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Development and Evaluation of a Simulation System Based Upon Standard Pedestrian Thoroughfare Methodologies

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DEVELOPMENT AND EVALUATION OF A SIMULATION SYSTEM BASED UPON STANDARD PEDESTRIAN THOROUGHFARE METHODOLOGIES

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by

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ABSTRACT

DEVELOPMENT AND EVALUATION OF A SIMULATION SYSTEM BASED UPON STANDARD PEDESTRIAN THOROUGHFARE METHODOLOGIES

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This study integrated *Highway Capacity Manual 2000* (*HCM*) methodologies into the ProModel simulation software package and then compared and contrasted the resultant data. The *HCM* methodologies were used to create the ProModel algorithms. Pedestrian thoroughfare system simulations were then run with these algorithms, and the software simulation outcomes were compared to the *HCM* outcomes for the same situational parameters.

The Central Washington University main campus thoroughfares were used as a case study. Videography at three locations for 4 days per location provided the pedestrian count and rate data. Peak pedestrian counts were entered into the simulation model for *HCM* level of service computation.

The model that resulted from this applied research effort can be used to evaluate the variables that influence the design of pedestrian thoroughfares elsewhere on the Central Washington University main campus because the *HCM* and simulation

model computations produced the same level of service values with the same situational parameters.

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CHAPTER I

INTRODUCTION

Purpose

This study was undertaken to determine whether existing simulation and modeling systems could be used to analyze and model pedestrian traffic flows. The study incorporates the *Highway Capacity Manual 2000* (*HCM*) (Transportation Research Board, National Research Council [TRB], 2000a) methodologies into a ProModel simulation and then compares and contrasts the results of the *HCM* calculations with the ProModel simulation. The Central Washington University (CWU) campus was used for the case study.

The TRB, a division of the National Research Council, advises the federal government on transportation facilities. ProModel is a simulation and analysis software tool, which provided the visualization of the *HCM* methodologies (ProModel Corporation, 2005).

Prior to this study, the researcher had used ProModel to simulate vehicle traffic flow on the CWU campus for the CWU Site and Development Committee. Analysis of pedestrian flow density is an extension of previous work, and an ongoing concern, for the CWU Site and Development Committee. The *HCM* devotes a complete chapter (chapter 18) to analyzing pedestrian flow (TRB, 2000a). While the *HCM* provides methodologies for determining the capacity and level of service (LOS) for pedestrians, it does not provide a graphical simulation tool. The CWU pedestrian traffic is modeled using the methods in the *HCM*.

Assumption

The area under observation for each location is a uniform segment of the walkway. The pedestrian walkway is between –3% and +3% grade, and there can be no doorway in the middle of the walkway segment where large volumes of pedestrians would emerge (TRB, 2000a). This phenomenon would be different from a cross flow of pedestrians at a walkway intersection. This is an outside environment with mild weather conditions.

Delimitation

The scope of this study focuses on pedestrian traffic on the CWU campus. Minor modifications to the simulation model would allow it to be applied to any pedestrian walkway.

Problem Statement

HCM methodologies rely on calculations and worksheets to determine pedestrian flow and LOS. Once the calculations are made, there is no way to visually simulate the pedestrian behavior characterized by the calculated solution. The simulation model provides a means of visualizing the various levels of service. Since many people are visually oriented, having a simulation tool becomes an important means of presenting information (Anderson, 2002).

Research Questions

1. Does the ProModel simulation allow us to simulate and analyze pedestrian traffic flow?

2. If ProModel does allow us to analyze pedestrian traffic flow, will it allow us to evaluate the range of situations that may occur?
3. How does ProModel simulation compare to the *HCM* model for determining walkway use?

Definition of Terms

Arrivals: "Any time new entities are introduced into the system, it is called an arrival" (ProModel Corporation, 2005). Using the path network, every pedestrian arrives at one end (Location A) of the simulation walkway segment and then arrives at its opposite end (Location B).

Capacity: "Person capacity is the maximum number of persons that can pass a given point during a specified period under prevailing conditions" (TRB, 2000a, p. 2-2). A capacity is calculated for a segment or point, so segments with different prevailing conditions will have different capacities. Capacity is not necessarily the maximum flow rate observed. The units for capacity are distance per time (TRB, 2000a, p. 2-2).

Demand: "Demand is the principal measure of the amount of traffic using a given facility" (TRB, 2000a, p. 2-2).

Entity: "Anything that a model processes is called an entity" (ProModel Corporation, 2005). Each pedestrian is considered an entity by the simulation software.

LOS: "a quality measure describing operational conditions within a traffic stream, generally in terms of such service measures as speed and travel time, freedom to maneuver, traffic interruptions, and comfort and convenience" (TRB, 2000a, p. 2-2).

Location: “Locations represent places in the system where entities are routed for processing, storage, or some other activity or decision making” (ProModel Corporation, 2005). All the pedestrians in the simulation model arrive at a location prior to being processed (moving through the system). There are locations at each end of the simulation walkways (Locations A and B).

Path network: “Entities moving by themselves between locations may also move on path networks if referenced in the move logic of the routing” (ProModel Corporation, 2005). All the pedestrians in the model move on the path network from one end (Location A) of the walkway to the other end (Location B) of the walkway.

Platoon: “A group of vehicles or pedestrians traveling together as a group” (TRB, 2000a, p. 5-12). These “groups” can be voluntary or involuntarily established. Sometimes factors like signal control or geometrics will cause platooning.

Processing: “Processing defines the routing of entities through the system and the operations that take place at each location they enter” (ProModel Corporation, 2005). Processing contains the *HCM* methodology algorithms.

Service flow rates: “The service flow rate is the maximum hourly rate at which persons or vehicles reasonably can be expected to traverse a point of uniform segment of a lane or roadway during a given period under prevailing roadway, traffic, and control conditions while maintaining a designated level of service. The service flow rates generally are based on a 15-min period” (TRB, 2000a, p. 2-3).

Shy distance: The distance a pedestrian maintains between him/herself and an obstruction in the walkway (TRB, 2000a).

Pedestrians: Individuals that are walking or jogging, not including bicyclists, individuals in wheel chairs, skateboarders, or individuals on scooters.

CHAPTER II

DESCRIPTION OF RESEARCH

Research Validity

Best and Kahn (1993) define reliability and validity as "the degree of consistency that the instrument or procedure demonstrates: whatever it is measuring, it does so consistently. Validity is that quality of a data-gathering instrument or procedure that enables it to measure what it is supposed to measure" (Best & Kahn p. 208). The methods chosen for this research adhere to this definition of research validity.

Methodology

The *HCM* is a product of the TRB (2000a). The Washington State Department of Transportation uses the *HCM* for all its traffic planning and roadway designs (R. Holmstrom, personal communication, April 18, 2007). The *HCM* model was chosen because it contains methodologies and procedures for determining capacities and LOS for pedestrian traffic flows, as well as traffic flows along freeways, highways, signalized and unsignalized intersections.

Establishing the LOS required obtaining field data for two parameters: the peak 15-min of pedestrian use and the pedestrian rate of travel. The peak 15-min parameter is the easiest to apply. The rate of travel can augment the peak 15-min parameter. Either parameter can be used to calculate the LOS for a walkway segment.

Videography was employed to obtain data about pedestrian use at three locations on the CWU main campus. All three locations were located along Walnut

Mall, the main campus pedestrian thoroughfare. Vehicle access to Walnut Mall was restricted to special permits, so the lack of vehicles allowed on the mall was another reason for using Walnut Mall to observe pedestrians. *HCM* pedestrian walkway calculation methodologies were applied after completing the videography and gathering the pedestrian data (TRB, 2000a).

Effective walkway width was then determined. When using a walkway, pedestrians do not generally use the full width of the walkway. The amount of walkway that pedestrians use defines the effective walkway width. Pedestrians shy away from obstructions like benches, garbage cans, light poles, hedges, and the edge of the mall reducing the effective walkway width. Vehicles on the walkway would also be considered an obstruction to pedestrians. Shy distances can be defined as the space pedestrians leave between an obstruction and themselves (TRB, 2000a). The *HCM* defines the effective walkway (Equation 1) in the following manner:

$$W_E = W_T - W_O, \tag{1}$$

where W_E = effective walkway width (ft), W_T = total walkway width (ft), and W_O = sum of widths from obstructions on the walkway (ft).

Defined next is the pedestrian unit flow rate. According to *HCM*, the pedestrian unit flow rate (Equation 2) is defined by dividing the peak 15-min flow rate by the effective walkway width.

$$v_p = v_{15} / (15 \times W_E), \tag{2}$$

where v_p = pedestrian unit flow rate (p/min/ft), v_{15} = peak 15-min flow rate (p/15-min), and W_E = effective walkway width (ft).

A pedestrian per square foot (p/ft^2) defines the density of pedestrians on a walkway. The Federal Highway Administration Safety (1998, p. 8) defines the area a person occupies as 3.23 ft^2 and a walking space of 8.07 ft^2.

Included in walkway element properties are the density of the traffic (Equation 3) or the amount of space in which a person has to walk. Space is "the inverse of density" (TRB, 2000a, p. 18-4).

$$\text{Space} = 1 / \text{density}. \tag{3}$$

These equations defined the matrix from which the ProModel simulation was created. The ProModel simulation provided an animated model of pedestrian walkway use.

The average pedestrian walking speed for CWU was also determined. To obtain an average pedestrian walking speed for campus, 5 pedestrian's walking speeds were recorded and then averaged for each 15-min period using Equation 4.

$$r_{15} = r_i / 5, \tag{4}$$

where r_i = individual pedestrian rate (ft/s) and r_{15} = average rate for 15-min period (ft/s). All 15-min periods were then averaged. Equation 5 established the average rate of pedestrians on the CWU campus.

$$r = \text{Sum of all } r_{15} \,/\, \text{Total number of } r_{15}, \tag{5}$$

where r_{15} = average rate for 15-min period (ft/s) and r = average pedestrian rate for CWU campus (ft/s).

Research Procedure

The initial study phase consisted of videography of pedestrians using walkways and intersections on CWU's main campus in Ellensburg. Prior to the commencement of videography, a human subjects' review application was completed, and authorization was given by the CWU Human Subjects Review Committee to proceed. While the pedestrians were recorded, the image was slightly out of focus to preserve the anonymity of the pedestrians.

A report of classroom use demonstrates that 79 to 93, of a total 114, classrooms are in use for each of the 9:00, 10:00, and 11:00 a.m. hours (Ryder, 2003). No other hours of the day match these classroom usage numbers. Videography was conducted on Monday through Thursday mornings from 8:30 to 11:30 at each location to observe the peak pedestrian traffic flows.

Three locations were chosen for observation of pedestrians. Figure 1 shows a map of the campus and the three observation locations. There was concern that

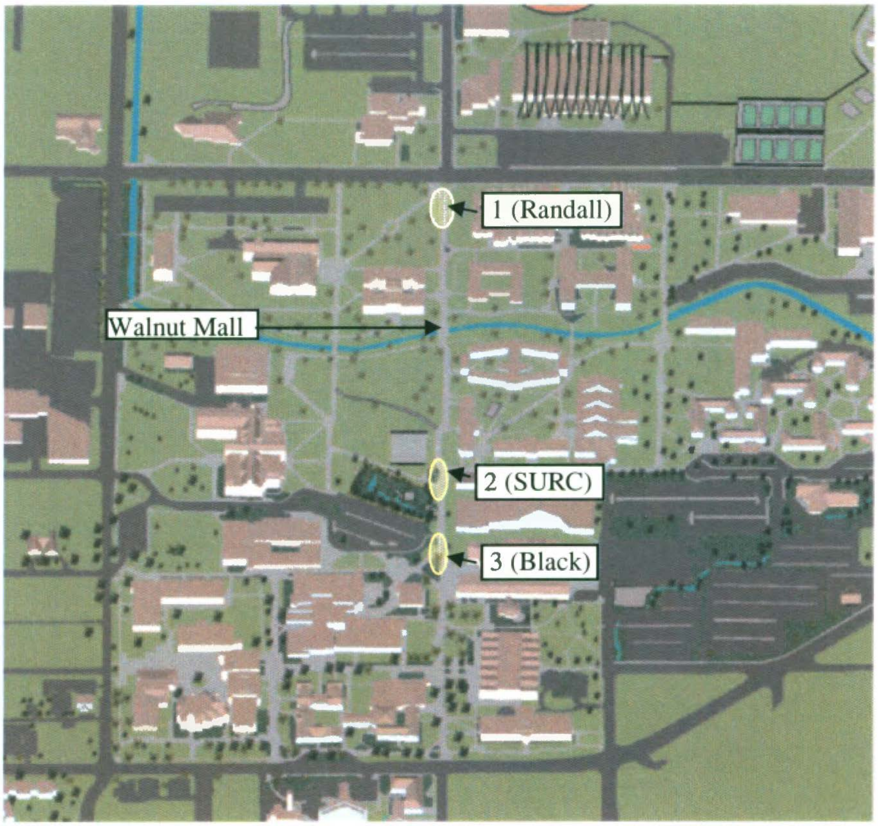

Figure 1. Map of Central Washington University campus pedestrian observation locations. Arrows indicate camera line of sight. Shading indicates observation segment.

pedestrians would alter their behavior if they knew they were being observed. Observation was then conducted from a vantage point that was least likely to alter pedestrian behavior. Location 1 was at the north end of the Walnut Mall, and pedestrians were observed from the Randall Hall roof. There are two major intersections near the middle of Walnut Mall. Location 2 was at the Student Union and Recreation Center (SURC), the first of the two major intersections. This segment of Walnut Mall was observed from the second floor of the SURC. Location 3 was from the roof of Black Hall, the second major intersection on Walnut Mall. At Location 1, the roof of Randall Hall, the video camera was mounted on a tripod located on the west end of the building looking west onto the Walnut Mall (see Figure 2). The camera was approximately 90 ft to the east of Walnut Mall and approximately 30 ft above the mall.

Figure 2. Camera view from Randall Hall roof to Walnut Mall.

The northwest corner of the second floor of the SURC was the second video location. The video camera tripod was taped to the window approximately 24 ft above and just to the east of the mall (see Figure 3). Location 3 was the roof of Black Hall. The video camera and tripod were on the northwest corner of the roof looking west onto the Walnut Mall (see Figure 4). The camera was approximately 60 ft to the east

Figure 3. Camera view from second floor of the Student Union and Recreation Center to Walnut Mall.

Figure 4. Camera view from the roof of Black Hall to Walnut Mall.

of Walnut Mall and approximately 30 ft above the mall. See Appendix A for additional photographs of each observation location's setup.

