

1. Report No. SWUTC/00/167510-1	2. Government Accession No.	3. Recipient's Catalog No.	
4. Title and Subtitle Platoon Pedestrian Movement Analysis: A Case Study Utilizing the Market Street Station in Denver, Colorado		5. Report Date December 2000	6. Performing Organization Code
7. Author(s) Scott Anthony James and C. Michael Walton		8. Performing Organization Research Report 167510-1	
9. Performing Organization Name and Address Center for Transportation Research University of Texas at Austin 3208 Red River, Suite 200 Austin, Texas 78705-2650		10. Work Unit No. (TRAIS)	11. Contract or Grant No. 10727  10727
12. Sponsoring Agency Name and Address Southwest Region University Transportation Center Texas Transportation Institute Texas A&M University System College Station, Texas 77843-3135		13. Type of Report and Period Covered	
15. Supplementary Notes Supported by general revenues from the State of Texas.		14. Sponsoring Agency Code	
<p>16. Abstract</p> <p>The objective of this paper is to provide empirical confirmation of a recommended evaluation methodology for platoon pedestrian movements at transit terminals.</p> <p>Transportation professionals are responsible for the orderly and safe operation and management of pedestrian facilities. In urban and near urban areas, the need to incorporate pedestrian oriented facilities can be quite pressing. Proposed new or urban renewal developments in combination with environmental or political pressures to discourage automobile use for short trips can require improvements to an underutilized pedestrian transportation infrastructure.</p> <p>Previous studies into pedestrian behavior and movements have yielded several evaluation methodologies, some of which are derived from the Highway Capacity Manual Level of Service calculations for vehicular movement. In the process of refining the results of these behavioral studies, various sub categories within pedestrian flow patterns have led to more specialized research.</p> <p>This paper presents the results of a specific experiment conducted to determine the behavioral characteristics of platoon pedestrian movement as found at the Market Street transit station in Denver, Co. The population defined in the study is intended to represent the typical transit oriented pedestrian patronage of a medium density urban city.</p>			
17. Key Words Pedestrian Behavior, Pedestrian Movement, Transit, Highway Capacity, Pedestrian Facilities		18. Distribution Statement No restrictions. This document is available to the public through NTIS: National Technical Information Service 5285 Port Royal Road Springfield, Virginia 22161	
19. Security Classif.(of this report) Unclassified	20. Security Classif.(of this page) Unclassified	21. No. of Pages 108	22. Price



**PLATOON PEDESTRIAN MOVEMENT ANALYSIS:  
A CASE STUDY UTILIZING THE MARKET STREET STATION  
IN DENVER, COLORADO**

by

Scott Anthony James  
C. Michael Walton

RESEARCH REPORT SWUTC/00/167510-1

Southwest Regional University Transportation Center  
Center for Transportation Research  
University of Texas at Austin  
Austin, Texas 78712

DECEMBER 2000



## **DISCLAIMER**

The contents of this report reflect the views of the authors, who are responsible for the facts and the accuracy of the information presented herein. This document is disseminated under the sponsorship of the Department of Transportation, University Transportation Centers Program in the interest of Information exchange. Mention of trade names or commercial products does not constitute endorsement or recommendation for us.

## **ACKNOWLEDGMENT**

The authors recognize that support for this research was provided by a grant from the U.S. Department of Transportation, University Transportation Centers Program to the Southwest Region University Transportation Center which is funded 50% with general revenue funds from the State of Texas.



## EXECUTIVE SUMMARY

The push to develop attractive engineering and architectural designs for incorporating the daily traveler into a non-automobile centered transportation scheme has renewed interest in pedestrian facilities. In this context there is a need to provide practicing transportation professionals with standards and guidelines by which pedestrian oriented facilities can be evaluated in a straightforward manner. This research paper presents the findings of a specific experiment conducted to determine the behavioral characteristics of platoon pedestrian movement as found at the Market Street transit station in Denver, Colorado.

The year 2000 version of the *Highway Capacity Manual* will incorporate revisions suggested as the result of a broad comparative literature review conducted by the Institute for Transportation Research and Education at North Carolina State University.

Among the recommendations for the year 2000 *HCM* is the suggestion to modify the current evaluation scheme for uninterrupted pedestrian facilities under platoon flow conditions. These modifications are to be applied for two specified cases: for pedestrian facilities that experience random platoon flow, and more specialized standards for facilities that experience routine or common platoon movement, such as transit terminals and large scale airports.

The recommendations for the 2000 *Highway Capacity Manual* for uninterrupted facilities (i.e. walkways and corridors) as applied to non-platoon movement are a composite set of standards that combine (and condense) the findings of previous studies. Using the methodology developed by Fruin and later used by other researchers, this study will analyze pedestrian movement as observed at the Market Street Transit Station in Denver, Colorado. The results of the study will be used to confirm the recommended evaluation methodology for the year 2000 Highway Capacity Manual, as it applies to non-platoon pedestrian movement along uninterrupted facilities.

The recommendations for the 2000 *Highway Capacity Manual* for uninterrupted facilities (i.e. walkways and corridors) as applied to routine platoon movement are

offered in two forms: a composite set of standards that combine the findings of previous studies, and a recommendation to use the findings of a specific study, conducted at three large airports, as applicable to transportation terminals and other facilities subjected to routine platoon pedestrian flow. The same method of analysis (i.e. density – flow rate calculations), will be used to determine if the two recommended methods of evaluating platoon pedestrian movement are reflective of the platoon pedestrian movements observed at the Market Street Transit Station in Denver, Colorado.

The experiment findings infer that the recommended evaluation methodology for the year 2000 Highway Capacity Manual, as it applies to routine platoon and non-platoon pedestrian movement(s) are applicable at the Market Street Transit Station in Denver, Colorado. Furthermore, the study findings show no strong parallel with the observations recorded in the large airport study. As the Market Street Station location in Denver, Colorado was specifically chosen to provide observations of platoon pedestrian movement at a transit station, it is likely that the evaluation methodology derived from observations at large scale airports does not apply to transit terminals similar to the Market Street Station.

## **ABSTRACT**

The objective of this paper is to provide empirical confirmation of a recommended evaluation methodology for platoon pedestrian movements at transit terminals.

Transportation professionals are responsible for the orderly and safe operation and management of pedestrian facilities. In urban and near urban areas, the need to incorporate pedestrian oriented facilities can be quite pressing. Proposed new or urban renewal developments in combination with environmental or political pressures to discourage automobile use for short trips can require improvements to an underutilized pedestrian transportation infrastructure.

Previous studies into pedestrian behavior and movements have yielded several evaluation methodologies, some of which are derived from the Highway Capacity Manual Level of Service calculations for vehicular movement. In the process of refining the results of these behavioral studies, various sub categories within pedestrian flow patterns have led to more specialized research.

This paper presents the results of a specific experiment conducted to determine the behavioral characteristics of platoon pedestrian movement as found at the Market Street transit station in Denver, Co. The population defined in the study is intended to represent the typical transit oriented pedestrian patronage of a medium density urban city.



# TABLE OF CONTENTS

<b>Chapter 1. Introduction</b> .....	1
1.1 Introduction to Study .....	1
1.2 Definition of Problem .....	1
1.3 Study Findings .....	3
<b>Chapter 2. Literature Review</b> .....	5
2.1 Background .....	5
2.2 Comprehensive Studies into Pedestrian Movement .....	5
2.3 Engineering and Design Guidelines for Pedestrian Facilities .....	6
2.4 Specialized Studies into Pedestrian Movement in Platoons .....	7
2.5 Development Trends which Address the Role of the Pedestrian .....	8
2.6 Pedestrian Advocacy Groups .....	9
2.7 Conclusions from Literature Review .....	9
<b>Chapter 3. Pedestrian Movement And Facilities Design</b> .....	11
3.1 The Role of the Pedestrian in Transportation .....	11
3.2 Review of Pedestrian Movements in Terms of Traffic Engineering .....	12
3.3 Current State of Pedestrian Facilities Evaluation Methodologies .....	15
3.4 Recommended Changes for the 2000 Highway Capacity Manual .....	18
3.5 Definition of Platoon Pedestrian Movement .....	22
3.6 Overview of Methods for Modeling Platoon Pedestrian Movement .....	23
3.7 Results of Davis-Braaksma Study .....	24
3.8 Comparison of Evaluation Methods for Platoon Adjusted Flow .....	25
3.9 Remaining Areas for Research .....	27
3.10 Summary .....	28
<b>Chapter 4. Methods Of Pedestrian Movement Analysis</b> .....	29
4.1 Applications of Level of Service Methodology to Pedestrian Movement Analysis .....	29
4.2 Brief Overview of Pedestrian Movement Studies .....	29
4.3 Site Specific Studies of Pedestrian Movements .....	31
4.4 Statement of Problem .....	31

<b>Chapter 5. Experimental Design And Scope Of Study .....</b>	<b>33</b>
5.1 Experimental Design and Scope of Research Study .....	33
5.2 Primary Objectives of Research Study .....	33
5.3 Site Selection .....	34
5.4 Data Collection Objectives .....	36
5.5 Review of Collected Prior to Analysis .....	39
5.6 Comparison of Site Selection with Previous Studies .....	40
5.7 Summary .....	40
<b>Chapter 6. Data Collection Results And Analysis .....</b>	<b>41</b>
6.1 Results of Data Collection Analysis .....	41
6.2 Overview of Observed Pedestrian Behavior .....	41
6.3 Development of LOS thresholds for Market Street Station Pedestrian Flows ...	42
6.4 Comparison of Market Street Station Findings with Previous Studies .....	46
6.5 Comparison of Market Street Station Results with Platoon Specific LOS Threshold Recommendations .....	48
6.6 Platoon Specific LOS Threshold Recommendations .....	51
6.7 Special Case Pedestrian Facilities .....	54
<b>Chapter 7. Conclusions And Recommendations .....</b>	<b>57</b>
7.1 Summary of Findings .....	57
7.2 Conclusions .....	58
7.3 Recommendations .....	58
7.4 Areas for Further Research .....	58
<b>Appendix A Summary Sheets for Volume/Flow Rate Studies .....</b>	<b>61</b>
<b>Appendix B Summary Sheets for Econometric Analysis of Platoon Pedestrian         Movement .....</b>	<b>69</b>
<b>Appendix C Sample Survey Forms (Short and Long) .....</b>	<b>81</b>
<b>References .....</b>	<b>93</b>

## LIST OF FIGURES

Figure 3.1	Relationship Between Speed and Available Space .....	15
Figure 5.1	Image of 16 <sup>th</sup> Street Pedestrian Mall in Denver, Co.....	37
Figure 5.2	Still Photograph of Transit Patrons Alighting at Market Street Station.	38
Figure 6.1	Still Photograph of Pedestrian Platoon Traversing Study Area .....	42
Figure A-1	Probability of Conflict Due to Cross Traffic Flows .....	62
Figure A-2	Average Lateral Spacing Observed During Uni-Directional Flow .....	63
Figure A-3	“Space Mean Speed” Chart from Chapter 3 .....	64
Figure A-4	Pedestrian Flow Volumes Versus Available Space Per Pedestrian.....	65
Figure A-5	Chart Comparing Several Studies’ Findings with Regard to Pedestrian Speeds Versus Available Space.....	67
Figure A-6	Chart Comparing Several Studies’ Findings with Regard to Pedestrian Flow Rates and Available Space .....	68
Figure B-1	Chart of Theoretical Speeds Relative to Pedestrian Density for Platoon Pedestrian Movements .....	78



## LIST OF TABLES

Table 3.1.	Recommended Level of Service Thresholds for Free Flow Movement on Pedestrian Walkways .....	16
Table 3.2	Recommended Level of Service Thresholds for Free Flow Movement on Pedestrian Walkways .....	17
Table 3.3	Highway Capacity Manual (1994) LOS Thresholds for Movement on Uninterrupted Pedestrian Walkways.....	18
Table 3.4	Walkway Level of Service (LOS) Thresholds by Available Space Per Pedestrian (m <sup>2</sup> /ped) .....	19
Table 3.5	Walkway Level of Service (LOS) Thresholds by Flow Rate (pedestrian/minute/meter).....	20
Table 3.6	Recommended HCM 2000 Walkway Level of Service (LOS) Criteria.	22
Table 3.7	Comparison of Platoon Adjusted LOS Thresholds for Pedestrian Walkways (space per pedestrian) .....	26
Table 3.8	Comparison of Platoon Adjusted LOS Thresholds for Pedestrian Walkways (pedestrian flow rates) .....	26
Table 4.1	1994 HCM Walkway Level of Service Thresholds.....	30
Table 5.1	Brief Summary of Population Sample Demographics .....	39
Table 6.1	LOS Thresholds for Denver, Colorado Market Street Bus Transfer Station (non-platoon flow conditions).....	43
Table 6.2	LOS Thresholds for Denver, Colorado Market Street Bus Transfer Station (platoon flow conditions) .....	45
Table 6.3	Comparison with Previous Studies for Non-Platoon Pedestrian Flow ...	47
Table 6.4	Comparison with Previous Studies for Routine Platoon Pedestrian Flow .....	49
Table 6.5	Comparison of 1994 & 2000 HCM LOS Thresholds with Market Street Station Study (non-platoon movement).....	50
Table 6.6	Comparison of 2000 HCM LOS Thresholds with Market Street Study (platoon movement in transit terminals).....	51

Table 6.7	Comparison of Platoon Adjusted LOS Thresholds from Three Sources .....	53
Table 6.8	Comparison of 2000 HCM Platoon Adjusted LOS Thresholds with Market Street Station Study.....	55
Table B-1	Summary of Critical Values from Market Street Station Observations .	77

# CHAPTER 1. INTRODUCTION

## 1.1 INTRODUCTION

Much attention has been paid to the need to devise and include non-automotive modes of transportation into the larger discussion of transportation networks. Specifically, the interest in preserving and developing historically dense and economically influential city centers has grown in direct response to the wide spread suburban development pattern that generates high numbers of automobile based trips. The push to develop attractive engineering and architectural designs for incorporating the daily traveler into a non-automobile centered transportation scheme has renewed interest in pedestrian facilities. Beneath the New Urbanism or Traditional Neighborhood Development movement is the assumption that improving the design, integration and operations of existing pedestrian facilities will likely make such future development patterns more viable.<sup>1</sup> In this context there is a need to provide practicing transportation professionals with standards and guidelines by which pedestrian oriented facilities can be evaluated in a straightforward manner.

This research study presents the results of a specific experiment conducted to determine the behavioral characteristics of platoon pedestrian movement as found at the Market Street transit station in Denver, Colorado. The population defined in the study is intended to represent the typical pedestrian patronage of a transit station.

## 1.2 DEFINITION OF PROBLEM

To assist traffic engineers in the evaluation of pedestrian facilities, several papers, comparative studies and evaluation methodologies have been developed over the past thirty years. Of most recent and widespread application are the guidelines set forth in the *Highway Capacity Manual*, which discusses the design and evaluation parameters of pedestrian facilities.<sup>2</sup> Much of the Highway Capacity Manual logic and argument is a refined derivation of previous studies done by researchers in the realm of pedestrian

---

<sup>1</sup> The definition and broader objectives of Traditional Neighborhood Development is taken from the Congress for New Urbanism website. Internet address: <http://www.cnu.org>

<sup>2</sup> Transportation Research Board (TRB). "*Highway Capacity Manual, Chapter 13: Pedestrians*" copyright 1994.

movement and behavior under specific spatial conditions and time constraints.<sup>3</sup> Principal reference studies are the comprehensive works *Pedestrian Planning and Design*, by John J. Fruin, and *Urban Space for Pedestrians*, by Pushkarev and Zupan.

The year 2000 version of the *Highway Capacity Manual* will incorporate revisions suggested as the result of a broad comparative literature review conducted by the Institute for Transportation Research and Education at North Carolina State University.<sup>4</sup>

Among the recommendations is the suggestion to modify the current evaluation scheme for uninterrupted pedestrian facilities under platoon flow conditions. These modifications are to be applied for two specified cases: for pedestrian facilities that experience random platoon flow, and more specialized standards for facilities that experience routine or common platoon movement, such as transit terminals and large scale airports.

The recommendations for the 2000 Highway Capacity Manual for uninterrupted facilities (i.e. walkways and corridors) as applied to non-platoon movement are a composite set of standards that combine (and condense) the findings of previous studies. Using the methodology developed by Fruin and later used by other researchers, this study will analyze pedestrian movement as observed at the Market Street Transit Station in Denver, Colorado. The results of the study will be used to confirm the recommended evaluation methodology for the year 2000 Highway Capacity Manual, as it applies to non-platoon pedestrian movement along uninterrupted facilities.

The recommendations for the 2000 Highway Capacity Manual for uninterrupted facilities (i.e. walkways and corridors) as applied to routine platoon movement are offered in two forms: a composite set of standards that combine the findings of previous studies, and a recommendation to use the findings of a specific study, conducted at three large airports, as applicable to transportation terminals and other facilities subjected to routine platoon pedestrian flow. The same method of analysis (density – flow rate

---

<sup>3</sup> Principally the works *Pedestrian Planning and Design*, by John J. Fruin, copyright 1971 and *Urban Space for Pedestrians*, by Pushkarev and John Zupan, copyright 1976.

<sup>4</sup> "Literature Synthesis for Chapter 13, "Pedestrians" of the *Highway Capacity Manual*" by Roupail, N., Hummer, J., Milazzo, J. and Allen, D.P. United States Department of Transportation, Federal Highway Administration. McLean, VA. February 1998

calculations), will be used to determine if the two recommended methods of evaluating platoon pedestrian movement are reflective of the platoon pedestrian movements observed at the Market Street Transit Station in Denver, Colorado.

