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16. Abstract

Current and proposed Americans with Disabilities Act (ADA) guidelines offer no specific guidance on acceptable maximum cross slopes where constraints of reconstruction prohibit meeting the 2-percent maximum cross-slope requirement for new construction. Two types of sidewalk test-section data across a sample of 50 individuals were collected, combined with an earlier sample of 17 records of participation, and analyzed here, with an emphasis on cross slopes. These examined heart-rate changes and user perception of discomfort levels, and they relied on a random-effects model and an ordered-probit model, respectively. Model estimates were used to deduce critical or unacceptable cross slopes for critical conditions and critical populations of persons with disabilities. Predicted values for the most severe or constrained cases ranged from 5.5 to 6 percent cross slope. These cases included 5 percent primary slope (main grade) and 45-ft long sections; and they were traversed by cane/crutch/brace and manual wheelchair users up to 80 years of age. When primary slopes were reduced to 0 percent in the perception estimates, the critical cross slopes for the critical case rose to 6 percent. For most other persons with disabilities, the critical cross slopes ranged from 6 to 9 percent or more. These values substantially exceed tentative design guidelines associated with the ADA for public sidewalks, which suggest a maximum cross slope of 2 percent.

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# Sidewalk Cross-Slope Design:
# Analysis of Accessibility for Persons with Disabilities

*by*

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Thomas W. Rioux

Research Report Number 0-4171-1

Research Project 0-4171
*Sample Size Expansion of Sidewalk Cross-Slope Variability with Respect to the Americans with Disabilities Act Accessibility Guidelines*

Conducted for the

TEXAS DEPARTMENT OF TRANSPORTATION
in cooperation with the
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# Disclaimers

The contents of this report reflect the views of the authors, who are responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official views or policies of the Federal Highway Administration or the Texas Department of Transportation. This report does not constitute a standard, specification, or regulation.

There was no invention or discovery conceived or first actually reduced to practice in the course of or under this contract, including any art, method, process, machine, manufacture, design or composition of matter, or any new and useful improvement thereof, or any variety of plant, which is or may be patentable under the patent laws of the United States of America or any foreign country.

# Implementation Recommendations

This research provides rigorous experimental support and other documentation for assessing requests for variances to the sidewalk cross-slope standards held by the U.S. Access Board and the Texas Department of Licensing and Regulation. The research results suggest that cross slopes as high as 10 percent are accessible to a wide variety of disabled persons. However, 6 percent is the maximum cross slope for designs which accommodate quite elderly manual wheel chair users under adverse main slope conditions (i.e., 5 percent main slope). Based on these results, cross-slopes higher than the current design standards are likely to be highly viable, when needed.

1. The researchers recommend that cross-slopes greater than 2 percent be considered a possible design strategy when right-of-way or other construction limitations make 2 percent cross-slopes a costly endeavor.

2. In locations where the 2 percent standard presents serious design difficulties, the researchers recommend that final plans be allowed to have cross-slopes of up to 10 percent, if main slope is minimal. When main slope is five percent or more, the researchers recommend that cross-slope not exceed 6 percent.

3. For detailed prediction of percentages of specific users with specific disabilities unable to negotiate sidewalks of known length, cross slope and main slope, the researchers recommend that one review the Project Research Report 4171-1, to make use of its predictive models and multiple probability plots. (This Summary Report's Figure 1 is an example of a probability plot.)

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Kara M. Kockelman, Ph.D.
*Research Supervisor*

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Research performed in cooperation with the Texas Department of Transportation and the U.S. Department of Transportation, Federal Highway Administration.

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# Chapter 1. Introduction and Objectives

The maximum cross-slope of sidewalks in this country is currently a subject of serious conversation. The proposed ADA guidelines in their different manifestations have consistently maintained a 2 percent maximum cross-slope requirement, carried over from previous accessibility guidelines (Access Board 1984) and variously expressed as 1:50 or (more recently) 1:48 (Public Rights of Way Access Advisory Committee [PROWACC], 2001). This requirement possibly derives from construction standards for a minimum required slope for drainage purposes, but review of the literature has not determined the original basis for this requirement (Taylor et al. 1999; Kockelman et al. 2000 and 2001).

Though there has been a lack of solid research until now, final standards have been adopted by the U.S. Access Board and the Texas Department of Licensing and Regulation (TDLR) at a maximum of 2 percent. Title II of the Americans with Disabilities Act (ADA) requires that the programs, activities, and services of public entities be accessible to and usable by individuals with disabilities (28 CFR 35.149-35.150). The ADA Accessibility Guidelines (ADAAG) provide standards for accessible design that meet the intent and requirements of ADA. Cross slopes are an important feature of the public rights-of-way (ROW), which provide such access. This research provides data, behavioral models, and rigorous results to the cross-slope design debate. This paper describes the work and the results, after first placing the work in its legal and practical context.

Existing rights-of-way constraints can at times create situations of "technical infeasibility" under the ADA in meeting the exacting requirements of the guidelines for new construction. A particular concern of agencies responsible for public sidewalks has been provision of a continuous 2 percent or less cross slope when constructing or reconstructing sidewalks in existing, space-constrained rights-of-way, particularly in urban areas with numerous driveway crossings. Public agencies face a high burden of responsibility in meeting accessibility requirements, but face a lack of guidance when the guidelines for new construction cannot be met in a reconstruction or retrofit situation. Many public agencies voiced their concerns regarding the cross-slope standards in comments on the proposed Section 14, as it was originally proposed, making it one of most controversial portions of the proposed guidelines (Taylor et al. 1999).

Taylor et al.'s (1999) and Kockelman et al.'s (2000) extensive literature reviews and continuing efforts in this area have concluded that there is essentially no research to support ADA's 2 percent cross-slope requirement, although a need for research on the effects of cross slope on sidewalk users with disabilities was noted as far back as 1979 (Brown et al. 1979). Related studies have relied on populations of young males, providing little information on maximum limits for the broadest range of sidewalk users with disabilities, particularly in an aging society. The purpose of this study is to provide a scientific basis for a range of cross slopes that meet the accessibility requirements of sidewalk users in those limited situations where the 2 percent requirement cannot be met. This is performed through a review of existing standards, the collection of detailed data sets over a variety of sidewalk situations, and test sites offering a variety of cross slopes and primary slopes, and regression analysis of both heart rate changes and user perceptions of pedestrian passages. Given the analytical results, estimates of critical cross slopes for a variety of persons with disabilities (across age, gender, mobility aide, and physical fitness level) were made to illuminate which cross slopes are most critical for design—and when.

# Chapter 2. Review of Standards

## Construction Tolerances

Interim design guidelines from the Access Board suggest restrictions on construction tolerances, citing the practice of the City of Roseville, California, of directing contractors to set extruding machines and forms at a 1.5 percent cross slope, or 1 percent for sidewalks with a steep running slope to ensure a final cross slope within the 2 percent maximum (Access Board, 1999). The Access Board is sponsoring research on tolerances in construction, bringing together construction industry interests through the Construction Specifications Institute (CSI) to develop recommendations on construction tolerances and measurement protocols for surface flatness, slope, vibration, and rollability. A technical assistance bulletin will be produced, with completion scheduled for Spring 2002. This issue is of importance to agencies responsible for public sidewalks since construction tolerances in right-of-way construction have historically been looser than in building construction (Access Board, 1999).

## Development of Final Guidelines

The Access Board had designated a Public Rights-of-Way Access Advisory Committee (PROWACC) to recommend guidelines for newly constructed or altered pedestrian facilities covered by Title II of the ADA or the Architectural Barriers Act (ABA). Within the total sidewalk PROWACC was thinking in terms of a three-dimensional spatial corridor of continuous and accessible travel with a clear width of at least 60 in. and a clear height of at least 80 in., free of abrupt changes in level and with a 48-in. “reduced vibration” zone. (PROWACC, 2001) This was an evolution of the “accessible route” in ADAAG for Title III entities and the “continuous passage” in proposed Section 14. The PROWACC report maintains concepts of “technical infeasibility,” “compliance to the maximum extent feasible,” and “equivalent facilitation” from current and proposed ADAAG (PROWACC, 2001, p. 13).

In recommended guidelines for new construction the minimum clear width of the pedestrian access route (“corridor of accessible travel”) may be reduced to 48 in. (from 60 in.) at (1) driveway and alley crossings, (2) parallel parking locations with constraints, (3) street fixtures, and (4) building entrances (PROWACC, 2001, p. 13).

## Construction in Existing ROW

The Access Board’s interim guidelines in the Accessible Rights-of-Way Design Guide provided the following statement: “Where sidewalks of excessive cross slope are being reconstructed, it may be possible—if there is sufficient width—to provide a 36-in.-wide continuous routing with a complying cross slope within the overall sidewalk width, blending adjacent surfaces to meet it” (Access Board, 1999, p. 47).

In further recognition of the constraints of constructing or reconstructing sidewalks in a developed right-of-way, the Design Guide noted that full accessibility of all elements of the constructed changes may not be feasible. In such situations the Design Guide recommended that decisions on accessible design features be made on a case-by-case basis, considering the effects of field conditions balanced with contributing factors (Access Board, 1999). Such uncertainties as these have led design engineers to request better information on threshold limits on such contributing factors as cross slope.

The PROWACC adopted a resolution in support of a requirement that sidewalks be included whenever a road is constructed or reconstructed in a public ROW in an urban area

(PROWACC, 2001). This is an area that directly concerns state transportation agencies and has already become an issue, as some cities and communities that originally requested not to have sidewalks in the urban ROW are now requesting the addition of sidewalks.

### Cross Slope Requirements

The Design Guide (Access Board, 1999) made numerous statements regarding cross slope as a major barrier for pedestrians who use mobility aids or have difficulty walking. The Design Guide stated that cross slopes exceeding 2 percent significantly impede forward progress on an uphill slope and compromise control and balance in downhill travel and on turns; and that crutch users have more difficulty with cross slope on a downhill running slope (Access Board, 1999, p. 37). In addition, the Design Guide stated "Driveway aprons … with steep, short side flares, can render a section of sidewalk impassable, especially when encountered in series. Compound cross slopes…may cause tipping and falling if one wheel of a wheelchair loses contact with the ground or the tip of a walker or crutch cannot rest on a level area. Wheelchair users whose upper trunk mobility is limited can be thrown from their seats by differentials in cross slope occurring over a small distance. Manual chairs, although more maneuverable than heavy battery-powered chairs, are much more likely to tip on compound slopes" (Access Board, 1999, p. 44) Presumably there was some research to support this detailed statement, but it was not referenced in the report and is unknown to the authors of this report.

PROWACC has also recommended further research on cross-slope effects in conjunction with "warp." *Warp* is the term used by the new Guidelines to connote the combination of primary and cross slopes and suggest planar change in more than one direction. The primary gradient (i.e., maximum slope) of such planes may not be aligned with the direction of travel or its cross-direction. Thus, warp is an important term for driveway flare descriptions. Judging by comments from mobility aid users participating in this study and from comments by PROWACC members (PROWACC, 2001, pp. 80-81), warp and planar changes seem to have a much greater impact on travel than increased cross slope by itself.

# Chapter 3. Review of Literature

## Basis for Cross-Slope Requirement

The ADA guidelines in their different manifestations have consistently maintained a 2 percent maximum cross-slope requirement, carried over from previous accessibility guidelines (Access Board, 1984) and variously expressed as 1:50 or (more recently) 1:48 (PROWACC, 2001). This requirement possibly derives from construction standards for a minimum required slope for drainage purposes, but review of the literature has not determined the original basis for this requirement (Taylor et al. 1999; Kockelman et al. 2000 and 2001). The PROWACC report refers to a short article published in 1986 in the *Journal of Rehabilitation Research and Development* (Brubaker et al.). This article was a "technical note" which is a means of exchanging information which might further the cause of research, but is somewhat limited in scope and often lacks comparison studies and is thus different from a "scientific article." The purpose of this short study primarily concerned the improvement of wheelchair performance through design. Wheelchair design has in fact changed in the 15 years since this study took place.

The authors find it arguable whether cross slope is the most significant problem in wheelchair mobility, but note that it was identified as such in a 1979 report on budget requirements for research needs (Brown et al. 1979). The PROWACC (2001) report cites the Brubaker et al. (1996) study as indicating, "that a 3 percent cross slope requires 50 percent more effort than a 2 percent cross slope" (p.99). What the study actually indicated was that, while power required to propel a wheelchair increased more than 100 percent from a level surface to a 2 degree (3.49 percent) cross slope, energy cost was only 30 percent greater than for a level surface. Neither of these indications supports the statement for a 50 percent increase in effort with one percent increase in cross slope, although this statement has been made elsewhere (Access Board [video], 1997).

Another relevant study was conducted by Chesney and Axelson (1996), who focused on developing a method to measure effort required by wheelchair users in traversing a variety of surfaces. Their conclusions indicate that the work required to negotiate a specific ramp angle may be used as a criterion for short-distance wheelchair travel. Such effort may be comparable to the short distance required to traverse a driveway. Chesney and Axelson (1996) also acknowledge the need to assess the impact over much longer distances, such as for single trips and for all trips during the day.

One interesting result of the Chesney and Axelson (1996) study is that the work-per-meter value on a two-percent primary grade does not change for marginally different cross slopes. This supports the possibility that a cross slope greater than 2 percent might be acceptable by wheelchair users when traversing short distances, and it also contradicts the statement that a 3 percent cross slope requires 50 percent more effort than a 2 percent (Access Board, 1997).

## Population and Needs of Mobility Aid Users

Much evidence exists to corroborate the need for improved sidewalk accessibility and to suggest research needed for such improvements. Kaye et al. (2000) noted that one-third of the wheelchair and scooter users in the 1994 National Health Institute Survey of disabilities (NCHS 1998) report wheelchair accessibility problems outside the home. Only 3.2 percent of other mobility aid users reported problems. Eighty-two percent of wheelchair users reported that their local transportation system is difficult to use or to get to. Only 66.9 percent said it is very difficult. Among mobility aid users in general, 68.3 percent reported difficulty with access to public transportation and 45.2 percent reported very difficult access. 39.9 percent of mobility aid users and 58.1 percent of wheelchair users reported that difficulty walking is or would be a problem for them in using public transit. While the majority of wheelchair use is of manual wheelchairs, the greatest percentage of these is among the elderly. Elderly wheelchair users report poorer health and are more likely to require assistance in daily activities, including assistance with mobility (Kaye et al. 2000; NCHS 1998).

The percentage of the U.S. population with disabilities is predicted to rise over the coming decades; and use of mobility aids increases with age (McNeil, 1997). In addition, while use of mobility aids has grown due to an aging population, growth in use exceeds what can be attributed to aging alone. From 1980 to 1990 use of crutches grew by 14 percent; canes by 53 percent; and wheelchair and walker use by 100 percent. The level of increase indicates that improved survival of trauma patients has added to the numbers of mobility aid users, and that improvements in design, image, and affordability have led to increased usage by the people who needed but did not use mobility aids previously (Russell et al. 1997).

While only 2.0 percent of the population of non-mobility aid users reported poor health, 29.5 percent of mobility aid users reported poor health, particularly among wheelchair, scooter, and walker users. The fraction of the working-age population is even greater, at 35.7 percent of users compared to 2.2 percent of non-users. The gap between elderly (65 and over) users and non-users is less, at 56.8 percent and 22.6 percent, respectively. Elderly wheelchair users report significantly worse health than users of other aids. Cane users are more likely to report good health (Kaye et al. 2000).

## Methodology of Studies of Mobility Aid Users

In an Australian study Bails et al. (1988) looked at the usability of public facilities by mobility aid users. Subjects were grouped as blind, ambulant, electric wheelchair users, or manual wheelchair users. Ambulant included users of sticks (canes), frames (walkers), and crutches. Responses of difficulty of access during field tests were recorded on a 1 to 5 scale, where 1 represented very easy access and 5 impossible for a subject to achieve access. Where more than 20 percent of a subject group could not use a feature, or had a degree of difficulty greater than 3, the test results were treated as practically significant and the subject of a possible amendment to Australian code (Bails et al. 1983). A later study focused on the needs of young mobility aid users in adult facilities and used a similar methodology, with the subject groups further broken down by age. Because Australia has no register, census, or survey data from which to draw inference of sample size and composition, a decision was made to aim for a minimum sample of ten subjects per group (Bails et al., 1988). But no statistical confidence levels were estimated using the results, and no multivariate models of access and response were constructed; such models would have allowed the researchers to control for a variety of factors at once, and draw keener conclusions.

A particularly relevant study pertains to research conducted on ramp slope for the U.S. Access Board (Sanford, 1996). This study focused specifically on running slope, rise and distance but also looked at cross slope and other relevant factors. The author refers to the 1986 Brubaker study as well as a second British source (Travers, 1991) which simply states that cross slope should not exceed 1:100 in order for a wheelchair user to maintain control, without citing any research as a basis. The Sanford (1996) study used 1990 National Health Institute Survey (NHIS) data for choosing sample percentages across age, gender, fitness, disability, and type of mobility aid. Based on the reference data, the Sanford study (1996) also notes the increased impact on disability and access needs of an aging population.

The Sanford (1996) study created two sampling frames reflecting U.S. population profiles of people with mobility impairments: one for current population and one representative of the population projections for 2010. A sample of 192 subjects was distributed by age and gender among seven categories of mobility aids and included an eighth category of individuals with mobility impairments who do not use aids. The author found the sample of the current population to be more practical to the purposes of the study than the projected population sample. The older population was already over represented in the subject population (73 percent of participants aged 55 and older); the author also felt that a larger sample of older subjects would result in more individuals who were unable to complete the test trials.

The test trials took place in a controlled indoor setting, rather than mimicking outdoor travel conditions. This study measured effort by pulse rate and oxygen saturation, and also measured subjective responses of difficulty rated on a 1 to 10 scale. Study data indicate that the greatest impacting factors in ascending a 30-ft long ramp are positive slope, distance, and manual wheelchair use. A conclusion was that most of the population could probably handle greater ramp slopes, with the primary exception of elderly female manual wheelchair users. The author did not recommend changes to guidelines for ramp slope and length due to a need for further research on the functional limitations of older wheelchair users. Recruitment efforts for the study suggested that although there are a high percentage of older female manual wheelchair users, the numbers who travel independently outdoors may be relatively small. There was, however, no data other than anecdotal evidence to discount older women as potential ramp users (Sanford, 1996).

# Chapter 4. Survey Methodology

This study was designed in the prior or first phase of this project (Kockelman et al. 2000 and 2001) with the objective of evaluating the usable range of sidewalk cross slopes with regard to user perception and effort. The prior phase administered perception tests to a variety of mobility aid users through on-site and Internet-based surveys. Tests of effort as measured by heart rate were also administered in on-site tests. The study used, and continues to use in this second phase, an ordered response model of user perception of sidewalk-section crossing difficulty and a weighted linear regression model of heart-rate deviation from resting rate. Model estimates permit determination of reasonable cross-slope maxima for users of a variety of mobility aids (Kockelman et al. 2001).

In the first phase, obstacles were encountered in recruiting sufficient numbers of test subjects. Fourteen different individuals participated, and provided 17 different records of participation (i.e., 17 data points, since a few of the 14 individuals participated using a couple different mobility aids). Due to this limited sample size this first phase was viewed as a prototype for a second-phase study to include larger sample sizes, longer heart-rate tests, and a stronger recognition of the population of interest (Kockelman, 2001). This second-phase study was recently conducted and is summarized here.

## Changes to the Study Design

Data for the first phase were collected using three types of survey instruments: an Internet-based survey in which respondents provided their perception of crossing comfort based on photos of sidewalk sections; a field survey in which participants stated their perceptions of ease of sidewalk use before and after crossing various sidewalk sections; and a field survey that recorded changes in heart rate in response to traversing distinct sidewalk sections. The Internet study generated a reasonably large sample size, but the attributes of the sidewalk sections were deemed too difficult to faithfully judge based on digital photos. Thus, this second phase of the study retained only the two types of field survey.

The two field sites in the first phase were chosen due to locations along bus routes identified as having high numbers of riders with disabilities. These two sites were retained for this study, with small modifications in the selection and measurement of individual sidewalk sections. The route through the parking lot used for the heart-rate study was reconfigured to have five long sections to be traversed in sequence, nonstop. Heart-rate studies were conducted only on this parking-lot traverse and not on sidewalk sections as was done in the first phase; these longer sections are more desirable since they better allow the working heart rates to stabilize, and thus generate more robust measures of response. All study participants in this second phase were encouraged to complete tests at all three sites, giving a broader range of comparative data.

## Subject Recruitment

Even though survey sites were selected for ease of transportation of subjects to and from the sites, there was great difficulty in recruiting subjects for the first phase. A possible explanation has been previously noted in the literature review portion of this paper as a high percentage of mobility aid users reporting difficulty of access to public transportation (Kaye et al. 2000). Participants in this second phase of the project were offered individual transportation to the test sites where possible, resulting in increased recruitment even though more time and effort were involved in actual testing than in the first phase.

Participants were offered a $25 cash payment as additional incentive. The study as designed for acquiring a broad range of data required much time and effort for participants. Completion of all the tests required from 1-1/2 to 4-1/2 hours, including travel time, and was very tiring for even relatively fit individuals. Participants who could not complete all the tests at one time often came back on another day to complete remaining tests. The target population for this study is often under- or unemployed, making the cash benefit an important incentive. Given the time and effort involved, in sometimes unpleasant outdoor conditions, a small remuneration seemed appropriate and necessary to recruit the required number of participants.

Even so, recruitment was still very difficult. The better fit and more able participants in this study tended to be fully employed and to own their own vehicles, not relying on public transportation or sidewalks. Having less interest in sidewalks, these participants were difficult to recruit. Many more people who expressed a true interest in sidewalk accessibility and a desire to help with the study were medically fragile and had to cancel scheduled tests, or were unable to complete tests once begun. Many people who have a real need and would like to use sidewalks, cannot. Conclusions on sidewalk accessibility should take into account that the more fragile population is possibly the more critical sidewalk user population.

Due to a desire to recruit a larger number of older subjects to reflect the aging of the population, initial recruitment efforts targeted residents of nursing homes, assisted-living centers, and retirement communities. Local facilities were mapped for access to public transportation, and letters explaining the study and the effort to recruit participants were mailed to facility directors at fifty-one sites. Letters were followed up with phone calls and offers to make presentations of study information to facility residents. A PowerPoint presentation was developed for this purpose, approximately 15 minutes in duration. Many facilities had no residents capable of independent travel, but seven responded with invitations to give a presentation, and fourteen subjects were recruited in this way.

Contact tear-off flyers were created and posted in various locations, given to participants to distribute to acquaintances, distributed at Texas Rehabilitation Commission field offices and at a Capital Metro MICAC (Mobility Impaired Citizens Advisory Council) meeting, recruiting six subjects. One of these subjects participated twice using different mobility aids, which he switches between on a normal basis, and was counted twice. A notice was sent to the electronic mailing list of all University of Texas at Austin students with disabilities but received no response. Articles were published in local newspapers (the *Austin-American Statesman* and *The Daily Texan*) and announced on local radio stations. An interest piece was reported by a TV news station, and another was reported by a radio news show, eliciting responses from which an additional twenty-five subjects were obtained. The remaining four subjects were recruited from personal contacts and by word of mouth. Data from fourteen individuals in the first phase were added to the data for fifty subjects in this second phase for a total of sixty-four individuals, or sixty-seven records (since a few of the first-phase individuals participated twice, with two different mobility aids).

## Population Sampling

While the aim of subject recruitment was primarily a larger sample, an important goal was to better represent the population of mobility aid users as a whole. Recruitment efforts produced subjects across a wide range of age and mobility aid types. A target sampling frame reflecting the population profile of U.S. mobility aid users (Table 4.1) was developed by calculating percentages of respondents to the 1994 National Health Institute Survey – Disability

(NHIS-D) across age, gender, and mobility aid type (NCHS 1998). (Note: Table 4.1 percentages add up to 99.86 due to rounding.)