The count line was created by placing a small stake in the ground on either side of the walkway. The stake had a flag attached to make the stake more visible in the video. Each pedestrian that crossed the predetermined walkway line was counted. All individuals were counted who passed within a two-person width (6 ft) of the flag and were headed in the direction of travel being observed. The pedestrians who passed within 6 ft of the flag were pedestrians who shortcut the counting flag and then rejoined the mall. An additional stake 20 ft from the count line was used to establish pedestrian flow rate at Locations 1 and 2 (see Figures 5 and 6). The pedestrian flow-rate flag was not used at Location 3 (see Figure 7), for there was enough data from the previous two locations to establish the average walking pace of a pedestrian on the CWU campus.

The pedestrian count was recorded to an Excel spreadsheet in 15-min intervals per day per direction (see Appendix B). This means that the total number of pedestrians that broke the vertical plane created by the stakes was recorded for each 15-min interval. Each hour was broken into four 15-min periods starting at the top of the hour and referred to as Periods 1–4. This distribution of 15-min periods was chosen to best represent the walkway use patterns as classes all begin at the top of the hour and are released at 50-min past the hour. During videography, at each 15-min interval, the lens was obscured for 1 s and the time and date were stated. This was done to aid the researcher during playback. The same three read-write compact discs

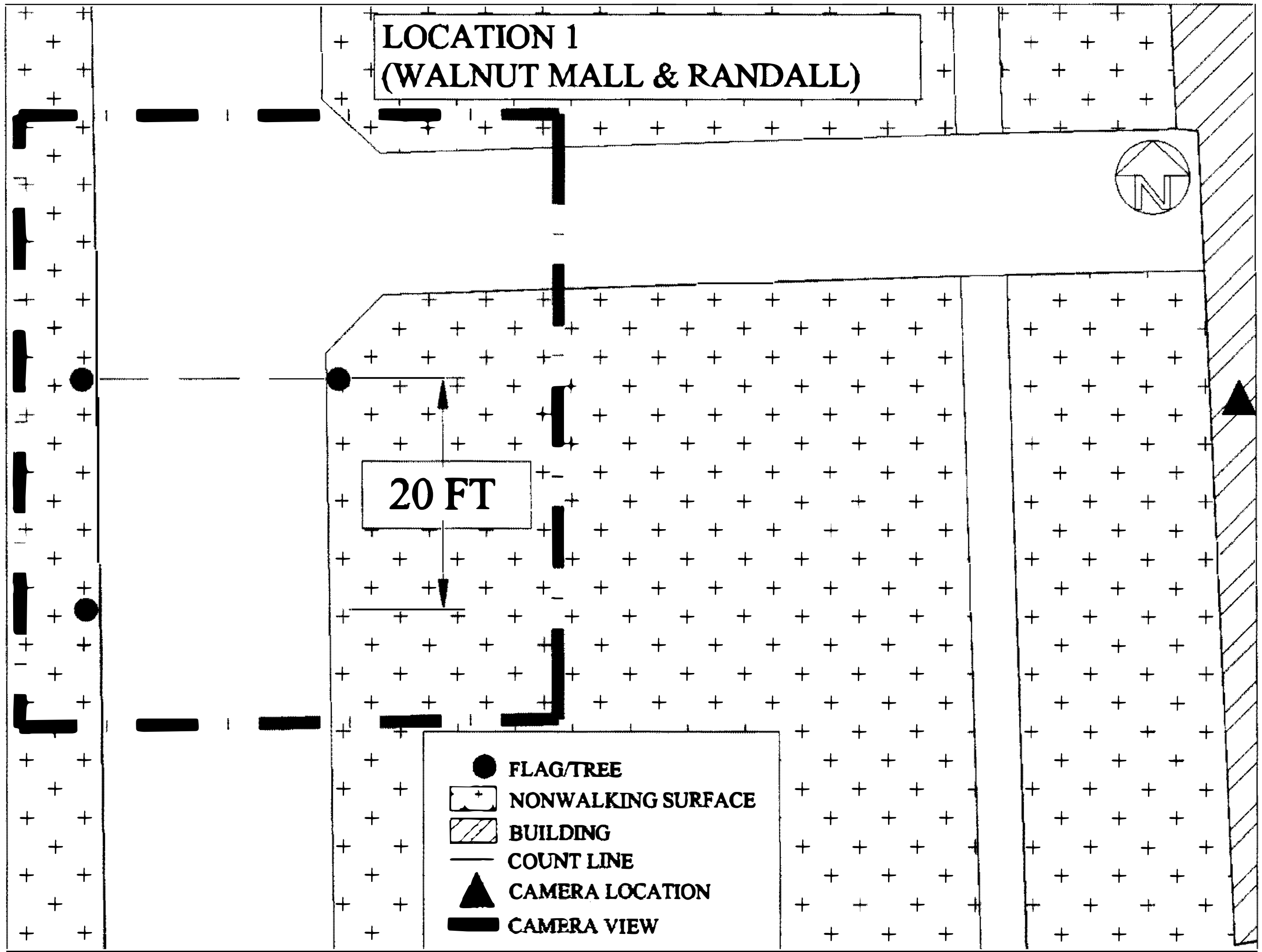

Figure 5. Plan view of Location 1 (Walnut Mall and Randall Hall).

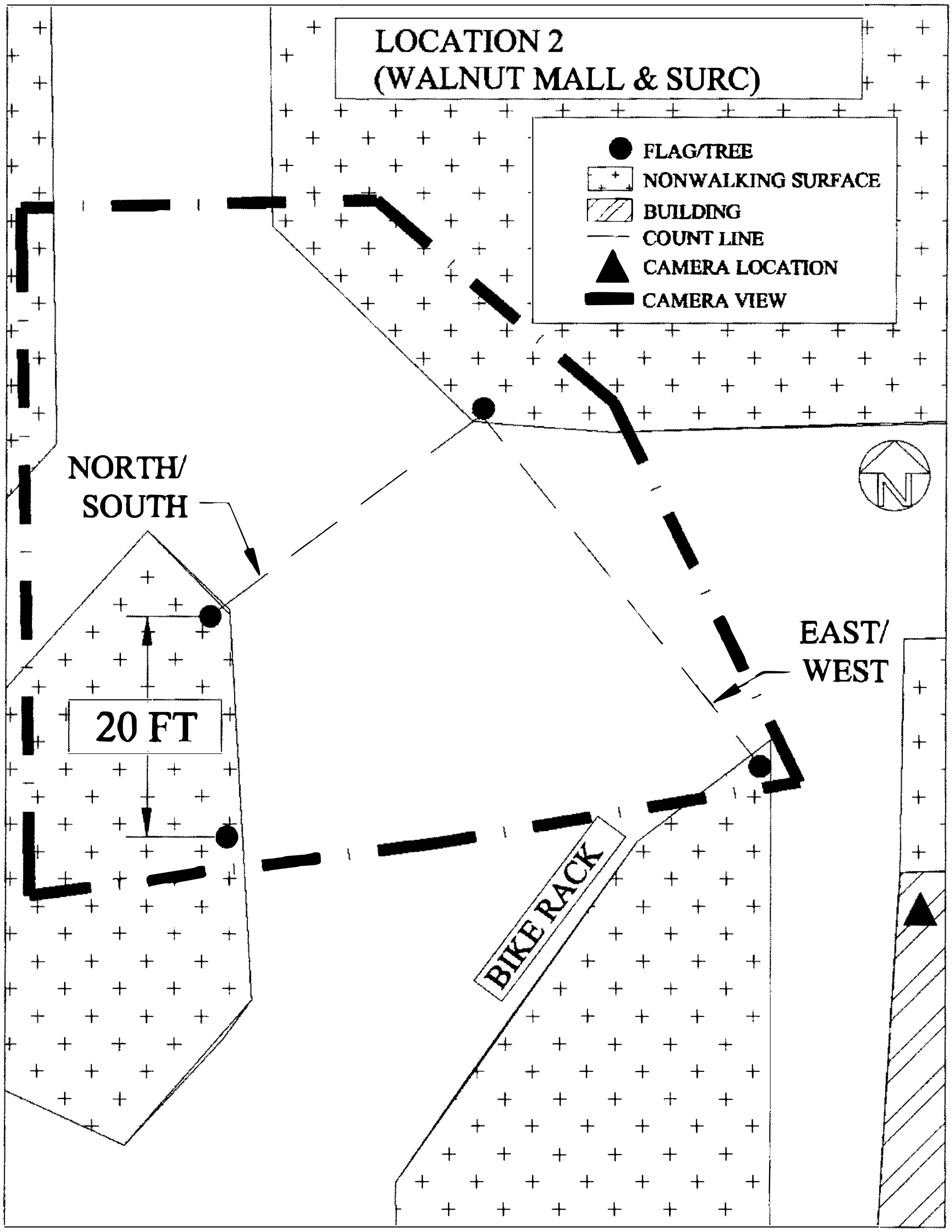

Figure 6. Plan view of Location 2 (Walnut Mall and Student Union and Recreation Center [SURC]).

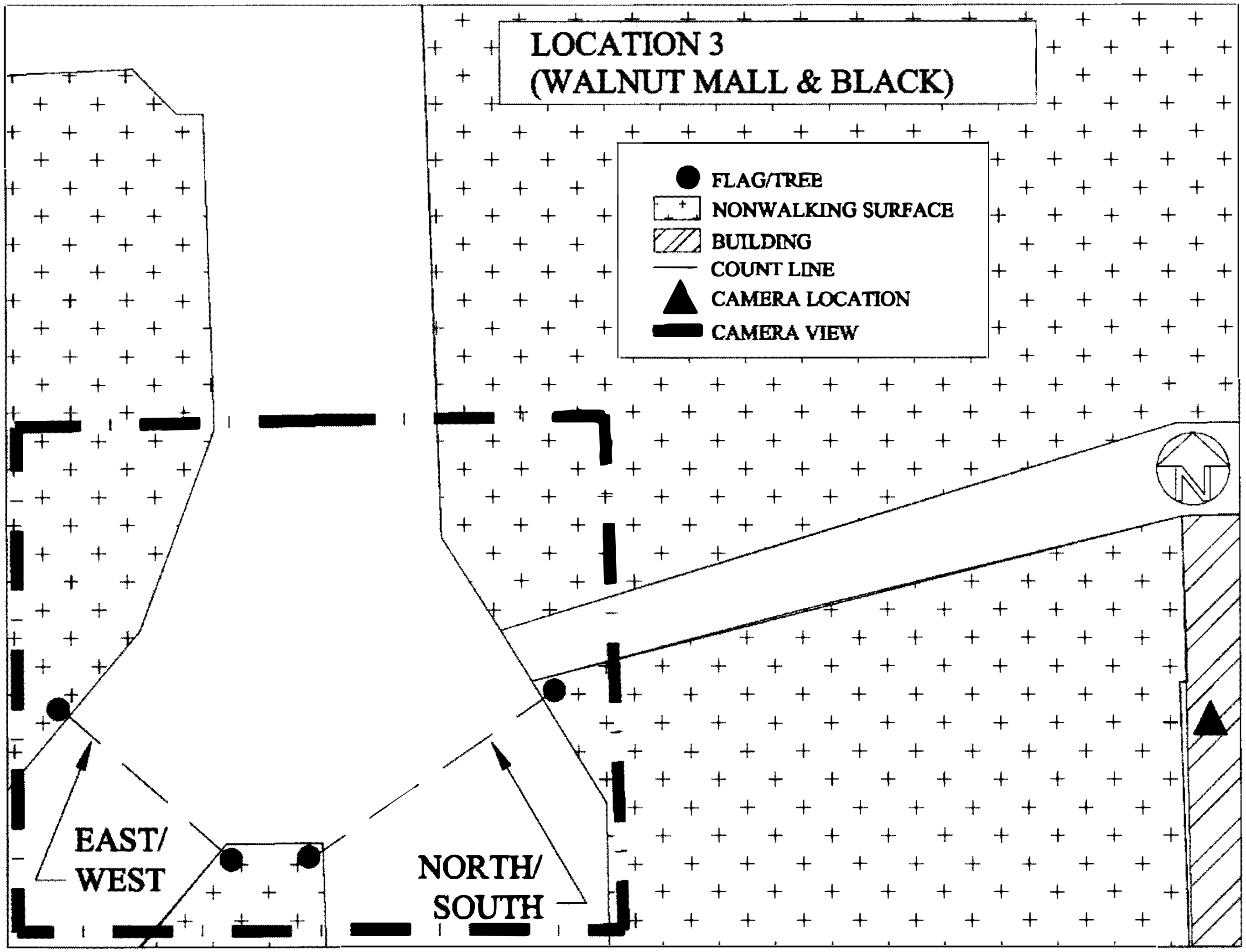

Figure 7. Plan view of Location 3 (Walnut Mall and Black Hall).

were used each day of videography and then copied to a hard disk. Stating the time and date ensured that there was no confusion about the date and time being observed if the file were accidentally copied to the incorrect folder on the computer hard drive. Obscuring the camera lens for 1 s allowed the researcher to play the video at four and eight times the normal speed, and to know when the 15-min period had completed. Increasing the playback speed of the video reduced the time to complete the pedestrian counts. During peak pedestrian traffic time, the video was reduced to normal speed.

After completing each 3-hr video session, the video was played back to count each of the pedestrians as they broke the plane of the line created by the stakes. With an Excel spreadsheet open while playing back the video, the researcher can press the "a" key every time a pedestrian breaks the plane of the flag line. This created a string of characters in the spreadsheet cell. The Excel function LEN (returns the number of characters in a text string) was used to return the number of characters in the string to give the pedestrian count. After all the data was entered, the peak 15-min pedestrian numbers were determined.

The next parameter to establish was the average pedestrian walking speed. The *HCM* states, "If 0 to 20 percent of the pedestrians are elderly, a walking speed of 4 ft/s is recommended for computations for walkways" (TRB, 2000a, p. 18-1). While there was a wide range of pedestrian ages on campus, the average pedestrian rate for CWU was established for persons from the ages of 18 to 25 years. The average age of the students on the CWU campus was 22.7 years in 2004, 22.6 years in 2005, and 22.3 years in 2006 (Cadman, 2007a).

As described previously, stakes with flags were installed adjacent to the walkway 20 ft apart (Figures 5 and 6). Twenty feet was a reasonable distance to fit in the camera viewfinder and provide enough distance to time a pedestrian moving from one flag to the other. At 4 ft/s, 10 ft seemed too short a distance to attempt to time accurately on the video. A 50 ft distance would make it difficult to remain fixed on the same subject in the video among all the other pedestrians. The walking speed of 4.5% of all the observed pedestrians was taken. This equated to 905 pedestrians of a total 20,352. The location of the flags for determining the pedestrian travel rate dictated that only pedestrians traveling north and south were timed. A maximum of 10 individuals' walking speed was recorded during a 15-min period. At Location 1, on occasion, there were not 5 pedestrians traveling in the direction being observed; thus the total of 10 individuals per 15-min period could not be reached. Five pedestrians were arbitrarily selected throughout the 15-min period and their speed recorded. The 5 pedestrians' travel speeds would then be averaged. Five were selected because two would not be enough to give an accurate average and 10 were too many individuals to keep track of because the video software being used is not sophisticated enough to put tags on individuals for tracking. Another reason for choosing 5 pedestrians was to help mitigate the human error in recording the time between flags. As the video was played back, a stopwatch was used to determine the number of seconds it took the pedestrian to travel from flag to flag. The human reaction time and any parallax in the video are sources of error. Parallax is when an object appears to change positions when the observer changes his/her position in relation to the object.