### **1.3 STUDY FINDINGS**

The experiment findings infer that the recommended evaluation methodology for the year 2000 Highway Capacity Manual, as it applies to routine platoon and non-platoon pedestrian movement(s) are applicable at the Market Street Transit Station in Denver, Colorado. Furthermore, the study findings show no strong parallel with the observations recorded in the large airport study. As the Market Street Station location in Denver, Colorado was specifically chosen to provide observations of platoon pedestrian movement at a transit station, it is likely that the evaluation methodology derived from observations at large scale airports does not apply to transit terminals similar to the Market Street Station in Denver, Colorado.



## CHAPTER 2. LITERATURE REVIEW

### 2.1 BACKGROUND

In the preparation for this research experiment, a broad review of the available studies and published papers on pedestrian movements was conducted. First, informal inquiries were made of professionals in the fields of pedestrian facilities research and design. Professional engineers, researchers and planners were contacted either via telephone or electronic mail to solicit commentary and opinion about the development and application of existing pedestrian facilities design standards and evaluation methodologies.<sup>5</sup> Consistent reference to the text, *Pedestrian Planning and Design* made clear the influence Fruin's work enjoyed, as well as the overall lack of recent, comprehensive engineering studies on the subject of pedestrian movement in the United States.<sup>6</sup>

This chapter will briefly discuss the critical points and aspects of the current pedestrian movement analysis methodologies as were available at the time of this research. In recognition of the specialized area of platoon pedestrian movement under examination in this study, material that does not directly apply to platoon pedestrian movement will not be discussed.

Grouped largely according to the area of interest, the following source documents were reviewed in preparation for this research project.

### 2.2 COMPREHENSIVE STUDIES INTO PEDESTRIAN MOVEMENT

*Pedestrian Planning and Design* by Prof. John J. Fruin (published 1971) serves as the seminal work in American studies of pedestrian movements. Fruin's text brings the reader from the fundamentals of human locomotion, up and down inclines and in confined spaces to the highly ordered movement of commuter pedestrians along a moving walkway. The text offers background commentary and observation on the

---

<sup>5</sup> Professional planners and engineers were informally interviewed in Portland, Seattle, San Jose, Houston, Dallas, Austin and Washington, D.C. to learn what, if any, recommended methodologies were widely used in the evaluation of pedestrian facilities.

<sup>6</sup> Phone call conversations with transportation professionals Mr. Peter Hackley of Carter-Burgess in Austin, TX, Mr. G. B. Arrington of Tri-Met in Seattle, WA, Mr. Joe Milazzo II of the Institute for Transportation Research and Education at North Carolina State University in Raleigh, NC.

definitions of personal space, which provide the transportation professional with insight into some of the social aspects of traffic engineering.

*Pedestrian Planning and Design* also provides the fundamental definitions for the analysis of pedestrian movement that have been uniformly adopted by transportation professionals in the United States. Fruin's methodology of pedestrian facility Levels of Service, provide a familiar means of determining acceptable levels of crowd density, as evaluated in terms of impeded movement within a traffic stream.<sup>7</sup>

*Urban Space for Pedestrians*, by Pushkarev and Zupan, published in 1976, offers a specific focus upon the impact that grouping or platooning of pedestrians has on a particular facility's operation<sup>8</sup> in terms of perceived pedestrian comfort. The inconsistent nature of pedestrian flow rates support the criticism of standard trip generation equations (based upon land use and total occupied space) as inadequate measures of pedestrian activity with regard to facilities design.

Platoon specific volume flow rates are used to evaluate areas that are more likely to experience periodic clusters of high volume pedestrian activity, such as urban transit centers, or multimodal hubs connecting two or more travel modes by means of walkways (i.e. airports and train/subway stations).

### **2.3 ENGINEERING AND DESIGN GUIDELINES FOR PEDESTRIAN FACILITIES**

In May of 1976, the Institute of Transportation Engineers published an informational report to serve as an introduction to the considerations for pedestrian facility development.<sup>9</sup> Among the cited concerns for facility operations and control was the need to address crowding within the travel streams. The report endorsed the same research methodology used by Fruin to develop the recommended threshold values for levels of service with regard to flow rates and available space on pedestrian facilities.

---

<sup>7</sup> Fruin, John J. *Pedestrian Planning and Design*. New York, NY. Metropolitan Association of Urban Designers and Environmental Planners Inc. Copyright 1971

<sup>8</sup> *Urban Space for Pedestrians*, Pushkarev and Zupan. Cambridge, Massachusetts: The MIT Press, 1975a pages 92-95.

<sup>9</sup> Institute of Transportation Engineers Technical Council Committee 5-R "Characteristics and Service Requirements of Pedestrians and Pedestrian Facilities" Traffic Engineering, Volume 46, Number 5, pp. 34-45. Copyright 1976

In 1980, another report was issued, titled “*Interim Materials on Highway Capacity*” Transportation Research Circular 212, again addressing the issues of evaluating pedestrian facilities in terms of densities and flow rates, this text included discussion of the influence of platoons (or “bunching”) upon pedestrian flow.

The 1994 edition of the *Highway Capacity Manual*, presents the recommended methods of evaluating pedestrian facilities in Chapter 13, titled “Pedestrians.” The current set of pedestrian evaluation standards as applied to walkways and platoon pedestrian movement are direct applications of the research studies done by Fruin, Pushkarev and Zupan.

“Quality of Service for Uninterrupted Pedestrian Facilities in the 2000 Highway Capacity Manual” contains recommended changes to the evaluation of pedestrian facilities as determined by the results of a comprehensive literature review. The literature review compared several pedestrian movement studies in order to compile a more consistent set of standards to be applied in the evaluation of pedestrian facilities. In the specialized area of predominately platoon movement, the year 2000 Highway Capacity Manual recommendations suggest using the findings of a study done in three large airports as the basis for evaluation.

#### **2.4 SPECIALIZED STUDIES INTO PEDESTRIAN MOVEMENT**

Separate studies have been conducted to examine subcategories of pedestrian movement, especially in areas of recurrent high volumes of pedestrian activity, such as public plazas, sporting events or mass transit stations. In Canada, a study was held to observe and analyze the behavior of pedestrians in airport terminals. The resultant papers discussed both the impacts of luggage laden passengers on flow rates (found to be minimal)<sup>10</sup> and the impacts of platoon pedestrian movement on overall flow streams<sup>11</sup> which were later incorporated into the recommendations for the 2000 Highway Capacity Manual.

---

<sup>10</sup> “Adjusting for luggage-laden pedestrians in airport terminals” by Dennis G. Davis and John P. Braaksma Transportation Research A Volume 22a Number 5, pp. 375-388. Copyright 1988.

<sup>11</sup> Davis, Dennis and John Braaksma. “Level-of-Service Standards for Platooning Pedestrians in Transportation Terminals”. In ITE Journal, April 1987.

Studies conducted outside the boundaries of the United States and Western Europe, reveal a high likelihood of cultural differences influencing the perception of personal space and crowding.<sup>12</sup> In particular, recent studies conducted in the Far East have presented findings that imply that higher densities will be tolerated at similar flowrates with Western facilities.<sup>13</sup> The perception of personal space is different to the degree that pedestrian movement will provide higher flowrates (and therefore higher capacity) at the same perceived level of crowding.

## **2.5 DEVELOPMENT TRENDS THAT ADDRESS THE ROLE OF THE PEDESTRIAN**

### **Traditional Neighborhood Development/New Urbanism**

Defined as a return to pre-World War II development patterns,<sup>14</sup> the principles behind Traditional Neighborhood Development (hereafter referred to as TND) are applied to pedestrian facilities as well. The objective of TND is to provide less automobile dependent travel routes and transportation networks at the level of the community. TND is the direct opposite of the “suburban sprawl” development scheme, where large numbers of detached single-family homes are built along wide streets. Such “suburban sprawl” developments often require extensive use of a private vehicle to access the nearest shopping or convenience centers. “Sprawl” development is also accused of clustering major attractants at or near the intersection of arterial streets and thereby discouraging pedestrian access.

TND emphasizes mixed land uses, higher density and smaller scale street networks. The goal is to provide a sense of connectivity and accessibility between residential, commercial and retail spaces, in order to reduce the total number of vehicle trips per household. Inherent in these proposals is the expectation that residents and visitors to such TND oriented areas will not need to use their private vehicle for short trips, and will opt to walk on improved and adequate pedestrian facilities.

---

<sup>12</sup> *The Hidden Dimension*, by Edward T. Hall, copyright 1955.

<sup>13</sup> “Pedestrian Facilities in Bangkok: A Case Study”. ITE Journal, November 1989. Tanaboriboon, Yordphol, Sim Siang Hwa and Chin Hoong Chor. “Pedestrian Characteristics Study in Singapore”. In *Journal of Transportation Engineering*,

<sup>14</sup> The definition of Traditional Neighborhood Development is provided by the Congress for New Urbanism website. Internet address: <http://www.cnu.org>

Several articles and published reports discuss the need to incorporate pedestrian facilities into residential and commercial developments. One publication reviewed the relationship between site design and pedestrian travel in mixed-use, medium density areas.<sup>15</sup> The fundamental argument being pedestrian travel demand could be accurately predicted in direct relationship with key factors in site design. This is a secondary position within the broader TND argument.

## **2.6 PEDESTRIAN ADVOCACY GROUPS**

WalkAmerica, a national advocacy group, petitions various government entities (EPA, USDOT, HUD, etc.) to provide improved facilities in areas of high (or potentially high) pedestrian activity.<sup>16</sup> Surrogate political groups at the local and state levels of government seek to combine downtown or urban renewal projects with improved pedestrian facilities and access, often in combination with transit developments.<sup>17</sup> In the course of researching management and operational issues related to platoon pedestrian movement, it became apparent that political pressure is often a strong incentive for the careful review and discussion of a proposed pedestrian facility.

## **2.7 CONCLUSIONS DRAWN FROM THE LITERATURE REVIEW**

It is apparent that several divergent interests are pushing the renewed interest in improved pedestrian facilities. Requests for strict engineering studies were often answered by planning documents and broad references to the need to increase the presence of qualitative elements in the design and evaluation process. Although this thesis will restrict itself to the discussion of evaluating pedestrian movement at transit stations, both in free flow and platoon groupings, a considerable amount of aesthetic and subjective evaluation is involved in the review of pedestrian facilities.

---

<sup>15</sup> "Effects of Site Design on Pedestrian Travel in Mixed-Use, Medium Density Environments" by Moudon, A.V. Department of Urban Design and Planning, University of Washington, Seattle, Washington. Copyright May 1997

<sup>16</sup> Information about WalkAmerica can be found on the organization website:  
<http://www.walkamerica.org>

<sup>17</sup> Walk Austin, WalkSacramento, WalkBoston and other affiliated organizations have petitioned their respective municipal and regional governments for improved pedestrian facilities.



## **CHAPTER 3. PEDESTRIAN MOVEMENT AND FACILITIES DESIGN**

### **3.1 THE ROLE OF THE PEDESTRIAN IN TRANSPORTATION**

Pedestrian is defined as “of, relating to, or made for a person traveling on foot; a walker.”<sup>18</sup> In the interests of the transportation professional, pedestrian movement is the mode of travel taken to access any given destination on foot. Even in the most automobile oriented environments (drive thru windows or theme parks) the need to access elements on foot remains prevalent. Addressing the type, level and ease of pedestrian access can be viewed as either an obstacle or an objective, depending upon one’s viewpoint.

The pedestrian is often the most vulnerable of all transportation networks users, and frequently, the most overlooked. Given the social and financial import placed upon the use of private and commercial vehicles, it is not surprising that most design engineers and management agencies actively track and record pedestrian movement as an influencing element upon the vehicular transportation network as whole, not as a separate travel mode unto itself.

Accidents between pedestrians and vehicles are examined in terms of minimizing conflict between the two modes, not necessarily maximizing access for either. Facilities for pedestrians are designed to meet minimum accessibility standards (most notably the federal requirements of the Americans with Disabilities Act). On rare occasions is the pedestrian the primary focus of a transportation network element, and then often such elements are often placed in relative isolation to other transportation modes and destinations. This is not hyperbole, but an oft overlooked fact of urban and suburban pedestrian facilities design. Two of the most prevalent complaints about pedestrian facilities design are poor integration with existing transportation networks and a lack of connectivity with major activity centers. There are numerous reasons and explanations for this situation, not least of which is the financial aspect of the matter.

---

<sup>18</sup> *The American Heritage Dictionary, 2nd College Ed.*, copyright 1985 by Houghton Mifflin Co. p 914.

### **3.2 REVIEW OF PEDESTRIAN MOVEMENTS IN TERMS OF TRAFFIC ENGINEERING**

Prior to the more specialized discussion of pedestrian movement in platoons at transit stations, an overview of the engineering evaluation of pedestrian movements is in order. Similar to the definition of vehicular movement, pedestrian facilities design has been analyzed in terms of its ability to process a given volume of moving individuals within a given period of time. The following definitions were presented by John J. Fruin in his text *Pedestrian Planning and Design* and are derived from accepted Highway Capacity Manual methodology for Level of Service calculations.<sup>19</sup>

#### **Flow or Volume**

Similar to the movement of automobiles, flow or volume with regard to pedestrian movements is expressed as the number of units per available space per given period of time. In most studies the volume is given as pedestrians per unit width (either meter or foot) per minute, a rate easy to visualize.<sup>20</sup>

$P = \text{ped/minute/meter (or ped/min/m)}$

For example, a standard 1.5 meter (five feet) wide sidewalk experiencing a flow rate of 1 person passing a fixed point every 10 seconds would correspond to a flow volume of 3.9 (~4) pedestrians per minute per meter width (ped/min/m).

#### **Speed**

The definition of locomotive speed is the amount of travel time required to traverse a given distance. In this study the travel speed is given both for single individuals as well as for the average speed within a platoon, reported in meters per minute.<sup>21</sup>

$S = \text{meters/minute (m/min)}$

---

<sup>19</sup> Fruin, John J. *Pedestrian Planning and Design*. New York, NY. Metropolitan Association of Urban Designers and Environmental Planners Inc. Copyright 1971

<sup>20</sup> Op cit.

<sup>21</sup> Op cit. p 38

## **Density**

Density is calculated as the number of pedestrians within a given area (pedestrians per square meter). For the sake of clarity, Fruin recommended using the reciprocal of the density value, square meters per pedestrian, which he labeled M, for pedestrian area Module.<sup>22</sup> This definition provides a more intuitive “space per pedestrian” value that better reflects the degree of crowding within a given space.

Density = pedestrians/ square meter => Module = square meter(s)/ pedestrian

For example, the study area for this experiment was 23.79 square meters in area. As pedestrians walk forward, they preserve a surrounding area of space around himself or herself. At the moment of highest density, a platoon of 33 individuals progressed through the study area, offering an average of 0.72 square meters per pedestrian, which, while somewhat crowded, is well removed from the “jam density” value of 0.25 square meters per pedestrian observed by Fruin and other researchers.

## **Headway (time and distance)**

Headway is defined as the time or distance separation between two successive pedestrians. In this study, the time headway is determined using fixed reference points (i.e. the boundaries of the study area) and a chronometer. The distance headway is calculated as the product of the documented individual speed and the time headway.<sup>23</sup> Distance headway is also referred to as “following distance.”

Time headway = elapsed time between successive pedestrians

Distance headway = average speed \* time headway

## **Pedestrian Flow Equation**

The critical product of the above definitions is the pedestrian flow equation. This equation is based upon fluid flow analysis techniques as they were applied to traffic engineering and design. Using the above definitions, the following equations can be constructed:

Flow or volume = average speed X average density (P = S x D)

Substituting the pedestrian area module (M) for density (D):

---

<sup>22</sup> Op cit. p 38

<sup>23</sup> Op cit. p 38

Flow volume = average speed / pedestrian area module ( $P = S / M$ )

Fruin observed that variances in average walking speeds corresponded with distinctions in pedestrian gender, age, and trip purpose. However, Fruin did not document a statistically significant influence of facility grade or the presence of hand held baggage (luggage) on average walking speeds.<sup>24</sup>

Central among Fruin's findings with regard to pedestrian movements under crowded conditions is the following: "as traffic density increases, pedestrian speed is decreased... as a result, all pedestrian speeds tend to have less variability as increased crowd density restricts the ability to pass."<sup>25</sup> These observations were made with respect to individual movements in a free flowing uni-directional stream. Fruin also noted, "traffic density has relatively little impact on individual walking speeds until average pedestrian area modules approach 40 square feet (3.72 square meters) per pedestrian."<sup>26</sup>

In the context of platoon formation and movement patterns, the above statements support the logic that higher density pedestrian crowds will exhibit more uniform speeds across various demographic categories.

As shown in Figure 3.1 below, uni-directional pedestrian traffic experiences normal mean speeds up to an average modular spacing of 25 square feet (2.32 square meters) per pedestrian, at which point walking speeds decline rapidly with the limit of 140 feet per minute (0.72 meter per second) reached at a density module of seven square feet (0.65 square meters) per pedestrian. Fruin inferred that at modules less than three square feet (0.28 square meters) per pedestrian, walking speeds go to zero and queue formation occurs.<sup>27</sup> This extreme value is often referred to as "jam density." While no observations of the degradation of pedestrian flow to the level of jam density are recorded, subsequent studies and statistical models predict the similar limiting values (0.25-0.5 square meters per pedestrian) at which point physical movement ceases.