**Table 4.1: U.S. Population of Persons with Disabilities, by Gender, Age, and Mobility Aid (Based on 1994 NHIS-D Survey)**

| **Mobility Aid Type** | **Gender and Age** | | | | | |
|---|---|---|---|---|---|---|
| | Male | | | Female | | |
| | 16-35 | 36-65 | 66+ | 16-35 | 36-65 | 66+ |
| Cane | 0.83 | 8.62 | 12.55 | 0.61 | 7.08 | 21.63 |
| Crutches | 0.59 | 1.90 | 0.81 | 0.51 | 1.17 | 0.73 |
| Walker | 0.19 | 1.37 | 3.3 | 0.17 | 2.76 | 11.23 |
| Manual Wheelchair | 0.51 | 2.39 | 2.69 | 0.34 | 2.76 | 5.86 |
| Electric Wheelchair | 0.07 | 0.32 | 0.24 | 0.07 | 0.37 | 0.27 |
| Scooter | 0.02 | 0.24 | 0.34 | 0.00 | 0.39 | 0.44 |
| Leg Brace | 0.46 | 1.46 | 0.88 | 0.49 | 1.17 | 0.81 |
| White Cane (Blind) | 0.10 | 0.27 | 0.19 | 0.05 | 0.32 | 0.29 |

(Units: percent)

The sample of individuals with disabilities actually surveyed is shown in Tables 4.2 and 4.3, depending on whether the original 1999 data set is included (Table 4.3) or not (Table 4.2). Thus, these tables are based on the sixty-seven data records from individuals participating in either the first or second phase of the study.

While the actual samples do not reproduce the frame well in each of the possible forty-eight categories, the major frame categories have been reasonably well sampled. And no survey is perfectly representative of the population from which it is drawn. However, observations can be weighted during analysis to correct for sample deviations from population percentages. This was done here, in the regression analyses of results, to reflect the proper population of persons with disabilities. Each observation's weight is the ratio of the population fraction the person represents and the person's own representation in the sample. In other words, the values in Table 4.1 are divided by the values in Table 4.2 or 4.3 (depending on the model being used) for each observation, based on the gender-age-mobility category of the observation. By weighting the data during analysis, any biases in parameter estimates related to measured variables are removed. (The weight tables are provided in Appendix C of this report.)

**Table 4.2: Sample Population, by Gender, Age and Mobility Aid (2001 Sample)**

| *Mobility Aid Type* | Gender and Age | | | | | |
|---|---|---|---|---|---|---|
| | Male | | | Female | | |
| | 16-35 | 36-65 | 66+ | 16-35 | 36-65 | 66+ |
| Cane | 2.00 | 6.00 | 6.00 | 0.00 | 10.00 | 4.00 |
| Crutches | 4.00 | 2.00 | 0.00 | 0.00 | 2.00 | 0.00 |
| Walker | 2.00 | 0.00 | 2.00 | 0.00 | 2.00 | 12.00 |
| Manual Wheelchair | 4.00 | 10.00 | 0.00 | 0.00 | 6.00 | 4.00 |
| Electric Wheelchair | 0.00 | 2.00 | 0.00 | 2.00 | 4.00 | 0.00 |
| Scooter | 0.00 | 0.00 | 0.00 | 0.00 | 2.00 | 0.00 |
| Leg Brace | 0.00 | 2.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| White Cane (Blind) | 4.00 | 2.00 | 0.00 | 4.00 | 0.00 | 0.00 |

(N=50, Units: percent)

**Table 4.3: Sample Population, by Gender, Age and Mobility Aid (1999 & 2001 Sample)**

| *Mobility Aid Type* | Male | | | Female | | |
|---|---|---|---|---|---|---|
| | 16-35 | 36-65 | 66+ | 16-35 | 36-65 | 66+ |
| Cane | 1.493 | 5.970 | 4.478 | 0.000 | 8.955 | 2.985 |
| Crutches | 2.985 | 1.493 | 0.000 | 0.000 | 1.493 | 0.000 |
| Walker | 1.493 | 0.000 | 1.493 | 0.000 | 1.493 | 8.955 |
| Manual Wheelchair | 2.985 | 11.940 | 0.000 | 1.493 | 5.970 | 2.985 |
| Electric Wheelchair | 0.000 | 4.478 | 0.000 | 2.985 | 7.463 | 0.000 |
| Scooter | 0.000 | 0.000 | 0.000 | 1.493 | 1.493 | 0.000 |
| Leg Brace | 0.000 | 1.493 | 0.000 | 0.000 | 0.000 | 0.000 |
| White Cane (Blind) | 2.985 | 2.985 | 0.000 | 2.985 | 2.985 | 0.000 |

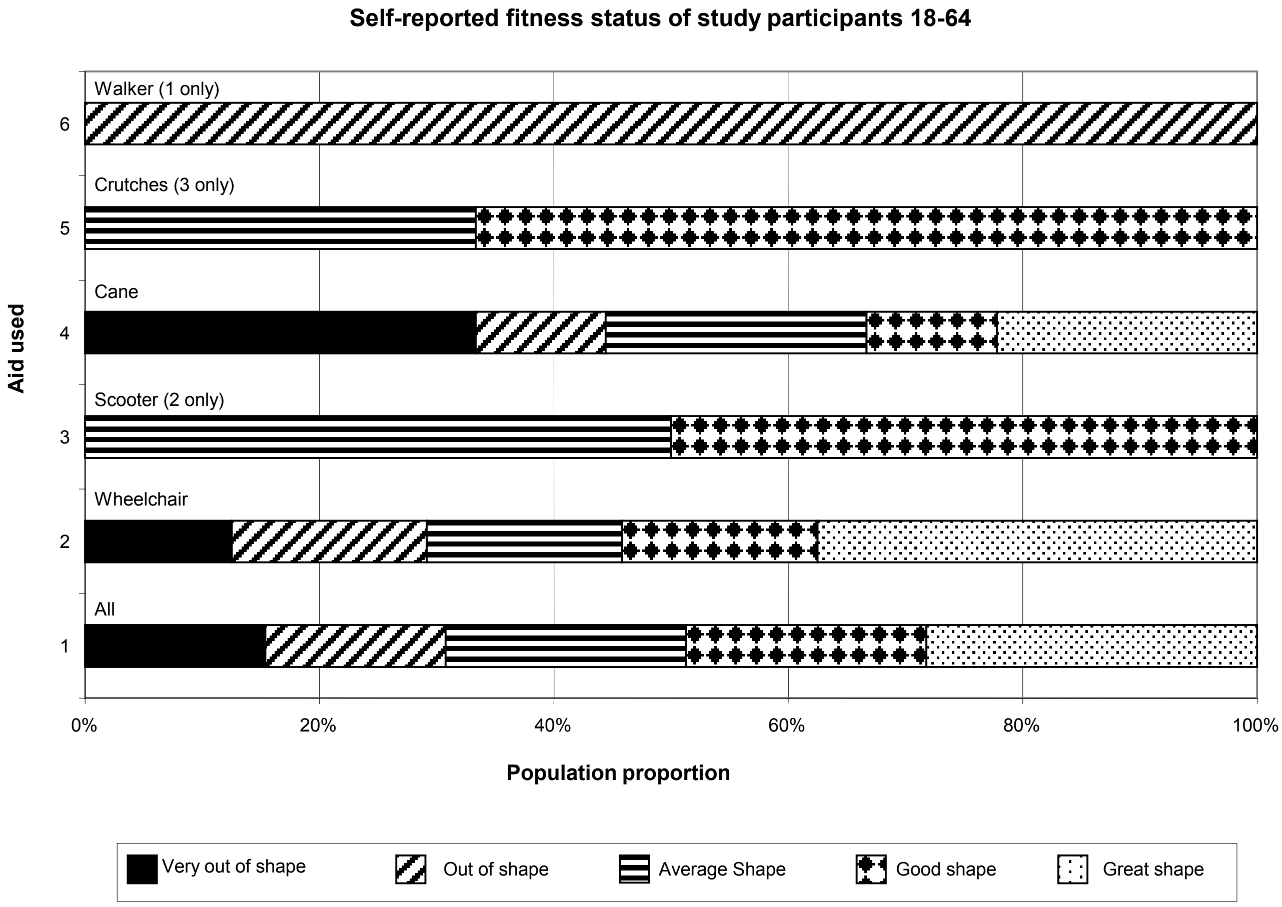
(N=67, Units: Percent)

Out of five “white cane” users, all were legally blind. (Two were completely blind and three had low vision. Two could see enough to affect their travel.)

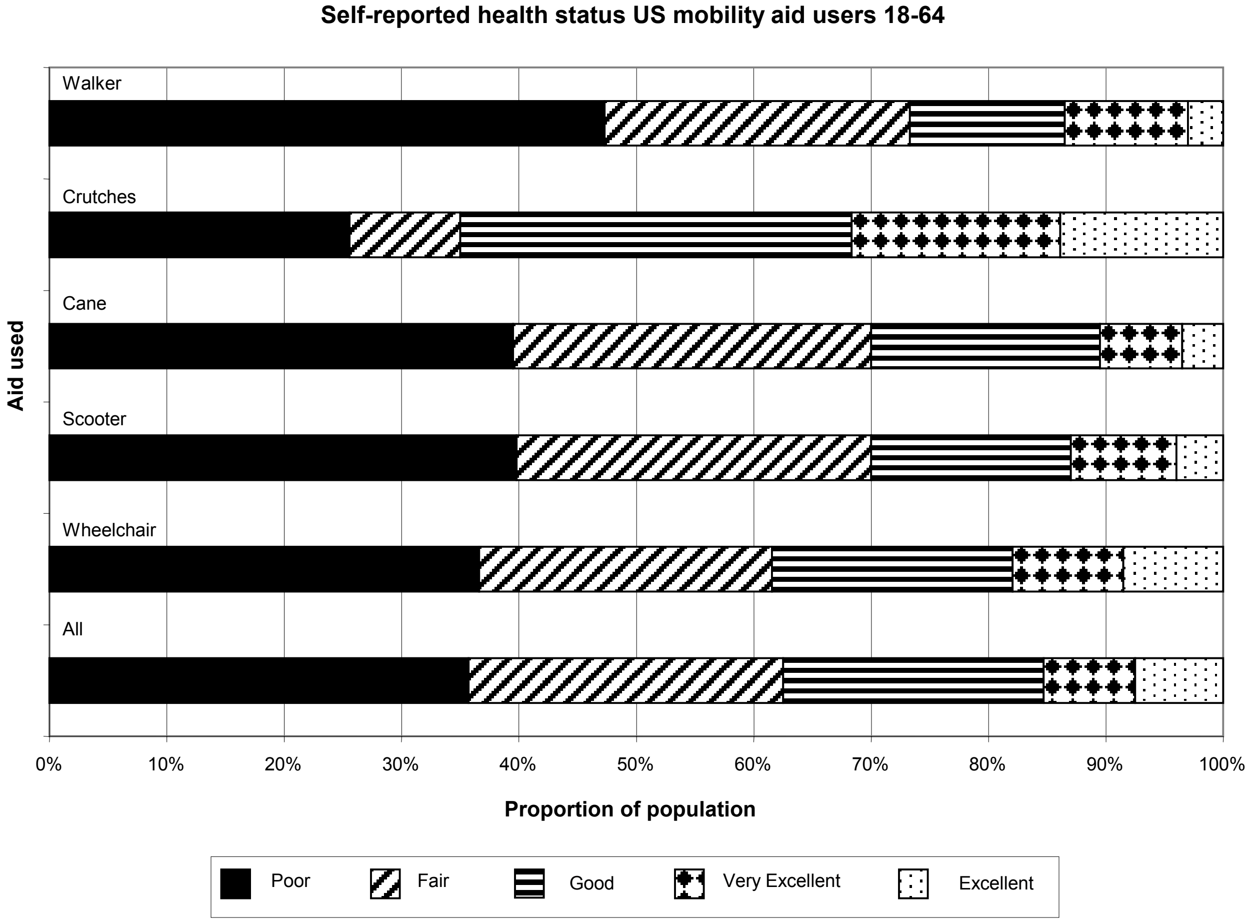
These sample sizes – cross-classified across age, gender, and mobility aid type – were compared to U.S. population perceived health responses in the Kaye (2000) study. The results are shown in Tables 4.4 through 4.7. As the tables show, study participants tended to report a higher level of fitness than the U.S. population of mobility aid users as a whole. Given the different sampling techniques and slight difference in the phrasing of questions, it is not clear that these results are strictly comparable. However, since the study required a good deal of effort, and this was explained before recruitment, it stands to reason that only the more fit individuals who felt capable of completing the tests would volunteer. A few who were not fit still had a desire to help with the study, and some people just wanted to see what they were capable of, as they normally did not have the opportunity to get to an accessible sidewalk. For many of these individuals, just having someone take them out and be available to assist if necessary was the primary reason for participation in the study.

Tables 4.4 through 4.7. Self-Reported Fitness Status of Study Participants, ages 18-64 and 65+, as compared to U.S. Population of Persons using Mobility Aides, ages 18-24 and 65+

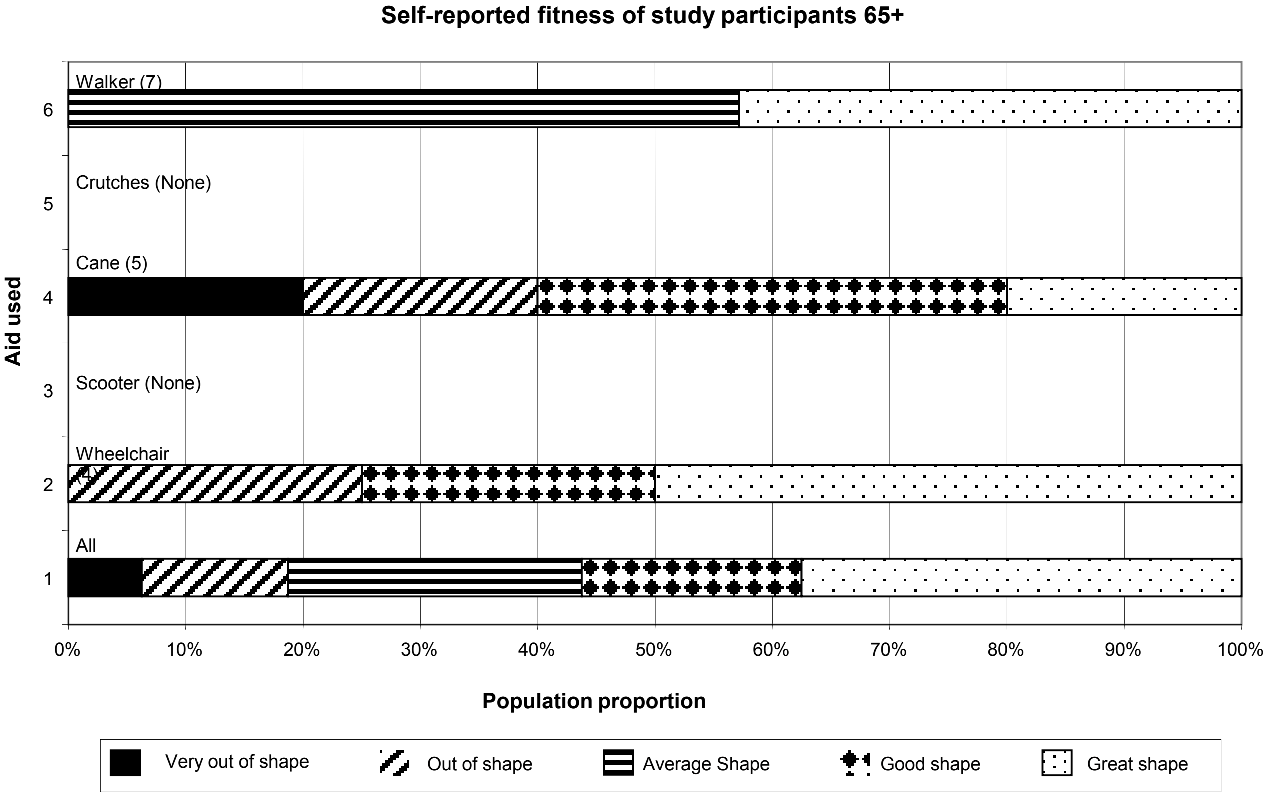
## Table 4.4



# Table 4.5

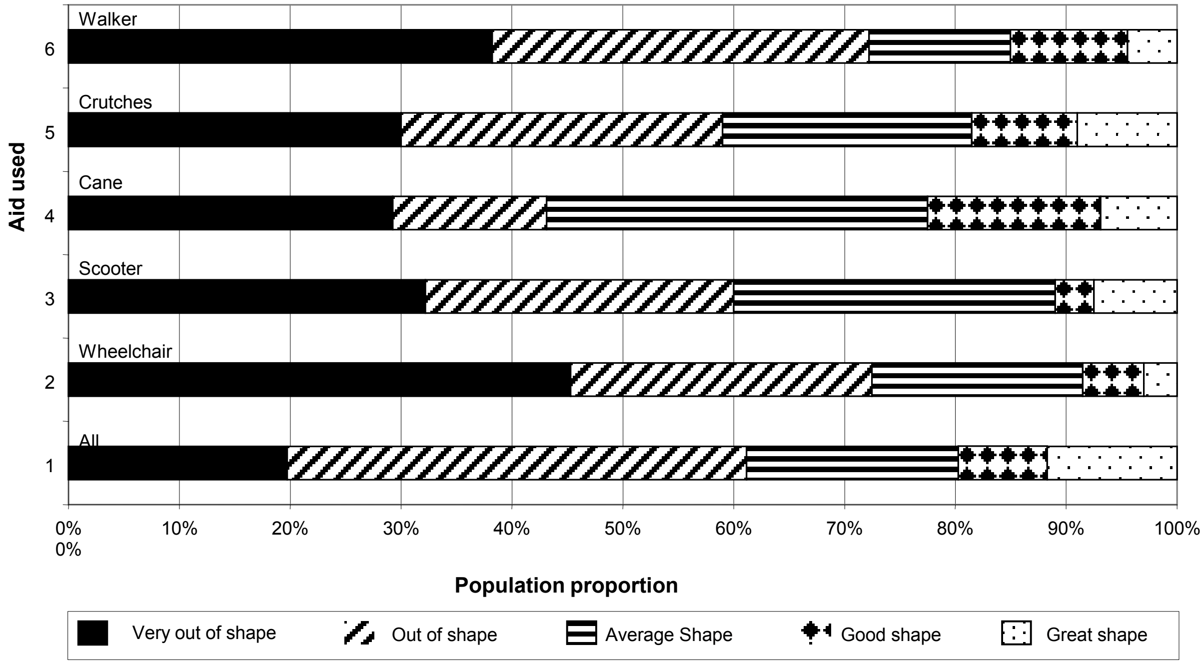

Self-reported health status US mobility aid users 18-64
Aid used
Walker
Crutches
Cane
Scooter
Wheelchair
All
0%
10%
20%
30%
40%
50%
60%
70%
80%
90%
100%
Proportion of population
Poor
Fair
Good
Very Excellent
Excellent

## Table 4.6


Self-reported fitness of study participants 65+
Aid used
6
Walker (7)
5
Crutches (None)
4
Cane (5)
3
Scooter (None)
2
Wheelchair (4)
1
All
0%
10%
20%
30%
40%
50%
60%
70%
80%
90%
100%
Population proportion
Very out of shape
Out of shape
Average Shape
Good shape
Great shape

## Table 4.7

**Self-reported health status US mobility aid** users 65+



## Participant Observations

One purpose for a study on accessibility is to gain input from individuals with disabilities. While such observations may provide only anecdotal evidence in a scientific study, this input can prove useful when considering all the individual case factors in a reconstruction situation.

One observation is that different users with disabilities sometimes have conflicting needs. While most mobility aid users find a high cross slope difficult to traverse, white cane (blind) users, who use their cane to find the edges of the sidewalk, rely on cross slope at driveway crossings to keep them from walking out into street traffic—i.e., if the cross slope increases noticeably at the driveway, they can keep themselves at right angle to the direction of slope and continue onto the sidewalk. If cross slope is not detectable, they can very easily follow the driveway out into the street. Indicators other than cross slope should be provided, and can be as simple as a change in surface texture indicating the edges of the pedestrian path.

Another conflict occurs over the detectable warnings for cane users on street-crossing curb-cuts. Most wheelchair users detest them and even find them hazardous or painful, and many users of walkers must stop and lift the walker over them. There is discussion of a resolution for this long-term conflict in the PROWACC (2001) report. (The resolution involves lower, rounded warning profiles, with spacing and row alignment such that wheelchair or walker wheels can pass through the warnings, without having to ride directly over them.)

Wheelchair and other aid users, particularly people using canes, made many observations indicating that changes in the pedestrian path are much more difficult to traverse than a constant cross slope. The most noted changes were warp, such as driveway flares or multidirectional curb cuts, and changes in level at expansion joints or other breaks in the sidewalk. Besides impeding mobility, these changes are hazardous and often result in injury. Keeping aware of and adjusting for these changes is very tiring, both physically and mentally, more so than the physical exertion of maintaining forward motion on a constant slope. Cane users, in particular, often have balance problems and have to concentrate very hard on changes in cross slope to avoid falling. Wheelchair users are in danger of tipping over on extreme cross slopes (e.g., cross slopes of 13 percent or higher).

During transportation to test sites, several participants observed sidewalks that were narrow, close to the street, and contained frequent flared driveway crossings, and stated that if they had to take that route, they would have to find some other method of getting there than using the sidewalk.

While participating in the tests, many wheelchair users, although following the test path of travel as directed and usually without much apparent difficulty, also demonstrated their normal means of sidewalk travel, which is to avoid the driveway cross slope by going to the top of the driveway where it flattens out, and coming back down to the sidewalk at the other side. Apparently the short primary slope traverse involved is easier than the longer forward cross slope traverse. There are recommended design guidelines for driveway crossings which mimic this pattern, without any primary or cross-slope traverse.

Elderly participants recruited from retirement homes and assisted living centers walked a great deal for exercise and health reasons and tended to report a high perceived level of fitness regardless of medical condition. However, these participants also had nowhere to go that was accessible by sidewalk and relied on vehicular transportation to go anywhere, usually provided by others. These residential facilities are typically located on marginal real estate at the metropolitan edges, near major traffic arteries, but far from public transportation, shopping, and services. Residents walk interior hallways or around the exterior grounds for exercise. Where public transportation was available, getting to the stops often involved crossing the major traffic artery, which is very hazardous for most of these elderly pedestrians.

Finally, sidewalk users with mobility impairments, the true users who have to use sidewalks to get around, said that they do whatever they have to do to get where they have to go. Except for the most fit, they also described how tired they became and how health problems became exacerbated or injuries occurred. Others described their evolution (or devolution) from walking with a cane or crutches, to a manual chair, to an electric wheelchair simply because they became so tired or because their condition worsened. Sidewalk design in itself is very important, but cannot by itself overcome an inhospitable pedestrian environment of long distances between public transportation stops and services, conflicts with vehicular traffic, and lack of shade or other amenities. Such issues are, however, beyond the scope of this project.

### Field Surveys

The field surveys were conducted under actual outdoor travel conditions during daylight hours and required subjects to traverse a series of delineated sections with varying cross slopes and other attributes. Tables 4.8, 4.9, and 4.10 provide the data corresponding to these sites.