The next phase was to apply the *HCM* methodologies to the field data that had been collected. This involved determining the effective walkway width, calculating the pedestrian unit flow rate, and determining the LOS from *HCM*'s Exhibit 18-3 (see Table 1) for each 15-min period (TRB, 2000a, p. 18-4). An LOS of “A” is the best, and “F” is the worst.

Table 1

Average Flow Level of Service Criteria for Walkways and Sidewalks

Level of service	Space (ft^2/p)	Flow rate (p/min/ft)	Speed (ft/s)	v/c ratio
A	> 60	≤ 5	> 4.25	≤ 0.21
B	> 40–60	> 5–7	> 4.17–4.25	> 0.21–0.31
C	> 24–40	> 7–10	> 4.00–4.17	> 0.31–0.44
D	> 15–24	> 10–15	> 3.75–4.00	> 0.44–0.65
E	> 8–15	> 15–23	> 2.50–3.75	> 0.65–1.0
F	≤ 8	Variable	≤ 2.50	Variable

Note. p = pedestrian; v/c = volume to capacity. From Transportation Research Board, National Research Council (2000a, p. 18-4, Exhibit 18-3). Copyright National Academy of Science, reproduced with permission.

If platoons (groups traveling together) are observed, there is a platoon-adjusted table (*HCM* Exhibit 18-4) available for determining the LOS values (TRB, 2000a, p. 18-5; see Table 2).

Table 2

Platoon-Adjusted Average Flow Level of Service Criteria for Walkways and Sidewalks

Level of service	Space (ft^2/p)	Flow rate[a] (p/min/ft)
A	> 530	≤ 0.5
B	> 90–530	> 0.5–3
C	> 40–90	> 3–6
D	> 23–40	> 6–11
E	> 11–23	> 11–18
F	≤ 11	> 18

Note. p = pedestrian. From Transportation Research Board, National Research Council (2000a, p. 18-5, Exhibit 18-4). Copyright National Academy of Science, reproduced with permission.
[a]Flow rates in the table represent average flow rates over a 5- to 6-min period.

This software was chosen to simulate the *HCM* walkway model because of this researcher's familiarity and previous experience with ProModel and its availability on campus,. Equations 1 and 2, defined by the *HCM*, were incorporated into the ProModel simulation. The simulation model then determined the LOS based on the values in Table 1.

After the simulation model completed execution, an output of the determined LOS was presented to the user. The ProModel background represented each of the locations along Walnut Mall. This was not necessary for the simulation but provided a visual frame of reference. Input parameters for peak 15-min pedestrian count, total walkway width, and sum of shy distances were created to accept user input values for *HCM* Equations 1 and 2.

CHAPTER III

LITERATURE REVIEW

Body of Knowledge

Many architectural design firms produce documentation on what comprises an effective pedestrian walkway. Cities, states, and the federal government also study and analyze pedestrian traffic flow. Several individual studies can also be found on modeling behavior of pedestrians. Teknomo (2007) has created a Web site for the study of pedestrian activity patterning, to be used in collaboration with other researchers. There is a growing knowledge base in dynamic pedestrian modeling (Asano, Sumalee, Kuwahara, & Tanaka, 2007). Companies, such as London's Intelligent Space Partnership Ltd., specialize in software packages for predicting pedestrian activity. The TRB (2000b) provides documentation and tools to aid in selecting a software analytical tool.

The TRB's parent organization, the National Research Council, was formed in 1916 by the National Academy of Science to advise the federal government and proliferate the knowledge of the science and technology communities. The National Research Council also supports the National Academy of Engineering, which was formed in 1964 as a parallel organization to the National Academy of Science. The National Academy of Engineering is a collection of exceptional engineers autonomous to the National Academy of Science but sharing in the responsibility of advising the federal government. The National Academy of Science was established as:

> a private, nonprofit, self-perpetuating society of distinguished scholars engaged in scientific and engineering research, dedicated to the furtherance of science and technology and to their use for the general welfare. Upon the authority of the charter granted to it by the Congress in 1863, the Academy has a mandate that requires it to advise the federal government on scientific and technical matters. (TRB, 2000a, p. iii)

The TRB's (2000a) *HCM* "provides a collection of state-of-the-art techniques for estimating the capacity and determining the level of service for transportation facilities" (p. vii). The *HCM* was first published in 1950. Since that time, the *HCM* has been republished in 1965, 1985, and 2000. Each publication is developed and revised through a rigorous review process overseen by the TRB.

ProModel Corporation was founded in 1988 by Dr. Charles Harrell. It specializes in software for simulating and analyzing processes (ProModel Corporation, 2007). The process can be a business process or a manufacturing process. As an example, ProModel is used as a visual tool to aid companies in improving manufacturing throughput and optimizing the manufacturing process. Companies can run "what if" scenarios, design, and plan new production lines prior to spending any money. ProModel software is used by 43 of the top Fortune 100 companies (ProModel Corporation, 2007).

CHAPTER IV

MODEL ANALYSIS

Highway Capacity Manual 2000 Methodologies

Applying Equations 1 and 2 will produce the *HCM* LOS for each of the walkway segments at each location. Equation 1 establishes the effective walkway width, and Equation 2 calculates the flow rate. The peak 15-min value was selected from the data collected at CWU (see Table 3). The mall segments that were observed had a total walkway width of 20 ft. In the *HCM*, all walkway segments are assumed to be uniform. There were no obstructions on or near the mall on the segments observed. Movable obstructions, such as vehicles, were not considered at the time of this study. The only shy distance was the edge of the mall for which a shy distance of 1 ft for each side was used (TRB, 2000a). Equation 1 established the effective walkway width at 18 ft, where 20 ft – (1 ft + 1 ft) = 18 ft. Since the peak 15-min numbers for each location are similar values for all 4 days, the maximum peak 15-min pedestrian count was used (Table 3). Location 1 (Randall Hall) was a simple bidirectional simulation. Locations 2 (SURC) and 3 (Black Hall) contained cross-flow and merging simulation problems. The *HCM* specifies that pedestrian cross-flows be calculated in the same manner as simple bidirectional traffic flow with the peak 15-min values totaled. Equation 2 was used to calculate the pedestrian flow rate for each location. The result for Location 1 was 198 p/15min / (15 × 18 ft) = 0.73 p/min/ft. The result for Location 2 was (475 + 245 p/15min) / (15 × 18 ft) = 2.67 p/min/ft. The result for Location 3 was (469 + 84 p/15min) / (15 × 18 ft) = 2.05 p/min/ft.

Table 3

Peak 15-min Pedestrian Counts per Location per Day

Date	Day	Direction of travel: North/south	Direction of travel: East/west
Location 1			
4/03/2007	Tuesday	188	
4/04/2007	Wednesday	179	
4/05/2007	Thursday	198	
4/09/2007	Monday	174	
Location 2			
3/27/2007	Tuesday	386	192
3/28/2007	Wednesday	473	220
3/29/2007	Thursday	475	245
4/02/2007	Monday	439	228
Location 3			
4/23/2007	Monday	469	84
4/24/2007	Tuesday	391	85
4/25/2007	Wednesday	408	82
4/26/2007	Thursday	353	158

After calculating the pedestrian flow rate, reference Table 1 to determine the LOS value unless platooning was observed. Table 2 contains the LOS values if platooning was observed. An LOS value of "E" would require referencing *HCM's* Exhibit 18-6 (TRB, 2000a, p. 18-5; see Table 4).

Table 4

Average Flow Level of Service E Criteria for Walkways and Sidewalks

Level of service	Space (ft^2/p)	Flow[a] (p/min/ft)	Speed (ft/s)	Density (p/ft^2)
E	≥ 13	≤ 23	≥ 3.28	≤ 0.07

Note. p = pedestrian. Transportation Research Board (2000, p. 18-5, Exhibit 18-6). Copyright National Academy of Science, reproduced with permission.
[a]Total of the major and minor flows.

All the calculated v_p flow rates, using Equation 2, were less than 5, indicating that each location has an LOS rating of "A." Given that the maximum peak 15-min value was used for each location, all subsequent times for each location will also have an LOS rating of "A."

Equations 4 and 5 were applied to the pedestrian rate data. The average pedestrian walking speed for CWU was 4.74 ft/s. This produces an LOS of "A."

ProModel Software

After the simulation model was developed, it was validated for its capability to simulate the number of pedestrians crossing the count line in a 3-hr period. Each stage of the model development was validated through a series of proof-of-concept models. A test model was created to test the "count line." Similar to the real world, a count line was created in the simulation model. Originally, the pedestrian count in the simulation model was conducted at the count line. In the course of development, the pedestrian count was made as the pedestrian enters the mall segment being tested. This negated the need for a pedestrian rate.

A pedestrian counter was incorporated to confirm the correct numbers of pedestrians were "moved" through the simulation model. Also, near the beginning of the simulation development only one entity, or pedestrian, was used to arrive at both locations. The locations (A and B) were at each end of the walkway segment to accept arriving entities that would then travel to the opposite location. Through testing it was determined that the pedestrian counts were incorrect. A second entity needed to be added. To obtain the correct pedestrian counts, Entity A would arrive at Location A and then travel to Location B. Conversely, Entity B would arrive at Location B and then travel to Location A. As each new proof-of-concept model was added, it was tested and confirmed before moving on to the next step. The final simulation model was produced through a compilation of the test models.

During the course of reviewing the videos, it was apparent that there was a distribution of pedestrians over the course of 1 hr. At CWU, the peak pedestrian traffic is from three-quarter past the hour until the top of the hour (Period 4). From 8:00 a.m. until 9:00 a.m., the most pedestrians were observed between 8:45 a.m. and 9:00 a.m. The same pattern was true from 9:00 a.m. until 10:00 a.m., and from 10:00 a.m. until 11:00 a.m. The observation allowed for the acceptance of the peak 15-min pedestrian count as an input to estimate the total amount of pedestrians that would cross the count line in 1 hr.

To obtain the average pedestrian distribution, the pedestrian count for each period (1--4) was divided by the total pedestrian count for that hour. This was done for each full hour of pedestrian observation. All the values for Period 1 on each day at each location were then averaged to ascertain the Period 1 pedestrian distribution. This averaging technique was then repeated for Periods 2–4. From the empirical data, the average pedestrian count distribution for Period 1 was 8.2% of the hourly total, Period 2 was 6.2%, Period 3 was 14.2%, and Period 4 was 71.3%. This distribution was then incorporated into the simulation model. The pedestrians who arrived to travel from "A" to "B" in the simulation model were based on this distribution.

The simulation model logic requires that the user input some values to enable the software to simulate and calculate the LOS (see Appendix C). The peak 15-min pedestrian count; the total walkway width; and the sum of shy distances, or walkway obstructions, were entered by the user. For Location 2 (SURC) and Location 3 (Black Hall), an additional peak 15-min parameter was added to the simulation model to accommodate the cross flow conditions. To view the ProModel parameters, see Appendixes D and E.

The ProModel simulation was run using the peak 15-min value from each location for each day (see Table 5). For every peak 15-min value from Table 5 that was used in the ProModel simulation, the LOS rating was "A" (see Figure 8). For additional simulation model screen shoots, see Appendix F.

Table 5

Comparison of Empirical Data and Simulation Model Data

Day	Direction of travel[a] North/south	East/west	Daily total Empirical	Model	Difference (%)
			Location 1		
Monday	174		611		9.00
Tuesday	188		653		10.26
Wednesday	179		663		3.17
Thursday	198		618		22.33
			Location 2		
Monday	439	228	2,306	2,550	10.58
Tuesday	386	192	2,782	2,214	−20.42
Wednesday	473	220	2,745	2,652	−3.39
Thursday	475	245	2,346	2,760	17.65
			Location 3		
Monday	469	84	1,981	2,118	6.92
Tuesday	391	85	1,808	1,824	0.88
Wednesday	408	82	1,894	1,878	−0.84
Thursday	353	158	1,945	1,956	0.57

[a] Maximum peak 15-min = For the location and the day, this was the maximum 15-min value recorded.

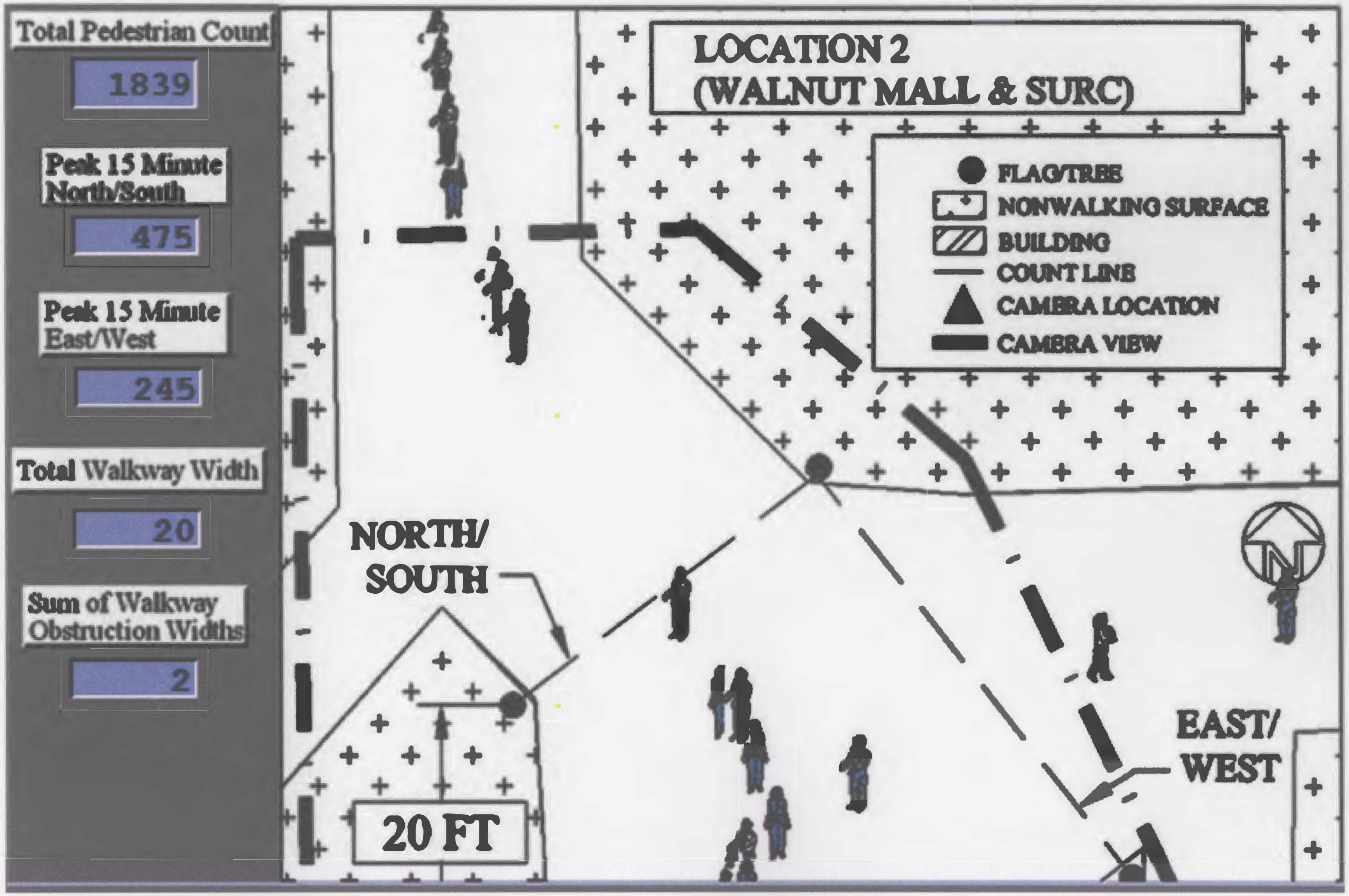

Figure 8. ProModel simulation model screen shot of Location 2 (Student Union and Recreation Center [SURC]).