---

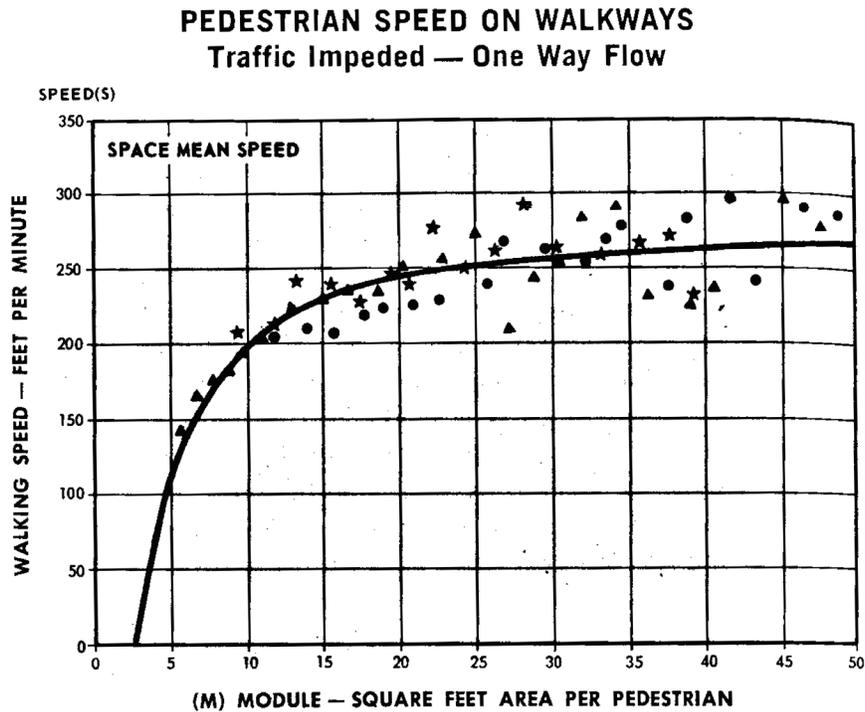
<sup>24</sup> Op cit. p 41-42

<sup>25</sup> Op cit.

<sup>26</sup> Op cit. p 42

<sup>27</sup> Op cit.

Figure 3.1. Relationship Between Speed and Available Space



Source: *Pedestrian Planning and Design*, p. 42 by John J. Fruin

### 3.3 CURRENT STATE OF PEDESTRIAN FACILITIES EVALUATION METHODOLOGIES

Using the information shown in the above chart and careful review of time lapse photographic images of pedestrian movements along Manhattan sidewalks, Fruin devised recommended Level of Service (LOS) thresholds for various elements, including stairwells, elevators, interrupted facilities and queuing areas. These other specialized evaluation methodologies are not discussed in this report. Of relevance to this study are the recommended LOS thresholds for free flow and platoon pedestrian movements along uninterrupted facilities (i.e. walkways and open air plazas). The following table displays the recommended thresholds as determined by Fruin's study.

**Table 3.1. Recommended Level of Service Thresholds for Free Flow Movement on Pedestrian Walkways (source: *Pedestrian Planning and Design*)<sup>28</sup>**

Level of Service	Flow rate * (ped/minute/meter)	Available Space per Pedestrian (m <sup>2</sup> /ped)	Recommended Use
A	<23	>3.3	large scale public plazas
B	23 – 33	2.3 – 3.3	transportation terminals for routine low level flows
C	33 – 49	1.4 – 2.3	transportation terminals serving high volumes
D	49 – 66	0.9 – 1.4	highest tolerable flows for public spaces
E	66 – 82	0.5 – 0.9	threshold of intolerable operation
F	var. – 82	<0.5	queue formation

\* The table values are to be applied to walkway conditions for a fifteen minute study period.

Fruin recommended various LOS thresholds to be used as the operating goals of certain facilities. For example, Level of Service A would be an attainable design goal only for public plazas or areas without frequent periods of extreme pedestrian flow. Levels of Service B and C are recommended for transportation terminals and other large pedestrian volume areas with routine demands but not abnormally high flow rates. Fruin recommended that areas for extreme public volumes be held to a standard operating Level of Service D or better, for use in locations where physical (or fiscal) constraints are prevalent and frequent flow stoppages are unavoidable.<sup>29</sup>

In the text *Urban Space for Pedestrians*, researchers Pushkarev and Zupan conducted similar investigations of pedestrian movements along several kinds of

<sup>28</sup> Op cit, pp 74-78.

<sup>29</sup> Op cit, pp 75.

facilities. Urban Space relied upon aerial photographs taken from altitudes high enough to show entire cross sections of large intersections. These images were then used to calculate level of service thresholds in roughly the same manner as Fruin’s research, with the valuable additional examination of the influence of platoon pedestrian movement. Pushkarev and Zupan also devised a seven-tier LOS scale with slightly more subjective criteria used to distinguish between the perceived levels of service. Both texts sought to quantify the amount of space necessary to allow for a given flow rate as well as perceived comfort with respect to crowding. The following table presents the recommended thresholds as devised by Pushkarev and Jeffery Zupan for flow along uninterrupted pedestrian facilities.

**Table 3.2. Recommended LOS Thresholds for Free Flow Movement on Pedestrian Walkways (source: *Urban Space for Pedestrians*)<sup>30</sup>**

Quality of Flow (LOS)	Flow rate (ped/minute/meter)	Available Space per Pedestrian (m <sup>2</sup> /ped)
Open (A+)	<0.5	>50
Unimpeded (A)	1.6 – 6.5	12 – 50
Impeded (B)	6.5 - 20	3.7 – 12
Constrained (C)	20 – 33	2.2 – 3.7
Crowded (D)	33 – 46	1.5 – 2.2
Congested (E)	46 – 60	1.0 – 1.5
Jammed (F)	60+	<1.0

As evident in the table, the definitions of “open flow” and “unimpeded” incorporate the same principle of Fruin’s work, namely that after a certain amount of open space surrounding an individual pedestrian, movement is no longer made in relation to other pedestrians. The clear difference in the values illustrates the highly subjective nature of determining “uninfluenced” movement. As the values of available space per person decrease, comparable observations to those by Fruin are made with respect to flow rates and probable “jam density.”

---

<sup>30</sup> Op cit, pp 74-78.

The aforementioned recommended thresholds were later included in the *Highway Capacity Manual, Chapter 13* discussion of uninterrupted pedestrian facilities with some modifications. The level of service categories A, B and C were redefined, reflecting the findings of Pushkarev and Zupan. The new definition of LOS E absorbed both categories D and E of Fruin’s study. The following table provides a summary listing of the current Level of Service thresholds for free flow pedestrian movement along walkways.

**Table 3.3. Highway Capacity Manual (1994 edition) LOS Thresholds for Free Flow Movement on Uninterrupted Pedestrian Walkways<sup>31</sup>**

Level of Service	Flow rate* (ped/minute/meter)	Available Space per Pedestrian (m <sup>2</sup> /ped)
A	<7	>12.1
B	7 – 17	3.7 – 12.1
C	17– 33	2.2 – 3.7
D	33– 49	1.4 – 2.2
E	49 – 82	0.6 – 1.4
F	var.	<0.6

\* The table values are to be applied to walkway conditions for a fifteen minute study period.

In practical terms, the 1994 HCM definitions created a very generous LOS A standard. The LOS thresholds also allow many facilities to operate at higher flow rates while still preserving a minimum LOS standard of D or better, rather than the stricter boundaries proposed by Fruin.

### **3.4 RECOMMENDED CHANGES FOR 2000 EDITION OF HIGHWAY CAPACITY MANUAL**

In order to recommend a consistent set of LOS thresholds, the Institute for Transportation Research and Education at North Carolina State University conducted a

<sup>31</sup> Transportation Research Board (TRB). “*Highway Capacity Manual, Chapter 13: Pedestrians*”. page 13-3, Table 13-8. 1994 edition.

comprehensive review of existing pedestrian movement evaluation methodologies.<sup>32</sup> One of the products of this comprehensive literature review was the comparison and review of existing pedestrian evaluation methodologies to be incorporated into an updated form.

The literature review examined all of the available published reports that dealt with pedestrian flow movement studies along several different types of facilities. Those findings dealing with flow along uninterrupted facilities (i.e. walkways) will be discussed in this report. A composite set of tables for the Level of Service thresholds for pedestrian flow along walkways were created. Information from the tables is reproduced below.

**Table 3.4. Walkway Level of Service (LOS) Thresholds by Available Space Per Pedestrian (m<sup>2</sup>/ped)<sup>33</sup>**

LOS	HCM	Fruin	Pushkarev-Zupan	Brilon (Germany)	Polus (Israel)	Tanaboriboon-Guyano (Thailand)
A	>12	>3.2	>12	>10	n/a	>2.38
B	3.7 – 12	2.3 – 3.2	4 – 12	3.3 – 10	n/a	1.6 – 2.38
C	2.2 – 3.7	1.4 – 2.3	2 – 4	2 – 3.3	1.67	0.98- 1.60
D	1.4 – 2.2	0.9 – 1.4	1.5 – 2	1.4 – 2	1.33 – 1.66	0.65 – 0.98
E	0.6 – 1.4	0.5 – 0.9	1.0 – 1.5	0.6 – 1.4	0.5 – 0.8	0.37 – 0.65
F	<0.6	<0.5	0.2 – 1	<0.6	n/a	<0.37

<sup>32</sup> Quality of Service for Uninterrupted Pedestrian Facilities in the *2000 Highway Capacity Manual* by Milazzo, J., Rouphail, N., Hummer, J., and Allen, D.P. *Transportation Research Record*, copyright 1999

<sup>33</sup> Op cit.

**Table 3.5. Walkway Level of Service (LOS) Thresholds by Flow Rate (pedestrian/minute/meter)<sup>34</sup>**

LOS	HCM	Fruin	Pushkarev-Zupan	Brilon (Germany)	Polus (Israel)	Tanaboriboon-Guyano (Thailand)
A	<6.6	<23	<7.0	n/a	n/a	<28
B	6.6 – 23	23 – 33	7 – 20	n/a	n/a	28 – 40
C	23 – 33	33 – 49	20 – 33	n/a	< 40	40 – 61
D	33 – 49	49 – 66	33 – 46	n/a	40 – 75	61 – 81
E	49 – 82	66 – 82	46 – 59	n/a	75 – 95	81 – 101
F	var.	var.	0 – 82 (var.)	n/a	unknown	var. or 101+

As can be seen in the tables, there is a marked difference between the results of studies conducted in the United States and those conducted elsewhere. In addition, strong argument can be made that cultural differences in the perception of personal space may account in large part for the different thresholds as expressed in terms of available space per pedestrian. This is most clearly evident at the extreme values, both in terms of maximum flow rate and the minimum available space per pedestrian, at which movement is assumed to cease.

The recommended changes to the 1994 HCM Level of Service thresholds for the year 2000 included the following:

- lowering the threshold for LOS A from >12 m<sup>2</sup>/ped to 5.6 m<sup>2</sup>/ped
- preserve the existing LOS thresholds for B, C, and D levels
- redefining the threshold at LOS F (obstructed movement) to be whenever available space falls below 0.75 m<sup>2</sup> per pedestrian

The rationale behind these adjustments was straightforward. The previously recommended definition of LOS A as offering more than 12 square meters per person was considered excessive and nearly impossible to attain as a design objective. Previous studies argued that when the amount of available space per pedestrian exceeds 3.7 square

<sup>34</sup> Op cit.

meters, individual movement is not influenced by adjacent or surrounding elements.<sup>35</sup> The resultant figure of 5.6 square meters was a compromise between extremes.<sup>36</sup>

It was determined that for design purposes, “unsatisfactory” conditions should be declared at the point where individual movements were constrained, but not necessarily impossible, as previously defined. Several researchers had agreed that individual movements were constrained in areas less than 0.75 square meters per pedestrian,<sup>37</sup> which is commonly defined as a “standard pedestrian buffer zone” for North Americans. It was noted that studies conducted in Asia and Europe provide slightly smaller definitions of the body ellipse,<sup>38</sup> and so the recommended spacing thresholds were for application in North America only. In addition, the maximum attainable flow rate (i.e. walkway capacity) is suggested to be 75 pedestrians per minute per meter width of walkway, which is slightly lower than previous HCM limits, but within the boundaries of available observations.

The table below presents the revised Level of Service thresholds for pedestrian facilities as presented for inclusion in the 2000 Highway Capacity Manual. These thresholds are for use when evaluating facilities that are not subject to heavy platoon flows.

---

<sup>35</sup> Fruin, John J. *Pedestrian Planning and Design*. New York, NY. Metropolitan Association of Urban Designers and Environmental Planners Inc. Copyright 1971, page 48.

<sup>36</sup> “Quality of Service for Uninterrupted Pedestrian Facilities in the 2000 Highway Capacity Manual,” by Milazzo, J. Roupail, N., Hummer, J., and Allen, D.P. *Transportation Research Record*, copyright 1999

<sup>37</sup> Op cit.

<sup>38</sup> Tanaboriboon, Yordphol, Sim Siang Hwa and Chin Hoong Chor. “Pedestrian Characteristics Study in Singapore”. In *Journal of Transportation Engineering*, May 1986

**Table 3.6. Recommended HCM 2000 Walkway Level of Service (LOS) Criteria<sup>39</sup>**

LOS	Available Space (m <sup>2</sup> /ped)	Flow rate (ped/min/m)
A	>5.6	<16
B	3.7 – 5.6	16 – 23
C	2.2 – 3.7	23 – 33
D	1.4 – 2.2	33 – 49
E	0.75 – 1.4	49 – 75
F	< 0.75	var.

### **3.5 DEFINITION OF PLATOON PEDESTRIAN MOVEMENT**

For the purposes of this study, a platoon of pedestrians is defined as the collection and ‘bunching together’ of non-associated travelers due to external constraints. A platoon can be created at a signalized crosswalk (similar to platoon creation at traffic signals), or it may be generated by a constricted point of entry or exit, that requires otherwise independent pedestrian movement to proceed interdependently. Previous studies have used athletic venues, transit terminals, exit points and signalized crossings to generate platoon movement.

In recognition of the different forms of pedestrian flow, studies have undertaken the task of reviewing what, if any, impact platoon pedestrian movements have upon flow rates and by inference, potential Levels of Service thresholds. Separate measures for evaluating platoon movements were developed for use in areas with high volume, high density pedestrian flows, such as those outside an emptying sports facility or near a large-scale transportation station.

---

<sup>39</sup> Transportation Research Board (TRB). *Highway Capacity Manual, Chapter 13: Pedestrians*. page 13-3, Table 13-8. 1994 edition.

### 3.6 OVERVIEW OF METHODS FOR MODELING PLATOON PEDESTRIAN MOVEMENT

In modeling platoon pedestrian movement, four basic methodologies have been developed: the “rule of thumb”, adjustment factors, additive adjustments and the revised LOS thresholds by the Canadian airport corridor study.<sup>40</sup>

The “rule of thumb” method assumes that the level of service experienced in platoons is one level lower than that during average flow conditions. In effect, the reviewer assumes that for platoon movements, LOS A is equivalent to LOS B under free flow conditions. Or, put another way, pedestrians traveling under LOS B densities and average speeds, will consider this flow rate optimum when traveling within a platoon. LOS F remains jam density, as most studies do not imply any realistic movement (either individually or collectively) at this density. This method is recommended in the 1980 publication, *Interim Materials*<sup>41</sup>.

Adjustment factors for platoon movement result from the ratio of platoon flow (that is the volume of pedestrians per minute per meter width) to average flow. Adjustment factors can be calculated for site-specific flows. For example, if a location were under review, and it exhibited platoon pedestrian movement, a small-scale observation study could be made to determine how “far off” the recommended thresholds are from observed behavior. Another set of flow rate and density calculations could be run and an appropriate adjustment factor could be devised. No study reviewed used this method, however, it is possible that in lieu of extensive observations, a lower volume location could be reviewed and modeled to account for regional or population specific differences (such as physically and/or visually impaired pedestrians at one location).

Additive adjustments are numerical “shortcuts” that allow for quick calculations across the whole Level of Service spectrum, independent of flow. This is the method recommended in Chapter 13 of the Highway Capacity Manual. The additive adjustment

---

<sup>40</sup> Op cit.

<sup>41</sup> Transportation Research Board (TRB). *Interim Materials on Highway Capacity*. Transportation Research Circular 212; 1980

of 13.1 pedestrians per meter width of travel lane allows greater densities of flow without necessarily recalculating new critical values along the density-flow rate curve.<sup>42</sup>

A study published in 1987, and conducted by researchers from Carleton University in Ontario, Canada,<sup>43</sup> postulated that routine platoon flow, such as that found in transit terminals, might be categorized by different LOS standards with respect to density. An important hypothesis within the study was that pedestrians within a confined area would tolerate higher density platoon movement in the interest of greater overall average speed.<sup>44</sup> The study chose sample populations of pedestrians from three large airports in Canada: Montreal International, Ottawa International and Lester B. Pearson Airport in Toronto.

The methodology developed by researchers in Canada introduced the hypothesis that at higher flow rates, pedestrians traveling in platoons would be willing to sacrifice personal space (thereby increasing overall platoon density) in order to travel at higher overall speeds.<sup>45</sup>

### **3.7 RESULTS OF BRAAKSMA-DAVIS PLATOON MOVEMENT STUDY**

A critical finding of the Canadian airport corridor study revealed that the existing rule of thumb methodology for estimating platoon flow for pedestrian movement along uninterrupted facilities would ‘underestimate unencumbered flow at speeds above 0.9 meters per second, and overestimate theoretical flows below that speed.’<sup>46</sup>

In brief, the recommended estimation method for platoon movement (the heretofore referred “rule of thumb”) which adds approximately 13 pedestrians per meter travel lane width per minute to the current flow volume estimates for a given LOS, is inaccurate in a region that experiences significant platoon flow. The Davis-Braaksma study revealed that for airport corridor pedestrian movement in platoons, travelers were more willing to endure higher platoon densities in exchange for higher overall speeds.

---

<sup>42</sup> Transportation Research Board (TRB). “*Highway Capacity Manual*”. Special Report 209, 1994 update to 1985 edition. HCM, p.13-11

<sup>43</sup> Davis, Dennis and John Braaksma. “Level-of-Service Standards for Platooning Pedestrians in Transportation Terminals”. In *ITE Journal*, April 1987.

<sup>44</sup> Op cit.

<sup>45</sup> Op cit.

