forecast has a certain degree of uncertainty.

Mr. Benz suggested additional literature for our review. In particular:

– Edward Hall's *The Hidden Dimension* and Robert Sommer's *Personal Space: The Behavioral Basis of Design* talk about "the underlying behavioral basis for pedestrian activities and the speed-density basis for the level of service concept";
– The second edition of his Pedestrian Time-Space publication from 1992, which provides additional discussion on the applications of the methodology developed in his first edition "Pedestrian Time-Space Concept: A New Approach to the Planning and Design of Pedestrian Facilities", Parsons Brinckerhoff Quade & Douglas, Inc., 1986 (already included in the project's literature review);

- His paper co-written with Jack Fruin "Pedestrian Time-Space Concept for Analyzing Corners and Crosswalks", Transportation Research Record 959, Transportation Research Board, National Research Council, Washington, D.C., 1984, which analyzes corners and crosswalks and could be useful for our future research.
- New developments and advances in "the theory and practice for pedestrian flow analysis and simulation of high volume, multi-directional and multi-activity facilities and spaces", even though Mr. Benz recognizes this is beyond the scope of the present project.

Sigurd Grava
Professor Emeritus of Urban Planning
Columbia University

Sigurd Grava's teaching and research focuses on urban transportation and infrastructure, among other things. He has studied urban areas throughout the world and has authored books and papers on issues related to regional transportation and the interaction between land use and transportation.

According to Mr. Grava, one of the main shortcomings of the project is the assumption that sidewalks are linear spaces with only two-directional movements. He would also add "External Environment" and "Pedestrian Intent" to the diagram on page 24. He also thinks that pedestrian walking speed appears to be relevant only for crosswalks.

Mr. Grava distinguishes between at least three modes of walking or using a public space: walking briskly towards a specific destination; meandering and enjoying the scene along the way; and tarrying, or not going anywhere specific. The current HCM methodology would be valid only for the first mode. In his opinion, it is not the personal characteristics but the mode and the mood – which differ from the trip purpose – which are the most important factors affecting pedestrian behavior.

Mr. Grava questions the generalized quantitative approach to pedestrian analysis by transportation experts. He agrees that a scientific, quantitative basis is needed, but he believes that it should be accompanied by a qualitative analysis, with established rankings and classifications. This is acknowledged in the TD's report, but no intent to develop the qualitative approach is shown. Mr. Grava also reminds the TD of the uncertain and chaotic nature of pedestrian behavior to prevent an attempt to be extremely precise when the subject studied is not precise by nature.

According to Mr. Grava, the concept of dynamic density might be of special importance to a pedestrian sidewalk study. This translates into determining the size of the personal space bubble, or how much space a person needs to feel comfortable, which in his opinion might be the key to determining pedestrian standards of service and shy distances.

Finally, Mr. Grava recommends that the study review William Whyte's *Social Life or Small Urban Spaces*, and to do a more thorough review of Gregory Benz's space-time analysis work.

Transportation Alternatives
Amy Pfeiffer
Program Director, Safe Routes for Seniors

Transportation Alternatives is a New York City based citizens group which focuses on urban mobility issues, and advocates for the expansion of the availability and use of alternative modes of transportation.

Amy Pfeiffer believes this study lacks:

- A consideration of vehicle speed as a factor in the correlation between vehicular and pedestrian volumes, and between pedestrian volumes and counts (page 79 of the report). In Pfeiffer's opinion, vehicular speed is an important factor in safety.
- The project's control location is not representative of the city, since its proximity to the center of city government means that this block is mainly used by government

workers who all travel at approximately the same time and only on weekdays; the block is quite empty during weekends.

– A consideration of how the use of the curb lane adjacent to each location affects pedestrians' behavior on the sidewalk; behavior is different if the curb lane is a travel lane, a bus lane, a parking lane or a bike lane. In particular, she states, this would affect the "shy distance" determination methodology (page 45, obstacle study methodology).

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