CHAPTER V

DISCUSSION AND CONCLUSIONS

Simulation

The correlation of empirical versus simulated data indicates as much as a 20% error (see Figure 9 for a graph of the difference column shown in Table 5). However,

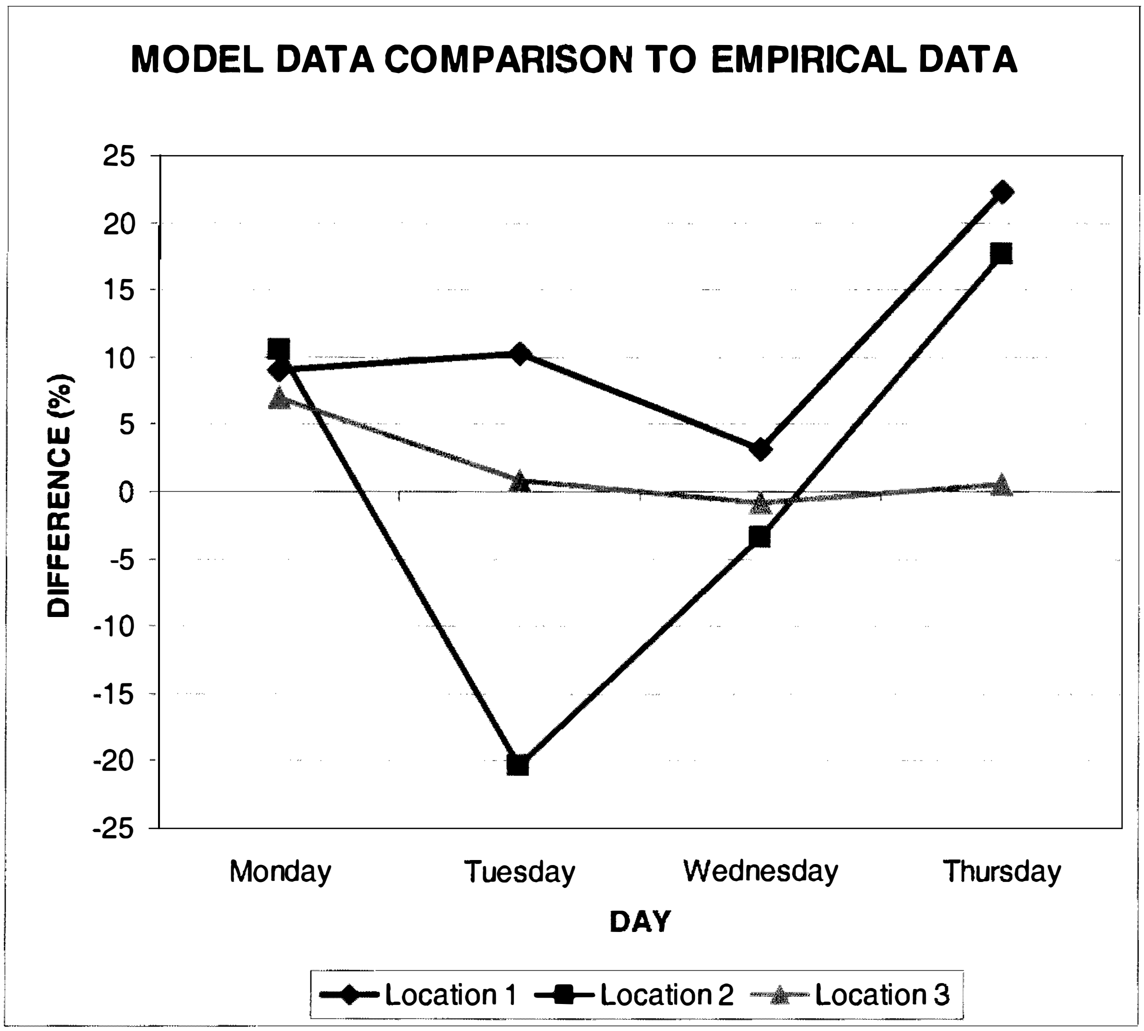

Figure 9. Percentage difference when comparing simulation model data to empirical data.

the errors do not affect the prediction of the LOS. CWU's malls are so wide that they can accommodate many more pedestrians before the LOS is reduced. The relationship between walkway width and peak number of pedestrians is greatly enhanced by CWU having 20-ft-wide malls. If CWU's malls were more narrow, it would not take as many pedestrians to reduce the LOS per mall segment. For example, at Location 1 (Randall Hall), the peak 15-min value did not exceed 200 pedestrians. The flow rate (v_p) value from Equation 2, with an effective walkway width of 18 ft, was less than 1 for 200 pedestrians producing an LOS "A." To reduce the LOS to a "B" would require the v_p value to be greater than 5. This would require a peak 15-min pedestrian count of over 1,350 or over a 500% increase in pedestrian traffic. Reaching an LOS of "F" would require 6,212 students, over 70% of the 2006 CWU student population, to cross the counting line at Location 1 in 15 min.

How well the model pedestrian count mimics the empirical data depends on how well the empirical data matches the average percentage distribution of pedestrians per hour (Period 1 = 8.2%, Period 2 = 6.2%, Period 3 = 14.2%, and Period 4 = 71.3%). One method of mitigating this error would be to create additional input variables for the simulation model. The user would specify what the pedestrian distribution was over a 1-hr time period.

The proximity of the count line to the SURC along with the first day of class for the quarter could explain the error in the SURC comparison. The CWU bookstore and Holmes Dining Hall are also located in the SURC. There may have been an unusual amount of traffic at "odd" times due to students purchasing books and not having a class routine developed. More research is needed to determine the cause of the increase in the error on the fourth day for Location 1 (Randall) and Location 2 (SURC).

Evaluation

Many different scenarios can be evaluated using the simulation model. To have the model determine the walkway LOS, enter the peak 15-min pedestrian count, the total walkway width, and the sum of walkway obstructions. At the completion of the simulation, the calculated LOS for that segment is displayed.

This model can be used for planning. For example, if construction were to close or partially close a pedestrian walkway, the simulation model allows the user to attempt several different walkway widths quickly and easily to determine the size of walkway to alleviate any pedestrian congestion around the construction site.

The current mall width was then evaluated in comparison to the expected CWU student growth rate based on the past 6 years of enrollment (see Figure 10). The average growth rate of CWU was determined to be 3.43% (Cadman, 2007b). To maximize the potential of the simulation model in hardscape planning, a growth rate of 5% over the next 20 years (2007–2027) was assumed. The current empirical data were extrapolated and run in the ProModel simulation. There was no change in the LOS rating of an "A" for Locations 1 and 3 (Figure 1). Location 2's rating degraded to an LOS of "B."

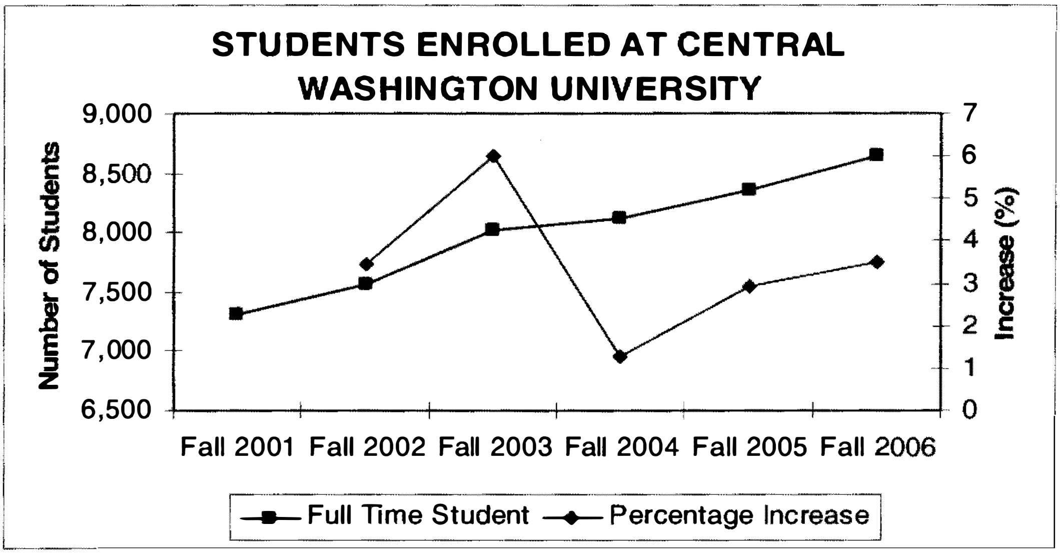

Figure 10. Number of students enrolled at Central Washington University and percentage of enrollment increase.

Conclusion

The *HCM* methodology includes the assumption that if the LOS for a walkway segment is acceptable at the peak pedestrian flow, then the LOS is acceptable for all other times. The *HCM* is a static model and provides a useful method for determining the LOS for walkway segment. Different scenarios can be modeled with ease.

The ProModel simulation adds visualization of the data to the scenarios. The modeling of the pedestrian average distribution provides a visual account of the pedestrians on the mall as they would be distributed over the course of a 1-hr time period. The context of the location being modeled was also displayed during the simulation. The model can provide the total number of pedestrians that would have used the mall during the 8:30 a.m. to 11:30 a.m. time period.

The ProModel simulation does allow us to simulate and analyze pedestrian traffic flow despite some error. The model enables us to evaluate a range of situations quickly and easily by changing the input parameters. In comparing *HCM* to the ProModel simulation, the *HCM* provides the necessary tools and information for design purposes; however for a presentation or to provide a visual model of pedestrian use, the ProModel simulation model has more impact on the viewers.

To better mitigate the errors in the simulation model, more data would need to be collected and analyzed. A more generic simulation model could be developed to accommodate a broader range of locations and scenarios, or consideration could be given to a more enhanced model simulating dynamic loading scenarios.

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APPENDIXES

Appendix A

Additional Setup Photographs

Figure A1. Setup photograph of Location 1 (Randall Hall) roof.

Figure A2. Setup photograph of Location 1 (Randall Hall) looking north.

Figure A3. Setup photograph of Location 1 (Randall Hall) looking west.

Figure A4. Setup photograph of Location 2 (Student Union and Recreation Center) northwest corner of the building.

Figure A5. Setup photograph of Location 2 (Student Union and Recreation Center) looking west.

Figure A6. Setup photograph of Location 2 (Student Union and Recreation Center) looking north.

Figure A7. Setup photograph of Location 3 (Black Hall) roof.

Appendix B

Pedestrian Data for Central Washington University Campus

LOCATION	DIRECTION OF TRAVEL	DATE	HOUR	TOTAL PEDS	TIME1 (s)	TIME2 (s)	TIME3 (s)	TIME4 (s)	TIME5 (s)
SURC	NORTH	3/27/2007	8:30	47	4.61	4.24	4.27	4.28	4.08
SURC	NORTH	3/27/2007	8:45	150	3.80	4.46	3.85	5.30	3.75
SURC	NORTH	3/27/2007	9:00	28	3.41	3.83	3.62	5.62	4.43
SURC	NORTH	3/27/2007	9:15	20	3.76	3.98	3.57	3.55	3.53
SURC	NORTH	3/27/2007	9:30	48	4.56	3.46	3.92	3.35	4.25
SURC	NORTH	3/27/2007	9:45	184	4.25	5.60	3.57	4.12	3.67
SURC	NORTH	3/27/2007	10:00	23	4.19	4.08	5.44	4.69	3.93
SURC	NORTH	3/27/2007	10:15	21	3.51	4.54	6.13	4.29	3.83
SURC	NORTH	3/27/2007	10:30	74	4.35	3.63	3.69	3.95	3.97
SURC	NORTH	3/27/2007	10:45	190	4.22	3.79	4.09	4.17	4.49
SURC	NORTH	3/27/2007	11:00	26	4.26	3.93	3.71	3.98	3.86
SURC	NORTH	3/27/2007	11:15	40	4.04	4.36	3.89	4.06	4.38
SURC	NORTH	3/28/2007	8:30	41	5.25	3.59	4.72	4.93	3.99
SURC	NORTH	3/28/2007	8:45	192	3.84	3.56	3.68	3.37	4.32
SURC	NORTH	3/28/2007	9:00	17	3.69	3.88	3.29	4.34	3.89
SURC	NORTH	3/28/2007	9:15	6	3.69				
SURC	NORTH	3/28/2007	9:30	25	4.74	4.64	4.81	4.38	4.02
SURC	NORTH	3/28/2007	9:45	189	3.80	4.64	4.43	4.11	3.88
SURC	NORTH	3/28/2007	10:00	25	3.46	3.89	3.97	4.90	4.07
SURC	NORTH	3/28/2007	10:15	22	4.06	4.69	4.86	3.83	5.29
SURC	NORTH	3/28/2007	10:30	65	5.31	5.21	4.83	4.14	5.31
SURC	NORTH	3/28/2007	10:45	210	4.18	4.32	4.92	4.04	4.48
SURC	NORTH	3/28/2007	11:00	28	3.48	3.70	4.98	4.97	3.71
SURC	NORTH	3/28/2007	11:15	39	3.64	4.00	4.09	3.68	3.72
SURC	NORTH	3/29/2007	8:30	25	3.71	5.18	4.73	4.51	4.24
SURC	NORTH	3/29/2007	8:45	157	3.91	3.70	3.98	4.74	4.03
SURC	NORTH	3/29/2007	9:00	11	4.40	4.39	4.24		
SURC	NORTH	3/29/2007	9:15	9	3.90	4.20	4.21		
SURC	NORTH	3/29/2007	9:30	36	5.12	5.15	3.83	4.83	4.07
SURC	NORTH	3/29/2007	9:45	178	3.78	4.81	3.88	4.27	3.58
SURC	NORTH	3/29/2007	10:00	18	3.36	5.05	4.50	5.12	5.59
SURC	NORTH	3/29/2007	10:15	17	3.61	4.11	4.11	3.83	4.55
SURC	NORTH	3/29/2007	10:30	34	5.17	4.76	4.14	4.02	3.98
SURC	NORTH	3/29/2007	10:45	191	4.53	3.42	3.53	4.65	4.20
SURC	NORTH	3/29/2007	11:00	18	3.31	3.95	3.80	3.75	4.21
SURC	NORTH	3/29/2007	11:15	42	4.68	3.96	3.52	4.11	4.86
SURC	NORTH	4/02/2007	8:30	31	4.23	4.07	3.60	3.88	3.58
SURC	NORTH	4/02/2007	8:45	164	3.80	4.38	3.88	3.93	4.11