<sup>46</sup> Op cit. p33

This finding is subject to several caveats. It has been noted previously that depending upon the culturally determined boundaries of personal comfort zones, densities along pedestrian facilities can vary, especially at the extremes, with Far Eastern pedestrians tolerating far higher densities than Western ones.<sup>47</sup> In addition, it is not beyond imagination to exclude airport pedestrian volumes on or before peak travel days as not being representative of routine pedestrian movement. However, while allowing for these extreme cases, it is significant that platoon movement in high-density flows implies a smaller definition of “personal space” than that which is normally assumed for pedestrian movements.<sup>48</sup>

### **3.8 COMPARISON OF EVALUATION METHODS FOR PLATOON ADJUSTED FLOW**

The value of the above methods for evaluating platoon pedestrian movement is in the need to accurately reflect the performance of pedestrian facilities under extreme or high volume demands without running complicated calculations or additional studies. In areas with low levels of pedestrian movement, platoon or otherwise, these specialized evaluations are not necessary. However, for facilities that are specifically designed to accommodate high volumes of pedestrians, and are therefore subject to the frequent generation of platoons due to peak demand and random arrival patterns, a specialized set of evaluation criteria is valuable. The following tables show comparisons of the platoon-adjusted values for level of service thresholds along uninterrupted pedestrian facilities.

---

<sup>47</sup> Tanaboriboon, Yordphol, Sim Siang Hwa and Chin Hoong Chor. “Pedestrian Characteristics Study in Singapore”. In *Journal of Transportation Engineering*, May 1986

<sup>48</sup> “Level of Service Standards for Platooning Pedestrians in Transportation Terminals” by Dennis G. Davis and John P. Braaksma. *ITE Journal April 1987 pp. 31-35.*

**Table 3.7. Comparison of Platoon Adjusted Level of Service Thresholds for Pedestrian Walkways (available space per pedestrian)**

LOS	Pushkarev/Zupan (m <sup>2</sup> /ped)	Interim Materials (m <sup>2</sup> /ped)	HCM (1994) (m <sup>2</sup> /ped)	Davis-Braaksma (m <sup>2</sup> /ped)
A	5.6+	12	12	1.7 – 2.3
B	3.7 – 5.6	4 – 12	3.7 – 12	1.3 – 1.7
C	2.2 – 3.7	2 – 4	2.2 – 3.7	1.0 – 1.3
D	1.5 – 2.2	1.5 – 2	1.4 – 2.2	0.8 – 1.3
E	1.0 – 1.5	1.0 – 1.5	0.6 – 1.4	0.7 – 0.8
F	< 1.0	0.6 – 1.0	< 0.6	< 0.7

**Table 3.8. Comparison of Platoon Adjusted Level of Service Thresholds for Pedestrian Walkways (pedestrian flow rates)**

LOS	Pushkarev/Zupan (ped/min/meter)	Interim Materials (ped/min/meter)	HCM (1994) (ped/min/meter)	Davis-Braaksma (ped/min/meter)
A	1.6 – 15	< 6	< 19.7	<37
B	15 – 20	6 – 20	19.7 – 36	37 – 46
C	20 – 33	20 – 33	36 – 46	46 – 57
D	33 – 46	33 – 46	46 – 62	57 – 68
E	46 – 59	46 – 59	62 – 95	68 – 75
F	59+	59 – 82	95+	75+ var

It is evident from the tables that several different interpretations exist with regard to the influence that platoon movement exerts on pedestrian facilities. There is a consistent assumption that a linear relationship is an accurate means of distinguishing

between non-platoon and platoon pedestrian levels of service for uninterrupted pedestrian walkways. Unfortunately, as reported in the Recommended 2000 HCM thresholds, no consistent set of thresholds for platoon pedestrian movement is available.

### **3.9 REMAINING AREAS FOR RESEARCH**

There is a lack of recent studies detailing pedestrian movements in several cases, requiring older studies to be applied in areas outside of their original zone of interest. While perhaps there is no great call for extensive studies into the safe, predictable movement of small volumes of pedestrians, there is (and has been for some time) expressed interest in the revitalization of traditional urban environments. Central to the economic development of any area is the convenient access for large numbers of people. Clearly, there is a need for more detailed research into the encouragement and predictable movement of large numbers of pedestrians in and through dense, urban environments. Engineers and city planners will be called to conduct more rigorous reviews of areas and intersections in terms of minimizing conflicts between vehicles and pedestrians. One method of minimizing conflict is to provide adequate facilities for all modes of interest.

Further research is needed to determine more clearly the interaction between pedestrians and vehicles at intersections, and along multiple use facilities, such as recreational use paths and trails. There is also need for studies that provide an inventory of street furniture designs and their respective success rates in attracting foot traffic.

In addition to the above mentioned general areas of study, an empirical ‘test’ of the recommended changes to the existing Highway Capacity Manual level of service thresholds would prove useful. Given the disparate opinions found in other studies, as well as the regional bias for the most influential North American studies (both Fruin and the researchers Pushkarev and Zupan used New York City as the location for their research), a research project focusing on the influence of platoon pedestrian movement may provide useful commentary and confirmation of the most recent set of recommended LOS thresholds.

### **3.10 SUMMARY**

As evidenced by the recent review and recommended changes to the existing evaluation methodologies for pedestrian facilities there is renewed interest in the scientific study of pedestrian movement. The next chapter will briefly explain the application of Level of Service methodologies to pedestrian movements.

## **CHAPTER 4. METHODS OF PEDESTRIAN MOVEMENT ANALYSIS**

### **4.1 APPLICATION OF LEVEL OF SERVICE METHODOLOGY TO PEDESTRIAN MOVEMENT ANALYSIS**

The primary method of evaluating a pedestrian facility's level of service is via density-flow rate calculations, similar to those employed for vehicle LOS studies. A given density and volume flow rate corresponds to a Level of Service, and as in vehicular movement, the higher the density the lower the perceived Level of Service, from the perspective of the pedestrian. Similar to LOS thresholds for vehicular movement, most pedestrian movement studies use a scale from LOS A to LOS F, corresponding to unrestricted or "free flow" movement and immobile or "jam density" conditions respectively.<sup>49</sup>

In principle, such density or flow rate thresholds may serve as operating goals, minimum standards or warning elements for the management of a given pedestrian facility. When such methodologies are included in the objectives phase of an urban improvement project (for example, a new or renovated athletic facility), they may serve as an important standard to be met for either present, estimated or expected pedestrian volumes.

### **4.2 A BRIEF REVIEW OF PREVIOUS PEDESTRIAN MOVEMENT STUDIES**

The tools most often available to the pedestrian facility designer or manager are anecdotal information, personal observations and experience, and the detailed evaluations of existing facilities that have predictable high volumes of pedestrians. The Highway Capacity Manual (1994 edition) provides several means of evaluating the effectiveness and design elements of sidewalks, intersections, and entrances.<sup>50</sup> These evaluation schemes are based upon density studies conducted previously<sup>51</sup> with the assumption that

---

<sup>49</sup> Most descriptions of pedestrian ease of movement will be taken from Chapter 13: Pedestrians of the *Highway Capacity Manual* (1994 edition)

<sup>50</sup> Transportation Research Board (TRB). "*Highway Capacity Manual*". Special Report 209, 1994 update to 1985 edition.

<sup>51</sup> Fruin, John J. *Pedestrian Planning and Design*. New York, NY. Metropolitan Association of Urban Designers and Environmental Planners Inc. Copyright 1971 Transportation Research

pedestrian flows and densities are more or less consistent across temporal and historical lines. More recent studies have shown a need to incorporate cultural differences into the evaluation of densities and volumes before drawing conclusions, especially when searching for the critical extreme values at which quality of service is considered “poor” or substandard, LOS E or F depending upon the researcher.<sup>52</sup>

The table below summarizes the recommended Level of Service thresholds for uninterrupted (i.e. walkways, sidewalks and corridors) pedestrian facilities as found in the Chapter 13 of the 1994 edition of the Highway Capacity Manual. This table is the same as shown earlier in Chapter 3.

**Table 4.1. 1994 HCM Walkway Level of Service Thresholds<sup>53</sup>**

Level of Service	Flow rate* (ped/minute/meter)	Available Space per Pedestrian (m <sup>2</sup> /ped)
A	<7	>12.1
B	7 – 17	3.7 – 12.1
C	17– 33	2.2 – 3.7
D	33– 49	1.4 – 2.2
E	49 – 82	0.6 – 1.4
F	var.	<0.6

\* The table values are to be applied to walkway conditions for a fifteen minute study period

The table above is for application to pedestrian walkways for free flow conditions.

---

Board. *Highway Capacity Manual* Special Report No. 209. Washington, DC.: Transportation Research Board, copyright 1985. Institute of Transportation Engineers Technical Council Committee 5-R “Characteristics and Service Requirements of Pedestrians and Pedestrian Facilities” *Traffic Engineering*, Volume 46, Number 5, pp. 34-45. Copyright 1976.

<sup>52</sup> Tanaboriboon, Yordphol and Jocelyn A. Guyano. “Level of Service Standards for Pedestrian Facilities in Bangkok: A Case Study”. *ITE Journal*, November 1989. Tanaboriboon, Yordphol, Sim Siang Hwa and Chin Hoong Chor. “Pedestrian Characteristics Study in Singapore”. In *Journal of Transportation Engineering*, May 1986.

<sup>53</sup> Transportation Research Board (TRB). “*Highway Capacity Manual*”. Special Report 209, 1994 update to 1985 edition.

### **4.3 SITE SPECIFIC STUDIES OF PEDESTRIAN MOVEMENTS**

A recurring comment made of pedestrian movement studies is the notion that to a certain extent, the quality and performance of a given facility depends greatly upon the population it serves. It may prove counterproductive to seek a “normal” or generic pedestrian flow pattern given the rapidly divergent characteristics of any given location. The dominance of New York City as a location for pedestrian movement research bolsters this argument. While pedestrian movement is perhaps viewed as more critical in areas of high density development, attempts to apply information and evaluation methodologies far from their sources are prone to criticism. It is hard to find credible claims of mass exodus studies at football stadia, urban festivals, parades or large scale airport terminals as representative of “typical flow” along any sidewalk in any city. The challenge lies in modeling pedestrian behavior that is at the same time routine and of high enough volume to provide an adequate sample population size.

### **4.4 STATEMENT OF PROBLEM**

The vast majority of pedestrian flow studies have taken place in large cities, on busy congested streets or within the immediate physical confines of a large entertainment or transit facility such as an airport, or athletic stadium. These locations provide excellent models for like environments, but what of the proposed outdoor mall in a new suburban development? Is it reasonable to expect people unaccustomed to crowded urban transportation conditions to welcome and accept large flows on a daily (or routine) basis?

In the interests of providing empirical data to support or refute the premise that platoon pedestrian movements are effectively modeled using current methodologies, a controlled experiment studying pedestrian movement along an uninterrupted facility was designed. Critical to the objectives of the experiment was the selection of a location with substantial, routine platoon pedestrian flows that would serve as a reasonably representative sample population for many modern facilities. The next chapter will detail the experimental design and scope of study for this research project.



## **CHAPTER 5. EXPERIMENTAL DESIGN AND SCOPE OF STUDY**

### **5.1 EXPERIMENTAL DESIGN AND SCOPE OF RESEARCH**

It is beyond the scope of this research study to conduct a comprehensive pedestrian movement analysis research experiment on the scale of Fruin's work done for *Pedestrian Planning and Design*. Instead, the focus is more specific, and hopefully will provide valuable commentary upon the most recently recommended set of evaluation criteria for walkway levels of service.

The findings of the literature review dealt with accepted evaluation methodologies for uninterrupted pedestrian facilities, such as sidewalks and public plazas, under certain conditions. The objective of the experiment was to confirm or refute the results of the literature review, namely to provide recent pedestrian flow data as empirical confirmation of the need for changes to the previous version of the Highway Capacity Manual's Chapter 13 on Pedestrian Facilities.<sup>54</sup>

In order to provide a "field test" for the recommended LOS thresholds for uninterrupted pedestrian facilities as well as avoid site specific charges of failing to provide "generic, large scale pedestrian volumes," this research experiment was designed and performed to study as close to a "routine" commuter pedestrian travel pattern as could be devised and observed.

### **5.2 PRIMARY OBJECTIVES OF RESEARCH STUDY**

A first assumption, or hypothesis, of the study is that pedestrians who are not confined physically, but still operate under routine conditions which generate platoon movements (such as those found at transit stations) will not behave similar to those not traveling in platoons. A second assumption is that pedestrians operating in platoons will not tolerate nor operate at the higher densities found in the airport study. The study proposes that the two populations ("airport" and "non-airport," if you will) are dissimilar enough to warrant separate studies and possibly even separate LOS thresholds. It is proposed that the densities tolerated by pedestrians on uninterrupted, but not artificially

---

<sup>54</sup> Op cit.

constrained, facilities will not approach the densities found in physically constrained environments.

The corridors of a large airport, while likely to generate high volumes of pedestrians are not likely to be fair representatives of routine conditions for platoon pedestrian movements. The combination of fixed (and often severe) time constraints, as well as the self-selecting nature of the population may make for higher tolerances on the part of the individual pedestrian, in the interest of successfully completing their trip. To use such a population as the model for any urban platoon movement on uninterrupted pedestrian facilities seems problematic. It may be more appropriate to classify platoon pedestrian movement in airport corridors as a separate population unto itself.

A final objective of the experiment is to determine if an alternative set of LOS threshold criteria are warranted for transit terminals beyond those proposed in either the recommendations for the *2000 HCM* or any other previous publication. While the recommendations for the year 2000 HCM drew their conclusions from a broad literature review, no new research was conducted to specifically test the applicability of the modified thresholds as they apply to any existing pedestrian facility. Specifically, the recommendation to use the airport flow rate study as the basis for evaluating transportation terminals subjected to routine platoon pedestrian movement, seemed to warrant further examination.

### **5.3 SITE SELECTION**

In an attempt to locate a pedestrian population of routine platoon movement, several potential environments were reviewed. It was not the interest of this study to repeat previous work done on or near college campuses, nor at major sports facilities, as both of these populations are open to the same site-specific charge leveled at the airport corridor study. However, short of revisiting the sites of previous research in New York City, there were few locations that promised a large number of pedestrians who typically were placed upon uninterrupted facilities in platoon movement patterns that would allow for easy study. Compounding this difficulty was the constant concern of time and research resources. Several locations do in fact offer combinations of numerous pedestrians, lengthy facilities and reasonably predictable platoon movements, however,

few were to be found in close proximity to Austin, Texas, home of the primary researchers.

Eventually the city of Denver, Colorado was chosen. The managing partner of the mall, Downtown Denver Partnership, claimed over 60,000 daily visitors along the 1.6-mile promenade. The designated custom shuttles have an operating capacity of 70 riders, and during rush hour operate with a 60-90 second headway.<sup>55</sup> The combination of an established transit system (both bus and rail) with an exclusively pedestrian space offered promising opportunities to observe and study pedestrian movements independent of vehicle interference.

Denver, Colorado offers a post ‘World War II boom’ city, with established and substantial suburban development along the major arterial and restricted access roadways. Denver has also sought to preserve and redevelop its urban core, for both political and economic reasons. The 16<sup>th</sup> Street Pedestrian Mall links to two established transit services, bus and light rail, as well as parallels a vibrant business district along 17<sup>th</sup> Street to the north. In combination with adjacent institutions of higher learning, a developing network of recreational hike and bike trails along the river, as well as the proximity of the professional baseball team’s stadium, this location combines many of the idealized components argued necessary to support high levels of pedestrian activity. In this context, data collected in Denver, Colorado, supplements the database of pedestrian movement studies by providing information about pedestrian movements in a relatively new, non-Eastern (or European) city.

Discussions with the personnel of the Downtown Denver Partnership and the Regional Transportation District proved encouraging. A site visit was planned for a non-holiday period, to videotape and interview “typical” patrons of the mall at both a transit station and an intermediate point along the mall. It was assumed that with such a high average daily clientele, variations in movement (platoon and free flow) as well as observed platoon densities would provide a large enough sample from which to derive

---

<sup>55</sup> Estimated peak hour headway for 16<sup>th</sup> Street Pedestrian Mall Shuttle buses provided by Mr. Kent Epperson, staff transportation planner of the Regional Transportation District of Denver, Colorado.

reasonable conclusions about non-physically confined platoon pedestrian movements along uninterrupted facilities.

#### **5.4 DATA COLLECTION OBJECTIVES**

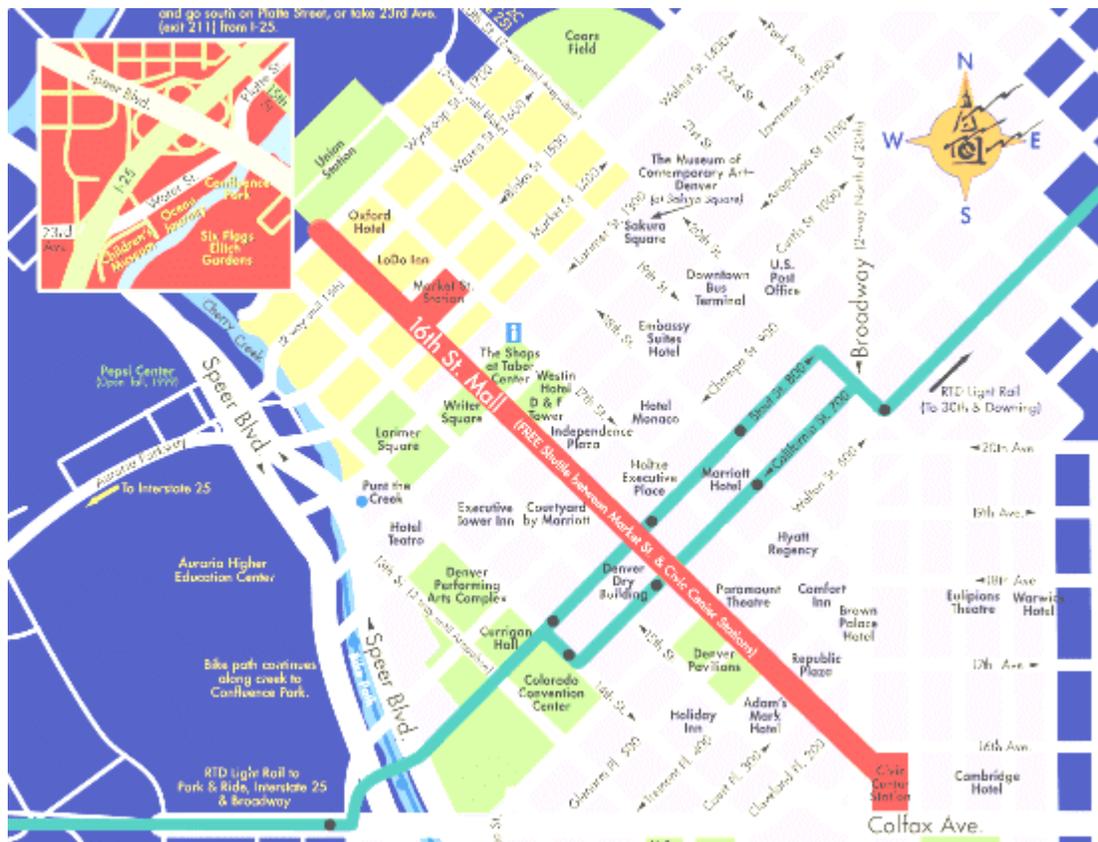
Two primary goals were set for the data collection:

- 1) to document pedestrian movements along uninterrupted facilities, both in platoon and free flow movements at or near a transit station and
- 2) to provide documented platoon density interpretations on the part of pedestrians within the stream.