## Table 4.8. Guadalupe Street Field Survey

| Number | Section | Length (ft) | Main Slope (%) | Cross Slope (%) | Description |
|---|---|---|---|---|---|
| 1 | 31 | 34.75 | 1.80 | 8.33 | Jiffy Lube Guadalupe driveway |
| 2 | 51 | 20.58 | 2.87 | 13.77 | Avenel Apartments south driveway |
| 3 | 52 | 18.92 | 3.00 | 12.80 | Avenel Apartments north driveway |
| 4 | 34 | 11.25 | 8.30 | 5.40 | 38 1/2th Street north sidewalk ramp |
| 5 | 33 | 37.00 | 1.78 | 5.12 | XpressLube Car Wash sidewalk |
| 6 | 35 | 14.75 | 0.60 | 9.00 | XpressLube Car Wash north driveway |
| 7 | 36 | 33.00 | 1.94 | 2.50 | Sidewalk north of XpressLube Car Wash |
| 8 | 53 | 19.00 | 1.37 | 7.10 | 517 West 39th west driveway |
| 9 | 8 | 31.17 | 2.47 | 2.67 | Rooster Andrews south driveway |
|  | **Total** | **220.42** |  |  |  |
|  | **Avgs.** | **24.49** | **2.33** | **6.80** |  |

## Table 4.9. South Lamar Boulevard Field Survey

| Number | Section | Length (ft) | Main Slope (%) | Cross Slope (%) | Description |
|---|---|---|---|---|---|
| 1 | 10 | 30.00 | 1.00 | 0.67 | Down Under Auto Sales south driveway |
| 2 | 7 | 21.00 | 2.43 | 2.58 | CPA sidewalk |
| 3 | 22 | 45.83 | 1.64 | 4.86 | FUMC south driveway |
| 4 | 23 | 74.00 | 1.34 | 2.63 | FUMC north driveway |
| 5 | 44 | 36.83 | 1.74 | 0.41 | Sidewalk at Bus Stop north of FUMC |
| 6 | 21 | 30.75 | 0.70 | 1.80 | Matt's El Rancho south driveway |
| 7 | 6 | 95.75 | 6.28 | 1.25 | Village Trailer Park sidewalk |
|  | **Total** | **334.17** |  |  |  |
|  | **Avgs.** | **47.74** | **2.82** | **2.04** |  |

**Table 4.10. Faith United Methodist Church (FUMC) Parking Lot Field Survey**

| Number | Section | Length (ft) (1-way) | Main Slope (%) (outbound) | Cross Slope (%) | Description |
|---|---|---|---|---|---|
| 1 | 61 | 110.00 | 1.18 | 6.15 | FUMC 1st Section – south end of parking lot west to east |
| | 62 | 17.75 | -6.15 | 1.00 | FUMC end 1st Section to beg 2nd Section |
| 2 | 63 | 114.67 | 1.33 | 5.98 | FUMC 2nd Section – north of 1st Section east to west |
| | 64 | 30.42 | -5.80 | 1.45 | FUMC end 2nd Section to beg 3rd Section |
| 3 | 65 | 112.75 | 1.43 | 5.28 | FUMC 3rd Section – north of 2nd Section west to east |
| | 66 | 18.00 | -5.50 | 0.80 | FUMC end 3rd Section to beg 4th Section |
| 4 | 67 | 103.75 | 1.05 | 5.20 | FUMC 4th Section – north of 3rd Section east to west |
| | 68 | 30.08 | -4.65 | 0.25 | FUMC end 4th Section to beg 5th Section |
| 5 | 69 | 85.83 | -0.90 | 4.85 | FUMC 5th Section – north of 4th Section west to east |
| | **Total Dist.** | **623.25** | | | |
| | **Averages** | **69.25** | **1.85** | **4.81** | |

In Table 4.10's description of the long parking lot sites, note that the first direction of the first four numbered sections were uphill, while the return was downhill. The fifth numbered section was downhill first, and uphill on the return. The relatively short section legs in between connect one major section to the next; thus, there are only four of these short sections. These were all downhill. "Turnaround" heart rate readings were taken at the end of the long sections, before turning around and going back. The heart rate was taken there and at the end of the return leg, before starting the short leg to the long section.

Table 4.11 provides the basic statistics for the attributes of the various test sections used along the three sites (9 along Guadalupe Street, 7 along Lamar Blvd., and 5 main sections at the FUMC). As evident, a variety of cross slopes and primary slopes were obtained, particularly on the Guadalupe Street sites, where conditions were most rigorous.

### Table 4.11. Basic Statistics for Attributes of Sidewalk Survey Sites

| Survey Sites | Attributes | Mean | Std.Dev. | Max | Min | **Model** |
|---|---|---|---|---|---|---|
| Guadalupe Street (9 sites) | Primary Slope (%) | 2.681 | 2.23 | 8.300 | 0.600 | OP[*] |
| | Cross Slope (%) | 7.410 | 4.01 | 13.77 | 2.500 | OP |
| | Length (ft) | 24.49 | 9.52 | 37.0 | 11.25 | OP |
| South Lamar Boulevard (7 sites) | Primary Slope (%) | -1.267 | 2.68 | 2.43 | -6.28 | OP |
| | Cross Slope (%) | 2.029 | 1.52 | 4.86 | 0.410 | OP |
| | Length (ft) | 47.74 | 27.2 | 95.75 | 21.0 | OP |
| Faith United Methodist Church Parking Lot (5 long sections) | Primary Slope[§] (%) | 0.815 | 0.969 | 1.425 | -0.900 | RE[**] |
| | Cross Slope (%) | 5.490 | 0.550 | 6.150 | 4.850 | RE |
| | Length (ft) – 1 direction | 105.4 | 11.7 | 114.6 | 85.8 | RE |

* OP = Ordered Probit Model of Sidewalk Discomfort Assessment

** RE = Random-Effects Model of Heart-Rate Changes

§ Primary slope was somewhat negated in the models because participants traversed the sections forward and back (in order to better stabilize heart rates).

Subjects were instructed to traverse the sidewalk sections at a comfortable pace, pausing as needed and simulating the way they would typically use a sidewalk. After traversing each section, subjects were asked to rank their comfort level on a scale of 1 to 5, with 1 signifying "very comfortable" and 5 signifying "very uncomfortable."[1]

Eight variables were observed for each sidewalk section: cross slope, primary slope, width, distance, setback from road, wet or dry pavement, the participant's comfort assessment, and the participants pre-assessment of the section's difficulty[2]. In addition, subjects were asked to provide a reason for their discomfort if they responded with a 3 or less on the comfort scale. Age, gender, fitness level, type of disability, and mobility aid were also recorded as explanatory variables. Information on and responses for all participants are provided in Appendix C.

Ease of sidewalk use is the objective of ADAAG design standards in this area, so the surveys focused on perceived comfort of subjects in traversing the sections. However, there was a need to establish a link between perceived comfort (or lack thereof) and a more scientific measure of physical effort. According to Kirkpatrick and Birnbaum (1997), the most reliable indication of physical effort is heart-rate measurement. Because heart rate increases in a linear fashion in relation to work and oxygen uptake during exercise, its measurement is therefore an appropriate way to test the correlation between perceived and actual effort (Williams and Wilkins, 1998*)*. Athletic-type pulse meters, which measure the heart rate in the earlobe and display the rate in beats per minute, were used to record heart rates.

Research on heart-rate measurement indicates that heart rates stabilize after 2 minutes of activity, but that 5 to 6 minutes of activity provide the most accurate measure of physical effort (Astrand et al. 1970). To get distances across a continuous sloping surface that would provide the necessary time of activity, a route of five sections was configured in a parking lot with both primary and cross slope. Subjects traversed each section in both directions (out and return), extending the exercise (and thus further stabilizing the working heart rate)—but largely negating the effect of primary slope (since outbound slopes were the opposite of inbound slopes). Sections were traversed in succession without stopping.[3] If a subject had to stop to rest, the test was stopped at that point, as the effect of continuous activity on heart rate would have been lost upon continuation. A resting heart rate was obtained and recorded before starting the test. Heart rates were recorded at each end of each section traverse; and traverse times were recorded for each total section traverse. As in the sidewalk sections, comfort-level responses were recorded for each section.

Out of 50 participants, only 40 completed the *entire* sequence of five parking-lot sections. Seven of the ten who did not provide a full set of data actually attempted but could not complete the sequence of five sections. Of these, some were in poor health and found the distance too great to complete without stopping. Some became tired and stopped because they had already overexerted themselves on a previous test. Of the three participants who did not provide a complete set of usable data for the parking-lot tests, one became ill and never attempted the test. Another very elderly female participant chose not to attempt the test. And the very first participant to complete the test did so in a different manner from all the following participants, so those results were not included in the dataset.

The *entire* sequence of five parking-lot sections was completed by twenty men and twenty women (as well as several more, from the 1999 data). Charts 4.1 through 4.3 illustrate average heart-rate changes in relation to slope for the forty observations obtained in the recent 2001 survey. Heart rate data for five women were dropped from the chart data because their recorded heart rates fell significantly from the resting heart rate. Three of the women had stated that, due to their medical condition and/or treatment, their vascularity had changed so that blood flow to the extremities was decreased and a pulse was hard to obtain, especially during exercise. It is likely that this decrease prevented the earlobe monitor from properly registering the heart rate, but in any case the recorded data were probably in error and were not included in the chart data (nor in the subsequent analyses).

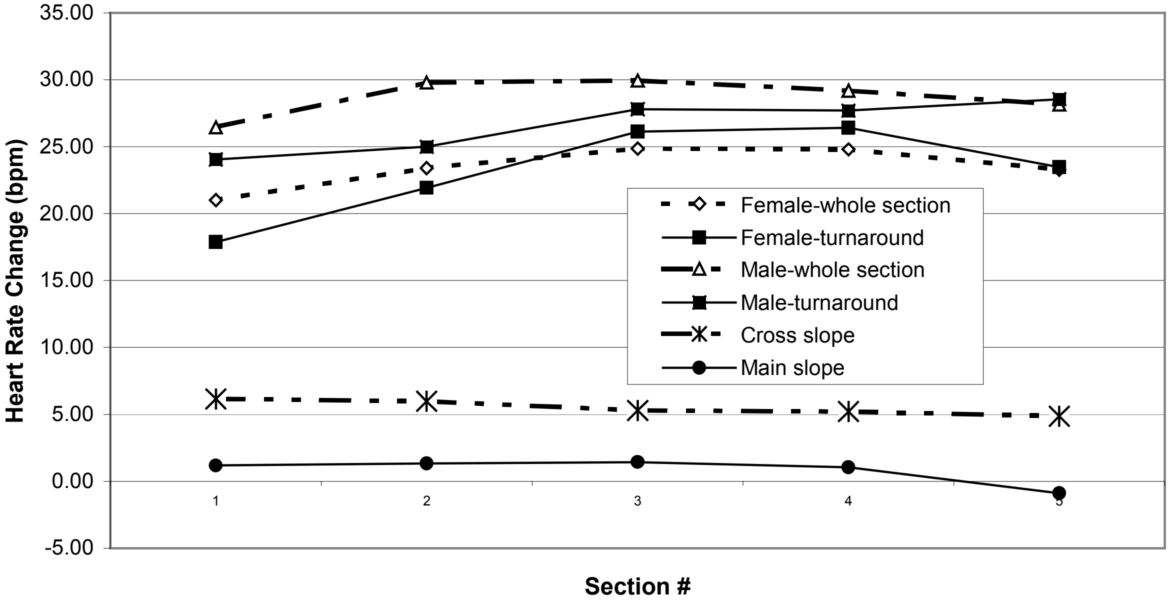


**Chart 4.1. Heart-Rate Changes and Cross and Main Slopes Across FUMC Sections**

Chart 4.1 has four heart-rate lines; two for men and two for women. Among these four, two represent one-way changes (mainly uphill, and taken at the "turnaround" point), and two represent out-and-back changes. Heart rate readings were taken at the turnaround points as well as at the end of the long return leg, before starting the short leg leading to the next long section. The results indicate that the average heart-rate change from resting was higher for men than for women. Men also started with a higher resting heart rate, recorded at an average of 68.5 bpm (beats per minute) compared to women at 63.8 bpm. Measurements of heart-rate changes for whole sections (i.e., out and back) give an indication of the effects of cross slope without main slope; measurements at the turnaround point include the effects of main slope. The average heart rate for women changes in accordance with the indications of the Astrand (1970) study, with heart rates stabilizing after Section 2 (a little over two minutes average time) and then dropping at the end of the test (5 to 6 minutes average time). The heart-rate changes for men follow this pattern for changes at the completion of the sections but not for heart-rate change at the turnaround point, indicating an inverse relationship to main slope.

The two superimposed black lines show the increase from resting heart rate to the first heart-rate reading at the turnaround point at the first section. Women started at zero because the heart-rate change is the first heart-rate reading minus the resting heart rate. The starting point of the black line for men is proportionately above that because their resting heart rate was higher. Section 5's main slope is only slightly negative (-.90) so it reads more as flat. Chart 4.2 provides speed information, which explains part of the male-versus-female heart-rate-change differences. Chart 4.3 illustrates the effect of main slope in each direction.

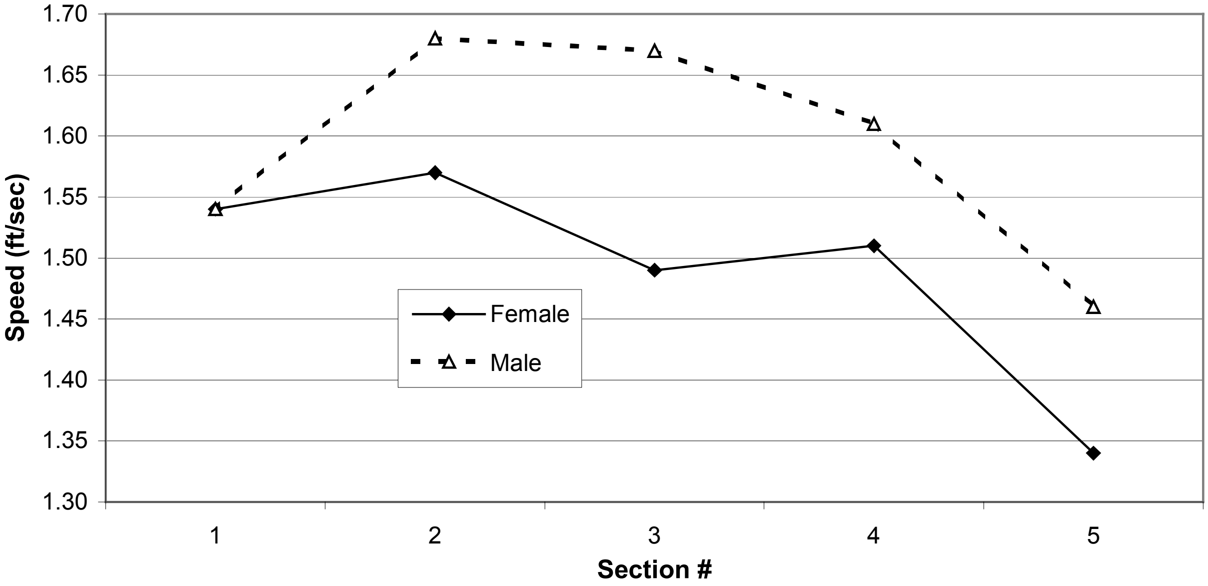


**Chart 4.2. Average Participant Speed (ft/sec) by Section (on FUMC Parking Lot)**

Chart 4.2 indicates a faster rate of travel in feet per second for men than for women, explaining higher pulse rates. The average time of completion for all five sections was 356.65 seconds for men, compared to 470.21 seconds for women.

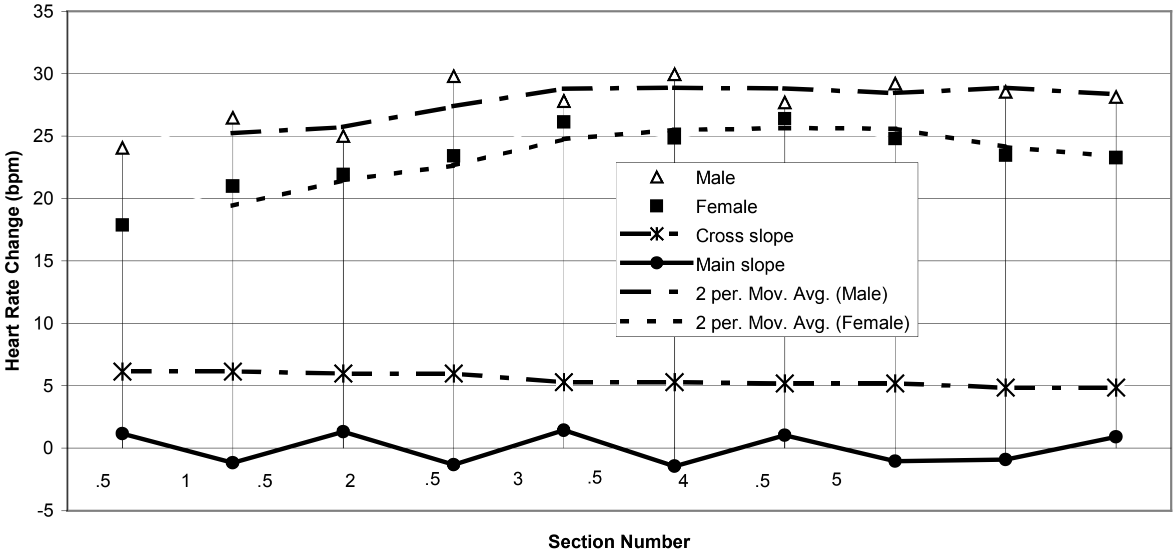


**Chart 4.3. Combined Heart-Rate Changes over Slopes in Both Directions**

Chart 4.3 again indicates that heart rates for women follow the expected model in relation to slope, but heart rates for men are inverse to main slope. Indications are that men tended to go faster and increase their heart rate on the "downhill" or return portion of each section. The main slope graph shows that slope broke pattern from Section 4 to the Section 5 turnaround point, remaining constant rather than increasing. Given the tendency of male subjects to increased heart rate on the downhill sections, this would explain the upturn of men's rates at the turnaround of Section 5 in Chart 4.1. The moving averages for both measurements (turnaround and end of section) follow the expected model for both men and women, indicating that the methodology of measuring effort through heart rate across 5 to 6 minutes of exercise is appropriate.

As mentioned above, several female participants actually experienced heart-rate reductions, as measured by the pulse monitors connected to their ear lobes. Participants number 1, 3, 9, and 18 all indicated that they expected problems in measuring their heart rates. Evidently, paraplegia can cause blood flow reductions in corporal extremities, such as the ear lobe, when people are exercising. Another healthy young female participant, respondent number 25, had strange heart-rate readings that could not be understood. For purposes of analysis, none of these five participants' data were included in the heart-rate model estimation process (or in the above charts).

# Chapter 5. Data Analysis Methodology

In order to predict comfort perceptions and heart-rate changes for sidewalk sections, this work relies on two statistical methods. One is a linear regression with correlated random effects that minimizes the sum of weighted least squares (WLS) of residuals. This was used to estimate heart-rate changes of the subjects before and after crossing sidewalk sections. The other model is more difficult to estimate because it is based on an ordered-response structure for user perceptions of comfort; it requires maximizing a non-quadratic likelihood function. Table 5.1 describes all variables and their definitions used in the two estimation models.

**Table 5.1. Definitions of Variables Used**

| Variable | Definition |
|---|---|
| ***Dependent variables:*** | |
| Sidewalk Assessment | 1 = Very comfortable to cross, 2 = Comfortable,<br>3 = Neutral, 4 = Uncomfortable,<br>5 = Very uncomfortable |
| Heart-rate Change1 | Change in heart rate (beats per minute [bpm])<br>(= Heart rate at the turning point – Resting heart rate) |
| Heart-rate Change2 | Change in heart rate (beats per minute [bpm])<br>(= Heart rate at the test end point – Resting heart rate) |
| ***Explanatory variables:*** | |
| Facility-related variables: | |
| MSLOPE | Average main slope (or "grade") of the sidewalk (%) |
| MSLOPE2 | Absolute value of MSLOPE |
| CSLOPE | Average cross slope of the sidewalk (%) |
| LENGTH | The length of a sidewalk section for one direction (ft) |
| LENGTH2 | The length of a sidewalk section for two directions (ft)<br>(= 2 * LENGTH) |
| LNLNTH, LNLNTH2 | Natural Log of LENGTH and LENGTH2 |
| HRREST | Resting heart rate of participant (bpm) |
| SPEED | Total section length divided by section completion time (ft/sec) |
| TOTALTIME | Total time negotiating FUMC sections until heart-rate reading taken (sec) |
| Personal variables: | |
| AGE | The age of the survey participant (years) |
| LNAGE | Natural logarithm of the age (in years) of the survey participant |
| MALE | 1 if the subject is a male, 0 otherwise |
| SHAPE | The self-assessed physical fitness level of the subject<br>(5 scales: 1 = very poor shape; 5 = in great shape) |
| AIDMWC | 1 if the subject used a manual wheelchair, 0 otherwise |
| AIDEWCSC | 1 if the subject used an electrical wheelchair or scooter, 0 otherwise |
| BLIND | 1 if the subject is legally blind, 0 otherwise |
| AIDCACRB | 1 if the subject used a cane or crutch or brace, 0 otherwise |
| AIDWALK | 1 if the subject used a walker, 0 otherwise |

Note: [*Variable Name*]W in the results presentation of the following chapter is the transformed variable with weighting factors.

## Random Effects Model of Heart Rate Changes

The heart-rate changes were calculated by subtracting the heart rate at the starting point from that at the ending point of the long, parking-lot survey sections. These changes can be explained by several explanatory variables, such as the section's primary slope, its cross slope, its length, and the gender, age, and physical shape of the participant.

The standard regression technique of ordinary least squares (OLS) is not best suited for this form of survey data since the error terms of the regression are very likely to be correlated across subjects, test sections, or both. Therefore, two-way and one-way random-effects models were investigated here; these estimate the correlations and construct an appropriate covariance matrix estimate to serve as a weight matrix. Then a weighted least squares (WLS) regression is run, resulting in more efficient predictions and (hopefully) unbiased estimates of estimator variance. (For a more detailed description of these statistical models, see, *e.g.*, Greene 2000.)

In a two-way random-effects model, the error terms are divided into three components: an individual-specific error, a test section-specific error, and a purely random error.

$$\begin{aligned} &Y_{in} = \vec{X}'_{in}\vec{\beta} + v_{in} \\ &\text{where } v_{in} = \alpha_i + \lambda_n + u_{in} \end{aligned} \tag{1}$$

In this model $Y_{in}$ is the heart-rate change of participant *n* on survey section *i*, $\vec{X}_{in}$ is the matrix of explanatory variables detailing this participant and the section, and $v_{in}$ is a total error term. The total error term is hypothesized to consist of $\alpha_i$, an error specific to the test section *i*, $\lambda_n$, an error specific to individual *n*, and $u_{in}$, a purely random error uniquely specific to person *n* on test section *i*.

Using the correlations of these different random components, three different weight matrices were prepared here. One was for the one-way random-effects model based on a test section-specific error term, another was for an individual-specific error term, and a third was for the two-way random-effects model shown in Eq. (1).

Correlations of the two-way model's error terms are shown in Eq. (2). The resulting weight/covariance matrix is shown in Eq. (3). Note that the off-diagonal elements of all off-diagonal sub-matrices are zero. And, under each of the one-way hypotheses, all off-block-diagonal sub-matrices are purely zero. For example, where only test-section correlations are present, $\Omega_{mn} = 0 \;\; for \;\; m \neq n$.

$$Corr(v_{im}, v_{jn}) = \begin{cases} if \;\; m = n, \;\; \rho_{ij} = \dfrac{Cov(\alpha_i, \alpha_j)}{\sigma_i \cdot \sigma_j} = \begin{cases} 1, & for \;\; i = j \\ \rho_{ij}, & otherwise \end{cases} \\ if \;\; m \neq n, \;\; \rho_{mn} = \dfrac{Cov(\lambda_m, \lambda_n)}{\sigma_m \cdot \sigma_n} = \begin{cases} \rho_{mn}, & for \;\; i = j \\ 0, & otherwise \end{cases} \end{cases} \tag{2}$$

where *i* and *j* index individual participants, and *m* and *n* index test sections.

Using the correlations, the weight matrix, W, can be formed as follows:

$$W = \begin{bmatrix} \Omega_1 & \Omega_{12} & \cdots & \Omega_{1N} \\ \Omega_{21} & \Omega_2 & \cdots & \Omega_{2N} \\ \vdots & \vdots & \ddots & \vdots \\ \Omega_{N1} & \Omega_{N2} & \cdots & \Omega_N \end{bmatrix}^{-1} \text{ where } \Omega_n = \begin{bmatrix} 1 & \rho_{12} & \cdots & \rho_{1I} \\ \rho_{21} & 1 & \cdots & \rho_{2I} \\ \vdots & \vdots & \ddots & \vdots \\ \rho_{I1} & \rho_{I2} & \cdots & 1 \end{bmatrix} \forall n$$

$$\text{and } \Omega_{mn} = \begin{bmatrix} \rho_{mn} & 0 & \cdots & 0 \\ 0 & \rho_{mn} & \cdots & 0 \\ \vdots & \vdots & \ddots & \vdots \\ 0 & 0 & \cdots & \rho_{mn} \end{bmatrix} \forall n \neq m \ \& \forall i, j \tag{3}$$

As described in the results section of this paper, the one-way random effects corresponding to individual participants were much stronger than those corresponding to the heart-rate test sections. Thus, this one-way random-effects model was the model chosen for all conclusions. This model's correlations and resulting weight matrix can be depicted as follows:

$$Corr(v_{im}, v_{jn}) = \rho_{mn} = \begin{cases} \dfrac{Cov(\lambda_m, \lambda_n)}{\sigma_m \cdot \sigma_n}, \ for\ i = j \\ 0\ , \ otherwise \end{cases} \tag{4}$$

$$W = \begin{bmatrix} \Omega_1 & \Omega_{12} & \cdots & \Omega_{1I} \\ \Omega_{21} & \Omega_2 & \cdots & \Omega_{2I} \\ \vdots & \vdots & \ddots & \vdots \\ \Omega_{I1} & \Omega_{I2} & \cdots & \Omega_I \end{bmatrix}^{-1} \text{ where } \Omega_i = \begin{bmatrix} 1 & \rho_{12} & \cdots & \rho_{1N} \\ \rho_{21} & 1 & \cdots & \rho_{2N} \\ \vdots & \vdots & \ddots & \vdots \\ \rho_{N1} & \rho_{N2} & \cdots & 1 \end{bmatrix} \forall i \tag{5}$$

Using the weight matrix, $W$, the estimator of a heart-rate change regression is as follows:

$$\hat{\beta}_{WLS} = (X'W\,X)^{-1}(X'W\,Y) \tag{6}$$

A two-step estimation method was used to incorporate weighting factors for national representation and for random effect correlations. In the first step, an OLS regression model was estimated using transformed $x$ and $y$ variables, where the original variables (including the constant vector) had been multiplied by the square root of the national weighting factor. The residuals of this model were then used to estimate a random-effects correlation matrix (by considering within-person and within-site covariances across residuals, relative to overall variances). In the one-way model case where correlations arise within persons (indexed by $n$) and not within sites (indexed by $i$), he correlation coefficient was calculated by the following equation:

$$\hat{\rho}_{persons} = \frac{\sum_{n=1}^{N}\left\{\sum_{i\neq j}^{I}(\hat{\varepsilon}_{in}\times\hat{\varepsilon}_{jn}) \Big/ \big(I_n(I_n-1)/2\big)\right\}}{\left(\sum_{n}^{N}\sum_{i}^{I}\hat{\varepsilon}_{in}^{2} \Big/ (I\times N)\right)} \tag{7}$$

In the second step of the estimation process, a WLS model was estimated using the inverse of the random-effects correlation matrix estimate as the weight matrix *W* and data transformed as described above (to correct for sample biases, relative to the national representation).