LOCATION	DIRECTION OF TRAVEL	DATE	HOUR	TOTAL PEDS	TIME1 (s)	TIME2 (s)	TIME3 (s)	TIME4 (s)	TIME5 (s)
SURC	NORTH	4/02/2007	9:00	12	4.35	3.59	4.10	3.95	4.08
SURC	NORTH	4/02/2007	9:15	8	3.98				
SURC	NORTH	4/02/2007	9:30	25	3.91	4.91	4.85	3.5	3.75
SURC	NORTH	4/02/2007	9:45	177	4.09	3.79	3.58	3.96	3.83
SURC	NORTH	4/02/2007	10:00	22	4.42	4.32	3.79	4.36	4.54
SURC	NORTH	4/02/2007	10:15	15	4.45	4.59	4.01	4.32	4.78
SURC	NORTH	4/02/2007	10:30	38	4.60	4.06	3.76	4.57	3.79
SURC	NORTH	4/02/2007	10:45	177	3.81	4.17	4.15	3.88	3.88
SURC	NORTH	4/02/2007	11:00	24	3.88	4.19	4.68	3.44	4.10
SURC	NORTH	4/02/2007	11:15	28	4.28	5.75	4.15	3.28	3.95
SURC	SOUTH	3/27/2007	8:30	20	4.36	3.92	4.87	4.27	4.75
SURC	SOUTH	3/27/2007	8:45	46	4.01	4.26	3.97	4.19	3.82
SURC	SOUTH	3/27/2007	9:00	22	3.69	4.17	3.65	4.82	4.93
SURC	SOUTH	3/27/2007	9:15	27	4.31	4.79	3.59	4.40	4.27
SURC	SOUTH	3/27/2007	9:30	112	4.51	4.02	3.93	4.40	5.46
SURC	SOUTH	3/27/2007	9:45	196	4.55	4.22	4.24	4.21	3.57
SURC	SOUTH	3/27/2007	10:00	28	4.40	3.86	3.89	4.78	4.28
SURC	SOUTH	3/27/2007	10:15	62	4.18	3.97	3.60	4.06	3.71
SURC	SOUTH	3/27/2007	10:30	90	4.34	3.98	4.01	4.28	3.92
SURC	SOUTH	3/27/2007	10:45	196	4.12	3.75	3.84	3.51	4.64
SURC	SOUTH	3/27/2007	11:00	36	4.00	4.35	5.01	4.17	3.44
SURC	SOUTH	3/27/2007	11:15	35	3.96	3.75	4.62	4.05	4.92
SURC	SOUTH	3/28/2007	8:30	30	3.43	4.54	4.61	4.14	4.26
SURC	SOUTH	3/28/2007	8:45	56	3.94	3.93	3.67	3.86	4.02
SURC	SOUTH	3/28/2007	9:00	14	4.49	4.34	3.52	3.72	4.11
SURC	SOUTH	3/28/2007	9:15	11	4.96	4.19	3.50	3.97	3.37
SURC	SOUTH	3/28/2007	9:30	43	3.64	3.49	4.04	3.54	4.58
SURC	SOUTH	3/28/2007	9:45	278	3.58	3.87	3.92	3.76	3.77
SURC	SOUTH	3/28/2007	10:00	33	3.66	4.11	4.16	3.59	3.94
SURC	SOUTH	3/28/2007	10:15	33	4.41	3.96	4.68	3.37	4.24
SURC	SOUTH	3/28/2007	10:30	48	4.27	3.92	4.26	3.70	3.59
SURC	SOUTH	3/28/2007	10:45	263	4.45	4.60	4.03	3.73	3.70
SURC	SOUTH	3/28/2007	11:00	46	4.08	4.30	4.15	3.76	4.68
SURC	SOUTH	3/28/2007	11:15	69	3.79	4.57	4.11	3.55	3.84
SURC	SOUTH	3/29/2007	8:30	9	4.04	4.31	4.06	4.80	4.07
SURC	SOUTH	3/29/2007	8:45	56	4.22	4.06	4.74	3.84	4.24
SURC	SOUTH	3/29/2007	9:00	16	4.54	4.61	4.35	4.26	3.54
SURC	SOUTH	3/29/2007	9:15	12	3.43	3.87	4.30	4.29	4.23
SURC	SOUTH	3/29/2007	9:30	37	4.87	4.83	5.00	3.72	4.78
SURC	SOUTH	3/29/2007	9:45	202	3.80	6.28	4.24	3.92	5.13
SURC	SOUTH	3/29/2007	10:00	32	4.23	3.93	4.47	3.94	4.89
SURC	SOUTH	3/29/2007	10:15	27	4.26	4.58	4.58	4.09	5.13

LOCATION	DIRECTION OF TRAVEL	DATE	HOUR	TOTAL PEDS	TIME1 (s)	TIME2 (s)	TIME3 (s)	TIME4 (s)	TIME5 (s)
SURC	SOUTH	3/29/2007	10:30	27	6.02	4.93	4.35	3.66	4.33
SURC	SOUTH	3/29/2007	10:45	284	5.43	4.51	4.42	4.11	3.96
SURC	SOUTH	3/29/2007	11:00	33	3.93	4.33	4.82	3.67	4.30
SURC	SOUTH	3/29/2007	11:15	27	4.69	4.37	4.38	4.14	4.34
SURC	SOUTH	4/02/2007	8:30	17	4.38	3.40	4.67	4.88	3.77
SURC	SOUTH	4/02/2007	8:45	72	4.51	4.65	4.50	3.86	3.57
SURC	SOUTH	4/02/2007	9:00	7	4.12	3.58			
SURC	SOUTH	4/02/2007	9:15	6	3.87	4.65			
SURC	SOUTH	4/02/2007	9:30	19	4.68	4.41	4.57	3.89	3.98
SURC	SOUTH	4/02/2007	9:45	252	4.47	4.25	3.98	4.10	3.72
SURC	SOUTH	4/02/2007	10:00	23	4.21	5.36	4.50	3.91	4.15
SURC	SOUTH	4/02/2007	10:15	23	4.33	4.56	3.96	4.60	4.32
SURC	SOUTH	4/02/2007	10:30	34	4.90	3.96	4.19	4.42	3.84
SURC	SOUTH	4/02/2007	10:45	262	5.14	4.44	4.28	3.99	4.04
SURC	SOUTH	4/02/2007	11:00	25	4.04	3.70	3.94	4.78	4.12
SURC	SOUTH	4/02/2007	11:15	19	4.39	3.88	3.78	3.51	3.89
SURC	EAST	3/27/2007	8:30	9					
SURC	EAST	3/27/2007	8:45	19					
SURC	EAST	3/27/2007	9:00	14					
SURC	EAST	3/27/2007	9:15	18					
SURC	EAST	3/27/2007	9:30	62					
SURC	EAST	3/27/2007	9:45	103					
SURC	EAST	3/27/2007	10:00	27					
SURC	EAST	3/27/2007	10:15	48					
SURC	EAST	3/27/2007	10:30	58					
SURC	EAST	3/27/2007	10:45	104					
SURC	EAST	3/27/2007	11:00	30					
SURC	EAST	3/27/2007	11:15	27					
SURC	EAST	3/28/2007	8:30	19					
SURC	EAST	3/28/2007	8:45	19					
SURC	EAST	3/28/2007	9:00	11					
SURC	EAST	3/28/2007	9:15	9					
SURC	EAST	3/28/2007	9:30	25					
SURC	EAST	3/28/2007	9:45	116					
SURC	EAST	3/28/2007	10:00	26					
SURC	EAST	3/28/2007	10:15	29					
SURC	EAST	3/28/2007	10:30	31					
SURC	EAST	3/28/2007	10:45	145					
SURC	EAST	3/28/2007	11:00	29					
SURC	EAST	3/28/2007	11:15	22					
SURC	EAST	3/29/2007	8:30	4					
SURC	EAST	3/29/2007	8:45	27					

LOCATION	DIRECTION OF TRAVEL	DATE	HOUR	TOTAL PEDS	TIME1 (s)	TIME2 (s)	TIME3 (s)	TIME4 (s)	TIME5 (s)
SURC	EAST	3/29/2007	9:00	12					
SURC	EAST	3/29/2007	9:15	5					
SURC	EAST	3/29/2007	9:30	24					
SURC	EAST	3/29/2007	9:45	88					
SURC	EAST	3/29/2007	10:00	20					
SURC	EAST	3/29/2007	10:15	17					
SURC	EAST	3/29/2007	10:30	19					
SURC	EAST	3/29/2007	10:45	156					
SURC	EAST	3/29/2007	11:00	28					
SURC	EAST	3/29/2007	11:15	30					
SURC	EAST	4/02/2007	8:30	5					
SURC	EAST	4/02/2007	8:45	17					
SURC	EAST	4/02/2007	9:00	5					
SURC	EAST	4/02/2007	9:15	5					
SURC	EAST	4/02/2007	9:30	13					
SURC	EAST	4/02/2007	9:45	111					
SURC	EAST	4/02/2007	10:00	19					
SURC	EAST	4/02/2007	10:15	35					
SURC	EAST	4/02/2007	10:30	25					
SURC	EAST	4/02/2007	10:45	129					
SURC	EAST	4/02/2007	11:00	18					
SURC	EAST	4/02/2007	11:15	8					
SURC	WEST	3/27/2007	8:30	44					
SURC	WEST	3/27/2007	8:45	105					
SURC	WEST	3/27/2007	9:00	17					
SURC	WEST	3/27/2007	9:15	9					
SURC	WEST	3/27/2007	9:30	42					
SURC	WEST	3/27/2007	9:45	83					
SURC	WEST	3/27/2007	10:00	20					
SURC	WEST	3/27/2007	10:15	27					
SURC	WEST	3/27/2007	10:30	54					
SURC	WEST	3/27/2007	10:45	88					
SURC	WEST	3/27/2007	11:00	25					
SURC	WEST	3/27/2007	11:15	28					
SURC	WEST	3/28/2007	8:30	34					
SURC	WEST	3/28/2007	8:45	121					
SURC	WEST	3/28/2007	9:00	17					
SURC	WEST	3/28/2007	9:15	9					
SURC	WEST	3/28/2007	9:30	24					
SURC	WEST	3/28/2007	9:45	77					
SURC	WEST	3/28/2007	10:00	17					
SURC	WEST	3/28/2007	10:15	10					

LOCATION	DIRECTION OF TRAVEL	DATE	HOUR	TOTAL PEDS	TIME1 (s)	TIME2 (s)	TIME3 (s)	TIME4 (s)	TIME5 (s)
SURC	WEST	3/28/2007	10:30	49					
SURC	WEST	3/28/2007	10:45	75					
SURC	WEST	3/28/2007	11:00	19					
SURC	WEST	3/28/2007	11:15	29					
SURC	WEST	3/29/2007	8:30	20					
SURC	WEST	3/29/2007	8:45	117					
SURC	WEST	3/29/2007	9:00	10					
SURC	WEST	3/29/2007	9:15	5					
SURC	WEST	3/29/2007	9:30	23					
SURC	WEST	3/29/2007	9:45	64					
SURC	WEST	3/29/2007	10:00	15					
SURC	WEST	3/29/2007	10:15	13					
SURC	WEST	3/29/2007	10:30	29					
SURC	WEST	3/29/2007	10:45	89					
SURC	WEST	3/29/2007	11:00	12					
SURC	WEST	3/29/2007	11:15	21					
SURC	WEST	4/02/2007	8:30	20					
SURC	WEST	4/02/2007	8:45	102					
SURC	WEST	4/02/2007	9:00	7					
SURC	WEST	4/02/2007	9:15	6					
SURC	WEST	4/02/2007	9:30	16					
SURC	WEST	4/02/2007	9:45	103					
SURC	WEST	4/02/2007	10:00	13					
SURC	WEST	4/02/2007	10:15	10					
SURC	WEST	4/02/2007	10:30	22					
SURC	WEST	4/02/2007	10:45	99					
SURC	WEST	4/02/2007	11:00	21					
SURC	WEST	4/02/2007	11:15	17					
RANDALL	NORTH	4/03/2007	8:30	7	4.10	4.65	4.37	4.85	4.57
RANDALL	NORTH	4/03/2007	8:45	47	4.21	4.43	4.79	3.85	4.17
RANDALL	NORTH	4/03/2007	9:00	6	4.60	3.72	3.74	4.28	4.18
RANDALL	NORTH	4/03/2007	9:15	3	4.31	4.03	4.03		
RANDALL	NORTH	4/03/2007	9:30	4	4.24	4.17	4.49	4.54	
RANDALL	NORTH	4/03/2007	9:45	100	4.58	4.10	4.16	3.46	3.66
RANDALL	NORTH	4/03/2007	10:00	8	4.02	4.38	3.87	3.79	4.75
RANDALL	NORTH	4/03/2007	10:15	3	3.94	5.82			
RANDALL	NORTH	4/03/2007	10:30	11	4.23	4.78	4.52	3.51	4.45
RANDALL	NORTH	4/03/2007	10:45	77	5.32	4.28	4.07	4.39	4.56
RANDALL	NORTH	4/03/2007	11:00	19	4.26	4.70	4.45	4.31	4.73
RANDALL	NORTH	4/03/2007	11:15	8	4.51	4.15	4.98	3.93	4.45
RANDALL	NORTH	4/04/2007	8:30	5	4.28	4.14	4.94	4.27	4.30
RANDALL	NORTH	4/04/2007	8:45	41	4.61	4.52	4.90	4.02	3.76