With regard to the first objective, nearly 10.5 hours of videotape were taken, primarily of pedestrian movements at the Market Street Transit station which served as a major transfer point for riders from urban and suburban commuter buses to the pedestrian mall shuttle buses (see Figure 5.1). An artificial cordon type barrier was drawn on the walkway before the shuttle bus loading platform (see Figure 5.2) and pedestrians traversing the “box” were used to determine platoon densities and average travel speeds.

Standard demographic data was derived from the tapes including, age (estimated within 10 years), gender, race and trip purpose (as inferred by style of dress, direction, speed and accessories). Well over 1000 individuals were observed traversing the cordoned area, with 767 being selected as representative of peak hour flow, both in and outside platoons. The times of study were morning and evening peak travel periods. The morning peak travel period was determined (with aid from RTD staff) to be from 7:30 am to 9:30 am. The evening peak period was determined to be from 4:30 PM to 6:30 pm. Four periods of pedestrian movements at the Market Street transit station were captured on videotape: Tuesday evening peak, Wednesday morning and evening peak and Thursday morning peak.

Figure 5.1. Schematic of 16<sup>th</sup> Street Pedestrian Mall in Denver, Colorado<sup>56</sup>



<sup>56</sup> Source of downtown map and diagram: Downtown Denver Partnership website. Internet address: [http://www.downtowndenver.com/map\\_dir.htm](http://www.downtowndenver.com/map_dir.htm)

**Figure 5.2. Still from Video of Transit Patrons Alighting at Market Street Station**



With regard to the second objective, gaining the participation of pedestrians at the transit station proved problematic. Prior to arrival in Denver two multiple choice survey forms had been developed, one considerably shorter than the other. The short survey was to be distributed within the traveling public and to have been filled out “on the fly” and dropped in a conveniently located repository downstream of the cordon study area.

The long survey form was reserved for individuals who would withdraw from the travel stream and answer more detailed questions about the perceived level of crowding and their personal tolerances of specific densities. Both surveys were visual in nature, and had been well received in pilot tests near the University of Texas campus. Unfortunately, the overwhelming majority of patrons at the transit station were too pressed for time to even attempt the short survey developed for the study.

The longer survey was clearly not a reasonable means of recording intra-stream opinion. While close to 120 long surveys were collected, smokers completed the vast

majority of these during their respites taken prior to boarding another bus. The obvious sampling bias rendered the long survey results inadmissible for inclusion in this study.

## 5.5 REVIEW OF COLLECTED DATA PRIOR TO ANALYSIS

While well over 1000 pedestrians were observed during the course of the data collection, only 767 were selected as representative of platoon and non-platoon pedestrian movement. A large portion of the observed pedestrians failed to either completely traverse the study area, would alter travel paths precluding accurate speed calculations or were not representative of the desired ideal uni-directional flow.

As a result, only two evening peak periods were used to calculate platoon movement thresholds. The selected peak travel periods for analysis were two separate days during the evening hours of 16:30 until 18:30. Individual speeds, following distance (measured as time to travel between two known points), gender, approximate age and trip purpose were recorded. Due to the time of day and the location chosen, very few of the observed pedestrians were not classified as “commuter.” Those who were obviously students and (most likely) of secondary school age were classified as “other/leisure” with regard to trip purpose. No statistically significant relationship was discovered between trip purpose and any other observed or derived value. Full statistical analysis charts and data tables are located in the Appendix.

Of the 767 selected individual pedestrians whose speeds, gender, following distance platoon/non-platoon movements were documented, 490 were observed during one evening peak period. The remaining 277 pedestrians were observed two days later at the same location. The following table provides a brief summary of the observed (and estimated) demographic characteristics of the population sample.

**Table 5.1. Brief Summary of Population Sample Demographics**

	Gender	Ethnicity (est.)	Trip Purpose	Age (est.)
Tuesday Evening Peak	62.8% female 38.2% male	83.9% Anglo 4.1 % Black 12% unknown	86.1% commuter 13.9% leisure/other	median – 35 Average – 37.6
Wednesday Evening Peak	59.9% female 40.1 % male	81.6% Anglo 7.6% Black 10.8% unknown	84.1% commuter 15.9% leisure/other	Median – 40 Average – 38.8

From the vantage point provided (the fourth story window of an adjacent office building), very few individual details were discernable. The need to preserve as much of the study area in the camera's angle of view precluded the ability to record specific features of each individual pedestrian. Of greater import were the individual travel times and relative densities of the observed platoons as they traversed the open air plaza en route from the shuttles to the Market Street bus transit station.

## **5.6 COMPARISON OF SITE SELECTION WITH PREVIOUS STUDIES**

The selection of the 16<sup>th</sup> Street Pedestrian Mall in Denver, provided an opportunity to consider the oft stated opinion that within the United States, there exists a geographic bias in terms of pedestrian movements. The two most influential studies (in the opinion of this researcher) are both based upon data collected in New York City. Other studies were developed in denser, older cities with well established transit systems. Even the study conducted in Canadian airports dealt with populations at far higher densities (and possibly from higher density origins) than is the norm for the newly proposed pedestrian oriented facilities in the rapidly developing western and southern United States. A hidden premise, not wholly developed in pedestrian movement studies, is the assumption that pedestrian movement is more or less uniform across geographic boundaries. This opinion is under increased scrutiny given the results from Far Eastern studies, as well as the aforementioned push to counter the western United States automobile dominated development phenomenon with Traditional Neighborhood Development programs.

## **5.7 SUMMARY**

This section reviews the process by which the study area was selected, the objectives of the data collection and the relative applicability of the study location with research locations in previous studies. The next chapter will present the results of the data collection and analysis.

## **CHAPTER 6. DATA COLLECTION AND ANALYSIS**

### **6.1 RESULTS OF DATA COLLECTION ANALYSIS**

As reviewed earlier, previous researchers have used data to determine the influences of speed upon flow density and volume for various pedestrian facilities. This experiment specifically isolated one form of pedestrian movement, uni-directional platoon influenced flow, for analysis to provide confirmation of the most recently recommended level of service thresholds for uninterrupted walkways.

The data collected represented the observations of pedestrians transferring from one transit vehicle to another. Due to the nature of the facilities, the time of day and the appearance of the observed pedestrians, this study assumes that the population studied is representative of commuter behavior en route between two transit vehicles. In fact, from all appearances, the majority of the observed pedestrians were participating in the timed transfer from a local shuttle bus service to a regional transit bus service.

### **6.2 OVERVIEW OF OBSERVED PEDESTRIAN BEHAVIOR**

The majority of the alighting passengers proceeded directly towards the Market Street Station, which houses its vehicle bays on a subterranean level below the plaza. The route of the movements followed a straight line distance of approximately 20 meters, from curb to building entrance, the first 10 of which were in the view of the recording video camera.

The artificial cordon study area for the experiment was a rectangular “box,” marked with heavy duty electrician’s duct tape, 23.79 square meters in area. The study area was positioned to encompass the highest probable direct route between a shuttle bus bay and the doors to the Market Street Station. No attempts were made to physically guide pedestrians to or through the cordon study area. Due to the short headway between arriving shuttle buses, as well as the uni-directional nature of flow, no significant cross traffic movements were observed or recorded during the time periods of highest flow.

**Figure 6.1. Still Photograph of Pedestrian Platoon Traversing Study Area.**



As marked on the captured image shown above, a chronometer was used to determine travel speeds and following distances for successive pedestrians. Due to the complicating factor of parallax, no attempt was made to calculate lateral spacing distances within a platoon. Instead, Fruin's observations of interpersonal spacing (derived from overhead still photographs) were used to calculate likely periods of maximum density.

### **6.3 DEVELOPMENT OF LOS THRESHOLDS FOR MARKET STREET STATION PEDESTRIAN FLOWS**

Using the methods developed by Fruin (and detailed earlier in Chapter 4), the data collected at the Market Street Station was used to develop a set of Level of Service thresholds for pedestrian movements. Observations of independent pedestrian movements were analyzed using the sum of least squares regression techniques. Similar to previous studies, density – flow rate charts were drawn and modeled to determine the critical values of jam density, maximum speeds and flow rates. Using the same scalar ratios as earlier studies, critical thresholds for the various levels of service were determined. The

following table presents the calculated LOS thresholds for non-platoon pedestrian flow, as observed at the Market Street Station in Denver, Colorado.

**Table 6.1. Level of Service Thresholds for Denver, Colorado Market Street Bus Transfer Station (non-platoon flow conditions)**

LOS	Available space (m <sup>2</sup> /ped)	Flow rate (ped/min/m)	Speed (m/min)
A	> 4.1	< 16	115
B	2.9 – 4.1	16 – 35	102 – 115
C	1.7 – 2.9	35 – 46	78 – 102
D	1.2 – 1.7	46 – 55	66 – 78
E	0.6 – 1.2	55 – 71	60 – 66
F	≤0.6	var. to 71	< 60

Using the same relationships derived by Fruin, and presented in detail by Pushkarev and Zupan, the following equations were applied to the observed speeds and calculated flow rates to determine the theoretical critical values for platoon and non-platoon pedestrian movement.

$$\text{Speed} = ((A + (A^2 - 4*B*\text{flow})^{0.5})/2)$$

Where A is the maximum theoretical speed and B is a calculated coefficient related to A in the following manner: B/A = critical threshold of available space per pedestrian below which physical movement is impossible (i.e. theoretical jam density).

For non-platoon pedestrian movement the equation above yields:

$$\text{Speed} = ((115.2 \text{ m/min} + (115.2^2 * 4 * 25.34)^{0.5})/2)$$

$$A = 115.2 \text{ meters/minute and } B/A = 0.22 \text{ m}^2/\text{ped}$$

Critical values:

Maximum predicted individual speed: 115 meters per minute (1.93 meters/sec)

Maximum theoretical flowrate: 71 pedestrians/minute/meter width

Threshold of available space at which individual movement becomes unstable: 0.58 square meters per person

The statistical analysis of the Market Street Station movements shows that for an individual pedestrian, movement should prove impossible when the available space is below 0.58 square meters, or approximately 6.2 square feet per person. The same data predicts a maximum individual speed of 115 meters per minute (377 feet per minute) and a maximum theoretical flow rate of 71 pedestrians per minute per meter width of walkway. For a standard 1.5 meter wide sidewalk, without obstructions, this maximum flow rate is the equivalent of just under 6400 pedestrians per hour.

The above parameters imply that pedestrians at this location operate at higher overall walking speeds than those observed elsewhere. The flowrates and thresholds of available space per pedestrian do not differ from those of other studies, with the understanding that higher individual speeds will result in overall lower flowrates, as long as each individual pedestrian maintains a similar personal 'buffer zone' of greater than 0.6 square meters. A more detailed presentation of the statistical analysis is found in the Appendix.

Observations from the same time period of platoon movements were analyzed, with the representative average values for density, speed and flowrate used to calculate another set of LOS thresholds. The following table presents the resultant LOS thresholds for platoon adjusted flow.

**Table 6.2. Level of Service Thresholds for Denver, Colorado Market Street Bus Transfer Station (platoon flow conditions)**

LOS	Available space (m <sup>2</sup> /ped)	Flow rate (ped/min/m)	Speed (m/min)
A	3.7 +	< 24	110 +
B	2.6 – 3.7	24 – 38	98 – 108
C	1.6 – 2.6	38 – 52	78 – 98
D	1.0 – 1.6	52 – 62	60 – 78
E	0.5 – 1.0	62 – 75	~ 60
F	≤0.5	var. to 75	zero

For platoon pedestrian movement the equation above yields:

$$\text{Speed} = ((109.8 \text{ m/min} + (109.8^2 * 4 * 26.35)^{0.5}) / 2)$$

$$A = 109.8 \text{ meters/minute and } B/A = 0.24 \text{ m}^2/\text{ped}$$

Key Findings of statistical analysis

Maximum predicted individual speed: 110 meters per minute (1.8 meters/sec)

Maximum theoretical flowrate: 75 pedestrians/minute/meter width

Threshold of available space at which individual movement becomes unstable: 0.53 square meters per person

With regard to movement within platoons, the analysis of the data shows that for an individual pedestrian, movement should prove impossible when the available space is below 0.53 square meters, or approximately 5.7 square feet. The same data predicts a maximum individual speed of 108 meters per minute (354 feet per minute) and a maximum theoretical flow rate of 75 pedestrians per minute per meter width of walkway. For a standard 1.5 meter wide sidewalk, without obstructions, this maximum flow rate is the equivalent of just over 6700 pedestrians per hour.

The influence of platoons, as reflected in the analysis, is minimal. The slight reduction in available space per pedestrian can be interpreted to reflect the closer proximity (as measured by smaller time headway between successive pedestrians) that

results from platoon movement. Such closer conditions will automatically result in higher flow rates and lower overall speeds, though not significantly. Direct observations of all movements at this location revealed consistently uniform speeds, whether the individual observed was confined to a platoon or not. For a more detailed presentation of the statistical analysis, please refer to the Appendix.

#### **6.4 COMPARISON OF MARKET STREET STATION FINDINGS WITH PREVIOUS STUDIES**

Foremost among the observations were the apparently elevated speeds of nearly all pedestrians traversing the study area. The average speed of all observations was 81 meters per minute, which is at the upper limit of previous LOS threshold predictions. This average speed is consistent, regardless of the existence of platoons or the density. The following charts will display the calculated values for the data collected in Denver, Colorado against those from previous studies. Both non-platoon and platoon influenced movements will be presented.

**Table 6.3. Comparison with Previous Studies for Non-Platoon Flow**

Researcher/ Location	Fruin/ Manhattan	Zupan/ Manhattan	Older/ London	Navin/ Washington, DC	Denver, Co.
Max. Flow (ped/min/m)	81	82	76	66	71
Max. Speed (m/min)	81.4	82	78.6	97.5	115
Jam Density (m <sup>2</sup> /ped)	0.25	0.35	0.26	0.37	0.25
Density for Max. Flow (m <sup>2</sup> /ped)	0.5	0.7	0.52	0.7	0.5

The values determined from data collected in Denver, Colorado, compare favorably with those from previous studies in London, New York City and Washington, D.C. Of interest is the increased maximum theoretical speed found in the Denver, Colorado study. These values were calculated for free flow movement, absent any identified influence of platoons.

One hypothesis for this increase in measured travel speeds is related to the total travel distance of the trip. The Denver, Colorado study was conducted at a transit transfer center. The total length of the pedestrian trip between transit vehicles at the Market Street station would be less than 150 meters, inclusive of stairwells and foyers. Average travel speeds have been determined to decrease as the average trip length increases. Perhaps the high individual speed values would not be present if the study location were not a bus transfer station or if the likely total distance to be traveled were longer.

A second hypothesis is directly a function of trip purpose. While walking is the mode of choice for the connecting route between two transit vehicles, the presence of closely timed transfers between transit service routes may encourage higher than normal travel speeds. Several single individuals at the Market Street Station, perceiving themselves to be tardy, “broke rank” and ran around an established platoon to enter the station sooner. These individuals were not included in the modeling of pedestrian movement, however, speeds in excess of 144 meters/minute (2.4 meters per second) were observed. It is not inconceivable that absent considerable time pressures, individual and platoon pedestrian movement behavior would involve lower overall travel speeds.

#### **6.5 COMPARISON OF MARKET STREET STATION RESULTS WITH PREVIOUS PLATOON SPECIFIC LOS THRESHOLD RECOMMENDATIONS**

Data collected at the Market Street Station provided an opportunity to compare platoon pedestrian flow movements with the results of previous studies. With the exception of theoretical maximum speeds, the data from the Market Street transfer station matches well with that from other locations, at least when compared at the extreme values. The higher maximum theoretical speed is suspicious, but can be accounted for by either (or both) of the aforementioned hypotheses explaining the perceived need for higher individual travel speeds.

**Table 6.4. Comparison with Previous Studies for Routine Platoon Flow**

Source/ Location	Zupan/ Manhattan	Interim Materials	HCM 2000/ Varied	Denver, Co.
Max. Theoretical Flow (ped/min/m)	59	82	59+	75
Maximum Theoretical Speed (m/min)	78	72	78	110
Jam Density (m <sup>2</sup> /ped)	1.0	0.6	1.0	0.5 3
Optimum Density for Max. Flow (m <sup>2</sup> /ped)	1.5	1.0	1.0	1.0

The following table will present the recommended thresholds for the various levels of service in the 1994 and 2000 Highway Capacity Manuals for free flow pedestrian flow movements.