**Ordered Probit Model of Discomfort**

In the assessment of test section difficulty via participant discomfort, the allowed response levels are discrete but ordered, across five levels: “very comfortable” (index 1) through “very uncomfortable” (index 5). Underlying each of these five values is hypothesized to be a latent value of discomfort. The boundaries distinguishing these underlying and unobserved continuous perceptions of discomfort are estimated as “threshold” values, via an ordered-probit model. In such models, unobserved variation (in participants and test sections here) in latent discomfort is incorporated via a standard normal error-term distribution, as follows:

$$T_{in}^{*} = X'_{in}\beta + \varepsilon_{in}, \qquad \varepsilon_{in} \sim iid\ N(0,1) \tag{8}$$

where $T_{\mathrm{in}}^{*}$ is the latent discomfort of an individual *n* traversing section *i* and $X_{in}$ is a vector of attributes describing person *n* and section *i*.

Since the latent value $T_{\mathrm{in}}^{*}$ is unobservable, The resulting observed discrete value of discomfort derives from the latent value $T_{\mathrm{in}}^{*}$ falling into a range between two thresholds, $\psi_{\mathrm{k}}$ and $\psi_{\mathrm{k+1}}$. These relationships between latent and categorized values are as follows:

$$T_{in} = \begin{cases} 1\ \text{(Very comfortable)} & ,\ if\ T_{in}^{*} \le \psi_1 \\ 2\ \text{(Comfortable)} & ,\ if\ \psi_1 < T_{in}^{*} \le \psi_2 \\ 3\ \text{(Neutral)} & ,\ if\ \psi_2 < T_{in}^{*} \le \psi_3 \\ 4\ \text{(Uncomfortable)} & ,\ if\ \psi_3 < T_{in}^{*} \le \psi_4 \\ 5\ \text{(Very uncomfortable)} & ,\ if\ \psi_4 < T_{in}^{*} \end{cases} \tag{9}$$

where the $\psi_{\mathrm{k}}$ are threshold values to be estimated and the $T_{in}$ are the observed discrete response levels. For example, $\psi_2$ defines the threshold value of $T_{in}^{*}$ that distinguishes responses of “Neutral” and “Uncomfortable.”

The probabilities of any individual-test section observation with attributes $X_{in}$ falling into the different response categories can be computed as follows:

$$\begin{aligned} P_n(1) &= \Pr(\text{Very comfortable}) \\ &= \Pr(T_n = 1) = \Pr(T_n^{*} \le \psi_1) = \Pr(X'_n\beta + \varepsilon_n \le \psi_1) \\ &= \Pr(\varepsilon_n \le \psi_1 - X'_n\beta) = \Phi(\psi_1 - X'_n\beta) \\ &\ \vdots \\ P_n(k) &= \Phi(\psi_k - X'_n\beta) - \Phi(\psi_{k-1} - X'_n\beta) \\ &\ \vdots \\ P_n(5) &= \Pr(\text{Very uncomfortable}) \\ &= 1 - \Phi(\psi_4 - X'_n\beta) \end{aligned} \tag{10}$$

where $\Phi(\cdot)$ is the cumulative standard normal distribution function. These probabilities are used in probit estimation software written for GAUSS matrix language. The estimation is conducted using the method of maximum likelihood, which provides an asymptotically maximally efficient set of parameter estimates—assuming the model specification is correct. All observations were weighted according to the ratio of the participant's population representation divided by his or her sample representation. This correction technique is also needed, for estimator unbiasedness.

Another statistical issue which is much more difficult to accommodate involves the duplication of participants in the data set. While it certainly is very useful to test a single person several times (on different sections, in this case), such repetition can dilute the statistical significance of the parameters by introducing cross-error correlations. To make explicit random effects in an ordered-probit specification (similar in spirit to the model used for heart-rate differences) would produce an intractable likelihood function. Maximization of this likelihood (for estimation of parameters) would require simulation. Due to this method's complexity, it was not pursued here. Therefore, it is expected that the resulting t-statistics may be somewhat higher than actual (and the standard errors of parameter estimates somewhat lower than actual).

# Chapter 6. Results

Two sets of results are discussed in this section. They correspond to the two different models (i.e., the random-effects and ordered-probit models), but both are interpreted and applied across the same set of explanatory variables. And the emphasis is on deducing critical cross slopes for a variety of sidewalk users with disabilities. The calculations underlying the critical cross slopes are provided here, and conclusions are drawn in the final section of this report.

## Estimation Results

### *Random-Effects Regression Model of Heart Rates*

Using a version of weighted least squares (WLS) regression (where the weight matrix is a set of correlation estimates), three alternative random-effects models were estimated based on the heart-rate-change data. These models were defined above, and, as noted, the one-way random-effects model for individual-specific error terms turned out to be the most appropriate of the three (based on the level of correlation across effects and model parameter signs and magnitudes). To be able to combine the original, 1999 data set and the current, 2001 data, heart rates were taken after each participant had traversed each section in both directions, thereby negating – to some extent – the effect of main slope (since one direction was uphill and the other was downhill). All heart-rate results shown here are based on this out-and-back response, based on a one-way random-effects model specification (permitting within-person or individual-specific random effects). Note, however, that the 1999 data set did not have data on time-till-completion of each test, a variable which assists in the model's prediction of heart-rate stabilization and permits control for participants' speed variations. (One expects a slight fall in rates as test time increases, and one expects higher heart rates for those who traverse the test sections fastest.) Thus, model estimates based on combined data sets do not control for these useful variables, since time data was only collected in the 2001 data set.

Several models' estimates are shown in this report to give readers a sense of the variations in results, as a function of model specification. Table 6.1 is provided in this section, and is used for computation of critical main slopes. It is a good example of the results of this model's application to the combined out-and-back heart-rate data when only the 2001 data are used, and thus the variables of TOTALTIME and SPEED can be included. Tables C7a and C7b in Appendix C provide models using the combined data sets (but missing time and speed variables), with and without CSLOPE.

Higher main slopes were estimated to produce higher heart-rate changes in all models, even though participants went out and back, negating to some extent the effect of main slope. Cross slope estimates, however, generally ran counter to expectations: under almost all model specifications, cross slope was estimated to be negatively related to heart-rate changes (and thus participant oxygen uptake and effort), everything else constant. In several cases, this cross-slope effect was estimated to be *statistically* significant (as was the main-slope effect). However, the cross-slope effect was *not* of great *practical* significance. Table 6.1's result is not statistically significant; this model predicts every 1 percent increase in cross slope to result in 0.096 fewer heartbeats per minute. In contrast, every increased percent of main grade is predicted to raise heart rates by 17.9 bpm. (Again, each test was run out and back, so half of each test was conducted downhill.)

The reasoning for such apparent heart-rate responses to cross slope may lie in the way the participants tackled the FUMC test sites: if they traversed the more cross sloped – and, thus, more difficult—sections more slowly, they could avoid increasing their heart rates, to some extent. (The speed variable should control for this in a linear sense, however.) Multicollinearity in explanatory variables can also obscure relationships, and the cross slope is strongly correlated with length (LENGTH2) and age (LNAGE), with correlation coefficients of +0.776 and +0.778, respectively. In addition, there was almost perfect correlation ($\rho = +0.942$) between LNAGE and LENGTH2. To test whether this collinearity was affecting the CSLOPE coefficient, the LENGTH variable was removed, but the resulting estimates still produced a negative coefficient estimate on the CSLOPE variable. Table 6.1 does not include a LENGTH variable, but it does include TOTALTIME and SPEED variables, which pick up the effect of length, while recognizing the importance of time.

Another reason for a strange or missing cross-slope effect is the limitation on cross sloping in the data set. Given the need for long test sections (for heart-rate stabilization) with very consistent or constant cross sloping on each section, a parking lot was selected for the heart-rate tests. Unfortunately, its cross slopes varied only between 4.85 and 6.15 percent (Tables 4.10 and 4.11), providing minimal variation for empirical discrimination of cross-slope impacts. Fortunately, the shorter perception tests (as described in Tables 4.8, 4.9, and 4.11) allowed much more variation in cross slopes, and thus resulted in more reasonable model results, as will be discussed in the following section.

Also counter to expectations, those who professed to be less fit were found to experience lesser heart-rate changes. This may be an effect of various factors, including self-characterization of fitness level. (More fit persons may be biased or hold themselves to different standards, characterizing themselves as somewhat less fit.) Or, in certain cases, less physically fit persons may exhibit less of a heart-rate response to travel activities. This was not the research team’s expectation, but it may be the case.

In a result that is consistent with the perception results (described below), males were predicted to experience lower heart-rate increases than the females – after controlling for SPEED choice. As noted in Chapter 4, the average rate of travel was quite a bit faster for men, with the average time of completion of all five parking-lot sections at 356.65 seconds, compared to 470.21 seconds for women. Evidently, the men worked harder on purpose (which was evident to the test proctor, who noticed several of the men essentially competing for time).

The reference mobility aid is a manual wheelchair (MWC), and persons using this device were estimated to experience higher heart-rate changes than all other user types, though the differences are only statistically significant for comparisons with electric wheelchair and scooter users (AIDEWSC). The results suggest that MWC users are the most critical population for heart-rate response (our proxy for effort) – assuming they begin with the same resting heart rate (and controlling for the other typical attributes, besides aid type).

The model’s goodness of fit was not very high: 8.1 percent of the variation in heart-rate changes was effectively explained by the variables controlled for in Table 6.1. However, most of the variables have statistically significant coefficients (i.e., parameter estimates statistically distinct from zero, signifying a measurable effect): t-statistics exceeding 1.96 or falling below –1.96 indicate very statistically significant results (via p-values of 0.05 or less). In addition, the level of within-person correlation was predicted to be very high, at +0.757. Thus, it was very helpful to run this as a random-effects model, recognizing the latent information on each individual that remains constant as he/she crosses different test sections.

**Table 6.1. One-Way Random-Effects Regression Model Results for Heart-Rate Changes**
*(Based on 2001 Data)*

| Variables | Coefficients | Std. Err. | t-stats |
|---|---|---|---|
| UNOW | 59.85 | 26.06 | 2.30* |
| MSLOPE2W | 17.90 | 6.241 | 2.86* |
| CSLOPEW | -0.0958 | 1.897 | -0.051 |
| SHAPEW | 6.013 | 2.367 | 2.54* |
| AGEW | -0.218 | 0.1476 | -1.48 |
| MALEW | -6.929 | 5.662 | -1.22 |
| TOTALTIMEW | -0.0675 | 0.0534 | -1.26 |
| SPEEDW | -43.99 | 19.85 | -2.22* |
| AIDWALKW | -6.415 | 11.33 | -0.566 |
| BLINDW | -6.126 | 26.20 | -0.234 |
| AIDCCBW | -4.693 | 8.759 | -0.536 |
| AIDEWSW | -26.67 | 16.41 | -1.62 |
| $N_{obs}$ | 190 | | |
| Adjusted $R^2$ | 0.081 | | |
| ρ (within person correlation) | 0.757 | | |

*Note: The reference mobility aid device is an AIDMWC.*
* *Statistically significant at the 0.05 significance level.*

*Ordered Probit Response Model of Discomfort*

Table 6.2 provides the ordered-probit response model results, using the 2001 data. Models were run which included the 1999 data as well, and these are provided in Appendix C (Table C8). However, those results showed a significant distinction for the 1999 data, as evidenced by a significant and positive estimate on the coefficient interacted with an indicator variable for YR1999. The distinction may be due to the use of different proctors during the tests, differences in respondent perceptions of response meanings, or other subjective issues. However, it is likely that the cross-slope and main-slope data are not perfectly valid for the older, 1999 observations. Sidewalks offer variable cross-sections and profiles (when one is talking about slopes on the order of 2 to 15 percent); and the 1999 participants were permitted to choose different paths when crossing almost all of the sections chosen for study here.

Thus, the 2001 survey team was unable to completely or satisfactorily reproduce the cross-slope and main-slope data of the first phase's (1999) data set, so those that are considered the current, most correct data for those tests may not be highly consistent with the tests that were actually conducted at that time (given the original proctor's difficulties in recalling the exact pathways of the original tests, two years later). Since the 1999 data are now two years old, rely on data that are very difficult to verify, and provide less than 30 percent of the observations to the ordered-probit models, these results were removed, producing a model of only the 2001 data (as shown in Table 6.2).

In all model cases, the goodness-of-fit measures (a likelihood ratio index or pseudo-$R^2$) were above 0.12, suggesting reasonably good fit for these models of highly subjective human response. Positive signs on coefficients indicate that having more of the associated variable adds to the latent discomfort level—and increases the probabilities of observing relatively high discomfort responses (e.g., 4's and 5's). And, if the latent discomfort rises enough, the expected discomfort level will pass a threshold (but all response types remain possible).

As expected, an increase in the section cross slope, primary slope, and length heighten user discomfort. And the effect of cross slope is more severe than that of main slope: 1 degree of cross slope is estimated to be worth 3.6 degrees of main slope, according to these results (3.6 = .149/.041).[4]

As suggested in the model, older participants were found to be less comfortable, even if they indicated they were in the same physical shape category (1–5) as younger participants. Of course, "shape" is a subjective term, and many older participants probably considered their abilities relative to their peers, rather than relative to the population at large. Males were predicted to feel more comfortable than females, which is consistent with heart-rate model results. And, as expected, persons in better shape experienced less discomfort.

Manual wheelchair (MWC) users were the reference category of user, and estimated to experience slightly less discomfort than the cane, crutch, brace (CACRB) users[5]. Thus, the CACRB users appear to be the critical class of sidewalk user, when considering personal perception. However, as in the case of the heart-rate models, the MWC and CACRB users are predicted to respond rather similarly, in a statistical sense; this suggests that they are both critical users. Those using walkers (WALK), electric wheelchairs, or scooters (EWSC), were predicted to experience the least discomfort, as well as lower heart-rate effects.

**Table 6.2. Ordered Probit Model Results for Discomfort**
(2001 Data only)

| *Variables* | Estimates | Std. Err. | t-stats |
|---|---|---|---|
| Thresh01 | 0.628 | 0.246 | 2.556* |
| Thresh02 | 1.739 | 0.250 | 6.955* |
| Thresh03 | 2.397 | 0.257 | 9.344* |
| Thresh04 | 3.159 | 0.272 | 11.634* |
| MSLOPE | 0.041 | 0.023 | 1.782* |
| CSLOPE | 0.149 | 0.012 | 12.137* |
| LENGTH | 0.011 | 0.003 | 3.469* |
| AGE | 0.006 | 0.002 | 2.499* |
| MALE | -0.364 | 0.090 | -4.022* |
| SHAPE | -0.112 | 0.034 | -3.267* |
| AIDWALK | -0.694 | 0.163 | -4.265* |
| BLIND | -0.281 | 0.407 | -0.691 |
| AIDCACRB | 0.180 | 0.130 | 1.387 |
| AIDEWCSC | -0.428 | 0.239 | -1.791* |
| Num. of Observations | 743 | | |
| Log-L (Constant) | -981.670 | | |
| Log-L (Restricted) | -855.895 | | |
| LRI** | 0.128 | | |

### Calculation of Critical Cross Slopes (and Main Slopes)

The estimation results shown in Table 6.2 assist estimation of “critical cross slopes,” which are defined as those cross slopes placing specific user types into unacceptable levels of effort or discomfort. This section describes such an application, by estimating the critical traversable cross slopes for various sidewalk situations involving several user types. This analysis is only performed using the assessment/discomfort data, because, as described above, cross slope was not estimated to increase heart rates. However, using a highly similar approach, critical main slopes have been computed based on the heart-rate results. And these are discussed first.

#### *Random-Effects Model of Heart Rate Changes*

As described earlier, heart-rate data were gathered from a large parking lot, where test-section lengths were long enough for heart-rate stabilization. However, due to site constraints cross slopes were not highly varied; the minimum cross slope value was 4.8 percent, and the maximum was 6.15 percent. An analysis of these data was unable to find a positive effect of cross slope on heart rate; the impacts of cross slope were ambiguous. Expectations of effort are that cross slope should increase effort and thus heart rate; however, individuals’ compensation mechanisms (such as slowing) and the correlation with other explanatory variables can obfuscate such relationships, particularly when deviations in this variable are minimal. However, as expected, heart-rate changes were predicted to rise with higher main slopes (even when rates were measured after participants had gone out and back, on opposing main slopes), longer sections, and manual wheelchairs users. After controlling for variables like fitness level and resting heart rate, age contributed in a negative way to heart-rate estimates. Assuming two-way movements, critical *main* slopes computed on the basis of these results lie between 8.8 percent and 9.9 percent (as shown below, in Table 6.3).

A 60-percent increase in heart rate, from a resting rate, was estimated to be critical by Kockelman et al. (2001), since this was the average increase associated with hitting a training or target heart rate of 75 percent of one’s maximum, calculated using the following standard formulae:

Max Heart Rate = 220 – Age (for males) & 226 – Age (for females)[6]

However, of the 17 persons sampled in 1999, the average resting heart rate was found to be 85.4 bpm; in 2001, it was just 65.3 bpm.[7] Thus, the average percent increase to achieve the target of 75 percent was much higher for the 2001 data set, as a function of the participant’s resting heart rates; in fact, it averaged 106 percent. Adjusting the target down, to 70 percent, was equivalent to a 92 percent increase, relative to resting rates. This more conservative level was used here, for computation of critical main-slopes. The following equation indicates how one can compute the critical main slope for a person *n*:

$$Critical\ Main\ Slope_{in} = \left(1/\hat{\beta}_{MSLOPEW}\right)\begin{pmatrix} 0.92\times HHREST_n - \hat{\beta}_{CONSTW} - \hat{\beta}_{CSLOPEW}CSLOPE_i \\ -\hat{\beta}_{SHAPEW}SHAPE_n - \hat{\beta}_{AGEW}SHAPE_n - \hat{\beta}_{MALEW}MALE_n \\ -\hat{\beta}_{AIDWAKW}AIDWAK_n - \hat{\beta}_{BLNDW}BLND_n \\ -\hat{\beta}_{AIDCCBW}AIDCCB_n - \hat{\beta}_{AIDEWSW}AIDEWS_n \end{pmatrix} \quad (11)$$

where $\hat{\beta}_x$ is the parameter estimate for variable *x* and $HHREST_n$ is the resting heart rate of an individual *n*.

As shown in Table 6.3, several person-site cases are examined for critical main-slopes, following the rule of a 92 percent increase in heart rate from one's resting rate. Across all these cases, an average (level-3) physical fitness level was assumed as was the 2001 data set's average resting heart rate (of 65.3 bpm). Gender was female (the critical gender) and cross slopes were fixed at zero. However, ages range from 20 to 80, and the four most affected mobility aid classes are examined. The most critical cases are for those using manual wheelchairs, as was discussed earlier.

**Table 6.3. Critical Main Slopes based on Heart Rate Changes (2001 data only)**

| Variables | AIDMWC | | | | AIDCACRB | | | |
|---|---|---|---|---|---|---|---|---|
| | Case1 | Case2 | Case3 | Case4 | Case1 | Case2 | Case3 | Case4 |
| CSLOPE | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| SHAPE | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 |
| AGE | 20 | 40 | 60 | 80 | 20 | 40 | 60 | 80 |
| MALE | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| TTIME | 343.55 | 343.55 | 343.55 | 343.55 | 343.55 | 343.55 | 343.55 | 343.55 |
| SPEED | 3.34 | 3.34 | 3.34 | 3.34 | 3.34 | 3.34 | 3.34 | 3.34 |
| Crit. Mslope (%) | 8.78 | 9.02 | 9.26 | 9.51 | 9.04 | 9.28 | 9.52 | 9.77 |

| **Variables** | BLIND | | | | AIDWALK | | | |
|---|---|---|---|---|---|---|---|---|
| | Case1 | Case2 | Case3 | Case4 | Case1 | Case2 | Case3 | Case4 |
| CSLOPE | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| SHAPE | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 |
| AGE | 20 | 40 | 60 | 80 | 20 | 40 | 60 | 80 |
| MALE | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| TTIME | 343.55 | 343.55 | 343.55 | 343.55 | 343.55 | 343.55 | 343.55 | 343.55 |
| SPEED | 3.34 | 3.34 | 3.34 | 3.34 | 3.34 | 3.34 | 3.34 | 3.34 |
| Crit. Mslope (%) | 9.12 | 9.36 | 9.60 | 9.85 | 9.13 | 9.38 | 9.62 | 9.86 |

### *Ordered Probit Model of Discomfort*

This critical cross-slope analysis yields the estimates of the maximum allowable cross slopes so that no more than 25 percent of users are expected to be uncomfortable or very uncomfortable. In other words, the probability that a user is *not un*comfortable is 0.75. The choice of a 25-percent threshold probability is a judgment call, and engineers and policymakers may care to design more conservatively, or liberally, depending on the specific situation (which will depend on site constraints and other attributes, including likely users and overall route accessibility). Figures and equations are provided here to facilitate the estimation of such probabilities.

The critical cross slope can be calculated for various person-section situations as shown in Table 6.4. The formula for the calculation is shown in Eq. (12). Two main slopes, 0 percent and 5 percent, are considered as well as all disability types. A significant site length of 40 feet was used. The critical gender, female, was used for these computations, and some very high (and thus critical) ages levels are provided: 70 and 80 years. Designing for 80-year-old users may be considered a conservative choice under many situations, since it reduces the critical cross slopes computed. However, the population of the U.S. is aging, so this set of sidewalk users is likely to increase. All situations involve assumption of fitness level 3. Males on shorter sections in better shape will produce predictions of even higher critical cross slopes than those shown here, in Table 6.4.

$$\begin{aligned}
&\mathit{Need}:\ \Pr\left(T_{in}^{*} = X_{in}{}'\beta < \psi_3\right) = 0.75 \\
&\rightarrow \mathit{Critical\ Cross\ Slope}_{in} = \\
&\left(1/\hat{\beta}_{CSLOPE}\right)\begin{pmatrix}
\hat{\mu}_3 - F^{-1}(0.75) - \hat{\beta}_{MSLOPE}MSLOPE_i - \hat{\beta}_{LENGTH}LENGTH_i \\
- \hat{\beta}_{AGE}AGE_n - \hat{\beta}_{MALE}MALE_n - \hat{\beta}_{SHAPE}SHAPE_n \\
- \hat{\beta}_{AIDWAK}AIDWAK_n - \hat{\beta}_{BLND}BLND_n \\
- \hat{\beta}_{AIDACB}AIDCCB_n - \hat{\beta}_{AIDEWS}AIDEWS_n
\end{pmatrix}
\end{aligned} \tag{12}$$

where *n* indicates an individual, *i* indicates a sidewalk section, and $\hat{\mu}_3$ is the estimate of the threshold distinguishing "neutral" from "uncomfortable" response. $F^{-1}(0.75)$ is the inverse function value for a cumulative standard normal distribution function at a probability of 0.75; thus, it's value is 0.674.