LOCATION	DIRECTION OF TRAVEL	DATE	HOUR	TOTAL PEDS	TIME1 (s)	TIME2 (s)	TIME3 (s)	TIME4 (s)	TIME5 (s)
RANDALL	NORTH	4/04/2007	9:00	7	3.82	3.18	3.36	4.15	3.95
RANDALL	NORTH	4/04/2007	9:15	0					
RANDALL	NORTH	4/04/2007	9:30	7	4.62	4.52	4.24	4.24	3.75
RANDALL	NORTH	4/04/2007	9:45	83	3.93	4.47	3.75	4.22	3.85
RANDALL	NORTH	4/04/2007	10:00	16	3.57	4.18	4.36	4.55	5.15
RANDALL	NORTH	4/04/2007	10:15	10	4.27	3.99	3.99	3.89	4.06
RANDALL	NORTH	4/04/2007	10:30	15	4.52	4.21	4.76	4.43	5.43
RANDALL	NORTH	4/04/2007	10:45	92	5.85	3.69	4.09	3.57	3.47
RANDALL	NORTH	4/04/2007	11:00	14	4.06	4.54	5.09	4.20	3.83
RANDALL	NORTH	4/04/2007	11:15	11	4.50	5.72	4.34	3.99	4.13
RANDALL	NORTH	4/05/2007	8:30	4	4.88	4.46			
RANDALL	NORTH	4/05/2007	8:45	39	4.31	4.10	4.17	3.94	3.25
RANDALL	NORTH	4/05/2007	9:00	5	4.79	4.06	4.69	3.76	
RANDALL	NORTH	4/05/2007	9:15	2	6.58	3.56			
RANDALL	NORTH	4/05/2007	9:30	13	4.40	5.29	4.41	6.34	4.29
RANDALL	NORTH	4/05/2007	9:45	80	4.20	4.08	3.90	4.11	4.15
RANDALL	NORTH	4/05/2007	10:00	14	4.21	4.42	4.09	3.49	4.67
RANDALL	NORTH	4/05/2007	10:15	5	4.62	4.73	3.24	4.29	4.24
RANDALL	NORTH	4/05/2007	10:30	8	5.96	4.96	5.90	4.20	4.09
RANDALL	NORTH	4/05/2007	10:45	85	4.36	3.61	4.04	4.27	6.05
RANDALL	NORTH	4/05/2007	11:00	20	4.38	3.45	4.49	3.79	3.89
RANDALL	NORTH	4/05/2007	11:15	10	3.79	3.98	3.85	4.33	4.27
RANDALL	NORTH	4/09/2007	8:30	3	4.44	4.85	3.92		
RANDALL	NORTH	4/09/2007	8:45	43	3.88	3.63	4.44	4.20	3.36
RANDALL	NORTH	4/09/2007	9:00	5	3.61	3.54	4.00	4.80	4.06
RANDALL	NORTH	4/09/2007	9:15	1	4.25				
RANDALL	NORTH	4/09/2007	9:30	11	4.21	3.80	4.61	4.64	4.52
RANDALL	NORTH	4/09/2007	9:45	75	4.93	3.94	3.97	3.47	3.84
RANDALL	NORTH	4/09/2007	10:00	10	4.33	4.42	3.99	4.18	4.35
RANDALL	NORTH	4/09/2007	10:15	7	3.63	3.86	3.20	4.79	4.50
RANDALL	NORTH	4/09/2007	10:30	13	4.19	4.54	3.60	4.66	3.67
RANDALL	NORTH	4/09/2007	10:45	82	4.49	4.46	4.08	3.90	3.86
RANDALL	NORTH	4/09/2007	11:00	11	3.71	3.34	3.96	5.06	4.81
RANDALL	NORTH	4/09/2007	11:15	7	4.21	4.89	4.04	4.26	4.23
RANDALL	SOUTH	4/03/2007	8:30	22	5.20	4.33	3.76	4.38	3.44
RANDALL	SOUTH	4/03/2007	8:45	60	3.78	4.95	3.71	4.50	3.84
RANDALL	SOUTH	4/03/2007	9:00	4	3.58	3.76	3.91	4.19	
RANDALL	SOUTH	4/03/2007	9:15	4	3.76	4.67	4.46	3.72	
RANDALL	SOUTH	4/03/2007	9:30	16	4.50	4.83	4.44	3.79	4.11
RANDALL	SOUTH	4/03/2007	9:45	88	4.37	3.91	3.89	4.49	4.79
RANDALL	SOUTH	4/03/2007	10:00	15	4.59	4.67	4.50	4.67	3.88
RANDALL	SOUTH	4/03/2007	10:15	7	3.71	4.05	5.18	3.73	4.32

LOCATION	DIRECTION OF TRAVEL	DATE	HOUR	TOTAL PEDS	TIME1 (s)	TIME2 (s)	TIME3 (s)	TIME4 (s)	TIME5 (s)
RANDALL	SOUTH	4/03/2007	10:30	23	4.61	4.07	4.21	5.04	3.88
RANDALL	SOUTH	4/03/2007	10:45	103	3.43	4.48	5.09	4.53	3.99
RANDALL	SOUTH	4/03/2007	11:00	11	4.53	3.94	4.56	4.60	4.14
RANDALL	SOUTH	4/03/2007	11:15	6	4.00	3.99	4.39	4.55	4.55
RANDALL	SOUTH	4/04/2007	8:30	36	4.50	4.82	4.44	4.04	3.94
RANDALL	SOUTH	4/04/2007	8:45	53	4.21	4.35	3.78	3.94	4.17
RANDALL	SOUTH	4/04/2007	9:00	4	3.87	4.53	4.13	4.88	
RANDALL	SOUTH	4/04/2007	9:15	5	4.00	4.22	4.22	4.05	4.45
RANDALL	SOUTH	4/04/2007	9:30	17	3.35	4.05	3.84	3.89	4.58
RANDALL	SOUTH	4/04/2007	9:45	96	4.17	4.04	4.75	4.11	4.27
RANDALL	SOUTH	4/04/2007	10:00	8	3.42	4.21	4.27	4.02	4.39
RANDALL	SOUTH	4/04/2007	10:15	9	4.19	4.73	3.92	4.32	3.96
RANDALL	SOUTH	4/04/2007	10:30	22	4.30	4.78	4.20	3.92	4.13
RANDALL	SOUTH	4/04/2007	10:45	85	4.60	4.13	3.70	3.97	3.92
RANDALL	SOUTH	4/04/2007	11:00	7	4.83	3.74	3.60	4.32	4.41
RANDALL	SOUTH	4/04/2007	11:15	21	3.81	3.51	4.70	4.75	4.19
RANDALL	SOUTH	4/05/2007	8:30	18	3.81	3.94	4.31	4.13	4.33
RANDALL	SOUTH	4/05/2007	8:45	54	4.66	4.06	4.11	3.96	4.06
RANDALL	SOUTH	4/05/2007	9:00	7	4.98	4.32	4.85	3.86	3.96
RANDALL	SOUTH	4/05/2007	9:15	8	3.74	3.76	5.21	4.25	4.27
RANDALL	SOUTH	4/05/2007	9:30	13	4.67	4.80	4.92	3.85	4.51
RANDALL	SOUTH	4/05/2007	9:45	85	3.78	5.77	4.25	6.06	4.79
RANDALL	SOUTH	4/05/2007	10:00	9	4.18	4.69	3.71	4.90	4.90
RANDALL	SOUTH	4/05/2007	10:15	4	4.39	4.17	4.37	4.29	
RANDALL	SOUTH	4/05/2007	10:30	17	4.26	4.61	4.12	4.02	4.65
RANDALL	SOUTH	4/05/2007	10:45	113	4.58	3.73	3.95	5.01	3.92
RANDALL	SOUTH	4/05/2007	11:00	2	4.76	4.10			
RANDALL	SOUTH	4/05/2007	11:15	3	5.08	3.74	3.72		
RANDALL	SOUTH	4/09/2007	8:30	21	4.36	3.73	4.25	4.23	3.98
RANDALL	SOUTH	4/09/2007	8:45	63	3.98	4.38	3.53	3.90	4.01
RANDALL	SOUTH	4/09/2007	9:00	6	4.56	3.96	3.62	5.68	4.87
RANDALL	SOUTH	4/09/2007	9:15	4	4.13	4.19	3.94	3.97	
RANDALL	SOUTH	4/09/2007	9:30	16	4.15	3.81	3.89	3.80	3.99
RANDALL	SOUTH	4/09/2007	9:45	85	3.91	4.34	4.68	4.21	4.05
RANDALL	SOUTH	4/09/2007	10:00	25	3.84	4.11	3.43	5.44	4.69
RANDALL	SOUTH	4/09/2007	10:15	6	4.04	3.93	4.32	4.40	4.37
RANDALL	SOUTH	4/09/2007	10:30	18	3.86	3.67	3.88	3.85	4.14
RANDALL	SOUTH	4/09/2007	10:45	92	4.06	3.57	4.03	3.64	4.30
RANDALL	SOUTH	4/09/2007	11:00	5	4.15	6.59	3.43	4.97	3.76
RANDALL	SOUTH	4/09/2007	11:15	2	4.02	3.96			
BLACK	NORTH	4/23/2007	8:30	80					
BLACK	NORTH	4/23/2007	8:45	88					

LOCATION	DIRECTION OF TRAVEL	DATE	HOUR	TOTAL PEDS	TIME1 (s)	TIME2 (s)	TIME3 (s)	TIME4 (s)	TIME5 (s)
BLACK	NORTH	4/23/2007	9:00	16					
BLACK	NORTH	4/23/2007	9:15	27					
BLACK	NORTH	4/23/2007	9:30	62					
BLACK	NORTH	4/23/2007	9:45	134					
BLACK	NORTH	4/23/2007	10:00	33					
BLACK	NORTH	4/23/2007	10:15	24					
BLACK	NORTH	4/23/2007	10:30	43					
BLACK	NORTH	4/23/2007	10:45	268					
BLACK	NORTH	4/23/2007	11:00	37					
BLACK	NORTH	4/23/2007	11:15	23					
BLACK	NORTH	4/24/2007	8:30	28					
BLACK	NORTH	4/24/2007	8:45	120					
BLACK	NORTH	4/24/2007	9:00	19					
BLACK	NORTH	4/24/2007	9:15	24					
BLACK	NORTH	4/24/2007	9:30	22					
BLACK	NORTH	4/24/2007	9:45	161					
BLACK	NORTH	4/24/2007	10:00	24					
BLACK	NORTH	4/24/2007	10:15	19					
BLACK	NORTH	4/24/2007	10:30	57					
BLACK	NORTH	4/24/2007	10:45	218					
BLACK	NORTH	4/24/2007	11:00	19					
BLACK	NORTH	4/24/2007	11:15	52					
BLACK	NORTH	4/25/2007	8:30	32					
BLACK	NORTH	4/25/2007	8:45	148					
BLACK	NORTH	4/25/2007	9:00	13					
BLACK	NORTH	4/25/2007	9:15	22					
BLACK	NORTH	4/25/2007	9:30	34					
BLACK	NORTH	4/25/2007	9:45	177					
BLACK	NORTH	4/25/2007	10:00	25					
BLACK	NORTH	4/25/2007	10:15	13					
BLACK	NORTH	4/25/2007	10:30	65					
BLACK	NORTH	4/25/2007	10:45	222					
BLACK	NORTH	4/25/2007	11:00	29					
BLACK	NORTH	4/25/2007	11:15	20					
BLACK	NORTH	4/26/2007	8:30	52					
BLACK	NORTH	4/26/2007	8:45	117					
BLACK	NORTH	4/26/2007	9:00	10					
BLACK	NORTH	4/26/2007	9:15	23					
BLACK	NORTH	4/26/2007	9:30	37					
BLACK	NORTH	4/26/2007	9:45	128					
BLACK	NORTH	4/26/2007	10:00	16					
BLACK	NORTH	4/26/2007	10:15	21					

LOCATION	DIRECTION OF TRAVEL	DATE	HOUR	TOTAL PEDS	TIME1 (s)	TIME2 (s)	TIME3 (s)	TIME4 (s)	TIME5 (s)
BLACK	NORTH	4/26/2007	10:30	44					
BLACK	NORTH	4/26/2007	10:45	197					
BLACK	NORTH	4/26/2007	11:00	46					
BLACK	NORTH	4/26/2007	11:15	32					
BLACK	SOUTH	4/23/2007	8:30	22					
BLACK	SOUTH	4/23/2007	8:45	123					
BLACK	SOUTH	4/23/2007	9:00	8					
BLACK	SOUTH	4/23/2007	9:15	12					
BLACK	SOUTH	4/23/2007	9:30	26					
BLACK	SOUTH	4/23/2007	9:45	220					
BLACK	SOUTH	4/23/2007	10:00	39					
BLACK	SOUTH	4/23/2007	10:15	14					
BLACK	SOUTH	4/23/2007	10:30	33					
BLACK	SOUTH	4/23/2007	10:45	201					
BLACK	SOUTH	4/23/2007	11:00	46					
BLACK	SOUTH	4/23/2007	11:15	21					
BLACK	SOUTH	4/24/2007	8:30	15					
BLACK	SOUTH	4/24/2007	8:45	100					
BLACK	SOUTH	4/24/2007	9:00	9					
BLACK	SOUTH	4/24/2007	9:15	9					
BLACK	SOUTH	4/24/2007	9:30	13					
BLACK	SOUTH	4/24/2007	9:45	230					
BLACK	SOUTH	4/24/2007	10:00	38					
BLACK	SOUTH	4/24/2007	10:15	21					
BLACK	SOUTH	4/24/2007	10:30	31					
BLACK	SOUTH	4/24/2007	10:45	145					
BLACK	SOUTH	4/24/2007	11:00	27					
BLACK	SOUTH	4/24/2007	11:15	34					
BLACK	SOUTH	4/25/2007	8:30	15					
BLACK	SOUTH	4/25/2007	8:45	105					
BLACK	SOUTH	4/25/2007	9:00	23					
BLACK	SOUTH	4/25/2007	9:15	9					
BLACK	SOUTH	4/25/2007	9:30	19					
BLACK	SOUTH	4/25/2007	9:45	228					
BLACK	SOUTH	4/25/2007	10:00	44					
BLACK	SOUTH	4/25/2007	10:15	17					
BLACK	SOUTH	4/25/2007	10:30	38					
BLACK	SOUTH	4/25/2007	10:45	186					
BLACK	SOUTH	4/25/2007	11:00	40					
BLACK	SOUTH	4/25/2007	11:15	18					
BLACK	SOUTH	4/26/2007	8:30	14					
BLACK	SOUTH	4/26/2007	8:45	88					