**Table 6.5. Comparison of 1994, and 2000 HCM LOS Thresholds with Those Determined in Market Street Station Study (non-platoon movement)**

LOS	1994 HCM (m <sup>2</sup> /ped) (ped/min/m)	2000 HCM (m <sup>2</sup> /ped) (ped/min/m)	Denver, Co. (m <sup>2</sup> /ped) (ped/min/m)
A	(>12)	(>5.6)	(>4.1)
	(<6.6)	(<16)	(<16)
B	(3.7 – 12)	(3.7 – 5.6)	(2.9 – 4.1)
	(6.6 – 23)	(16 – 23)	(16 – 35)
C	(2.2 – 3.7)	(2.2 – 3.7)	(1.7 – 2.9)
	(23 – 33)	(23 – 33)	(35 – 46)
D	(1.4 – 2.2)	(1.4 – 2.2)	(1.2 – 1.7)
	(33 – 49)	(33 – 49)	(46 – 55)
E	(0.6 – 1.4)	(0.75 – 1.4)	(0.6 – 1.2)
	(49 – 82)	(49 – 75)	(55 – 71)
F	(< 0.6)	(< 0.75)	(<0.6)
	var.	var.	var. to 71

In light of previous comments ascribing higher overall speeds to the unique nature of a bus transfer terminal, the slightly higher than previously recommended LOS thresholds for the first three (A through C) categories are to be expected. As the available space per traveling individual decreases, the observed thresholds become more uniform. The primary difference between the definitions of LOS F and LOS E across the three evaluations is the determination that for the year 2000 HCM, LOS F should reflect the typical body ellipse for North Americans (0.75 square meters), and that any crowd densities allowing less space should be considered F. The method of analysis for the 1994 and Market Street Station thresholds define LOS F as occurring when (theoretically) physical movement becomes impossible and queue formation results. This is the same standard originally proposed in Fruin’s research.

## 6.6 PLATOON SPECIFIC LOS THRESHOLD RECOMMENDATIONS

The 1994 Highway Capacity Manual suggested that site specific studies should be conducted to determine the impact and frequency of platoons upon a given facility's operation.<sup>57</sup> Barring specific data, the 1994 HCM recommended using the "rule of thumb" to determine likely flow rates within a given LOS. The rule of thumb adds 13.1 pedestrians per meter width per minute of travel to each LOS category to account for the increased density of platoons. The 1994 HCM also states that the LOS perceived in platoons is often one level lower than that determined by average flow criteria.<sup>58</sup>

For the purposes of this study, the platoon specific recommendation in the year 2000 HCM will be examined as it applies to the observations of the Market Street Station in Denver, Colorado. The following table will present the recommended thresholds for the various levels of service in the 2000 Highway Capacity Manual for platoon influenced pedestrian flow movements.

**Table 6.6. Comparison of 2000 HCM LOS Thresholds for Transportation Terminals with the Market Street Station Study (platoon pedestrian movements)**

LOS	2000 HCM (m <sup>2</sup> /ped)	2000 HCM (ped/min/m)	Denver, Co. (m <sup>2</sup> /ped)	Denver, Co. (ped/min/m)
A	>49	<1.6	>3.7	<24
B	8 – 49	1.6 – 10	2.6 – 3.7	24 – 38
C	4 – 8	10 – 20	1.6 – 2.6	38 – 52
D	2 – 4	20 – 36	1.0 – 1.6	52 – 62
E	1 – 2	36 – 59	0.5 – 1.0	62 – 75
F	< 1.0	59+	<0.5	Var. to 75

In the recommended thresholds for the 2000 HCM regarding routine platoon movement, researchers relied upon the findings presented in *Urban Space for Pedestrians*

<sup>57</sup> Transportation Research Board (TRB). "Highway Capacity Manual". Special Report 209, 1994 update to 1985 edition. HCM, p.13-11

<sup>58</sup> Op cit. p 13-11.

by Pushkarev and Zupan, to determine the influence of platoon movement.<sup>59</sup> The line of reasoning employed combined the recommended available space thresholds of the Pushkarev-Zupan study, with a metric version of the "rule of thumb" adjustment factor for flow rates, which adds 13.1 pedestrians per meter width per minute of flow to each flow rate category.

The recommendation hinges upon the definition of "open flow" (and other space based categories) as applying to platoon movement along walkways. Critical to the interpretation of the platoon specific thresholds is the understanding of "open flow" as used by the primary researchers. In the text, first discussion of "open flow" is applied in the context of movement in a homogeneous stream<sup>60</sup> and not in platoon influenced conditions. The second application of the term "open flow" in the context of platoon movement is used to describe at what point pedestrians in platoon movement perceive their surroundings to be equivalent to LOS A as defined by Fruin's study. The text clearly states, "If the designer wants to attain... what Fruin calls "service level A", not on the average, but in platoons, then 130 sq ft (12 m<sup>2</sup>) per person is the minimum average space allocation."<sup>61</sup> The table in the text is not as clear, and may lead the reader to assume that "open flow" in platoon movement is attained when the available space per person meets or exceeds 50 square meters.

As evident in Table 6.6, the resulting thresholds ascribe an amount of available space per pedestrian within a platoon that is excessive, or at least, far above any other recommended non-platoon flow thresholds. The values are consistent with those proposed by Pushkarev and Zupan for non-platoon flow, which were considered overly generous for non-platoon flow conditions.

It is this researcher's understanding that the definition of 'Open flow' cited in the Pushkarev-Zupan study, refers to homogeneous streams of pedestrians, absent the presence of platoons. In this manner, "Open Flow" thus defined would be the outer limit of LOS A thresholds found in other studies, and not the recommended amount of

---

<sup>59</sup> Milazzo, et. al based upon work done by Pushkarev and Zupan in *Urban Space for Pedestrians*.

<sup>60</sup> *Urban Space for Pedestrians*, Pushkarev and Zupan. Cambridge, Massachusetts: The MIT Press, 1975a, page 94.

<sup>61</sup> Op cit. page 99.

available space to determine LOS A quality of service within a platoon. Comments in the Urban Space text support this interpretation.<sup>62</sup>

In light of this apparent miscalculation, the original set of thresholds (presented in *Pedestrian Planning and Design*), as modified by any of the aforementioned adjustment methods for platoon flow, seems more applicable. As shown in Table 6.7, adjustment of Fruin’s values by means of the rule of thumb adjustment (an additional 13 pedestrians per minute per meter width to the flow rates) would not create the seemingly low density recommended flow rate thresholds as found in the proposed changes for the year 2000 HCM, and would be comparable to those derived from observations at the Market Street station in Denver, Colorado.

**Table 6.7. Comparison of Platoon Adjusted LOS Thresholds**

LOS	Pedestrian Planning (m <sup>2</sup> /ped) (ped/min/m)	2000 HCM (m <sup>2</sup> /ped) (ped/min/m)	Market Street (m <sup>2</sup> /ped) (ped/min/m)
A	(>2.5) (<36)	(>49) (<1.6)	(>3.7) (<24)
B	(1.3 – 2.5) (36 – 46)	(8 – 49) (1.6 – 10)	(2.6 – 3.7) (24 – 38)
C	(0.8 – 1.3) (46 – 62)	(4 – 8) (10 – 20)	(1.6 – 2.6) (38 – 52)
D	(0.5 – 0.8) (62 – 79)	(2 – 4) (20 – 36)	(1.0 – 1.6) (52 – 62)
E	(0.3 – 0.5) (79 – 95)	(1.0 – 2) (36 – 59)	(0.5 – 1.0) (62 – 75)
F	(<0.3) var. to 95	(<1.0) 59+	(<0.5) var. to 75

<sup>62</sup> Op cit, page 91 – side bar describing the lower range of unimpeded flow as “considered excessive” for a design standard based solely upon pedestrian densities.

The recommended space thresholds for Fruin's table were calculated by interpolation between known space and flow rate threshold values. The values are approximate. Alternatively, the thresholds devised from observed platoon pedestrian movement at the Market Street Station could be applied to areas with significant and recurrent platoon movement.

## **6.7 SPECIAL CASE PEDESTRIAN FACILITIES**

For transportation terminals, the year 2000 HCM recommendations distinguished between pedestrian facilities that experience random levels of platoon pedestrian movement and transportation terminals (such as airports and other locations with similar pedestrian platooning tendencies), which expect and tolerate higher levels of platooning.<sup>63</sup> The recommended LOS thresholds for transportation terminals are derived from those values calculated from the observations made in three large scale Canadian airports.<sup>64</sup> The recommendations also include the limiting value of 0.75 square meters per pedestrian as the critical threshold below which LOS F is declared. Following is a table comparing the 2000 HCM recommended LOS thresholds for transportation terminals and the platoon adjusted thresholds for the observations at the Market Street Station in Denver, Colorado.

---

<sup>63</sup> Quality of Service for Uninterrupted Pedestrian Facilities in the *2000 Highway Capacity Manual* by Milazzo, J., Roupail, N., Hummer, J., and Allen, D.P. *Transportation Research Record*, copyright 1999

<sup>64</sup> Davis, Dennis and John Braaksma. "Level-of-Service Standards for Platooning Pedestrians in Transportation Terminals". In *ITE Journal*, April 1987.

**Table 6.8. Comparison of 2000 HCM Platoon LOS Thresholds with Those from the Market Street Station Study (transportation terminals)**

LOS	2000 HCM (m <sup>2</sup> /ped)	2000 HCM (ped/min/m)	Denver, Co. (m <sup>2</sup> /ped)	Denver, Co. (ped/min/m)
A	>2.3	<37	>3.7	<24
B	1.3 – 2.3	37 – 57	2.6 – 3.7	24 – 38
C	1.0 – 1.3	57 – 68	1.6 – 2.6	38 – 52
D	0.8 – 1.0	68 – 75	1.0 – 1.6	52 – 62
E	0.75 – 0.8	~ 75	0.5 – 1.0	62 – 75
F	<0.75	< 75	<0.5	Var. to 75

Apparent from the above table, the observations at the Market Street Station in Denver do not imply the same degree of dense platoon movement as the results from the airport study. Critical to the understanding of the differences between the airport observations and those at the Market Street station is the method of observations. In the airport study, travel times and spacing within the platoon were determined by the placement of researchers within the flow stream.<sup>65</sup> Individual researchers would maintain a respectful distance from the observed subject, while timing the passage between two fixed points along the airport walkway. In this manner, a “floating pedestrian” method was developed and provided the data for analysis. Observations of speed and distance were analyzed using standard statistical techniques.

As mentioned earlier, the Market Street station study was conducted as a cordon type data collection experiment using a video camera and chronometer. Individual pedestrians were observed alighting from several transit vehicles and proceeded across the cordon study area into the Market Street station. Direct calculation of individual speeds as well as instantaneous identification of platoons were recorded using a video playback machine and monitor. The data collected was then analyzed using standard statistical methods.

---

<sup>65</sup> Op cit.

The resulting data infers that at the Market Street station, pedestrian movement is only slightly influenced by the presence of platoons. The close parallel between the findings of the Market Street station study and those of Fruin done thirty years earlier highlight the similarity of the analysis methods.

## **CHAPTER 7. CONCLUSIONS AND RECOMMENDATIONS**

### **7.1 SUMMARY OF FINDINGS**

- 1) According to the statistical analysis and comparison with previous studies, it is apparent that observations of pedestrian movement at the Market Street Station in Denver, Colorado provide similar judgments of space, density and individual speeds as other pedestrian movement studies conducted in the United States.
- 2) The results of statistical analysis for the Denver data imply that neither the 2000 recommended thresholds for routine platoon movement, nor the Davis-Braaksma thresholds for routine platoon movement are applicable to transit stations similar to the Market Street station in Denver, Colorado.
- 3) The recommended LOS thresholds for non-platoon movements in the year 2000 Highway Capacity Manual are applicable to the individual pedestrian movements as observed at the Market Street station in Denver, Colorado.
- 4) The recommended LOS thresholds for platoon and non-platoon movement based upon the Denver data are unlikely to be generally applicable, due to the apparently high average travel speeds and presumed shorter total trip distance. It is more likely that for commuter non-platoon movement within transit stations, the speeds and flow rates observed will be appropriate.
- 5) the recommended LOS thresholds for platoon movement, based upon the Denver data are more reflective of transit station behavior (rapid pace, close bunching, uniform speeds and short overall distances) than other previously cited studies

## **7.2 CONCLUSIONS**

Using Fruin's evaluation methodology and linear regression statistical analysis methods, the Denver data yields results similar to previous studies for non-platoon movement and dissimilar results when compared to the year 2000 HCM recommended thresholds for pedestrian walkway LOS under platoon influenced conditions. The platoon adjusted uninterrupted pedestrian facility LOS evaluation methodology derived from the Davis-Braaksma airport study does not apply to transportation terminals similar to the Market Street station bus transfer terminal in Denver, Colorado. The 2000 HCM LOS thresholds recommended for intermediate and infrequent platoon flow are based upon an erroneous interpretation of the findings presented by researchers Pushkarev and Zupan in *Urban Space for Pedestrians*.

## **7.3 RECOMMENDATIONS**

A first recommendation is that the 2000 HCM thresholds for non-platoon movement be incorporated, and for routine platoon flow, the additive adjustment of 13.1 pedestrians/min/meter be adopted instead of either recommended set of platoon specific thresholds. It is evident from the observations made at the Market Street Station in Denver, Colorado, that neither the consolidated platoon adjusted LOS thresholds for walkways, nor the specialized case of platoon adjusted LOS thresholds for transportation terminals adequately reflect the data results of the Denver study. A further recommendation is to conduct a thorough study of multiple large scale transit terminals to observe, document and model pedestrian movements in several categories prior to the suggestion of future modifications to the Highway Capacity Manual guidelines.

## **7.4 AREAS FOR FURTHER RESEARCH**

Movements in platoons, as observed during timed transfers should be observed over a moderate distance (greater than 150 meters) to determine what effect travel distance has over average platoon speeds. Individual movements can be observed and modeled “upstream” from the transit station to determine what influence the presence of timed transfers has upon average individual walking speeds. In addition, observations of non-peak hour travel can be used to bolster, or refute claims that transportation terminals

by their nature encourage higher degrees of pedestrian platoon density, or whether the influence of peak hour travel is the more critical factor.



## **APPENDIX A. SUMMARY SHEETS FOR PEDESTRIAN VOLUME AND FLOW RATE STUDIES**

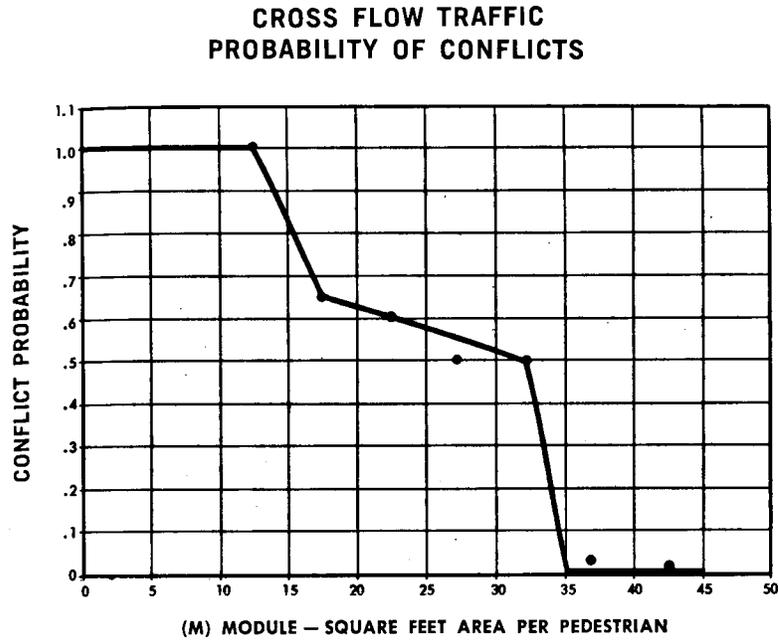
As mentioned in the text, the majority of pedestrian movement analyses use the method derived by John Fruin for his work, *Pedestrian Planning and Design*. Subsequent studies by other researchers expanded upon the fundamental relationships between flow, density and individual travel speeds as observed and recorded by Fruin.

It is not the purpose of this study to redefine the statistical methods of analysis utilized by the previous researchers, instead, established relationships were incorporated into the evaluation of new pedestrian flow movement data collected at the Market Street Station in Denver, Colorado. What follows is a brief summarization of the evaluation methodology developed in the previous pedestrian movement studies that serves as the basis of the statistical analysis used in this research study.

Fruin's findings about the relationship between speed and volumetric flow rates were interpreted in terms of spatial density. In Chapter 3, reference to the "space mean speed" graphic was made to help illustrate the critical thresholds at which, according to Fruin's analysis of time lapse photography, individual walking speeds were influenced by the amount of available space to maneuver.

Fruin determined that the probability of conflict between two pedestrians was significantly higher when the available space to maneuver was less than 40 square feet per pedestrian. The probability of conflicting movements during cross traffic flows approaches one when the observed available space is less than 15 square feet per pedestrian. Fruin used time-lapse photos from an overhead perspective in combination with real time observations to determine these relationships.

**Figure A-1. Reproduction of Probability of Conflict Due to Cross Traffic Flows**



**Figure 3.5**

To determine what the likely lateral spacing values were for individual pedestrians, Fruin plotted observed lateral spacing tendencies in queuing areas and along walkways. Using these values, a comparative set of lateral spacing tendencies was developed to provide a conservative definition of personal space per pedestrian.