**Table 6.4. Critical Cross Slopes based on Perception of Discomfort (2001 Data Only)**

| Variables | Case 1 | Case 2 | Case 3 | Case 4 | Case 5 | Case 6 | Case 7 | Case 8 | Case 9 | Case 10 | Case 11 | Case 12 | Case 13 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| MAINSLP (%) | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 5 | 5 | 5 | 5 | 5 | 5 |
| LENGTH (ft.) | 40 | 40 | 40 | 40 | 40 | 40 | 40 | 40 | 40 | 40 | 40 | 40 | 40 |
| AGE | 20 | 30 | 40 | 50 | 60 | 70 | 80 | 20 | 40 | 50 | 60 | 70 | 80 |
| MALE | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| SHAPE | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 |
| AIDCCB | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| Critical CSLOPE (%) | 8.812 | 8.428 | 8.044 | 7.660 | 7.276 | 6.892 | 6.508 | 7.448 | 6.680 | 6.296 | 5.913 | 5.529 | 5.145 |
| AIDMWC | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| Critical CSLOPE (%) | 10.020 | 9.636 | 9.253 | 8.869 | 8.485 | 8.101 | 7.717 | 8.657 | 7.889 | 7.505 | 7.121 | 6.737 | 6.354 |
| BLIND | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| Critical CSLOPE (%) | 11.911 | 11.527 | 11.143 | 10.760 | 10.376 | 9.992 | 9.608 | 10.548 | 9.780 | 9.396 | 9.012 | 8.628 | 8.245 |
| AIDEWSC | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| Critical CSLOPE (%) | 12.900 | 12.516 | 12.132 | 11.748 | 11.364 | 10.981 | 10.597 | 11.536 | 10.768 | 10.385 | 10.001 | 9.617 | 9.233 |

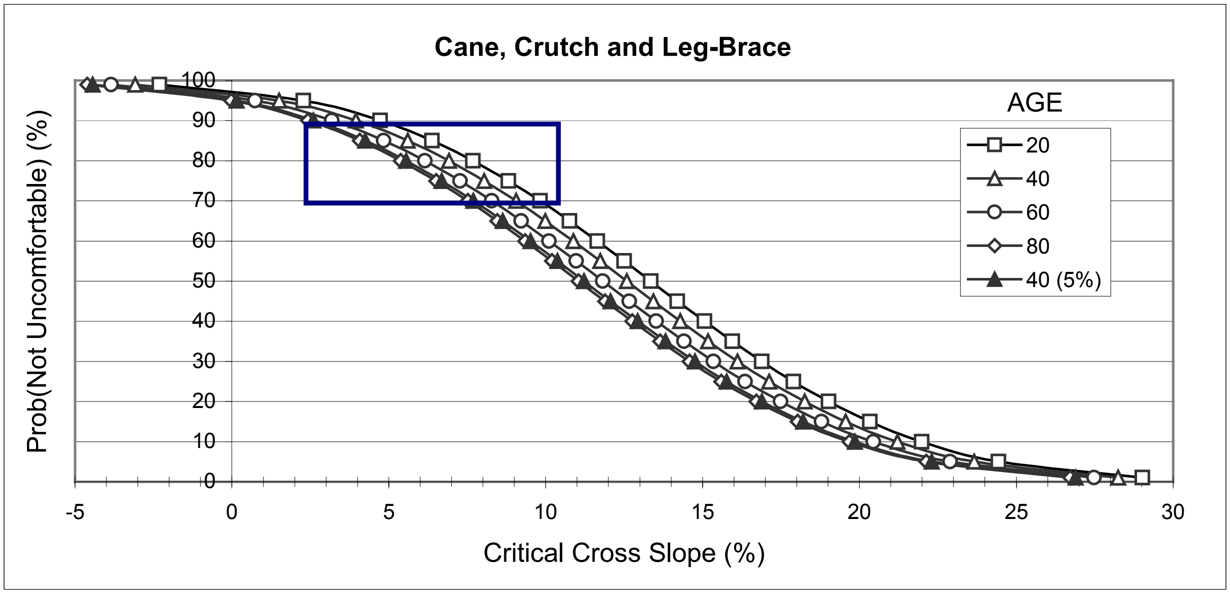
Case 13 is a very difficult case and the most critical shown above, in Table 6.4. It suggests a critical cross slope of 5.14 percent, when primary slope is 5 percent, section length is 40 ft., and the user is an 80-year-old female using the critical mobility aid: a cane or crutch (or leg brace, effectively). For younger users, less severe grades, shorter sections, and different mobility aids, the critical cross slopes are all higher. Table 6.4's predictions are all well above the ADAAG standard of 2 percent.

Assuming that the critical threshold occurs when 25 percent of users predicted to rate a section uncomfortable or very uncomfortable (and the other 75 percent rate it as not uncomfortable), and assuming the critical user group to be an 80 year-old female of "average" fitness using a cane, crutches, or a leg brace, these results recommend a maximum cross slope for design of 5.1 percent, when main slope is 5 percent, and 6.5 percent, when zero main slope exists. The model results of Table 6.2 and the implications of Eq. 12 provide the mechanism for these calculations.

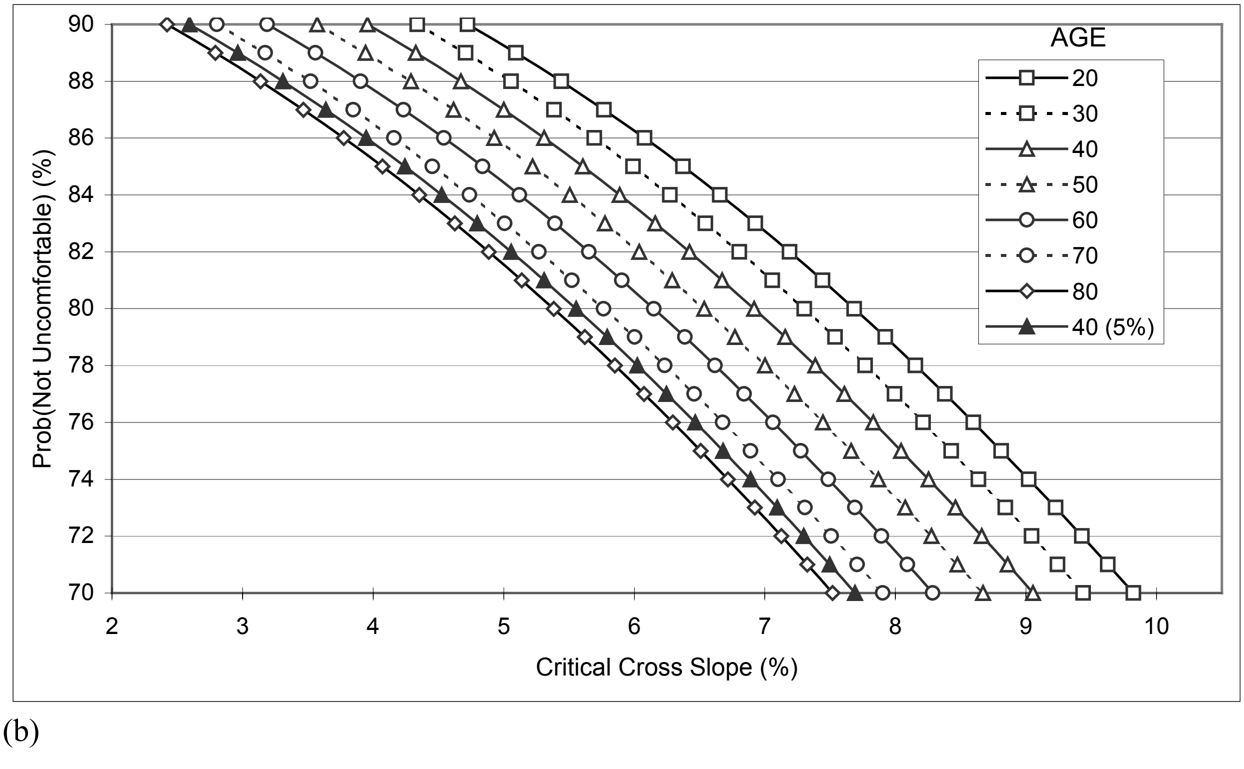
Depending on one's assumption of threshold probability of discomfort, the results can vary. For assumptions other than a 25 percent threshold or to estimate what fraction of certain user classes would be uncomfortable under specific circumstances, one can apply Eq. 12 with Table 13's results in a variety of ways. To facilitate these computations, a series of figures are provided here. Figures 6.1 through 6.3 plot the estimated probabilities of a variety of users *not* being uncomfortable versus cross slope. The sections of most interest are likely to be for probabilities of no discomfort lying between 0.70 and 0.90; notationally:

$$\Pr\left( T_{in}^{*} = X_{in}{}' \beta < \psi_{3} \right) = 0.70 \text{ to } 0.90 \qquad (13)$$

So, in these regions, the figures have been expanded, producing two figures for each of the three most critical mobility types (CACRB, MWC, BLIND).

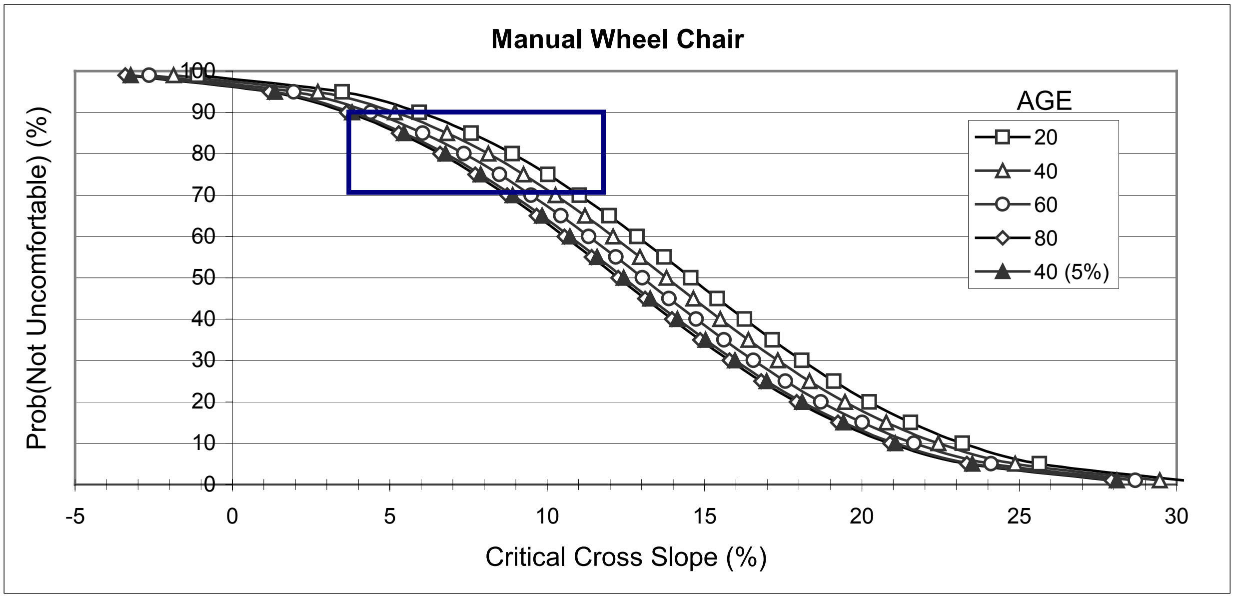


(a)

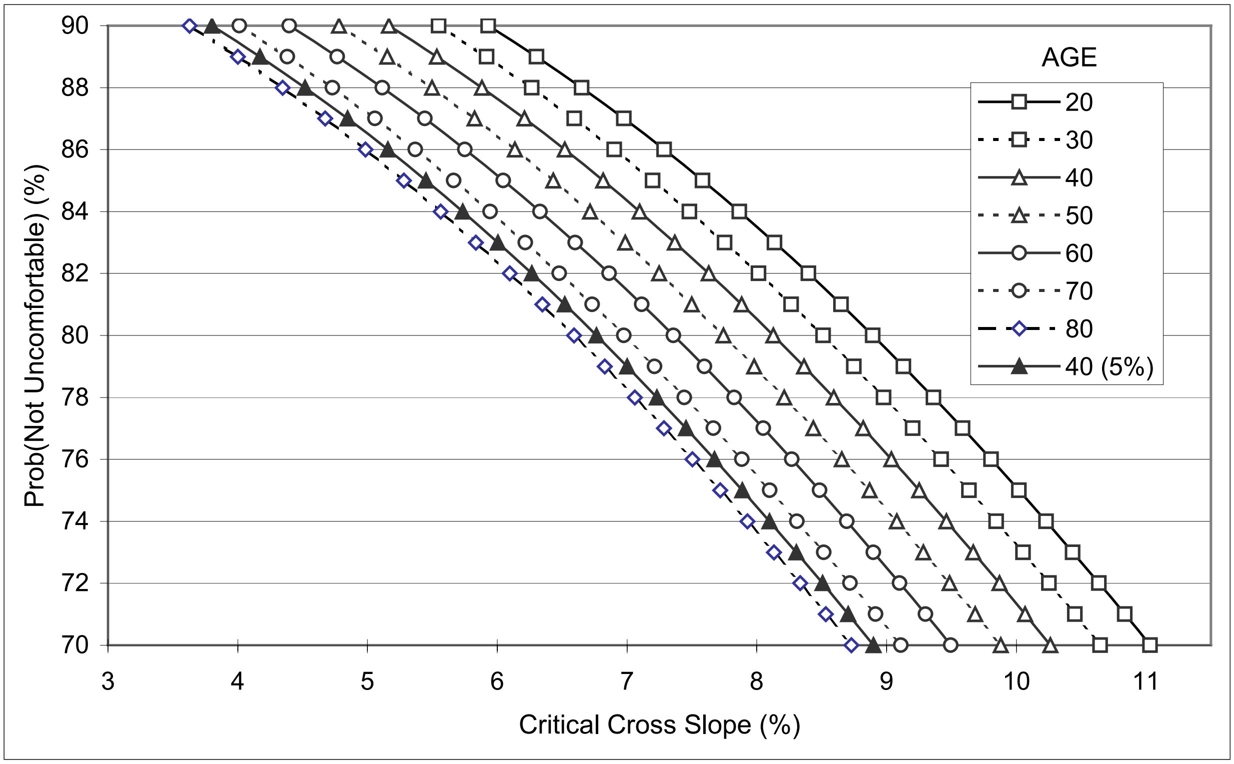


(b)

Figure 6.1. Probability Participant using Cane, Crutch or Leg-brace is Not Uncomfortable (Participant = Female of average physical fitness, 40 ft long sidewalk with 0 percent main slope – unless indicated by the legend to be 5 percent)

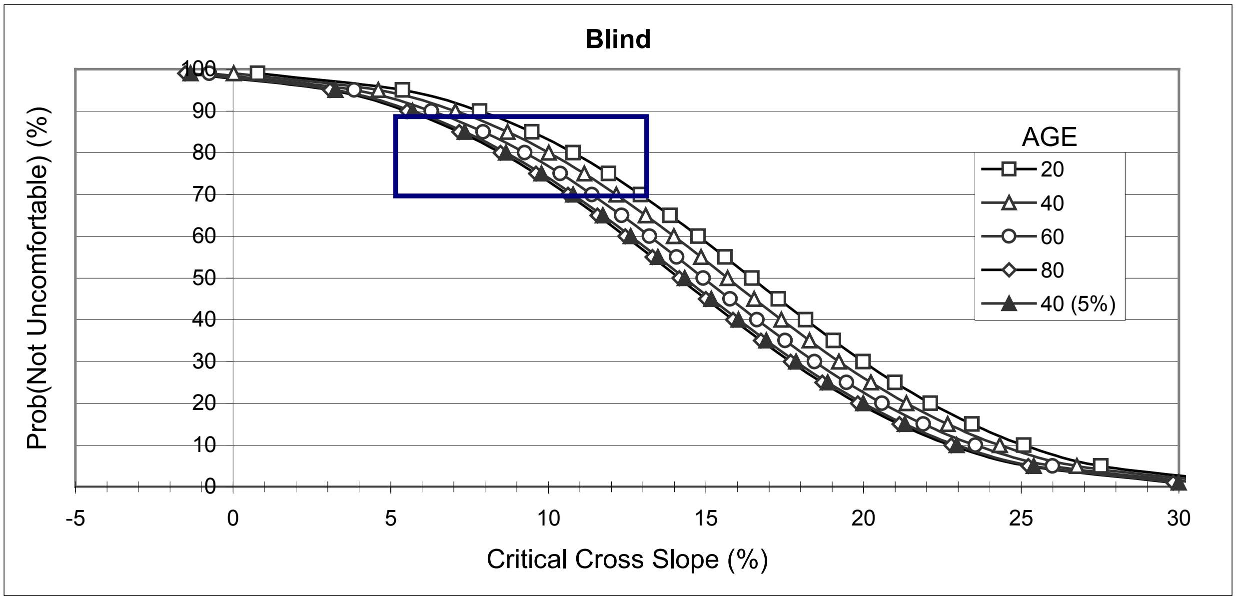


(a)

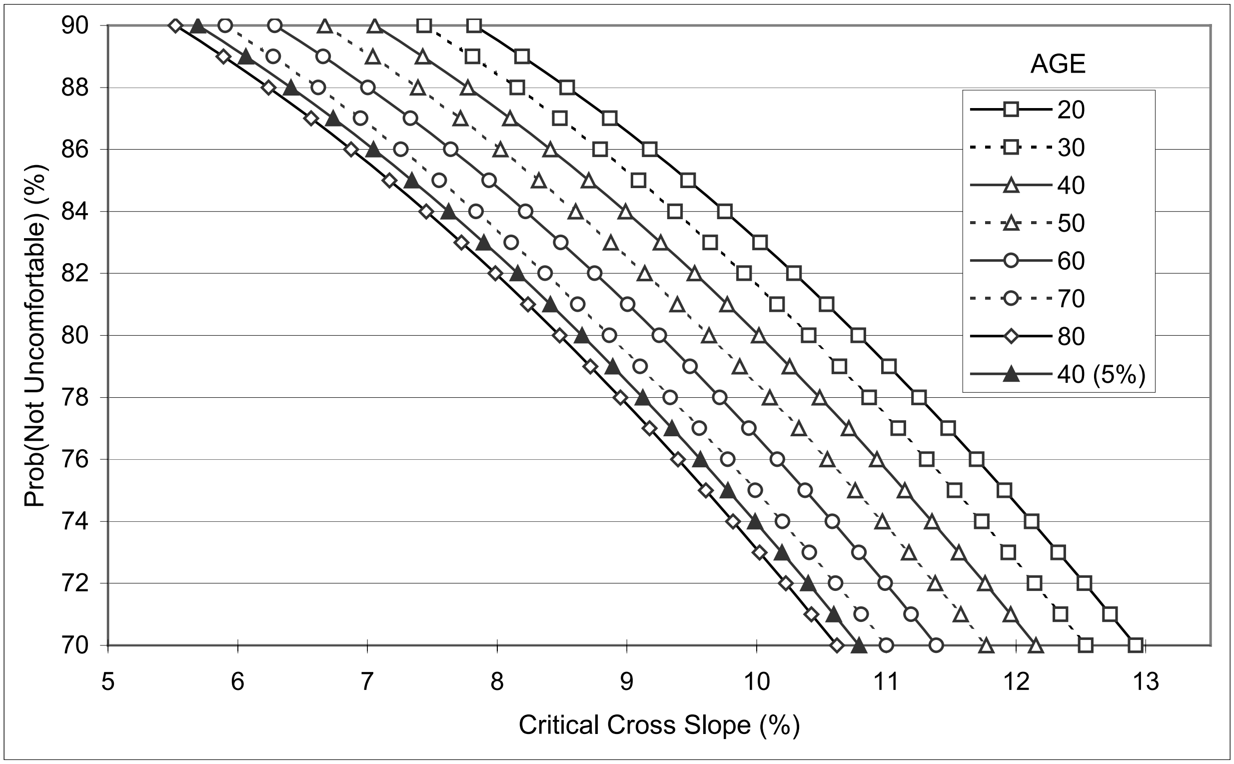


(b)

Figure 6.2. Probability Participant using Manual Wheelchair is Not Uncomfortable (Participant = Female of average physical fitness, 40 ft long sidewalk with 0 percent main slope – unless indicated by the legend to be 5 percent)



(a)



(b)

Figure 6.3. Probability Blind Participant (using White Cane) is Not Uncomfortable (Participant = Female of average physical fitness, 40 ft long sidewalk with 0 percent main slope – unless indicated by the legend to be 5 percent)

It is also of interest to consider how many of the critical user populations are unable to comfortably negotiate paths with no cross slope at all. Clearly, if this is a high percentage, it may be impossible to design pathways for such persons without exposing the users to some discomfort (or such high discomfort that they consider the section impassable). Calculations of this nature have been pursued using the input data provided in Table 6.5; the final row of this table provides the model estimates of the percentage of users who would be either uncomfortable or very uncomfortable on such a section (or unable to traverse it at all).

**Table 6.5. Percent of Persons Experiencing Discomfort at Zero Cross Slope (2001 Data Only)**

| Variables | *Case 1* | Case 2 | Case 3 | Case 4 | Case 5 | Case 6 | Case 7 | Case 8 |
|---|---|---|---|---|---|---|---|---|
| CSLOPE | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| MSLOPE | 0 | 5 | 0 | 5 | 0 | 5 | 0 | 5 |
| LENGTH | 35 | 35 | 45 | 45 | 35 | 35 | 45 | 45 |
| AGE | 70 | 70 | 70 | 70 | 80 | 80 | 80 | 80 |
| MALE | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| SHAPE | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 |
| AIDCCB | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| Pr(4&5) | 0.0396 | 0.0603 | 0.0504 | 0.0751 | 0.0448 | 0.0674 | 0.0566 | 0.0836 |

According to Table 6.5, there are from 4.0 to 8.4 percent of users in these rather critical categories (females in manual wheelchairs, ages 70 and 80) that would respond as having experienced discomfort on a cross slope of *zero* percent. Under the model assumptions, it is theoretically impossible to find a cross slope where 100 percent of the respondents would not experience discomfort. And this is a reasonable belief about the population: in general, there is always someone who will respond in some fashion. Such distinctions are due to the presence of other variables, such as additional disabilities or high personal sensitivity to sidewalk travel. It may be futile to pursue a policy where everyone is accommodated by a design. In general, good design involves trade-offs; to accommodate 100 percent of a population under all conditions is costly and extremely difficult, if not impossible.

Before closing, it should be mentioned that a threshold slope for many persons taking the tests was on the order of 12 percent: this was noted when several participants could not negotiate survey sites numbers 2 and 3 along the Guadalupe Street set of sections. Such a cross slope seems clearly inaccessible, to a variety of user types. It serves as an upper reference point on this work, and it appears consistent with the model results – which are subject to a much more tolerable definition of accessibility, of course (related to users experiencing discomfort – rather than being wholly unable to cross a section).

# Chapter 7. Conclusions and Recommendations

Two types of sidewalk test-section data across a sample of sixty-four individuals (or sixty-seven test records) were collected for this research. Fourteen of the participants provided seventeen distinct records for a 1999 survey; the other 50 participated in a more recent (2001) effort of highly similar design. The two data response types monitored in these surveys were heart-rate changes (as a proxy for oxygen uptake and thus effort) and user perception of discomfort levels.

The two response types required distinct statistical approaches: a random-effects and an ordered-probit model. Given some criteria of "acceptable" versus "unacceptable" heart-rate changes and user perception levels, both sets of model estimates can then be "inverted" to deduce critical cross slopes for critical conditions and critical populations of persons with disabilities. This computation was done here for the user perception of discomfort data, since these data's results yielded the positive relation expected (between degree of cross-sloping and the discomfort level). This inversion was based on an assumption that a design criterion would be "unacceptable" if it could be expected to cause 25 percent or more of the users of a critical type to consider the section uncomfortable.

Predicted critical cross-slope values for the most severe cases considered ranged from 5.1 to 7.4 percent or more cross sloping. The cases examined included 5 percent primary slope (main grade) and 40-ft long sections. They were traversed by 20- to 80-year-old cane, crutch, or leg brace users. When primary slopes were reduced to 0 percent in the perception estimates, the critical cross slopes for these critical user types rose to 6.5 and 8.8 percent. For other persons with disabilities, the critical cross slopes ranged from 6 percent to 12 percent or more.

The results suggest that cane and crutch users *perceive* the most difficulty with cross sloping; and manual wheelchair users are a close second. Manual wheelchair users were estimated to have the highest *heart-rate* responses to various sidewalk conditions. Together, these two groups represent over 65 percent of the U.S. population of persons with disabilities.