LOCATION	DIRECTION OF TRAVEL	DATE	HOUR	TOTAL PEDS	TIME1 (s)	TIME2 (s)	TIME3 (s)	TIME4 (s)	TIME5 (s)
BLACK	SOUTH	4/26/2007	9:00	43					
BLACK	SOUTH	4/26/2007	9:15	17					
BLACK	SOUTH	4/26/2007	9:30	17					
BLACK	SOUTH	4/26/2007	9:45	188					
BLACK	SOUTH	4/26/2007	10:00	28					
BLACK	SOUTH	4/26/2007	10:15	15					
BLACK	SOUTH	4/26/2007	10:30	38					
BLACK	SOUTH	4/26/2007	10:45	156					
BLACK	SOUTH	4/26/2007	11:00	49					
BLACK	SOUTH	4/26/2007	11:15	24					
BLACK	EAST	4/23/2007	8:30	7					
BLACK	EAST	4/23/2007	8:45	5					
BLACK	EAST	4/23/2007	9:00	10					
BLACK	EAST	4/23/2007	9:15	3					
BLACK	EAST	4/23/2007	9:30	8					
BLACK	EAST	4/23/2007	9:45	28					
BLACK	EAST	4/23/2007	10:00	13					
BLACK	EAST	4/23/2007	10:15	5					
BLACK	EAST	4/23/2007	10:30	15					
BLACK	EAST	4/23/2007	10:45	32					
BLACK	EAST	4/23/2007	11:00	6					
BLACK	EAST	4/23/2007	11:15	6					
BLACK	EAST	4/24/2007	8:30	1					
BLACK	EAST	4/24/2007	8:45	12					
BLACK	EAST	4/24/2007	9:00	6					
BLACK	EAST	4/24/2007	9:15	11					
BLACK	EAST	4/24/2007	9:30	3					
BLACK	EAST	4/24/2007	9:45	40					
BLACK	EAST	4/24/2007	10:00	17					
BLACK	EAST	4/24/2007	10:15	4					
BLACK	EAST	4/24/2007	10:30	6					
BLACK	EAST	4/24/2007	10:45	32					
BLACK	EAST	4/24/2007	11:00	3					
BLACK	EAST	4/24/2007	11:15	7					
BLACK	EAST	4/25/2007	8:30	4					
BLACK	EAST	4/25/2007	8:45	11					
BLACK	EAST	4/25/2007	9:00	0					
BLACK	EAST	4/25/2007	9:15	4					
BLACK	EAST	4/25/2007	9:30	13					
BLACK	EAST	4/25/2007	9:45	32					
BLACK	EAST	4/25/2007	10:00	9					
BLACK	EAST	4/25/2007	10:15	5					

LOCATION	DIRECTION OF TRAVEL	DATE	HOUR	TOTAL PEDS	TIME1 (s)	TIME2 (s)	TIME3 (s)	TIME4 (s)	TIME5 (s)
BLACK	EAST	4/25/2007	10:30	17					
BLACK	EAST	4/25/2007	10:45	22					
BLACK	EAST	4/25/2007	11:00	9					
BLACK	EAST	4/25/2007	11:15	4					
BLACK	EAST	4/26/2007	8:30	52					
BLACK	EAST	4/26/2007	8:45	117					
BLACK	EAST	4/26/2007	9:00	10					
BLACK	EAST	4/26/2007	9:15	23					
BLACK	EAST	4/26/2007	9:30	12					
BLACK	EAST	4/26/2007	9:45	36					
BLACK	EAST	4/26/2007	10:00	4					
BLACK	EAST	4/26/2007	10:15	11					
BLACK	EAST	4/26/2007	10:30	7					
BLACK	EAST	4/26/2007	10:45	35					
BLACK	EAST	4/26/2007	11:00	16					
BLACK	EAST	4/26/2007	11:15	7					
BLACK	WEST	4/23/2007	8:30	9					
BLACK	WEST	4/23/2007	8:45	42					
BLACK	WEST	4/23/2007	9:00	11					
BLACK	WEST	4/23/2007	9:15	2					
BLACK	WEST	4/23/2007	9:30	8					
BLACK	WEST	4/23/2007	9:45	56					
BLACK	WEST	4/23/2007	10:00	15					
BLACK	WEST	4/23/2007	10:15	9					
BLACK	WEST	4/23/2007	10:30	17					
BLACK	WEST	4/23/2007	10:45	47					
BLACK	WEST	4/23/2007	11:00	14					
BLACK	WEST	4/23/2007	11:15	13					
BLACK	WEST	4/24/2007	8:30	13					
BLACK	WEST	4/24/2007	8:45	43					
BLACK	WEST	4/24/2007	9:00	2					
BLACK	WEST	4/24/2007	9:15	4					
BLACK	WEST	4/24/2007	9:30	9					
BLACK	WEST	4/24/2007	9:45	45					
BLACK	WEST	4/24/2007	10:00	12					
BLACK	WEST	4/24/2007	10:15	8					
BLACK	WEST	4/24/2007	10:30	27					
BLACK	WEST	4/24/2007	10:45	49					
BLACK	WEST	4/24/2007	11:00	10					
BLACK	WEST	4/24/2007	11:15	9					
BLACK	WEST	4/25/2007	8:30	13					
BLACK	WEST	4/25/2007	8:45	48					

LOCATION	DIRECTION OF TRAVEL	DATE	HOUR	TOTAL PEDS	TIME1 (s)	TIME2 (s)	TIME3 (s)	TIME4 (s)	TIME5 (s)
BLACK	WEST	4/25/2007	9:00	9					
BLACK	WEST	4/25/2007	9:15	1					
BLACK	WEST	4/25/2007	9:30	8					
BLACK	WEST	4/25/2007	9:45	50					
BLACK	WEST	4/25/2007	10:00	10					
BLACK	WEST	4/25/2007	10:15	6					
BLACK	WEST	4/25/2007	10:30	14					
BLACK	WEST	4/25/2007	10:45	52					
BLACK	WEST	4/25/2007	11:00	6					
BLACK	WEST	4/25/2007	11:15	5					
BLACK	WEST	4/26/2007	8:30	7					
BLACK	WEST	4/26/2007	8:45	41					
BLACK	WEST	4/26/2007	9:00	1					
BLACK	WEST	4/26/2007	9:15	4					
BLACK	WEST	4/26/2007	9:30	7					
BLACK	WEST	4/26/2007	9:45	48					
BLACK	WEST	4/26/2007	10:00	5					
BLACK	WEST	4/26/2007	10:15	3					
BLACK	WEST	4/26/2007	10:30	24					
BLACK	WEST	4/26/2007	10:45	54					
BLACK	WEST	4/26/2007	11:00	12					
BLACK	WEST	4/26/2007	11:15	9					

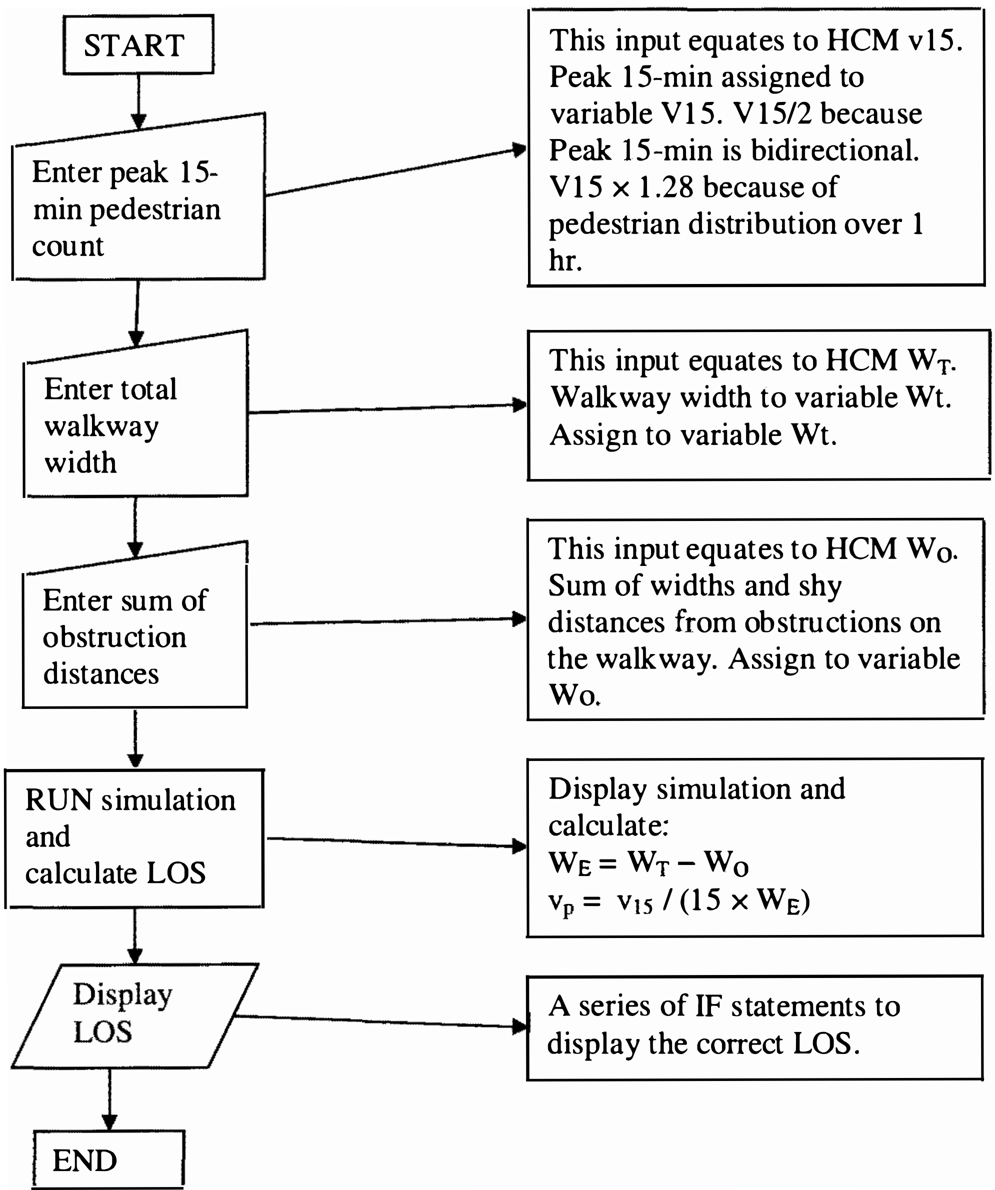
Note. Highlighted cells are average values due to data corruption. RANDALL = Randall Hall (Location 1); SURC = Student Union and Recreation Center (Location 2); and BLACK = Black Hall (Location 3).

Appendix C

Simulation Logic

FLOW CHART

PROCESS NOTES



Appendix D

ProModel Parameters for Bidirectional Flow

```
*********************************************************************
***
*                    Formatted Listing of Model:                   *
*          C:\Program Files\ProModel\Models\thesis_rand.MOD            *
*********************************************************************
***
 ??????:
#
#Final version of the simulation for two-way pedestrian traffic using HCM
 calculations and methodologies
  Time Units:                    Minutes
  Distance Units:                 Ft
  Initialization Logic:            ANIMATE 20.0
                          PROMPT "Please enter the peak 15 minute pedestrian count
value", v_V15
                          PROMPT "Please enter the total walkway width (ft)", v_Wt
                          PROMPT "Please enter the sum of widths and shy distances
from obstructions on the walkway (ft)", v_Wo

  Termination Logic:              IF v_Wo >= v_Wt THEN
                          {
                          DISPLAY "The walkway obstruction value is greater than or
equal to the total walkway width.  Please re-enter values."
                          }
                          ELSE
                          {
                          v_WE = v_Wt - v_Wo
                          v_VP = v_V15 / (15 * v_WE)
                          m_LOS
                          }

*********************************************************************
***
*                         Locations                          *
*********************************************************************
***

 Name      Cap Units Stats      Rules      Cost
```

Loc1	INF 1	Time Series	Oldest, ,
Loc2	INF 1	Time Series	Oldest, ,

****
*   Entities   *
****

Name	Speed (fpm)	Stats	Cost
Worker	150	Time Series	
Operator	150	Time Series	

****
*   Path Networks   *
****

Name	Type	T/S	From	To	BI	Dist/Time	Speed Factor
Net1	Passing	Speed and Distance	N1	N2	Bi	84	1
			N2	N3	Bi	82	1

****
*   Interfaces   *
****

Net	Node	Location
Net1	N1	Loc1
	N3	Loc2

****
*   Processing   *
****

```
                   Process              Routing
Entity  Location Operation          Blk  Output  Destination Rule     Move Logic
-------- -------- ------------------  ---- -------- ----------- -------  ------------
Worker   Loc1                        1   Worker  Loc2       FIRST 1  INC v_COUNT
                                                     MOVE ON Net1

Worker   Loc2                        1   Worker  EXIT       FIRST 1
Operator Loc2                        1   Operator Loc1      FIRST 1  INC v_COUNT
                                                     MOVE ON Net1


Operator Loc1                        1   Operator EXIT      FIRST 1

*******************************************************************
***
*                        Arrivals                   *
*******************************************************************
***

 Entity   Location Qty Each              First Time Occurrences Frequency  Logic
 -------- -------- ------------------------ ---------- ----------- ---------- ------------
 Worker   Loc1    (v_V15*1.28)/2; ped_arrive        3        60
 Operator Loc2    (v_V15*1.28)/2; ped_arrive        3        60
 Worker   Loc1    (v_V15*1.28)/2; ped_arrive        1
 Operator Loc2    (v_V15*1.28)/2; ped_arrive        1

*******************************************************************
***
*                        Attributes                 *
*******************************************************************
***

 ID       Type       Classification
 ---------- ------------ --------------
 a_RATE   Integer    Entity

*******************************************************************
***
*                     Variables (global)                *
*******************************************************************
***

 ID       Type       Initial value Stats
```

```
----------- ------------ ------------- -----------
#
#Total amount of pedestrians that crossed the line.  Later, set up logic
 to store the peak 15-min total.
 v_COUNT    Integer     0           Basic
#
#This is the peak 15 minute pedestrian count value.
#The peak 15 minute pedestrian count is the sum of pedestrians moving in
 both directions.
#(For a give 15 minute time period, sum the two pedestrian count values.)
#(Peak 15 = Direction A + Direction B for the same time period.)
 v_V15      Integer     200         None
#
#This is the total width of the walkway
 v_Wt       Integer     20          None
#
#This is the total amount of shy distances
 v_Wo       Integer     2           None
#
#This is the effective width of the walkway.  WE = Wt - Wo
 v_WE       Integer     0           None
#
#This is the pedestrian unit flow rate (p/min/ft) is VP = V15/(15*WE)
 v_VP       Integer     0           None

*****************************************************************
***
*                        Macros                          *
*****************************************************************
***

 ID          Text
 --------------- ------------
 m_LOS        # Determine LOS
           IF v_VP <= 5 THEN
            BEGIN
            DISPLAY "LOS for this segment = A"
            GOTO FINISH
            END
           IF v_VP > 5 AND  v_VP <= 7 THEN
            BEGIN
            DISPLAY "LOS for this segment = B"
            GOTO FINISH
```

```
END
IF v_VP > 7  AND  v_VP <= 10 THEN
 BEGIN
 DISPLAY "LOS for this segment = C"
 GOTO FINISH
 END
IF v_VP > 10 AND  v_VP <= 15 THEN
 BEGIN
 DISPLAY "LOS for this segment = D"
 GOTO FINISH
 END
IF v_VP > 15 AND  v_VP <= 23 THEN
 BEGIN
 DISPLAY "LOS for this segment = E"
 GOTO FINISH
 END
IF v_VP > 23 THEN
 BEGIN
 DISPLAY "LOS for this segment = Variable"
 GOTO FINISH
 END

FINISH:
```

```
*********************************************************************
***
*                        Arrival Cycles                        *
*********************************************************************
***

ID         Qty / %     Cumulative   Time (Hours) Value
---------- ------------ ------------ ------------ ------------
ped_arrive Percent      No           .25          8
                        .5           6
                        .75          14
                        1            72
```