Figure A-2. Average Lateral Spacing as Observed in Uni-Directional Flow

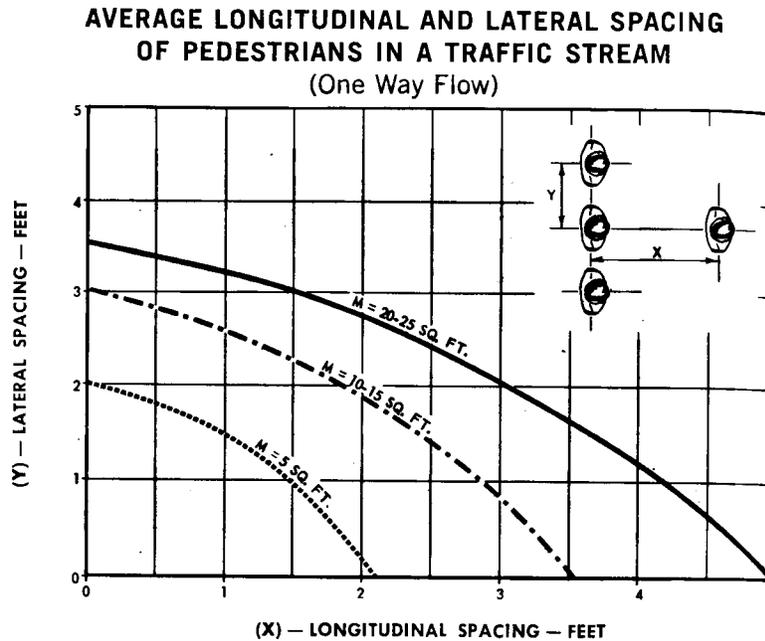
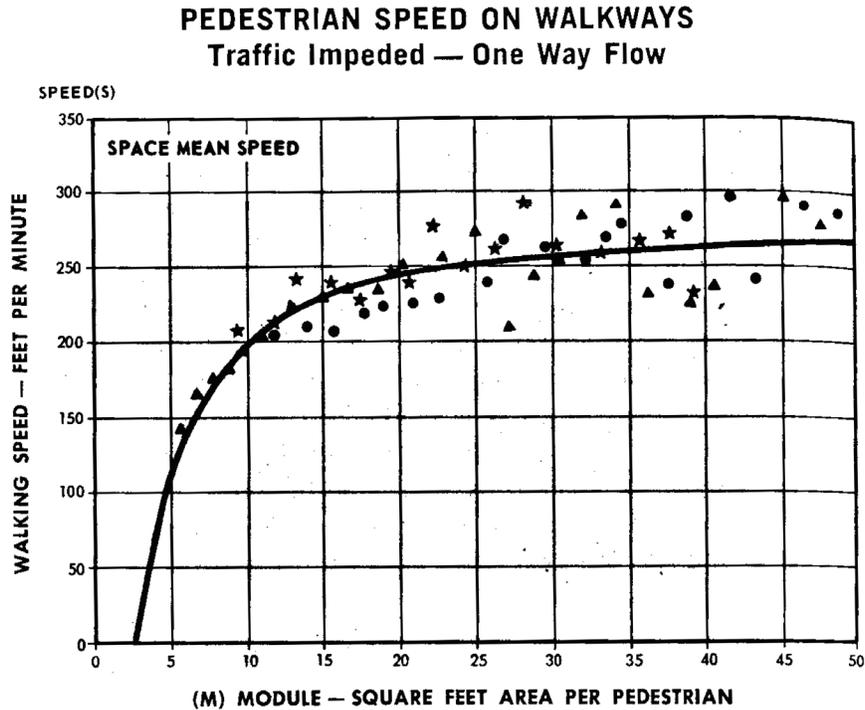


Figure 3.4

In addition, observed pedestrian spacing (a value he called the pedestrian “module”) values were plotted with respect to individual walking speeds. Fitting a curve to the observations, Fruin calculated the influence of available space upon individual walking speeds, and determined a set of critical extreme values. These “thresholds of influence” were used as guiding parameters in the evaluation of the Market Street Station data analysis. Repeated below is the graphic Fruin developed to represent uni-directional flow along an uninterrupted pedestrian walkway.

Figure A-3. Reproduction of Space Mean Speed Chart from Pedestrian Planning and Design by John J. Fruin

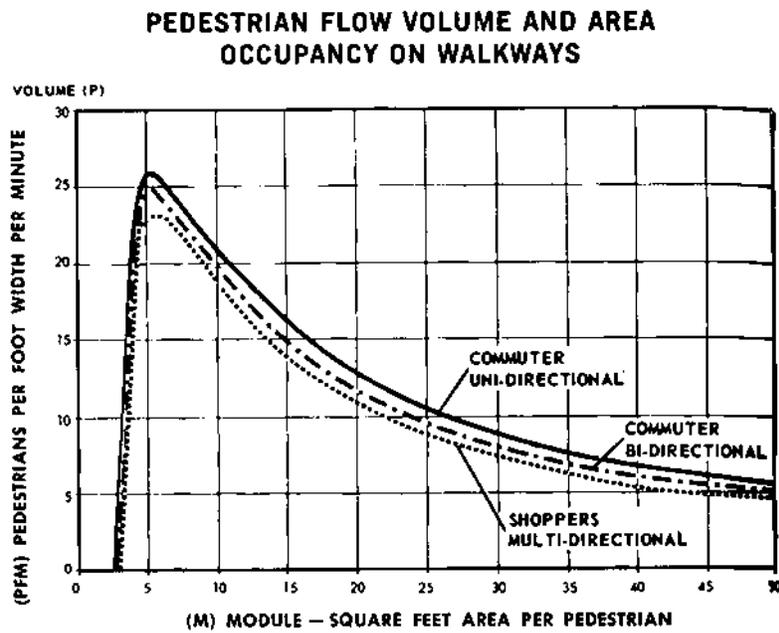


As presented in the figure, Fruin observed individual walking speeds to be unaffected by surrounding pedestrians at spacing above 40 square feet per pedestrian, or approximately 3.7 square meters. Fruin's findings also inferred that walking speeds theoretically drop to zero at spacing below 5 square feet per pedestrian (0.46 square meters).

Fruin's next parameter was the observed flow rates versus available space per pedestrian. The observations were made with three distinctions among the studied population: uni-directional and bi-directional commuters and multi-directional shoppers. Fruin's findings showed slight differences in flow rates among the three distinctions. Plotting pedestrian module values in relationship

with calculated flow rates, Fruin devised a relationship between available space per pedestrian and the overall probable flow rates along a walkway. The Market Street Station data collection location was chosen and aligned to document primarily uni-directional commuters with limited cross traffic flow.

**Figure A-4. Reproduction of Pedestrian Flow Volumes Versus Available Space Per Pedestrian Along Walkways**



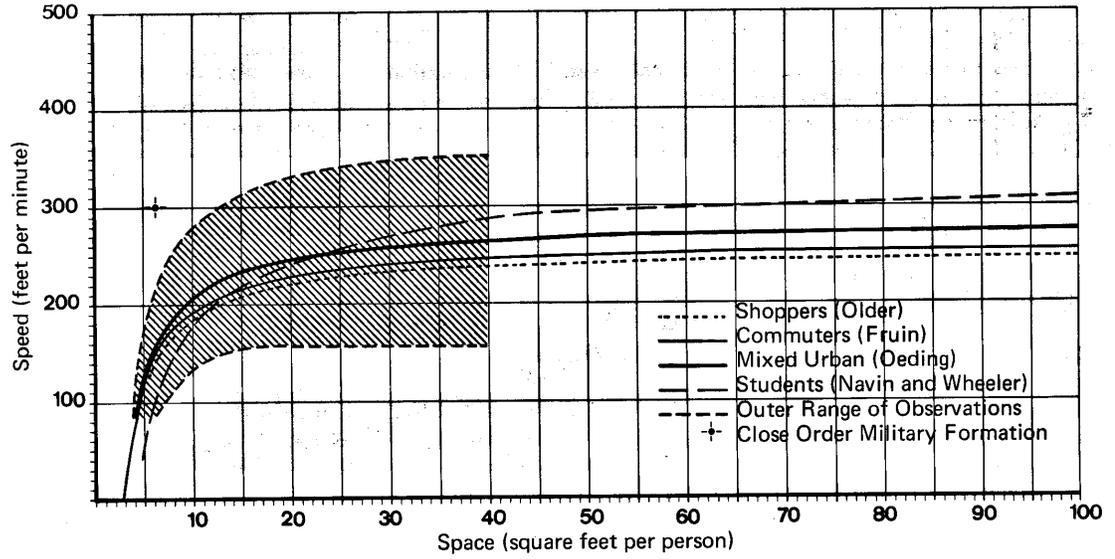
**Figure 3.3**

As evident in the chart, the critical threshold for unstable flow rates occurs when the available space per pedestrian nears 5 square feet (0.46 square meters). Also, these observations provide theoretical maximum flow rates during periods of high density. Fruin determined that slightly more than 25 pedestrians per foot width per minute (approximately 83 pedestrians per meter wide per minute) of travel is the highest likely sustainable flow rate for a walkway.

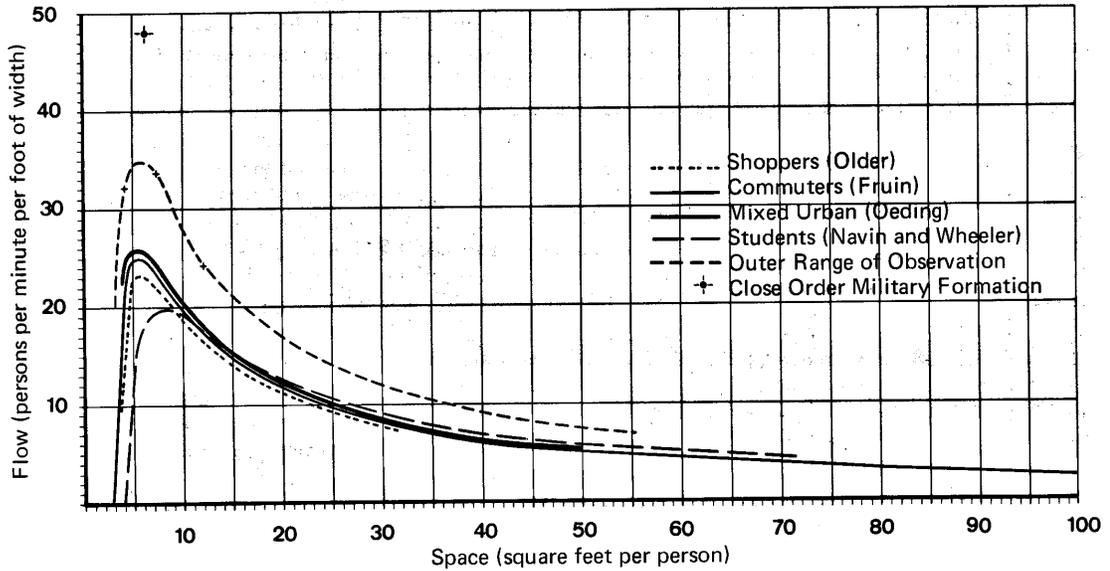
Combining the observations of cross traffic flows, lateral spacing patterns, speed versus available space and flow rates versus available space, Fruin devised a set of recommended Level of Service thresholds for uninterrupted pedestrian facilities. Similar observations and analysis were conducted to recommend thresholds for queuing areas, stairwells, moving walkways and elevators.

Subsequent studies used Fruin's methods of data collection and analysis to describe pedestrian movements elsewhere and under more specialized conditions. The findings of Pushkarev and Zupan served to confirm that while other locations may yield slightly different values, the fundamental relationships among the parameters as defined by Fruin remained consistent, thus solidifying *Pedestrian Planning and Design* as the reference text of choice for studying pedestrian movement.

**Figure A-5. Chart from Urban Space for Pedestrians Comparing Several Studies Results' with Regard to Pedestrian Individual Speeds Versus Available Space**



**Figure A-6. Chart from Urban Space for Pedestrians Comparing Several Studies with Regard to Pedestrian Flow Rates and Available Space**



As evident in the charts above, the contributions of later studies offered more confirmation of Fruin's observations than any new refinement of the evaluation methodology. The next section will detail the calculations done using the observations from the Market Street Station in Denver, Colorado.

## APPENDIX B. SUMMARY SHEETS FOR STATISTICAL ANALYSIS OF PEDESTRIAN MOVEMENT

The following pages summarize the statistical analysis conducted on the data collected from the Market Street Station in Denver, Colorado. Due to the limitations of the data, only the critical values of individual and platoon speeds, individual and platoon densities and probable thresholds of flow rates versus pedestrian area modules were derived.

### SUMMARY OF DATA COLLECTED

The following tables display the general characteristics of the observations from the first day's evening peak hour pedestrian movements. Both platoon and non-platoon movements are included in these summary tables. No statistically significant correlation was found between any demographic variable (gender, race or age) and predicted speeds, volume flow rates or observed densities.

GENDER (zero value is male, one value is female)

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	.00	187	38.2	38.2	38.2
	1.00	303	61.8	61.8	100.0
Total		490	100.0	100.0	

AGE (in estimated years)

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	20.00	10	2.0	2.0	2.0
	25.00	29	5.9	5.9	8.0
	30.00	81	16.5	16.5	24.5
	35.00	140	28.6	28.6	53.1
	40.00	118	24.1	24.1	77.1
	45.00	49	10.0	10.0	87.1
	50.00	47	9.6	9.6	96.7
	55.00	10	2.0	2.0	98.8
	60.00	6	1.2	1.2	100.0
	Total	490	100.0	100.0	

RACE (zero value is Caucasian, one value is African-American, two value is other/unknown)

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	.00	411	83.9	83.9	83.9
	1.00	20	4.1	4.1	88.0
	2.00	59	12.0	12.0	100.0
Total		490	100.0	100.0	

TRIP PURPOSE (zero value is commuter, one value is presumed leisure/student/other)

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	.00	422	86.1	86.1	86.1
	1.00	68	13.9	13.9	100.0
Total		490	100.0	100.0	

The following tables display the general characteristics of the observations from the second day's evening peak hour pedestrian movements. Both platoon and non-platoon movements are included in these summary tables. Similar to the first day's observations, no statistically significant correlation was found between any demographic variable (gender, race or age) and predicted speeds, volume flow rates or observed densities.

GENDER (zero value is male, one value is female)

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	.00	111	40.1	40.1	40.1
	1.00	166	59.9	59.9	100.0
Total		277	100.0	100.0	

AGE (in estimated years)

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	10.00	3	1.1	1.1	1.1
	20.00	5	1.8	1.8	2.9
	25.00	11	4.0	4.0	6.9
	30.00	44	15.9	15.9	22.7
	35.00	60	21.7	21.7	44.4
	40.00	59	21.3	21.3	65.7
	45.00	52	18.8	18.8	84.5
	50.00	32	11.6	11.6	96.0
	55.00	9	3.2	3.2	99.3
	60.00	2	.7	.7	100.0
	Total	277	100.0	100.0	

RACE (zero value is Caucasian, one value is African-American, two value is other/unknown)

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	.00	226	81.6	81.6	81.6
	1.00	21	7.6	7.6	89.2
	2.00	30	10.8	10.8	100.0
	Total	277	100.0	100.0	

TRIP PURPOSE (zero value is commuter, one value is presumed leisure/student/other)

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	.00	233	84.1	84.4	84.4
	1.00	43	15.5	15.6	100.0
	Total	276	99.6	100.0	
Missing	System	1	.4		
	Total	277	100.0		

The following table is reproduced from the body of the main text to provide composite values for the data collected:

	Gender	Ethnicity (est.)	Trip Purpose	Age (est.)
Tuesday Evening Peak	62.8% female 38.2% male	83.9% Anglo 4.1 % Black 12% unknown	86.1% commuter 13.9% leisure/other	Median – 35 Average – 37.6
Wednesday Evening Peak	59.9% female 40.1 % male	81.6% Anglo 7.6% Black 10.8% unknown	84.1% commuter 15.9% leisure/other	Median – 40 Average – 38.8

## **CALCULATION OF PEDESTRIAN MOVEMENT LEVEL OF SERVICE THRESHOLDS**

Observation data was divided into individual pedestrian movements (representative of non-platoon conditions) and average speeds and densities within identified platoons. The data was entered into an Excel™ spreadsheet and analyzed using linear regression statistical methods (ordinary least squares method). The resulting equations yielded calculated maximum theoretical speeds and flow rates with respect to density. These critical values were then used to determine speed versus density curves which provided corresponding regions of average speeds for both platoon and non-platoon conditions.

Using the same relationships derived by Fruin, and presented in detail by Pushkarev and Zupan, the following equations were applied to the observed speeds and calculated flow rates to determine the theoretical critical values for platoon and non-platoon pedestrian movement.

$$\text{Speed} = ((A + (A^2 - 4*B*\text{flow})^{0.5})/2)$$

Where A is the maximum theoretical speed and B is a calculated coefficient related to A in the following manner: B/A = critical threshold of available space per pedestrian below which physical movement is impossible (i.e. theoretical jam density).