Current ADA cross-slope design regulations for public sidewalks indicate a maximum design standard of 2 percent; this requirement is less than one half of the values estimated to be critical here. The results obtained here suggest that cross slopes greater than 2 percent should be considered a possible design strategy when right-of-way or other construction limitations make 2 percent cross slopes a costly endeavor. Moreover, such cross sloping should be considered in concert with other factors, such as the length of the section and type of likely users. The results provided in this report provide methods for evaluating the accessibility of any number of sidewalk sections, based on length, cross slope, main slope, and user characteristics. Also, the study provides a method for estimating the percentage of sidewalk users who will experience discomfort when no cross sloping and/or no main sloping exists. Such users may have other mobility issues that the public cannot address through regulation of sidewalk cross-slope design, so a 100-percent-of-users rule may be impossible to meet.

This research provides rigorous experimental support and other documentation for assessing requests for variances to the sidewalk cross-slope standards held by the U.S. Access Board and the Texas Department of Licensing and Regulation. The research results suggest that cross slopes as high as 10 percent are accessible to a wide variety of disabled persons. However, 6 percent is the maximum cross slope for designs which accommodate quite elderly manual wheel chair users under adverse main slope conditions (i.e., 5 percent main slope). Based on these results, cross-slopes higher than the current design standards are likely to be highly viable, when needed.

The results of this research support the implementation of cross-slopes of 6 percent or more, when the main slope is minimal, in cases where it is not feasible or is structurally impractical to provide the prescribed cross-slope. When main slopes reach 5 percent, cross slopes of 5 percent may be more reasonable. In terms of a cross slope that is wholly inaccessible to certain users, a critical cross slope for the most sensitive participants in these tests was on the order of 12 percent, a point when these persons could not negotiate two particular survey sites. In locations where the 2 percent standard presents serious design difficulties, the researchers recommend that final plans be allowed to have cross-slopes of up to 10 percent, if main slope is minimal. When main slope is five percent or more, the researchers recommend that cross-slope not exceed 6 percent.

Sidewalk design is a critical consideration when aiming to provide reasonable access to all persons. And access is fundamental to one’s full participation in society. It is hoped that this work will facilitate accessible design for all sidewalk users, particularly those with disabilities.

# Endnotes

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[1] In the actual survey, these values were reversed (so that 1 was very hard and 5 was very easy). These numbers have been reversed so that the perception models are consistent with the heart-rate models: harder sidewalk sections produce higher results (e.g., 4's and 5's, or higher heart-rate changes). The benefit of this conversion in scores is that the signs of the coefficient estimates in the perception and heart-rate-change models are fully consistent.

[2] This response was taken on a scale of 1 to 5, in advance of the subject's actually traversing the section.

[3] Since the purpose of this test was to maintain activity across a continuous cross sloped surface long enough for heart rates to stabilize, participants were instructed to move from section to section without stopping, in continuous motion. Perception questions for the previous section were asked while the participant was moving to the next section.

[4] This ratio is consistent with Appendix C's results based on the 1999 and 2001 data sets combined and using a 1999YR indicator variable; the ratio is much lower (at 1.31) when the data are fully combined, without an indicator variable.

[5] A reference device type was needed since this model will be inestimable without removal of such an indicator. If all 5 device classes observed in the sample population were included in the explanatory variable set, their values would sum to one for every observation. This is equivalent to having a constant term in the model. And the probit specification being used cannot accommodate such a constant term, because the first threshold is not fixed. If this threshold were fixed (to equal zero, for example), one could include a constant term or the reference aid device's indicator variable and the model would be estimable (i.e., all the parameters would be statistically identifiable).

[6] Typically, adult resting heart rates average 72 bpm, while highly trained aerobic athletes may register at 40 bpm or lower. Rates will vary as a function of fitness level, age, and even gender. "Maximal heart rate generally declines with age from about 220 beats per minute in childhood to about 160 beats per minute at age 60. This fall in heart rate is fairly linear, decreasing by approximately 1 beat per minute per year." (Fahy 1997, p. 1)

[7] Low starting rates were generally as expected by the participants that exhibited these. At least one of these respondents was extremely athletic; the others simply indicated that such low rates were normal for them.

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# Appendices

# APPENDIX A. RECRUITING INFORMATION

## A.1. LIST OF CONTACTS FOR RECRUITMENT

Advocacy, Inc., Jonas Schwartz, 454-4816
ARC, Rosemary Alexander, 476-7044
ARCIL (Austin Resource Center for Independent Living), Ramon Rivera, 832-6349
Capital Metro, Nancy Crowther, 389-7583
Cap Metro MICAC (Mobility Impaired Citizens Advisory Committee), Paul Hunt, 460-7518
Channel 36 TV, Suzy Cohen, 703-5294
KLBJ-AM radio, Michelle Fox, 832-4027
SILC (State Independent Living Council), Ted Thayer, 371-7353
Texas Rehabilitation Commission, Ron Trull, 424-4143

- TRC North Austin Field Office 9411 Parkfield Dr. #500
- TRC South Austin Field Office 2416-A S. Lamar Blvd.

Texas School for the Blind, Karen Johnson, 206-9399
University of Texas, Dean of Students Office, Students with Disabilities Coordinator, Peter Flynn, numbers@mail.utexas.edu
University of Texas, Department of Special Education, Joellen Simmons, simmons.joellen@mail.utexas.edu

## A.2. EMAIL TO UT STUDENTS WITH DISABILITIES MAIL LIST

PARTICIPANTS NEEDED - $25
for a study on enhancement of sidewalk accessibility for pedestrians with disabilities. Study will involve physical activity in outdoor conditions.

We are seeking volunteers who use mobility aids (electric and manual wheelchairs, electric scooters, walkers, canes, braces, and crutches) to participate in this research project. The test sites we are using are located in central and south Austin and are accessible by Capital Metro buses. Excluding travel time to and from the study sites, we estimate that it will take 30–45 minutes to complete the study. Participants will be asked to traverse several test sections and answer several questions about each test section concerning the ease or difficulty of traversing the test section. Participants will receive $25 after completing all test sections and signing a receipt (we do not need a Social Security number).

Participation in this study will provide input for possible accessible sidewalk design in the future.

If interested or for more information, please contact Lydia Heard at 232-7828 (lydiaheard@hotmail.com) or Tom Rioux at 471-0153 (rioux@mail.utexas.edu) .

## A.3. LETTER TO ASSISTED LIVING CENTER DIRECTORS

25-Oct-2000

Director
<name>
<address>
<city>, Texas <zip>

Dear Director,

I am a principal investigator of a research project at the Center for Transportation Research at The University of Texas at Austin. We are investigating the sidewalk cross slope (the slope from left to right as you walk up or down a sidewalk) for the Texas Department of Transportation (TxDOT) so that sidewalks designed, constructed, or altered by TxDOT will be accessible to persons with disabilities as defined by the Americans with Disabilities Act.

I am seeking volunteers who use mobility aids (electric and manual wheel chairs, electric scooters, walkers, canes, and crutches) to participate in this research project. If needed, I will have a research assistant come to your facility, travel with the volunteer to the bus stop, ride the bus with the volunteer to the study site, assist the volunteer during the study, ride the bus with the volunteer back to the bus stop, and travel with the volunteer back to your facility. Excluding travel time to and from the study site, I estimate that it will take approximately 30-45 minutes to complete the study. The volunteers will be asked to traverse several test sections and answer several questions about each test section concerning the ease or difficulty of traversing the test section.

I would like to come to your facility, give a brief overview of our project, ask for volunteers, and leave some information about the project. Please contact Margaret Stephens at 232-4252 or margstephns@mail.utexas.edu. Please do not hesitate to contact me if you have further questions at 471-0513 or rioux@mail.utexas.edu.

Sincerely,

Tom Rioux, Ph.D., P.E.
Research Engineer
Center for Transportation Research
The University of Texas at Austin

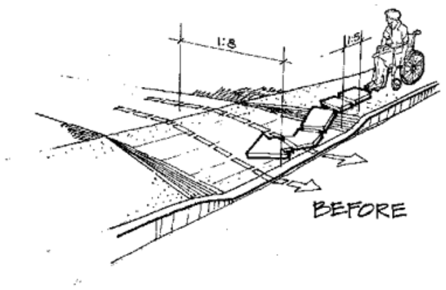
## A.4 RECRUITMENT TEAR-OFF FLYER

VOLUNTEERS NEEDED
$25

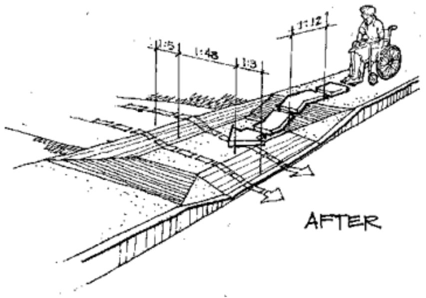
---

for a study on enhancement of sidewalk accessibility for pedestrians with disabilities. Study involves physical activity in outdoor conditions.

Persons with mobility impairments requiring use of a **cane, crutches, walker, wheelchair** or other mobility aids are needed for this study.



Participation in this study will provide input for possible accessible sidewalk design in the future.



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A project of the University of Texas at Austin
**Civil Engineering – Center for Transportation Research**
Contact: Thomas W. Rioux, Ph.D., P.E. 471-0513,
rioux@mail.utexas.edu or Lydia Heard, 232-7828, lydiaheard@hotmail.com *(by 3/30/2001)*

Sidewalk Study $25
232-7828 (3/30/01)

Sidewalk Study $25
232-7828 (3/30/01)

Sidewalk Study $25
232-7828 (3/30/01)

Sidewalk Study $25
232-7828 (3/30/01)

Sidewalk Study $25
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232-7828 (3/30/01)

Sidewalk Study $25
232-7828 (3/30/01)

Sidewalk Study $25
232-7828 (3/30/01)

Sidewalk Study $25
232-7828 (3/30/01)

## A.5. PRESS RELEASE

Note to editors and news producers:
The University of Texas at Austin Office of Public Affairs is providing the following press release in the form of text within this message. The article also will be posted in the "New Releases" section of the Office of Public Affairs web site, located at www.utexas.edu/opa.

Contact: Becky Rische, (512) 471-7272
Date: March 27, 2001
Seeking real-life standards: UT Austin seeks paid volunteers
to test sidewalk designs for the Americans with Disabilities Act

AUSTIN, Texas - Austin-area residents with mobility impairments are being sought to help researchers at The University of Texas at Austin's College of Engineering develop better sidewalk design standards to comply with the federal Americans with Disabilities Act. Volunteers will be paid and may contact UT Austin researcher Lydia Heard at (512) 232-7828 for more information. The study already is in progress, and volunteers may sign up immediately.

Dr. Tom Rioux, the UT research engineer conducting the study, said the purpose is to determine the best angle for sidewalks to slope into the street for people using wheelchairs, scooters, walkers, crutches and canes. Rioux, who works in the department of civil engineering and transportation, is working to determine the most useful sidewalk grade with Dr. Kara Kockelman, assistant professor of civil engineering, and Heard, a research assistant.
Rioux said the researchers want sidewalk standards and designs to reflect real-life situations involving real people. "We want to assure the regulations accommodate the true human factors involved in negotiating a sidewalk for folks with disabilities," said Rioux.

Volunteers qualify if they are currently using mobility aids including canes, crutches, walkers, braces, wheelchairs or scooters. They will be paid $25. They may be provided with transportation, or accompanied on public transportation, both to and from the test areas as needed. They will be asked to help with the tests at three different Austin sites.
Volunteers will wear heart rate monitors to measure their physical exertion at one of the test sites. After each test section, they will answer questions regarding the effort required by the differently sloped sidewalks.

The study, sponsored by the Texas Department of Transportation, will provide the necessary information for designing better sidewalks to comply with the Americans with Disabilities Act. For more information, contact Lydia Heard at (512) 232-7828 or Becky Rische at (512) 471-7272.

# APPENDIX B. SURVEY FORMS AND SITE IMAGES

## B.1. PARTICIPANT INFORMATION SHEET

## The University of Texas at Austin Center for Transportation Research
## Sidewalk Cross Slope Study – Participant Information Form

---

**Please Print**

Name: ______________________________________________

Address: ______________________________________________

Phone: ______________________________________________

E-mail: ______________________________________________

Emergency Contact: _______

What is your disability? __Hard of Hearing __Deaf __Low Vision __Blind
__Difficulty Walking __Artificial Foot __Artificial Leg __Artificial Hip
Other: __________________

What is your mobility aid? __Manual Wheelchair __Electric Wheelchair __Crutch
__Cane __Brace __Walker __Scooter __Leg Brace __Foot Brace
__Other: ______________________________________________

| | | | | | |
|---|---|---|---|---|---|
| What kind of shape do you consider yourself to be in? | Very Out of Shape | | Average Shape | | In Great Shape |
| | 1 | 2 | 3 | 4 | 5 |

What is your age? ________________________________________

What is your gender? ____Male ______Female

Are you right- or left- handed? ___Right ______Left

| | | | | | |
|---|---|---|---|---|---|
| How important are sidewalks for you? | Very Important | | | | Not Important |
| | 1 | 2 | 3 | 4 | 5 |

How many days per week do you travel on sidewalks? ______Days per week

On a day when you travel on sidewalks,
what is the distance you normally travel? ___Miles or Blocks (circle one)

How far do you think you could travel on perfectly flat and smooth sidewalks without having to rest for more than a couple of minutes? ____ miles/blocks

## B.2. SURVEY FORM – GUADALUPE STREET

# The University of Texas at Austin Center for Transportation Research
# Sidewalk Cross Slope Study Field Survey Form for Guadalupe Street

---

Date:______________________________
Proctor: ____________________________

**Participant Information**

Name: ______________________________________________________________

Address: ______________________________________________________________

Phone: ______________________________________________________________

E-mail: ______________________________________________________________

Emergency Contact: _______________________________________________________

Pre-Test Checklist:

___ Signed Consent Form on file

___ Participant Information Sheet completed

*Ask the following questions during the test*

Guadalupe Section 1 (#31): Jiffy Lube Guadalupe driveway

7. Pavement condition: Wet Dry (circle one)

*Ask before section*

How difficult does this section *appear to* be? 1 2 3 4 5

Very Hard ... Easy

**Ask after section**

How comfortable were you in traversing this section? Very Uncomfortable ... Very Comfortable

1 2 3 4 5

If #3 was 3 or less, then what was the main reason for your discomfort? ______________________________

(examples: traffic, pavement surface, cross slope, main grade, length)

If #3 was 3 or less, how many of these sections would you be comfortable negotiating in one trip?

| | |
|---|---|
| __0 | __1 total |
| __2 total | __1 per block |
| __2 per block | __3+ per block |

Guadalupe Section 2 (#51): Avenel Apartments south driveway

8. Pavement condition: Wet Dry (circle one)

*Ask before section*

| | | | | | |
|---|---|---|---|---|---|
| How difficult does this section *appear to* be? | 1<br>Very Hard | 2 | 3 | 4 | 5<br>Easy |

**Ask after section**

| | | | | | |
|---|---|---|---|---|---|
| How comfortable were you in traversing this section? | Very Uncomfortable<br>1 | 2 | 3 | 4 | Very Comfortable<br>5 |

If #8 was 3 or less, then what was the main reason for your discomfort? ______________________________________________

(examples: traffic, pavement surface, cross slope, main grade, length)

| | | |
|---|---|---|
| If #8 was 3 or less, how many of these sections would you be comfortable negotiating in one trip? | _0 | _1 total |
| | _2 total | _1 per block |
| | _2 per block | _3+ per block |

Guadalupe Section 3 (#52): Avenel Apartments north driveway

9. Pavement condition: Wet Dry (circle one)

*Ask before section*

How difficult does this section *appear to* be? 1 2 3 4 5
Very Hard Easy

**Ask after section**

How comfortable were you in traversing this section? Very Uncomfortable Very Comfortable
1 2 3 4 5

If #13 was 3 or less, then what was the main reason for your discomfort? ______________________________________________

(examples: traffic, pavement surface, cross slope, main grade, length)

| | | |
|---|---|---|
| If #13 was 3 or less, how many of these sections | __0 | __1 total |
| would you be comfortable negotiating | __2 total | __1 per block |
| in one trip? | __2 per block | __3+ per block |

Guadalupe Section 4 (#34): 38 1/2th Street north sidewalk ramp

10. Pavement condition: Wet Dry (circle one)

*Ask before section*

How difficult does this section *appear to* be? 1 2 3 4 5
Very Hard Easy

**Ask after section**

How comfortable were you in traversing this section? Very Uncomfortable Very Comfortable
1 2 3 4 5

If #18 was 3 or less, then what was the main reason for your discomfort? ________________________________________
(examples: traffic, pavement surface, cross slope, main grade, length)

If #18 was 3 or less, how many of these sections would you be comfortable negotiating in one trip?
_0 _1 total
_2 total _1 per block
_2 per block _3+ per block

Guadalupe Section 5 (#33): XpressLube Car Wash sidewalk

11. Pavement condition: Wet Dry (circle one)

*Ask before section*

How difficult does this section *appear to* be? 1 2 3 4 5
Very Hard Easy

**Ask after section**

How comfortable were you in traversing this section? Very Uncomfortable 1 2 3 4 5 Very Comfortable

If #23 was 3 or less, then what was the main reason for your discomfort? ______________________________
(examples: traffic, pavement surface, cross slope, main grade, length)

If #23 was 3 or less, how many of these sections would you be comfortable negotiating in one trip?
__0 __1 total
__2 total __1 per block
__2 per block __3+ per block

Guadalupe Section 6 (#35): XpressLube Car Wash north driveway

12. Pavement condition: Wet Dry (circle one)

*Ask before section*

| | | | | | |
|---|---|---|---|---|---|
| How difficult does this section *appear to* be? | 1 | 2 | 3 | 4 | 5 |
| | Very Hard | | | | Easy |

**Ask after section**

| | | | | | |
|---|---|---|---|---|---|
| How comfortable were you in traversing this section? | Very Uncomfortable | | | | Very Comfortable |
| | 1 | 2 | 3 | 4 | 5 |

If #28 was 3 or less, then what was the main reason for your discomfort? ______________________________
(examples: traffic, pavement surface, cross slope, main grade, length)

| | | |
|---|---|---|
| If #28 was 3 or less, how many of these sections would you be comfortable negotiating in one trip? | _0 | _1 total |
| | _2 total | _1 per block |
| | _2 per block | _3+ per block |

Guadalupe Section 7 (#36): sidewalk north of XpressLube Car Wash

13. Pavement condition: Wet Dry (circle one)

*Ask before section*

| | | | | | |
|---|---|---|---|---|---|
| How difficult does this section *appear to* be? | 1 | 2 | 3 | 4 | 5 |
| | Very Hard | | | | Easy |

**Ask after section**

| | | | | | |
|---|---|---|---|---|---|
| How comfortable were you in traversing this section? | Very Uncomfortable | | | | Very Comfortable |
| | 1 | 2 | 3 | 4 | 5 |

If #33 was 3 or less, then what was the main reason for your discomfort? ____________________________________________

(examples: traffic, pavement surface, cross slope, main grade, length)

| | | |
|---|---|---|
| If #33 was 3 or less, how many of these sections would you be comfortable negotiating in one trip? | __0<br>__2 total<br>__2 per block | __1 total<br>__1 per block<br>__3+ per block |

Guadalupe Section 8 (#53): 517 West 39th west driveway

14. Pavement condition: Wet Dry (circle one)

*Ask before section*

| | | | | | |
|---|---|---|---|---|---|
| How difficult does this section *appear to* be? | 1 | 2 | 3 | 4 | 5 |
| | Very Hard | | | | Easy |

**Ask after section**

| | | | | | |
|---|---|---|---|---|---|
| How comfortable were you in traversing this section? | Very Uncomfortable | | | | Very Comfortable |
| | 1 | 2 | 3 | 4 | 5 |

If #38 was 3 or less, then what was the main reason for your discomfort? ______________________________________________
(examples: traffic, pavement surface, cross slope, main grade, length)

| | | |
|---|---|---|
| If #38 was 3 or less, how many of these sections would you be comfortable negotiating in one trip? | __0 | __1 total |
| | __2 total | __1 per block |
| | __2 per block | __3+ per block |

Guadalupe Section 9 (#8): Rooster Andrews south driveway

15. Pavement condition: Wet Dry (circle one)

*Ask before section*

How difficult does this section *appear to* be? 1 2 3 4 5
Very Hard Easy

Ask after section

How comfortable were you in traversing this section? Very Uncomfortable Very Comfortable
1 2 3 4 5

If #43 was 3 or less, then what was the main reason for your discomfort? ______________________________
(examples: traffic, pavement surface, cross slope, main grade, length)

| | | |
|---|---|---|
| If #43 was 3 or less, how many of these sections | __0 | __1 total |
| would you be comfortable negotiating | __2 total | __1 per block |
| in one trip? | __2 per block | __3+ per block |

Ask these questions after completion of the test

| | | | | | |
|---|---|---|---|---|---|
| How comfortable was the overall test for you? | Very Uncomfortable | | | | Very Comfortable |
| | 1 | 2 | 3 | 4 | 5 |

How many such trips could you make in one day?

____0 ____1
____2 ____3-5
____6-10 ____11+

Is the number of trips in #47 enough to satisfy your travel needs? ____Yes __No

| | | | | | |
|---|---|---|---|---|---|
| How would you rate the automobile traffic during the test? | Very Heavy | | | | Very Light |
| | 1 | 2 | 3 | 4 | 5 |

If the participant did not complete all test sections, list the last section number completed ______

PLEASE THANK THE PERSON FOR PARTICIPATING IN THE STUDY!!!

APPENDIX** SURVEY FORM – SOUTH LAMAR BLVD.

# The University of Texas at Austin Center for Transportation Research
# Sidewalk Cross Slope Study Field Survey Form for South Lamar Blvd.