Appendix E

ProModel Parameters for Cross Flow

```
********************************************************************
***
*                    Formatted Listing of Model:                    *
*            C:\Program Files\ProModel\Models\thesis_surc.MOD            *
********************************************************************
***

 ??????:
#
#Final version of the simulation for two-way pedestrian traffic using HCM
 calculations and methodologies
  Time Units:                  Minutes
  Distance Units:              Ft
  Initialization Logic:        ANIMATE 20.0
                         PROMPT "Please enter the peak 15 minute pedestrian count
value for North/South travel", v_V15_NS
                         PROMPT "Please enter the peak 15 minute pedestrian count
value for East/West travel", v_V15_ES
                         PROMPT "Please enter the total walkway width (ft)", v_Wt
                         PROMPT "Please enter the sum of widths and shy distances
from obstructions on the walkway (ft)", v_Wo

  Termination Logic:           IF v_Wo >= v_Wt THEN
                         {
                         DISPLAY "The walkway obstruction value is greater than or
equal to the total walkway width.  Please re-enter values."
                         }
                         ELSE
                         {
                         v_WE = v_Wt - v_Wo
                         v_VP = (v_V15_NS + v_V15_ES) / (15 * v_WE)
                         m_LOS
                         }


********************************************************************
***
*                        Locations                        *
```

****
***

Name	Cap	Units	Stats	Rules	Cost
North	INF	1	Time Series	Oldest, ,	
South	INF	1	Time Series	Oldest, ,	
East	INF	1	Time Series	Oldest, ,	
West	INF	1	Time Series	Oldest, ,	

****
***
* Entities *
****
***

Name	Speed (fpm)	Stats	Cost
Worker	150	Time Series	
Operator	150	Time Series	
Machinist	150	Time Series	
Inspector	150	Time Series	

****
***
* Path Networks *
****
***

Name	Type	T/S	From	To	BI	Dist/Time	Speed Factor
Net1	Passing	Speed & Distance	N1	N2	Bi	85.68	1
			N2	N3	Bi	56.51	1
			N4	N5	Bi	57.66	1
			N5	N6	Bi	56.75	1

****
***
* Interfaces *
****
***

Net Node Location

```
---------- ---------- ----------
Net1      N1        North
          N3        South
          N4        East
          N6        West

*******************************************************************
***
*                    Processing                    *
*******************************************************************
***

                Process               Routing

Entity    Location Operation        Blk  Output    Destination Rule     Move Logic
--------- -------- ------------------   ---- --------- ----------- -------  ------------
Worker    North                     1   Worker    South     FIRST 1  INC v_COUNT
                                                            MOVE ON Net1

Worker    South                     1   Worker    EXIT      FIRST 1
Operator  South                     1   Operator  North     FIRST 1  INC v_COUNT
                                                            MOVE ON Net1


Operator  North                     1   Operator  EXIT      FIRST 1
Machinist East                      1   Machinist West      FIRST 1  INC v_COUNT
                                                            MOVE ON Net1

Machinist West                      1   Machinist EXIT      FIRST 1
Inspector West                      1   Inspector East      FIRST 1  INC v_COUNT
                                                            MOVE ON Net1

Inspector East                      1   Inspector EXIT      FIRST 1

*******************************************************************
***
*                    Arrivals                    *
*******************************************************************
***

Entity    Location Qty Each                 First Time Occurrences Frequency  Logic
--------- -------- ---------------------------- ---------- ----------- ---------- ------------
Worker    North    (v_V15_NS*1.28)/2; ped_arrive        3          60
```

```
 Operator  South   (v_V15_NS*1.28)/2; ped_arrive        3        60
 Worker    North   (v_V15_NS*1.28)/2; ped_arrive        1
 Operator  South   (v_V15_NS*1.28)/2; ped_arrive        1
 Machinist East    (v_V15_ES*1.28)/2; ped_arrive        3        60
 Inspector West    (v_V15_ES*1.28)/2; ped_arrive        3        60
 Machinist East    (v_V15_ES*1.28)/2; ped_arrive        1
 Inspector West    (v_V15_ES*1.28)/2; ped_arrive        1

*******************************************************************
***
*                    Attributes                    *
*******************************************************************
***

 ID        Type         Classification
 ---------- ------------ --------------
 a_RATE    Integer      Entity

*******************************************************************
***
*                  Variables (global)                  *
*******************************************************************
***

 ID        Type         Initial value Stats
 ---------- ------------ ------------- -----------
#
#Total amount of pedestrians that crossed the line.  Later, set up logic
 to store the peak 15-min total.
 v_COUNT   Integer      0            Basic
#
#This is the peak 15 minute pedestrian count value.
#The peak 15 minute pedestrian count is the sum of pedestrians moving in
 both directions.
#(For a give 15 minute time period, sum the two pedestrian count values.)
#(Peak 15 = Direction A + Direction B for the same time period.)
 v_V15_NS  Integer      200          None
#
#This is the total width of the walkway
 v_Wt      Integer      20           None
#
#This is the total amount of shy distances
 v_Wo      Integer      2            None
```

```
#
#This is the effective width of the walkway.  WE = Wt - Wo
 v_WE       Integer     0           None
#
#This is the pedestrian unit flow rate (p/min/ft) is VP = V15/(15*WE)
 v_VP       Integer     0           None
#
#This is the peak 15 minute count value for East/West
 v_V15_ES   Integer     0           None

*****************************************************************
***
*                          Macros                          *
*****************************************************************
***

 ID           Text
 --------------- ------------
 m_LOS        # Determine LOS
            IF v_VP <= 5 THEN
             BEGIN
             DISPLAY "LOS for this segment = A"
             GOTO FINISH
             END
            IF v_VP > 5 AND  v_VP <= 7 THEN
             BEGIN
             DISPLAY "LOS for this segment = B"
             GOTO FINISH
             END
            IF v_VP > 7  AND  v_VP <= 10 THEN
             BEGIN
             DISPLAY "LOS for this segment = C"
             GOTO FINISH
             END
            IF v_VP > 10 AND  v_VP <= 15 THEN
             BEGIN
             DISPLAY "LOS for this segment = D"
             GOTO FINISH
             END
            IF v_VP > 15 AND  v_VP <= 23 THEN
             BEGIN
             DISPLAY "LOS for this segment = E"
             GOTO FINISH
```

```
 END
IF v_VP > 23 THEN
 BEGIN
 DISPLAY "LOS for this segment = Variable"
 GOTO FINISH
 END

FINISH:
```

```
*****************************************************************
***
*                     Arrival Cycles                     *
*****************************************************************
***

 ID        Qty / %     Cumulative   Time (Hours) Value
 ---------- ------------ ------------ ------------ ------------
 ped_arrive Percent      No          .25         8
                          .5          6
                          .75          14
                          1           72
```

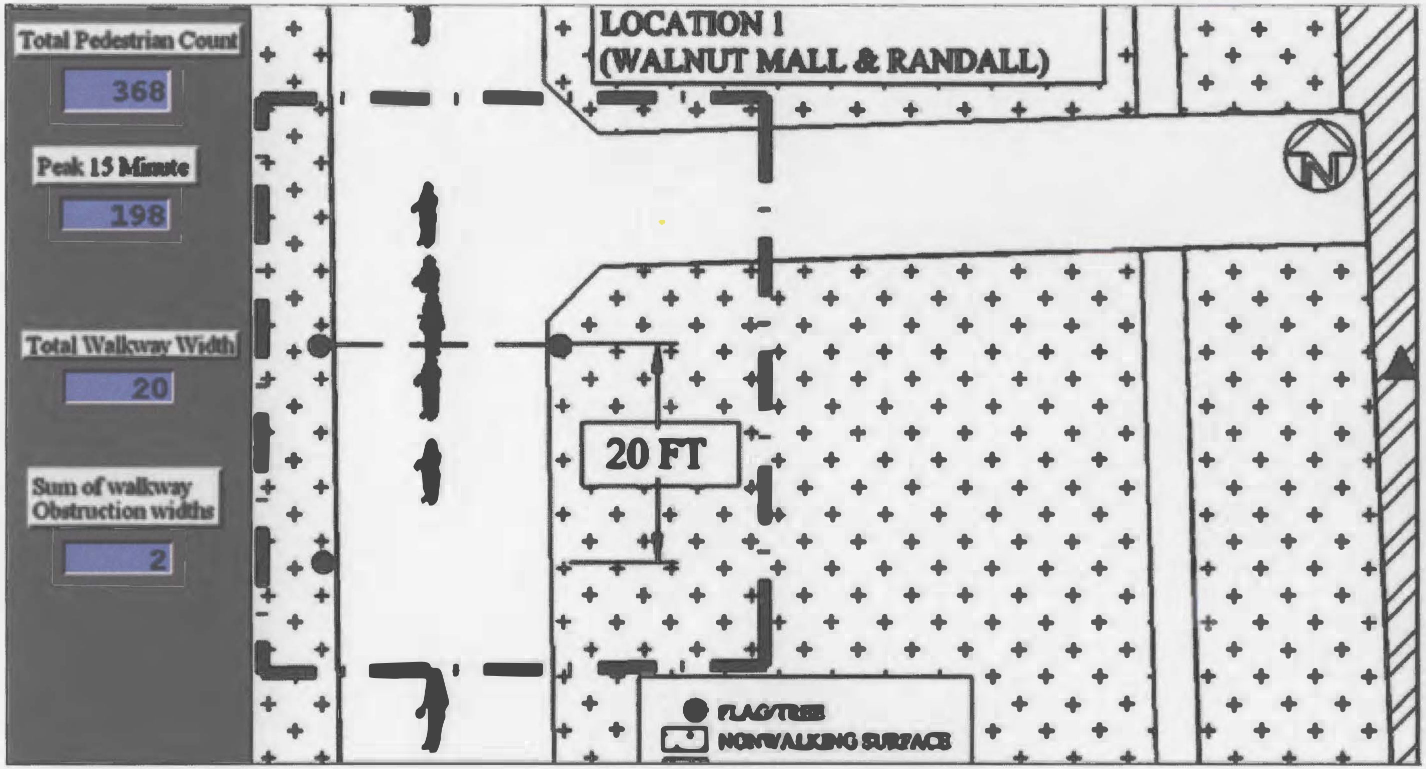


Figure F1. ProModel simulation model screen shot of Location 1 (Randall Hall).

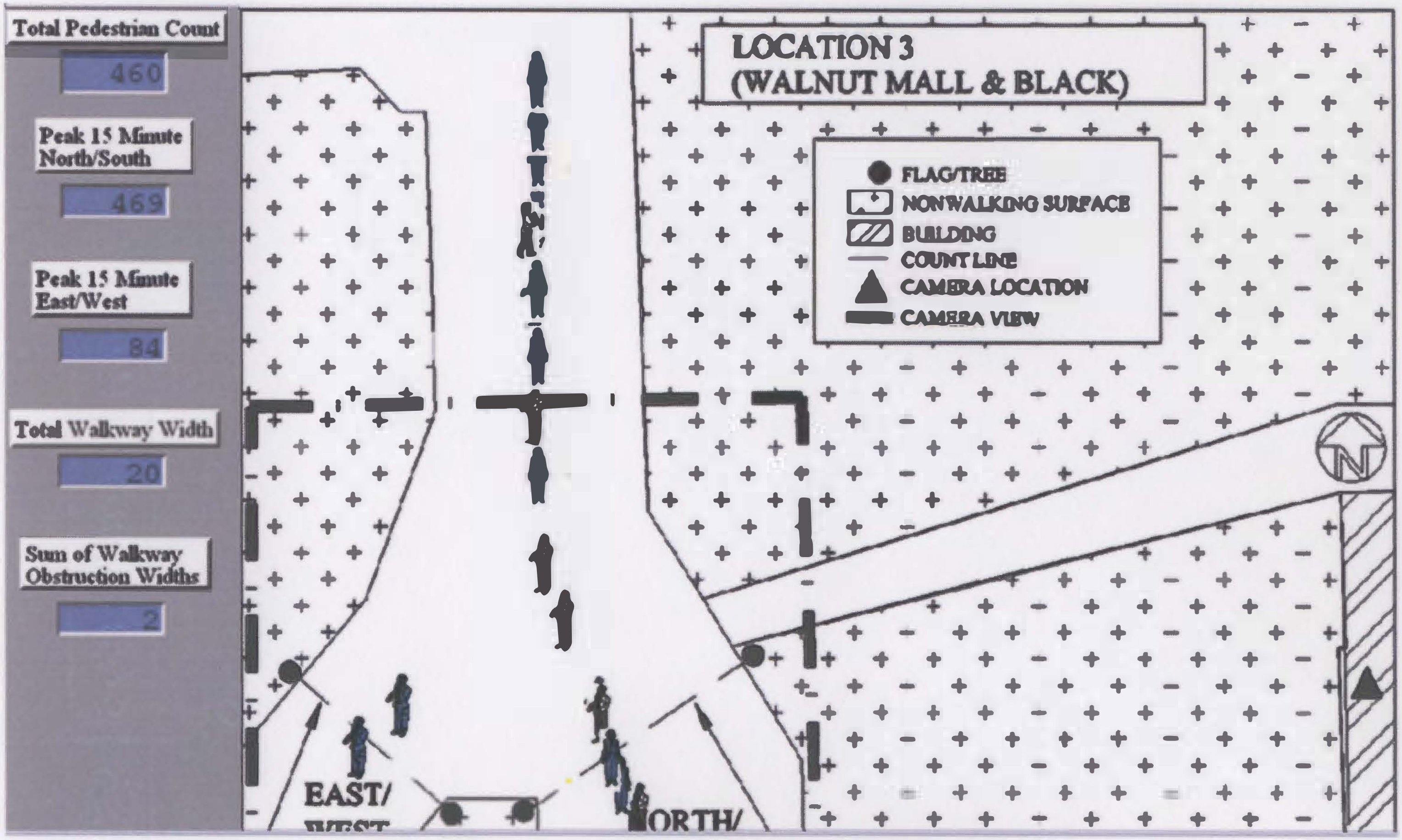


Figure F2. ProModel simulation model screen shot of Location 3 (Black Hall).