For non-platoon pedestrian movement the equation above yields:

$$\text{Speed} = ((115.2 \text{ m/min} + (115.2^2 * 4 * 25.34)^{0.5})/2)$$

$$A = 115.2 \text{ meters/minute and } B/A = 0.22 \text{ m}^2/\text{ped}$$

For platoon pedestrian movement the equation above yields:

$$\text{Speed} = ((109.8 \text{ m/min} + (109.8^2 * 4 * 26.35)^{0.5}) / 2)$$

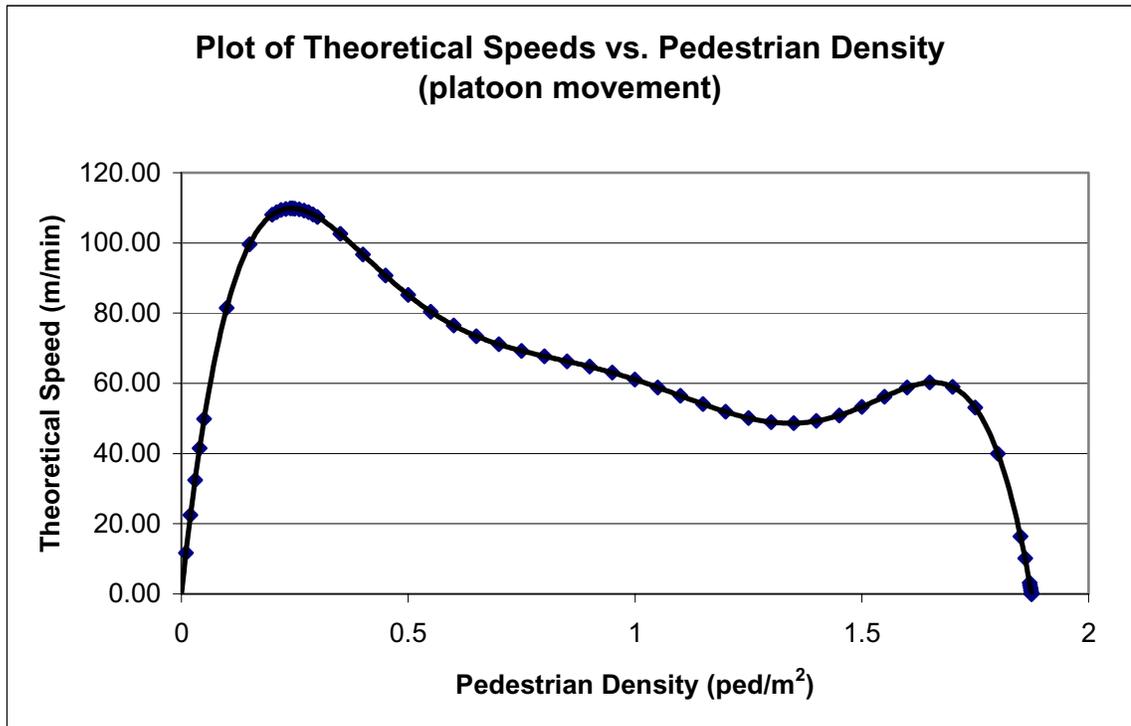
$$A = 109.8 \text{ meters/minute and } B/A = 0.24 \text{ m}^2/\text{ped}$$

The above values are summarized in the following table.

**Table B–1. Summary of Critical Values from Market Street Station Observations**

<b>Crowd Conditions</b>	<b>Max. Speed (meters/min)</b>	<b>Max. Flow rate (ped/m/min)</b>	<b>Jam Density (ped/m<sup>2</sup>) [m<sup>2</sup>/ped]</b>	<b>Adjusted R<sup>2</sup> Value</b>
Non-Platoons	115 m/min	71 ped/m/min	(1.7) [0.58]	0.905
Platoons	110 m/min	75 ped/m/min	(1.9) [0.53]	0.873

**Figure B-1. Chart of Theoretical Speeds Relative to Pedestrian Density for Platoon Movements.**



Similar to the calculations done by previous researchers, the above chart was used to determine the critical density value at which speeds become unstable. Parallel calculations were done to determine at what densities the theoretical flow rate becomes unstable. The values were scaled to provide stepwise incremental increases in flow rates on par with those determined by Fruin as logical intermediate Levels of Service Thresholds. Prior to adopting Fruin's scalar evaluation, the area under the flow rate – density curve was subdivided into six equal areas. Unfortunately, the resultant thresholds did not correspond well with either the observations of Fruin, nor later researchers. In the absence of independent analysis confirming the applicability of an arbitrary subdivision of the flow rate – density curve, it was decided to use the Fruin methodology of

scalar multiples of the jam density value, with results more consistent with the field observations recorded by previous studies.



**APPENDIX C. SAMPLE SURVEYS  
(LONG AND SHORT FORMS)**

**This study is being conducted by the Center for Transportation Research at  
The University of Texas at Austin.**

**Sample Survey (Long Form)**

Start time: \_\_\_\_\_

Thank you for agreeing to participate in this survey.

The purpose of this study is to determine what level(s) of crowd density are comfortable (or not) for patron of the 16<sup>th</sup> Street Mall.

This research is to be used to develop guidelines for the operation of outdoor pedestrian facilities.

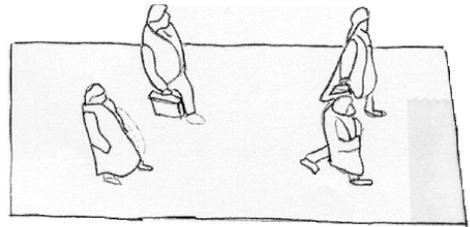
Please ask questions of the researcher if anything is unclear.

Please rank each of the following pictures in terms of **personal comfort level with respect to crowd density.**

VERY COMFORTABLE      VERY UNCOMFORTABLE  
 0   1   2   3   4   5



VERY COMFORTABLE      VERY UNCOMFORTABLE  
 0   1   2   3   4   5



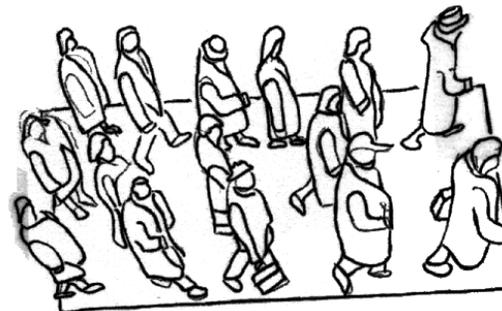
VERY COMFORTABLE      VERY UNCOMFORTABLE  
 0   1   2   3   4   5



VERY COMFORTABLE      VERY UNCOMFORTABLE  
 0   1   2   3   4   5

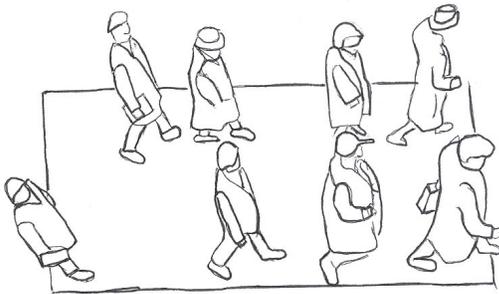
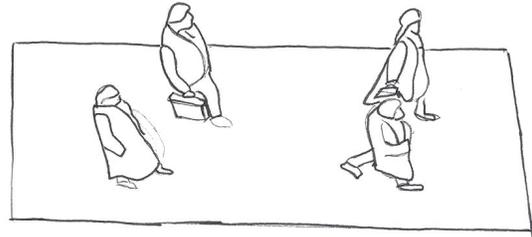
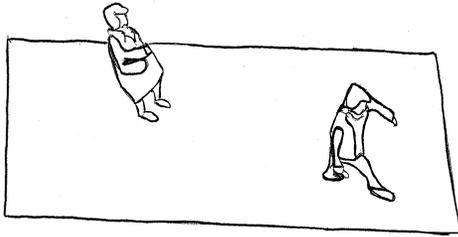


VERY COMFORTABLE      VERY UNCOMFORTABLE  
 0   1   2   3   4   5



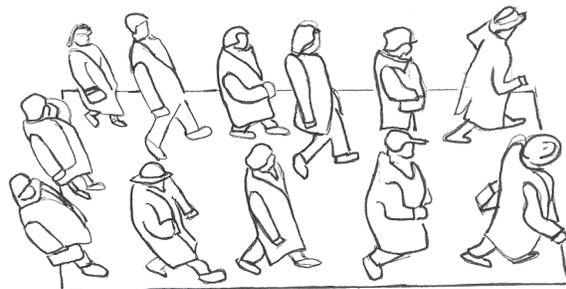
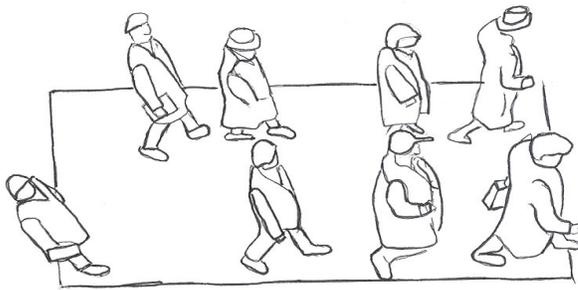
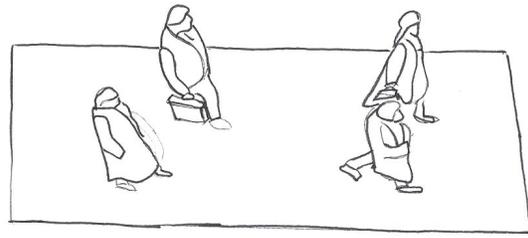
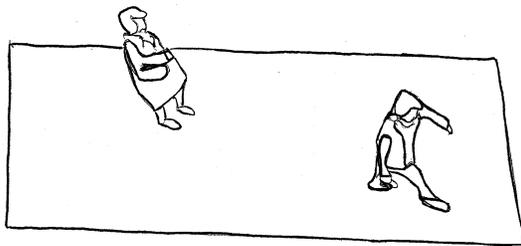
Please mark the appropriate picture.

How crowded is the sidewalk **now**?



Please mark the appropriate picture.

How crowded is **too crowded** for comfort?



**Please answer the following questions:**

What is the purpose of your visit to the 16<sup>th</sup> street mall? Circle one.

Work   shop   dining                      leisure                      other

How did you arrive at the 16<sup>th</sup> street mall?

Light Rail   Bus              Car              Walk                      Other

What is the distance (in city blocks) you will walk to arrive at your destination?

≤1-2              2-4              4-6                                      7-8                                      9+

What is your age bracket? Please circle one.

≤ 18   19-25   26-35   36-45   46-55   56-65   65+

What is your gender?            Male            female

Is the sidewalk currently too crowded for your  
personal comfort?

Yes            No

**Optional questions:**

Ethnicity: circle one.

White    Black    Hispanic            other/multiple

Individual yearly income: circle one.

≤\$20,000    \$20-\$30,000    \$30-\$40,000    \$40-60,000

\$60,000+

**Thank you very much. Have a pleasant visit.**

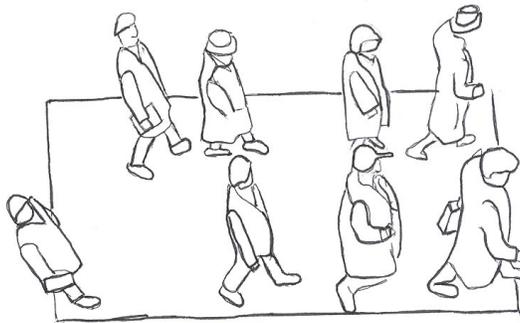
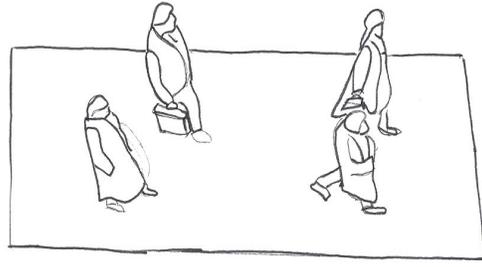
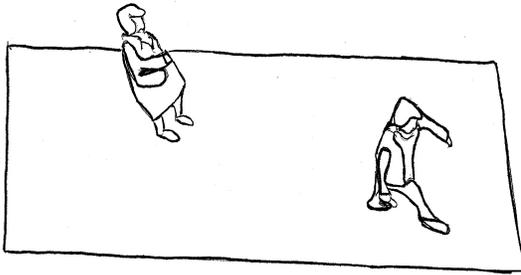
## **Comments**

**This study is being conducted by the Center for Transportation Research at  
The University of Texas at Austin.**

**Sample Survey (Short Form)**

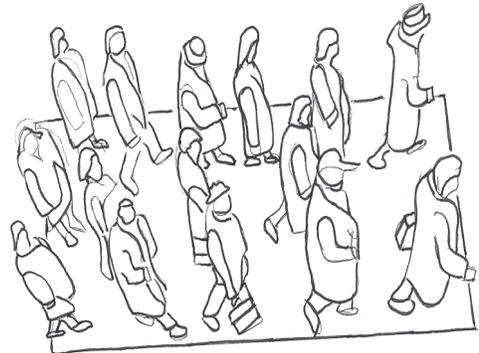
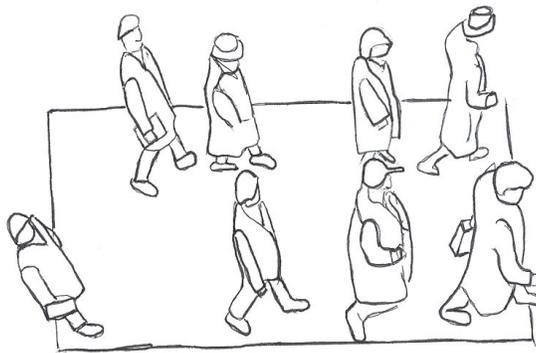
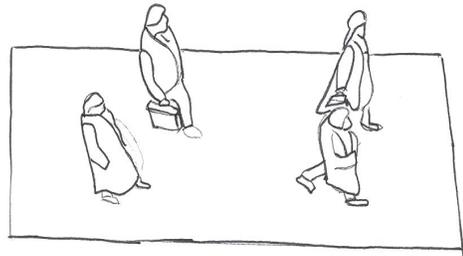
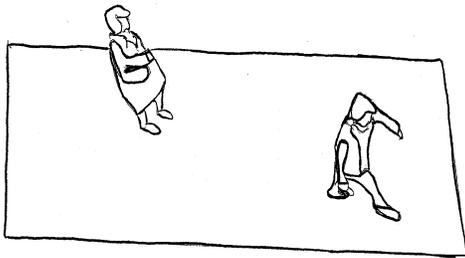
PLEASE MARK THE APPROPRIATE PICTURE.

HOW CROWDED IS THE SIDEWALK **NOW**?



**PLEASE MARK THE APPROPRIATE PICTURE**

**HOW CROWDED IS TOO CROWDED FOR COMFORT?**



**AGE:**  $\leq 18$  19-25 26-35 36-45 46-55 56-65 65+

**GENDER:** MALE FEMALE

**PLEASE PUT CARDS INTO ORANGE BOX. THANK YOU.**

## REFERENCES

Davis, Dennis G. and Braaksma, John P. "Adjusting for luggage-laden pedestrians in airport terminals." *Transportation Research A Volume 22a Number 5*, pp. 375-388. Copyright 1988.

Davis, Dennis G. and Braaksma, John P. "Level of Service Standards for Platooning Pedestrians in Transportation Terminals." *ITE Journal April 1987* pp. 31-35.

Fruin, John J. *Pedestrian Planning and Design*. New York, NY. Metropolitan Association of Urban Designers and Environmental Planners Inc. Copyright 1971

Institute of Transportation Engineers Technical Council Committee 5-R "Characteristics and Service Requirements of Pedestrians and Pedestrian Facilities" *Traffic Engineering*, Volume 46, Number 5, pp. 34-45. Copyright 1976.

Khisty, C. Jotin. "Pedestrian Cross Flows in Corridors". In *Transportation Research Record* 847, Transportation Research Board, 1982.

Lam, William H.K.; John F. Morrall and Herbert Ho. "Pedestrian Flow Characteristics in Hong Kong". *Transportation Research Record* 1487, Transportation Research Board, 1995.

Milazzo II, Joseph S.; Nagui M. Roupail, Joseph E. Hummer, and D. Patrick Allen "Quality of Service for Uninterrupted Pedestrian Facilities in the 2000 Highway Capacity Manual." *Transportation Research Record*, copyrights 1999.

Milazzo II, Joseph S.; Nagui M. Roupail, Joseph E. Hummer, and D. Patrick Allen "Literature Synthesis for Chapter 13, "Pedestrians" of the *Highway Capacity Manual*." United States Department of Transportation, Federal Highway Administration. McLean, VA. February 1998.

Milazzo II, Joseph S.; Nagui M. Roupail, Joseph E. Hummer, and D. Patrick Allen. "Quality of Service for Interrupted Pedestrian Facilities in the 2000 Highway Capacity Manual." Offered for presentation at the 78th Annual Meeting of the Transportation Research Board, and for subsequent publication in the *Transportation Research Record*, November 1998. TRB paper 99-0131.

Moudon, A.V. "Effects of Site Design on Pedestrian Travel in Mixed-Use, Medium Density Environments." Department of Urban Design and Planning, University of Washington, Seattle, Washington. Copyright May 1997

Navin, Francis P.D. and R. J. Wheeler. "Pedestrian Flow Characteristics". In *Traffic Engineering*, June 1969.

Polus, Abishai; Joseph Schofer and Ariela Ushpiz. "Pedestrian Flow and Level of Service" *Journal of Transportation Engineering*, American Society of Civil Engineers, January 1983.

Pushkarev, Boris; with Zupan. *Urban Space for Pedestrians*. Cambridge, Massachusetts: The MIT Press, 1975a.

Pushkarev, Boris and Zupan. "Capacity of Walkways". In *Transportation Research Record* 538, Transportation Research Board 1975b.

Roupail, Nagui; Joseph Hummer, Joseph Milazzo II, D. Patrick Allen. "Recommended Procedures for Chapter 13, Pedestrians of the *Highway Capacity Manual*". Federal Highway Administration Report, February 1998b.

Tanaboriboon, Yordphol and Jocelyn A. Guyano. "Level of Service Standards for Pedestrian Facilities in Bangkok: A Case Study". *ITE Journal*, November 1989.

Tanaboriboon, Yordphol, Sim Siang Hwa and Chin Hoong Chor. "Pedestrian Characteristics Study in Singapore". In *Journal of Transportation Engineering*, May 1986.

Transportation Research Board (TRB). *Interim Materials on Highway Capacity*. Transportation Research Circular 212; 1980.

Transportation Research Board. *Highway Capacity Manual* Special Report No. 209. Washington, DC.: Transportation Research Board, copyright 1985.

Transportation Research Board (TRB). "*Highway Capacity Manual*". Special Report 209, 1994 update to 1985 edition.