Date:______________________________
Proctor: ____________________________

**Participant Information**

Name: __________________________________________________________

Address: __________________________________________________________

Phone: ___________________________________________________________

E-mail: ___________________________________________________________

Emergency Contact: ________________________________________________

Pre-Test Checklist:

___ Signed Consent Form on file

___ Participant Information Sheet completed

*Ask the following questions during the test*

South Lamar Section 1 (#10): Down Under Auto Sales south driveway

*16. Pavement condition: Wet Dry (circle one)*

Ask before section

How difficult does this section *appear to* be? 1 2 3 4 5
Very Hard Easy

**Ask after section**

How comfortable were you in traversing this section? Very Uncomfortable Very Comfortable
1 2 3 4 5

If #3 was 3 or less, then what was the main reason for your discomfort? ____________________________________________
(examples: traffic, pavement surface, cross slope, main grade, length)

If #3 was 3 or less, how many of these sections would you be comfortable negotiating in one trip?
__0 __1 total
__2 total __1 per block
__2 per block __3+ per block

South Lamar Section 2 (#07): CPA sidewalk

*17. Pavement condition: Wet Dry (circle one)*

Ask before section

| | | | | | |
|---|---|---|---|---|---|
| How difficult does this section *appear to* be? | 1 | 2 | 3 | 4 | 5 |
| | Very Hard | | | | Easy |

**Ask after section**

| | | | | | |
|---|---|---|---|---|---|
| How comfortable were you in traversing this section? | Very Uncomfortable | | | | Very Comfortable |
| | 1 | 2 | 3 | 4 | 5 |

If #8 was 3 or less, then what was the main reason for your discomfort? ______________________________

(examples: traffic, pavement surface, cross slope, main grade, length)

| | | |
|---|---|---|
| If #8 was 3 or less, how many of these sections would you be comfortable negotiating in one trip? | _0 | _1 total |
| | _2 total | _1 per block |
| | _2 per block | _3+ per block |

South Lamar Section 3 (#22): Faith UMC south driveway

*18. Pavement condition: Wet Dry (circle one)*

Ask before section

How difficult does this section *appear to* be? 1 2 3 4 5
Very Hard Easy

**Ask after section**

| | | | | | |
|---|---|---|---|---|---|
| How comfortable were you in traversing this section? | Very Uncomfortable | | | | Very Comfortable |
| | 1 | 2 | 3 | 4 | 5 |

If #13 was 3 or less, then what was the main reason for your discomfort? ______________________________________________
(examples: traffic, pavement surface, cross slope, main grade, length)

If #13 was 3 or less, how many of these sections would you be comfortable negotiating in one trip?
_0 _1 total
_2 total _1 per block
_2 per block _3+ per block

South Lamar Section 4 (#23): Faith UMC north driveway

*19. Pavement condition: Wet Dry (circle one)*

Ask before section

How difficult does this section *appear to* be? 1 2 3 4 5
Very Hard Easy

**Ask after section**

How comfortable were you in traversing this section?
Very Uncomfortable Very Comfortable
1 2 3 4 5

If #18 was 3 or less, then what was the main reason for your discomfort? ______________________________
(examples: traffic, pavement surface, cross slope, main grade, length)

If #18 was 3 or less, how many of these sections would you be comfortable negotiating in one trip?
__0 __1 total
__2 total __1 per block
__2 per block __3+ per block

South Lamar Section 5 (#44): Sidewalk at Bus Stop north of FUMC

*20. Pavement condition: Wet Dry (circle one)*

Ask before section

| | | | | | |
|---|---|---|---|---|---|
| How difficult does this section *appear to* be? | 1 | 2 | 3 | 4 | 5 |
| | Very Hard | | | | Easy |

**Ask after section**

| | | | | | |
|---|---|---|---|---|---|
| How comfortable were you in traversing this section? | Very Uncomfortable | | | | Very Comfortable |
| | 1 | 2 | 3 | 4 | 5 |

If #23 was 3 or less, then what was the main reason for your discomfort? ______________________________
(examples: traffic, pavement surface, cross slope, main grade, length)

If #23 was 3 or less, how many of these sections would you be comfortable negotiating in one trip?
__0 __1 total
__2 total __1 per block
__2 per block __3+ per block

South Lamar Section 6 (#21): Matt's El Rancho south driveway

*21. Pavement condition: Wet Dry (circle one)*

Ask before section

How difficult does this section *appear to* be? 1 2 3 4 5
Very Hard Easy

**Ask after section**

How comfortable were you in traversing this section?
Very Uncomfortable Very Comfortable
1 2 3 4 5

If #28 was 3 or less, then what was the main reason for your discomfort? ____________________________________________
(examples: traffic, pavement surface, cross slope, main grade, length)

If #28 was 3 or less, how many of these sections would you be comfortable negotiating in one trip?

| | |
|---|---|
| _0 | _1 total |
| _2 total | _1 per block |
| _2 per block | _3+ per block |

South Lamar Section 7 (#06): Village Trailer Park sidewalk

*22. Pavement condition: Wet Dry (circle one)*

Ask before section

| | | | | | |
|---|---|---|---|---|---|
| How difficult does this section *appear to* be? | 1 | 2 | 3 | 4 | 5 |
| | Very Hard | | | | Easy |

**Ask after section**

| | | | | | |
|---|---|---|---|---|---|
| How comfortable were you in traversing this section? | Very Uncomfortable | | | | Very Comfortable |
| | 1 | 2 | 3 | 4 | 5 |

If #33 was 3 or less, then what was the main reason for your discomfort? ________________________________________
(examples: traffic, pavement surface, cross slope, main grade, length)

| | | |
|---|---|---|
| If #33 was 3 or less, how many of these sections would you be comfortable negotiating in one trip? | _0 | _1 total |
| | _2 total | _1 per block |
| | _2 per block | _3+ per block |

Ask these questions after completion of the test

| | | | | | |
|---|---|---|---|---|---|
| How comfortable was the overall test for you? | Very Uncomfortable | | | | Very Comfortable |
| | 1 | 2 | 3 | 4 | 5 |

| | | |
|---|---|---|
| How many such trips could you make in one day? | ______0 | ______1 |
| | ______2 | ______3-5 |
| | ______6-10 | ______11+ |

Is the number of trips in #37 enough to satisfy your travel needs? ____Yes __No

| | | | | | |
|---|---|---|---|---|---|
| How would you rate the automobile traffic during the test? | Very Heavy | | | | Very Light |
| | 1 | 2 | 3 | 4 | 5 |

If the participant did not complete all test sections, list the last section number completed

______

PLEASE THANK THE PERSON FOR PARTICIPATING IN THE STUDY!!!

APPENDIX** SURVEY FORM – FAITH UNITED METHODIST CHURCH LOT

# The University of Texas at Austin Center for Transportation Research Sidewalk Cross Slope Study Field Survey Form for FUMC Parking Lot

Date:______________________________
Proctor: ____________________________

**Participant Information**

Name: ____________________________________________________________

Address: _________________________________________________________

Phone: ____________________________________________________________

E-mail: ___________________________________________________________

Emergency Contact: ________________________________________________

Pre-Test Checklist:

___ *Signed Consent Form on file*

___ Participant Information Sheet completed

___ Maximum heart rate calculated

___ Maximum heart rate programmed on monitor

Maximum heart rate = 204 – (0.69 x Age)

Participant Age: ________

Maximum heart rate: ________bps

*Ask the following questions during the test*

Faith United Methodist Church Parking Lot: Section 1 (#61)

23. Pavement condition: Wet Dry (circle one)

How difficult does this section *appear to* be? 1 2 3 4 5
Very Hard Easy

***Resting*** heart rate at start of section 61: ________bps

Heart rate at turnaround section 61: ________bps

Ask while traversing section 62 (between 61 and 63)

Elapsed time: ____________

Heart rate after section 61: ________bps

How comfortable were you in traversing this section? Very Uncomfortable Very Comfortable
1 2 3 4 5

If #7 was 3 or less, then what was the main reason for your discomfort? ________________________________________________
(examples: traffic, pavement surface, cross slope, main grade, length)

If #7 was 3 or less, how many of these sections would you be comfortable negotiating in one trip?

__0 __1 total
__2 total __1 per block
__2 per block __3+ per block

Faith United Methodist Church Parking Lot: Section 2 (#63)

24. Pavement condition: Wet Dry (circle one)

How difficult does this section *appear to* be? 1 2 3 4 5
Very Hard Easy

Heart rate at turnaround section 63: ________bps

Ask while traversing section 64 (between 63 and 65)

Elapsed time: ____________

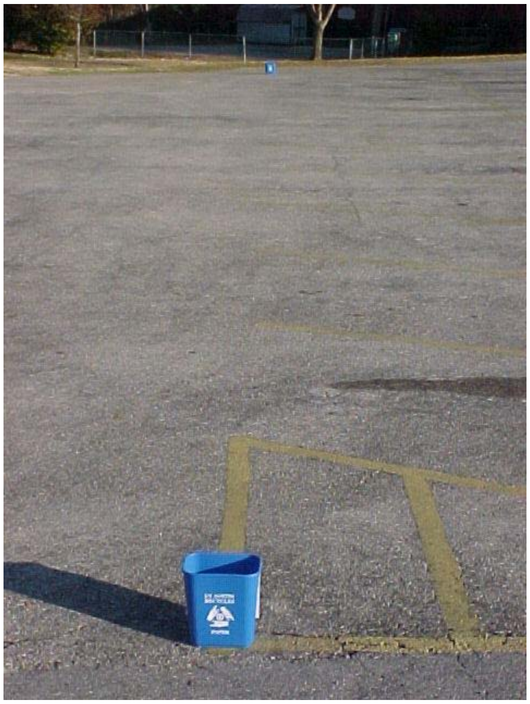
Heart rate after section 63: ________bps

How comfortable were you in traversing this section?
Very Uncomfortable Very Comfortable
1 2 3 4 5

If #15 was 3 or less, then what was the main reason for your discomfort? ____________________________________
(examples: traffic, pavement surface, cross slope, main grade, length)

If #15 was 3 or less, how many of these sections would you be comfortable negotiating in one trip?
__0 __1 total
__2 total __1 per block
__2 per block __3+ per block

Faith United Methodist Church Parking Lot: Section 3 (#65)



25. Pavement condition: Wet Dry (circle one)

How difficult does this section *appear to* be? 1 2 3 4 5
Very Hard Easy

Heart rate at turnaround section 65: ________bps

Ask while traversing Section 66 (between 65 and 67)

Elapsed time: ____________

Heart rate after section 65: ________bps

How comfortable were you in traversing this section? Very Uncomfortable Very Comfortable
1 2 3 4 5

If #23 was 3 or less, then what was the main reason for your discomfort? ________________________________________________
(examples: traffic, pavement surface, cross slope, main grade, length)

If #23 was 3 or less, how many of these sections would you be comfortable negotiating in one trip?
__0 __1 total
__2 total __1 per block
__2 per block __3+ per block

Faith United Methodist Church Parking Lot: Section 4 (#67)

26. Pavement condition: Wet Dry (circle one)

How difficult does this section *appear to* be? 1 2 3 4 5
Very Hard Easy

Heart rate at turnaround section 67: ________bps

Ask while traversing section 68 (between 67 and 69)

Elapsed time: ____________

Heart rate after section 67: ________bps

How comfortable were you in traversing this section? Very Uncomfortable Very Comfortable
1 2 3 4 5

If #31 was 3 or less, then what was the main reason for your discomfort? ________________________________________________
(examples: traffic, pavement surface, cross slope, main grade, length)

If #31 was 3 or less, how many of these sections would you be comfortable negotiating in one trip?
__0 __1 total
__2 total __1 per block
__2 per block __3+ per block

Faith United Methodist Church Parking Lot: Section 5 (#69)

27. Pavement condition: Wet Dry (circle one)

How difficult does this section *appear to* be? 1 2 3 4 5

Very Hard Easy

Heart rate at turnaround section 69: ________bps

Ask at end of section 69

Elapsed time: ____________

Heart rate after section 69: ________bps

How comfortable were you in traversing this section? Very Uncomfortable Very Comfortable

1 2 3 4 5

If #39 was 3 or less, then what was the main reason for your discomfort? ________________________________________________

(examples: traffic, pavement surface, cross slope, main grade, length)

If #39 was 3 or less, how many of these sections would you be comfortable negotiating in one trip?

_0 _1 total
_2 total _1 per block
_2 per block _3+ per block

*Ask these questions after completion of the test*

| | | | | | |
|---|---|---|---|---|---|
| How comfortable was the overall test for you? | Very Uncomfortable | | | | Very Comfortable |
| | 1 | 2 | 3 | 4 | 5 |

| | | |
|---|---|---|
| How many such trips could you make in one day? | ______0 | ______1 |
| | ______2 | ______3-5 |
| | ______6-10 | ______11+ |

Is the number of trips in #43 enough to satisfy your travel needs? ____Yes ___No

| | | | | | |
|---|---|---|---|---|---|
| How would you rate the automobile traffic during the test? | Very Heavy | | | | Very Light |
| | 1 | 2 | 3 | 4 | 5 |

If the participant did not complete all test sections, list the last section ______ and the number of parking spaces (counting forward and back, if applicable) ______ completed.

**PLEASE THANK THE PERSON FOR PARTICIPATING IN THE STUDY!!!**

# APPENDIX C. DATA ANALYSIS

## C.1. RECORD-WEIGHT CALCULATIONS

The following table shows which category each individual belongs to in 1999 and 2001 sidewalk survey.

**Table C.1 Individual ID Numbers for Participants in 1999 & 2001 Sidewalk Surveys**

| ***Mobility Aid Type*** | Male | | | Female | | |
|---|---|---|---|---|---|---|
| | 16-35 | 36-65 | 66+ | 16-35 | 36-65 | 66+ |
| Cane | 26, | 12,46,47,**5** | 2,5,21, | | 22,27,28,29,49,**10** | 14,20, |
| Crutches | 36,44, | 37, | | | 42, | |
| Walker | 6, | | 4, | | 25, | 3,7,8,13,48,50 |
| Manual Wheelchair | 31,33, | 11,23,32,39,45,<br>14,15,17 | | 1 | 1,38,43,**8** | 9,15, |
| Electric Wheelchair | | 41, 6,12 | | 10 / **2** | 24,35, **4,7,11** | |
| Scooter | | | | 3 | 40, | |
| Leg Brace | | 30, | | | | |
| White Cane (Blind) | 16,17, | 34,**16** | | 18,19 | 9,13 | |

**Bold** numbers correspond to the original, 1999 dataset participants.
Total sample size is 67 persons.

Since there are cells with zero observations in this detailed table, it is best to collapse a category until the category has an observation. The following four tables show percentage of the U.S. population and the survey samples, following such a merger of appropriate cells.

**Table C.2: U.S. Population Percentage in Collapsed Categories**

| Mobility Aid Type | Gender and Age | | | | | |
|---|---|---|---|---|---|---|
| | Male | | | Female | | |
| | 16-35 | 36-65 | 66+ | 16-35 | 36-65 | 66+ |
| Cane | 0.83 | 8.62 | 12.55 | 29.32 | | |
| Crutch | 3.30 | | | 2.41 | | |
| Walker | 4.86 | | | 14.16 | | |
| Manual Wheelchair | 5.59 | | | 0.34 | 2.76 | 5.86 |
| Electric Wheelchair | 0.63 | | | 0.71 | | |
| Scooter | 1.43 | | | | | |
| Leg Brace | 5.27 | | | | | |
| White Cane (Blind) | 0.56 | | | 0.66 | | |

(Units: %)

**Table C.3: Survey Sample Percentage in Collapsed Categories – For Combined (1999 & 2001) Data (N=67)**

| *Mobility Aid Type* | Gender and Age | | | | | |
|---|---|---|---|---|---|---|
| | Male | | | Female | | |
| | 16-35 | 36-65 | 66+ | 16-35 | 36-65 | 66+ |
| Cane | 1.493 | 5.970 | 4.478 | 11.940 | | |
| Crutches | 4.478 | | | 1.493 | | |
| Walker | 2.985 | | | 10.448 | | |
| Manual Wheelchair | 14.925 | | | 1.493 | 5.970 | 2.985 |
| Electric Wheelchair | 4.478 | | | 10.448 | | |
| Scooter | 2.985 | | | | | |
| Leg Brace | 1.493 | | | | | |
| White Cane (Blind) | 5.970 | | | 5.970 | | |

(Units: %)

**Table C.4: Survey Sample Percentage in Collapsed Categories – For 2001 Data Only (N=50)**

| Mobility Aid Type | Gender and Age | | | | | |
|---|---|---|---|---|---|---|
| | Male | | | Female | | |
| | 16-35 | 36-65 | 66+ | 16-35 | 36-65 | 66+ |
| Cane | 2.0 | 6.0 | 6.0 | 14.0 | | |
| Crutches | 6.0 | | | 2.0 | | |
| Walker | 4.0 | | | 14.0 | | |
| Manual Wheelchair | 14.0 | | | 10.0 | | |
| Electric Wheelchair | 2.0 | | | 6.0 | | |
| Scooter | 2.0 | | | | | |
| Leg Brace | 2.0 | | | | | |
| White Cane (Blind) | 6.0 | | | 4.0 | | |

(Units: %)

Finally, dividing the table for U.S. population by the two separate tables for sample proportions (using the 1999 and 2001 data sets for the heart-rate models and just the 2001 data set for the assessment model) produces the following weight tables:

**Table C.5: Final Weight Matrix for the Combined Dataset (N=67)**

| Mobility Aid Type | Male | | | Female | | |
|---|---|---|---|---|---|---|
| | 16-35 | 36-65 | 66+ | 16-35 | 36-65 | 66+ |
| Cane | 0.556 | 1.444 | 2.803 | 2.456 | | |
| Crutches | 0.737 | | | 1.615 | | |
| Walker | 1.628 | | | 1.355 | | |
| Manual Wheelchair | 0.375 | | | 0.228 | 0.462 | 1.963 |
| Electric Wheelchair | 0.141 | | | 0.068 | | |
| Scooter | 0.479 | | | | | |
| Leg Brace | 3.531 | | | | | |
| White Cane (Blind) | 0.094 | | | 0.111 | | |

**Table C.6: Final Weight Matrix for the 2001 Data Only (N=50)**

| Mobility Aid Type | Male | | | Female | | |
|---|---|---|---|---|---|---|
| | 16-35 | 36-65 | 66+ | 16-35 | 36-65 | 66+ |
| Cane | 0.415 | 1.437 | 2.092 | | 2.094 | |
| Crutches | 0.550 | | | 1.205 | | |
| Walker | 1.215 | | | 1.011 | | |
| Manual Wheelchair | 0.399 | | | 0.896 | | |
| Electric Wheelchair | 0.315 | | | 0.118 | | |
| Scooter | 0.715 | | | | | |
| Leg Brace | 2.635 | | | | | |
| White Cane (Blind) | 0.093 | | | 0.165 | | |

Note: Most weight values span several cells because of the sparseness of the matrix over the sample sizes used here. With a maximum possible number of usable responses at 67 and 50 (for the combined & 1999 data sets) and 48 possible cells, several cells lacked an observation. Rather than assigning a weight of infinity (i.e., the population percentage for that cell divided by the sample percentage) to an observation that does not exist (i.e., the sample percentage was zero for that cell), ages (and then gender, in the cases of scooter and leg brace users) were merged.

## C.2. ADDITIONAL MODEL RESULTS

### Table C7a. One-Way Random Effects Regression Model Results for Heart-Rate Changes

(With ***CSLOPEW*****:** Combined Data 1999 & 2001)

| Variables | Coefficients | Std. Err. | t-stats |
|---|---|---|---|
| UNOW | 63.181 | 18.463 | 3.422* |
| MSLOPE2W | 3.423 | 1.340 | 2.555* |
| CSLOPEW | -2.148 | 0.790 | -2.719* |
| LENGTH2W | 0.035 | 0.031 | 1.140 |
| LNAGEW | -9.003 | 3.449 | -2.610* |
| SHAPEW | 7.098 | 1.246 | 5.695* |
| MALEW | -5.959 | 2.937 | -2.029* |
| HRRESTW | -0.239 | 0.131 | -1.820 |
| AIDCCBW | -2.759 | 4.576 | -0.603 |
| AIDWALKW | -12.925 | 5.794 | -2.231* |
| BLINDW | -7.663 | 16.712 | -0.459 |
| AIDEWSCW | -25.564 | 8.317 | -3.074* |
| Num. of Observations | 316 | | |
| ρ (within person correlation) | 0.226 | | |
| $R^2_{adj}$ | 0.331 | | |

Note: The reference mobility aid device is an AIDMWC.

* Statistically significant at the 0.05 significance level.

### Table C7b. One-Way Random Effects Regression Model Results for Heart-Rate Changes

(Without ***CSLOPEW*****:** Combined Data 1999 & 2001)

| Variables | Coefficients | Std. Err. | t-stats |
|---|---|---|---|
| UNOW | 55.014 | 18.349 | 2.998* |
| MSLOPE2W | 3.280 | 1.360 | 2.411* |
| LENGTH2W | 0.019 | 0.031 | 0.638 |
| LNAGEW | -11.067 | 3.383 | -3.271* |
| SHAPEW | 7.432 | 1.247 | 5.961* |
| MALEW | -7.986 | 2.854 | -2.799* |
| HRRESTW | -0.108 | 0.123 | -0.878 |
| AIDCCBW | -1.692 | 4.584 | -0.369 |
| AIDWALKW | -12.956 | 5.827 | -2.224* |
| BLINDW | -9.635 | 16.781 | -0.574 |
| AIDEWSCW | -23.006 | 8.292 | -2.775* |
| Num. of Observations | 316 | | |
| ρ (within person correlation) | 0.219 | | |
| $R^2_{adj}$ | 0.320 | | |

**Table C8. Ordered Probit Model Results for Discomfort (Combined Data: 1999 & 2001)**

| Variables | Estimates | Std. Err. | t-stats |
|---|---|---|---|
| Thresh01 | 1.736 | 0.590 | 2.942* |
| Thresh02 | 2.774 | 0.593 | 4.680* |
| Thresh03 | 3.370 | 0.595 | 5.664* |
| Thresh04 | 4.114 | 0.600 | 6.861* |
| MSLOPE | 0.036 | 0.019 | 1.959* |
| CSLOPE | 0.131 | 0.011 | 12.060* |
| LNLNTH | 0.337 | 0.115 | 2.938* |
| LNAGE | 0.195 | 0.096 | 2.023* |
| MALE | -0.387 | 0.077 | -5.028* |
| SHAPE | -0.125 | 0.029 | -4.342* |
| AIDWALK | -0.617 | 0.135 | -4.567* |
| BLIND | 0.132 | 0.354 | 0.373 |
| AIDCACRB | 0.161 | 0.108 | 1.488 |
| AIDEWCSC | -0.075 | 0.205 | -0.367 |
| *YR1999* | 2.370 | 0.327 | 7.239* |
| Num. of Observations | 1045 | | |
| Log-L (Constant) | -1395.550 | | |
| Log-L (Restricted) | -1209.860 | | |
| LRI** | 0.133 | | |

Note: The reference mobility aid device is an AIDMWC

* Statistically Significant at the 0.05 significance level

** Likelihood Ratio Index (or Pseudo-$R^2$)

As the above table reveals, the *YR1999* variable's coefficient is large and statistically significant. This implies that the responses of participants in 1999 and 2001 data are very different. This distinction may be due to the inability to completely and satisfactorily reproduce the cross-slope and main-slope data of the earlier data set. Given that the 1999 data are now two years old, rely on data that are harder to verify, and provide less than 30 percent of the data set, these results were removed to produce a model of only the 2001 data (as provided in the body of this report, in Table 6.2). The following result is based on the same model as the above table except for removal of the *YR1999* variable.

**Table C9. Ordered Probit Model Results for Discomfort (Without *YR1999* dummy variable)**

| Variables | Estimates | Std. Err. | t-stats |
|---|---|---|---|
| Thresh01 | 0.136 | 0.208 | 0.651 |
| Thresh02 | 1.133 | 0.210 | 5.395* |
| Thresh03 | 1.683 | 0.213 | 7.911* |
| Thresh04 | 2.358 | 0.220 | 10.734* |
| MSLOPE | 0.089 | 0.016 | 5.480* |
| CSLOPE | 0.117 | 0.010 | 11.286* |
| LENGTH | 0.014 | 0.002 | 5.888* |
| AGE | 0.003 | 0.002 | 1.354 |
| MALE | -0.311 | 0.075 | -4.137* |
| SHAPE | -0.157 | 0.029 | -5.432* |
| AIDWALK | -0.866 | 0.134 | -6.478* |
| BLIND | 0.152 | 0.345 | 0.442 |
| AIDCACRB | -0.034 | 0.105 | -0.327 |
| AIDEWCSC | 0.242 | 0.199 | 1.211 |
| Num. of Observations | 1045 | | |
| Log-L (Constant) | -1395.550 | | |
| Log-L (Restricted) | -1249.630 | | |
| LRI** | 0.105 | | |

Note: The reference mobility aid device is an AIDMWC

* Statistically Significant at the 0.05 significance level

** Likelihood Ratio Index (or Pseudo-$R^2$)

## C.3 DATA SET

### Table C10. 1999 & 2001 Data Files

(next two pages)

1st page of excel sheet here

2nd page of excel sheet here

Abbreviated Legend of Definitions for Data Tables:

The above data spreadsheets use abbreviations. Several of the definitions of these are shown here. For additional insight into the responses, please see Appendix B's questionnaires.

Mobility Aid:
CAN = cane
CRU = crutch
BRA = brace
WAL = walker
SCO = scooter
MWC = manual wheelchair
EWC = electric wheelchair
WHC = white cane

***Pavement condition:*** W = wet; D = Dry; N = not completed

***Comfort level scale***: 1 = very uncomfortable or unable to cross; 5 = very comfortable

***Comfort ≤ 3; # sections:*** The number of sections or blocks of equal difficulty the subject could complete if the comfort level was less than or equal to three. Possible responses (as shown in the survey forms of Appendix B) are zero, 1 total, 2 total, 1 per block (1B), 2 per block (2B), 3+ per block (3+B).

***Daily trips:*** Participant estimate of the number of trips comparable to this set of sections which participant could complete in one day

***Sufficient #?:*** Yes or No = Participant response as to whether that number of daily trips is sufficient for their normal travel needs

## C.4 REGRESSION COEFFICIENT CORRELATION MATRICES

**Table C10a: Correlation Matrix of the Parameter Estimates in the Ordered Probit Assessment Model (Combined Data: 1999+ 2001)**

| | MSLOPE | CSLOPE | LNLNTH | LNAGE | MALE | SHAPE | AIDWALK | BLIND | AIDCCB | AIDEWSC | YR1999 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| MSLOPE | 1.000 | 0.002 | 0.719 | -0.005 | -0.007 | 0.010 | -0.013 | 0.003 | 0.008 | 0.006 | 0.370 |
| CSLOPE | 0.002 | 1.000 | 0.352 | 0.029 | -0.032 | -0.019 | -0.055 | 0.006 | -0.002 | 0.011 | 0.310 |
| LNLNTH | 0.719 | 0.352 | 1.000 | 0.012 | -0.019 | -0.007 | -0.025 | 0.000 | -0.011 | -0.004 | 0.615 |
| LNAGE | -0.005 | 0.029 | 0.012 | 1.000 | 0.218 | -0.091 | -0.066 | 0.171 | -0.018 | 0.057 | 0.683 |
| MALE | -0.007 | -0.032 | -0.019 | 0.218 | 1.000 | -0.191 | 0.051 | 0.031 | -0.077 | 0.111 | 0.074 |
| SHAPE | 0.010 | -0.019 | -0.007 | -0.091 | -0.191 | 1.000 | 0.039 | -0.031 | 0.179 | -0.042 | -0.022 |
| AIDWALK | -0.013 | -0.055 | -0.025 | -0.066 | 0.051 | 0.039 | 1.000 | 0.168 | 0.655 | 0.283 | 0.016 |
| BLIND | 0.003 | 0.006 | 0.000 | 0.171 | 0.031 | -0.031 | 0.168 | 1.000 | 0.222 | 0.136 | 0.107 |
| AIDCCB | 0.008 | -0.002 | -0.011 | -0.018 | -0.077 | 0.179 | 0.655 | 0.222 | 1.000 | 0.355 | 0.065 |
| AIDEWSC | 0.006 | 0.011 | -0.004 | 0.057 | 0.111 | -0.042 | 0.283 | 0.136 | 0.355 | 1.000 | -0.036 |
| YR1999 | 0.370 | 0.310 | 0.615 | 0.683 | 0.074 | -0.022 | 0.016 | 0.107 | 0.065 | -0.036 | 1.000 |

Table C10b: Correlation Matrix of the Parameter Estimates in the Ordered Probit Assessment Model (2001 Data Only)

| | MSLOPE | CSLOPE | LENGTH | AGE | MALE | SHAPE | AIDWALK | BLIND | AIDCCB | AIDEWSC |
|---|---|---|---|---|---|---|---|---|---|---|
| MSLOPE | 1.000 | -0.076 | 0.747 | 0.001 | -0.007 | 0.005 | -0.019 | 0.001 | 0.008 | -0.004 |
| CSLOPE | -0.076 | 1.000 | 0.256 | 0.035 | -0.045 | -0.019 | -0.057 | -0.003 | 0.015 | -0.031 |
| LENGTH | 0.747 | 0.256 | 1.000 | 0.020 | -0.023 | -0.008 | -0.036 | -0.002 | -0.009 | -0.014 |
| AGE | 0.001 | 0.035 | 0.020 | 1.000 | 0.161 | -0.179 | -0.236 | 0.163 | -0.153 | 0.016 |
| MALE | -0.007 | -0.045 | -0.023 | 0.161 | 1.000 | -0.241 | 0.060 | 0.026 | -0.050 | 0.147 |
| SHAPE | 0.005 | -0.019 | -0.008 | -0.179 | -0.241 | 1.000 | 0.005 | -0.095 | 0.126 | -0.203 |
| AIDWALK | -0.019 | -0.057 | -0.036 | -0.236 | 0.060 | 0.005 | 1.000 | 0.170 | 0.674 | 0.366 |
| BLIND | 0.001 | -0.003 | -0.002 | 0.163 | 0.026 | -0.095 | 0.170 | 1.000 | 0.226 | 0.156 |
| AIDCCB | 0.008 | 0.015 | -0.009 | -0.153 | -0.050 | 0.126 | 0.674 | 0.226 | 1.000 | 0.415 |
| AIDEWSC | -0.004 | -0.031 | -0.014 | 0.016 | 0.147 | -0.203 | 0.366 | 0.156 | 0.415 | 1.000 |

**Table C11: Correlation Matrix of the Parameter Estimates in the Random Effects Heart Rate Regression Model (2001 Data Only)**

| | MSLOPE2W | CSLOPEW | SHAPEW | AGEW | MALEW | TTIMEW | SPEEDW | AIDWAKW | BLNDW | AIDCCBW | AIDEWSW |
|---|---|---|---|---|---|---|---|---|---|---|---|
| MSLOPE2W | 1.000 | 0.950 | 0.563 | 0.791 | 0.261 | 0.842 | 0.709 | 0.146 | -0.443 | 0.755 | -0.270 |
| CSLOPEW | 0.950 | 1.000 | 0.584 | 0.828 | 0.274 | 0.881 | 0.703 | 0.154 | -0.463 | 0.787 | -0.283 |
| SHAPEW | 0.563 | 0.584 | 1.000 | 0.567 | 0.285 | 0.502 | 0.478 | 0.350 | -0.387 | 0.381 | -0.131 |
| AGEW | 0.791 | 0.828 | 0.567 | 1.000 | 0.207 | 0.767 | 0.571 | 0.296 | -0.389 | 0.612 | -0.216 |
| MALEW | 0.261 | 0.274 | 0.285 | 0.207 | 1.000 | 0.252 | 0.150 | -0.034 | -0.173 | 0.323 | -0.242 |
| TTIMEW | 0.842 | 0.881 | 0.502 | 0.767 | 0.252 | 1.000 | 0.348 | 0.210 | -0.388 | 0.755 | -0.312 |
| SPEEDW | 0.709 | 0.703 | 0.478 | 0.571 | 0.150 | 0.348 | 1.000 | 0.084 | -0.413 | 0.454 | -0.094 |
| AIDWAKW | 0.146 | 0.154 | 0.350 | 0.296 | -0.034 | 0.210 | 0.084 | 1.000 | -0.138 | -0.299 | -0.145 |
| BLNDW | -0.443 | -0.463 | -0.387 | -0.389 | -0.173 | -0.388 | -0.413 | -0.138 | 1.000 | -0.250 | -0.121 |
| AIDCCBW | 0.755 | 0.787 | 0.381 | 0.612 | 0.323 | 0.755 | 0.454 | -0.299 | -0.250 | 1.000 | -0.262 |
| AIDEWSW | -0.270 | -0.283 | -0.131 | -0.216 | -0.242 | -0.312 | -0.094 | -0.145 | -0.121 | -0.262 | 1.000 |

## APPENDIX D. GAUSS PROGRAM CODE

### *Ordered Probit Model*

```
/**********************************************************************
**   ORDERED PROBIT MODEL
**   Written by Dr. Chandra Bhat (1999)
**   Modified for sidewalk project by Young-Jun Kweon (August 2001)
**********************************************************************/

/*= Include MaxLik library =*/
library maxlik;
#include maxlik.ext;

/*= Reset global variables for maxlik =*/
maxset; /* "proc(0) maxset" procedure in maxlik.src */;

/*= Clear the global symbols for this program=*/
clearg ncon, _indep, threlbl, inf, minf, _weight;

/*= dataset for analysis: Sidewalk project=*/
dataset = "E:\\Sidewalk\\9901\\R082701\\ASSESS\\ASSESS01.DAT" ;

/**********************************************************************
              Specification of variables area
**********************************************************************/
/* definition of independent variables (exclude constant because
   program is set up to estimate all boundary thresholds; some other
   programs(e.g. Limdep) will include constant in independent
   variables, but then will normalize first threshold to be zero;
   these are equivalent because location parameter of latent propensity
   variable is not identifiable) */
/* If the equation does include a constant term, one of the threshold
   parameters is not identified.  We normalize the first to 0. */


@------------------ Unrestricted model estimation -------------------@
ivname = { MSlope CSlope LENGTH AGE MALE SHAPE
              .......................................   AIDWALK BLIND AIDCACRB AIDEWCSC };
@ Base is AIDMWC @

{ varnam, iv1 } = indices (dataset, ivname');
/*
---- Variables list -----
ASSESS MSlope CSlope Length lnlnth SHAPE
```

```
AGE lnage MALE AIDMWC AIDEWC AIDCRUT
AIDCANE AIDBRAC AIDWALK AIDSCTR BLIND
AIDCACRB AIDEWCSC Weight UNO ;

--> Variables list from data in the same order of data
Original file is "E:\Sidewalk\9901\R082701\ASSESS\Base\Assess.xls"
*/

/* Dependent variable (dv) should take the values 1,2,3,... for this
   estimation code. So if dv in your model takes 0,1,2,..., recode dv =
   dv+1. This does not affect results in any way; put your dv label in
   data set on the right side; so if dv is "Stops" in your data set,
   then "stops" will appear on right side */

{ dvname, dv1 } = indices(dataset, "ASSESS" );

/* Provide pointer to weight variable; if no weight is to be used, then
   construct a variable labeled as "uno" which takes a value '1' for
   each observation in data set, and use "uno" as weight variable as
   below  */

{ weight, _weight } = indices(dataset, "WEIGHT");

@{ weight, _weight } = indices(dataset, "UNO");@
/* Use this instead of the above line if you don't want to use weight*/


/* Output file name for "dumping" results */
/* output file = e:\sidewalk\run2\sidewalk.out on; */

/* if you are providing your own start values, put  _stols = 0, otherwise
   _stols = 1 */

_stols = 1;

/* if _stols = 0, provide start values below starting with threshold
   values and then coefficients on independent variables; so if you
   have a dv taking values 1,2, and 3, then the thresholds will be
   -inf, threshold1, threshold2, +inf; you have to provide start values
   of threshold1, threshold2, and coefficients on independent variables
   (in that order);
   coeffs. on independent variables should be in the same order as
   their listing in the independent variable specification earlier */

/* Also, if _stols = 0, provide number of thresholds to be estimated in
   ncon; in above example, ncon will be equal to 2 */
```

```
if _stols == 0;
  b = { 1.2817,2.4209,3.0777,3.7734,
                  0.0744,0.1265,0.1277,0.0,0.0,0.0,0.0,0.0,0.0,0.0 };
   ncon=4;
else;
  b = (init(dataset)) | zeros(rows(iv1),1);   /* rows(iv1) = rows(varnam) */
endif;

/*************************************************************************
                Main Program area begins
*************************************************************************/
/* USER WILL NOT HAVE TO MODIFY ANYTHING BELOW */

/* Define infinity and - infinity for practical calculation purposes of
  cumulative normal distribution function */
inf = 1e+300;
minf = -1e+300;

/* Associating columns with variable names for output */
threlbl =  0 $+  "Thresh" $+ ftocv(seqa(1, 1, ncon), 2, 0);

/* Maxlik global variable definitions */
_max_ParNames = threlbl | varnam;

@_max_Options = { bfgs stepbt }; @

/* bfgs (decent method), stepbt (line search method) */
/* bfgs: Broyden, Fletcher, Goldfard, Shanno */

_max_Options = { newton brent central };

/* _max_Options = { brent newton central file };            */
/* sets the line search method to BRENT, the descent method */
/* to NEWTON, the numerical gradient method to central      */
/* differences, and __OUTPUT = 1.                           */
/*   Line Search:  ONE, STEPBT, HALF, BRENT, BHHHSTEP       */
/*   Algorithms:  STEEP, BFGS, DFP, NEWTON, BHHH, PRCG      */
/*   Gradient method:  CENTRAL, FORWARD                     */

@_max_GradProc = &lgd; /* Grdient method --> Dr. Bhat's code */@

_max_CovPar = 1;

__title = "SIDEWALKS CROSS SLOPE ASSESSMENT ORDERED PROBIT
ESTIMATION";
```

```
__row = 200;


@----------- Unrestricted model estimation (Continued) -------------@
/*- Maxlik procedure call for unrestriced log-likelihood estimation-*/
{ x, f, g, cov, retcode } = maxprt( maxlik(dataset, 0, &lpr, b) );
/*- Print the covariance matrix -*/
print "    The Covariance matrix: ";;
format /mat /on /mb1 /ros 10,6;
print cov;

/*- Print the Log-likelihood function -*/
print;
print "    Log likelihood value (Unrestricted): ";;
log1 = f * _max_NumObs;
print log1;
@-----------------------------------------------------------------@

@------------------- Restricted model estimation -------------------@
@ivname = { weight };@
ivname = { UNO };
{ varnam, iv1 } = indices (dataset, ivname');

if _stols == 0;
  b = { 1.2817,2.4209,3.0777,3.7734,0.0 };
  ncon=4;
else;
  b= (init(dataset)) | zeros(rows(iv1), 1);
endif;

__title = "RESTRICTED MODEL (CONSTANT ONLY MODEL) ESTIMATION";
_max_ParNames= threlbl | varnam;

/*- Maxlik procedure call for restriced log-likelihood estimation-*/
{ x, f, g, cov, retcode } = maxprt(maxlik(dataset, 0, &lpr, b));

/*- Print the restricted log-likelihood -*/
log0 = f * _max_NumObs;
print "    Log likelihood value (Restricted): ";;
print log0;
@-----------------------------------------------------------------@

print "    Likelihood Ratio Index(LRI) :  " ;;
print (1 - log1 / log0);
```

```
@---- Procedure to determine starting values of thresholds if user does
      not provide ----@

 proc init(dataset);
 local fin, dta, obs, c, i, j, st, p, s, n;
 open fin = ^dataset;
 do until eof(fin);
   dta = readr(fin, 2000);
   obs = rows(dta);
   c = unique(dta[.,dv1], 1);
   n = rows(c);
   ncon = n-1;

   i = 0;
   s = zeros(n, 1);
   do until i == n;
     i = i + 1;
     s[i] = sumc(dta[., _weight] .* (dta[., dv1] .== i));
   endo;
 endo;
 fin = close(fin);

 clear p;
 j = 0;
 do until j == n;
   j = j + 1;
   p = p | s[j] + p[rows(p)];
 endo;

 p = trimr(p, 1, 1) / p[rows(p)];
 st = cdfni(p);
 retp(st);
endp;


@-------- procedure for log likelihood function calculation --------@
proc lpr(x, dta);
  local newv, y, tu, tl, cdfu, cdfl, cdfd, z10;
  y = dta[., dv1];
  tu = submat(minf | x[1:ncon] | inf, y+1, 0)  -  (dta[., iv1']) *
       x[ncon+1:rows(x)];
  tl  = submat(minf | x[1:ncon] | inf, y, 0)  -  (dta[., iv1']) *
       x[ncon+1:rows(x)];
  cdfu = cdfn(tu);
  cdfl = cdfn(tl);
```

```
  cdfd = cdfu - cdfl;

  if cdfd > 0;
     z10= ln(cdfd);
  else;
     z10= ln(cdfd - ((cdfd .<= 0) .* (cdfd - .0001)));
  endif;
  retp(dta[., _weight] .* z10);
endp;


@-------- procedure for gradient searching --------@
proc lgd(x, dta);
  local newv, y, tu, tl, pcfu, pcfl, cdfu, cdfl, cdfd, pcfd, tempy, g,
  z9, mask, mask1, mask2;
  y = dta[., dv1];
  tu = submat(minf | x[1:ncon] | inf, y+1, 0)  -  (dta[., iv1']) *
      x[ncon+1:rows(x)];
  tl = submat(minf | x[1:ncon] | inf, y, 0)  -  (dta[., iv1']) *
      x[ncon+1:rows(x)];

  pcfu = pdfn(tu);
  pcfl = pdfn(tl);
  pcfd = pcfu - pcfl;

  cdfu = cdfn(tu);
  cdfl = cdfn(tl);
  cdfd = cdfu - cdfl;

  if cdfd > 0;
    z9= (cdfd);
 else; @ --> CHECK! There was no 'else;' in the original code @
    z9= (cdfd - ((cdfd .<= 0) .* (cdfd - .0001)));
  endif;

  tempy = - pcfd ./ z9;
  mask = reshape(seqa(1, 1, ncon+2)', rows(y), ncon + 2);
  mask1 = mask .== y;
  mask2 = mask .== (y + 1);
  g = (mask1 .* (-pcfl ./ z9)) + (mask2 .* (pcfu ./ z9));
  g = g[., 2:ncon+1] ~ tempy .* dta[., iv1'];
  retp(dta[., _weight] .* g);
endp;

output off;
```

### ***Weighted Least Square Model (One-way and Two-way Random Effect)***

```
/*********************************************************/
/*   GLS-RE(Weighted Least Square Random Effect)MODEL           */
/*   Written by Yong Zhao and Young-Jun Kweon                   */
/*   For sidewalk project (August 2001)                         */
/*********************************************************/

external proc indices2;
clearg _weight;

/* dataset for analysis ==For sidewalk project, it's "HRDIFF" */

dataset = "E:\\Sidewalk\\9901\\R090901\\HRDIFF2\\HRDF2w.DAT" ;

/* Create One-Way REVC Matrix */
open fin = ^dataset;
if fin == -1;
  errorlog "ERROR: File not found: " $+ dataset;
  end;
endif;
nobs = rowsf(fin);
obs  = readr( fin, nobs ) ;

/* All variables are transformed by multiplying by sqrt(weight) */
/* Variable Lists */
/* TSQ ISQ ASQ YD1999 HRDIFF2w MSlope2w Cslopew LENGTH2w LNLNTH2w
   SHAPEw AGEw LNAGEw MALEw AIDMWCw AIDWALKw BLINDw AIDCCBw
   AIDEWSCw HRRESTw UNOw
*/

ivname = { UNOw MSlope2w LENGTH2w
         LNAGEw SHAPEw MALEw
         AIDCCBw AIDWALKw BLINDw AIDEWSCw } ;
@ Base group is AIDMWCw @

dvname = { HRDIFF2w } ;
{ depvar,depindx,indvars,indindx } = indices2(dataset,dvname,ivname') ;
xw = obs[ . , indindx ] ;
yw = obs[ . , depindx ] ;

varname = { TSQ } ;
{ varnam, varindx } = indices (dataset, varname');
siteID = obs[.,varindx] ;
c = unique(obs[.,varindx], 1) ;
nsite = rows(c) ;
```

```
varname = { ISQ };
{ varnam, varindx } = indices (dataset, varname');
personID = obs[.,varindx];
c = unique(obs[.,varindx], 1);
nperson = rows(c);

varname = { UNOw } ;
{ varnam, varindx } = indices (dataset, varname');
sqrtW = obs[.,varindx] ;


__altnam={ivname'|dvname }; @ name of the variables @
__con=0; @ non constant @
_olsres = 1;

{ vnam,m,b,stb,vc,stderr,sigma,cx,rsq,resid,dwstat } =
        OLS(dataset',depindx,indindx);

close(fin);

/* Form the residuals into matrix format (nperson*nsite) */
err=zeros(nperson,nsite);
m=rows(resid);
resid=resid./sqrtw; @ Transfer the residuals back to w/o weight factors==avoid heterostochasticity @
i=1;
do while i<=m;
  r_err=personID[i,1];
  c_err=siteID[i,1];
  err[r_err,c_err]=resid[i,1];
  i=i+1;
endo;

rho1=0;
sum1=0;
sum2=0;
n=1;
sumn=0;

do while n<=nperson;
  i=1;
  do while i<=nsite;
    j=1;
    do while j<=nsite;
      if i/=j;
        sum1=sum1+err[n,i]*err[n,j];
```

```
        sumn=sumn+1;
      endif;
      j=j+1;
    endo;
    sum2=sum2+err[n,i]^2;
    i=i+1;
  endo;
  n=n+1;
endo;
rho1=(sum1/sumn)/(sum2/(nperson*nsite));

/* Generate the VCRE1 matrix */
N=rows(siteID);
sID=siteID';
pID=personID';
VCRE1=zeros(N,N);
i=1;
do while i<=N;
  j=1;
  do while j<=N;
    if i==j;
      VCRE1[i,j]=1;
    else;
      if (siteID[i,1] /= sID[1,j]) and (personID[i,1] == pID[1,j]);
        VCRE1[i,j]=rho1;
      endif;
    endif;
    j=j+1;
  endo;
  i=i+1;
endo;

/* Take the inverse of VCRE1 matrix */
W = inv( VCRE1 ) ; /* W matrix */

/* Independent varibles */
/* Dependent variable   */
dvname= { HRDIFF2w } ;

/* The title of the the output */
title = "HEART RATE CHANGE: HRDIFF2 (GLS: One-way Random Effect)";

/*----------------------------------------------------------------*/
/*                  Main Program area begins                    */
/*----------------------------------------------------------------*/
```

```
/* USER WILL NOT HAVE TO MODIFY ANYTHING BELOW */
/* Open file using name in variable DATASET    */

        open fin = ^dataset;
        if fin == -1;
            errorlog "ERROR: File not found: " $+ dataset;
            end;
        endif;
        nobs = rowsf(fin);
        { depvar,depindx,indvars,indindx } =
                            indices2(dataset,dvname,ivname');
        nvar = rows( indindx ) ;
        nvar1 = nvar + 1;
        obs=readr( fin, nobs ) ;
        x=obs[ . , indindx ] ;
        y=obs[ . , depindx ] ;
                close(fin);

/* WLS procedure call */
{ b,stdb,sigma2,t,pvt,R2,wtR2,wtadjR2 } = wlsPs( y, x, w );

vc = vcx(x);
if indindx[1] == 20.0; /* 20st variable is "UNOw" */
                x1 = x[ . ,2:rows(indindx)] ;
                vc = vcx(x1);
elseif indindx[1] !== 20.0 ;
                vc = vcx(x);
endif;
cx = corrvc(vc);

/* Print the output   */
                @print vc;@
                print cx;

                print; print;
        print "==========================================================";
        print title;
        print "==========================================================";
        print ftos(nobs,"Valid cases:  %*.*lf",10,0);;
        print ftos(depvar,"   Dependent variable: %*.*s",8,8);

        /* Note that UNOw is not a constant term since it's not fixed */
        /* We cannot calculate R-2      with UNOw                    */
/*
        if indindx[1] == 21.0; @ if there is no constant term @
          print ftos(R2 ,"R-squared:    %*.*lf",10,3);;
```

```
      print ftos(wtR2,"   Weighted R-squared: %*.*lf",8,3);
      print ftos(adjR2,"Weighted AdjR-2: %*.*lf",7,3);;
    elseif indindx[1] !== 21.0 ;
      print ftos("R2, wtR2 and wtadjR2 cannot be calculated");;
    endif;
*/
    print ("R2, wtR2 and wtadjR2 cannot be calculated");;
    print ;
    print ftos(sqrt(sigma2) ,"   Std. Err of Est:    %*.*lf",8,3);
    print ; print;
    print "                      Standard              Prob ";
    print "Variable    Estimate     Error      t-value      >|t| ";
    print "----------------------------------------------------";

    omat = indvars~b~stdb~t~pvt;
    mask = 0~1~1~1~1;
    let fmt[5,3] = "-*.*s" 9 8 "*.*lf" 12 6 "*.*lf" 12 6 "*.*lf" 12 6 ""\
       "*.*lf" 10 3;
    call printfm(omat,mask,fmt);
            print;
            print "===============< End of Results >=================";

/*----------------------------------------------------------------------
**  wlsPs
**
**  Purpose:   weighted least squares. Solves b = argmin (y-xb)'W(y-xb),
**          where W is a NxN weight matrix, with weights along
**             ............................................................   the diagonal and zeros off-diagonal.
**
**
**  Usage:     { b,stdb,sigma2,t, pvt, R2, wtR2, wtadjR2 } = wlsPs( y,x,w );
**
**  Input:    w  -    NxN matrix, weights
**          y       Nx1 vector, dependent variable
**          x       NxK matrix, explanatory variables
**
**  Output:    b   -   Kx1 vector, estimated coefficients
**          stdb    Kx1 vector, standard deviations for b
**          sigma2  scalar, variance of residuals
**          t       Kx1 vector, estimated t stat
**          pvt     Kx1 vector p-value of t
**          R2      scalar, R2
**          wtR2    scalar, Weighted R2
**          wtadjR2   scalar, Weighted adjusted R2
----------------------------------------------------------------------*/
```

```
Proc (8) = wlsPs( y,x,w );

  local N,k,df,b,e,sigma2,varb,stdb,t,pvt,R2,wtR2,wtadjR2 ;

  N = rows(y);
  k = cols(x);
  df= N-k ;

/* Direct multiplication saves memory space   */
  b = inv(x'*W*x )*(x'*W*y) ; /* Coefficients */

  e = y -x*b ;
  sigma2 = e'*W*e/(N-k) ;
  varb = sigma2*inv(x'*W*x) ;
  stdb = sqrt( diag(varb) ) ;

  t = b./stdb ;
  pvt = 2*cdftc(abs(t),df) ;

/* R2 and adjR2 should be weighted by the w matrix           */
/* Note that UNOw is not a constant term since it's not fixed */
/* We cannot calculate R-2 etc. with UNOw                    */
/* Although the following equations will calculate them       */
/* the print code will not report them                       */

  R2      = 1 - e'*e/( (y-meanc(y))'*(y-meanc(y)) );
  wtR2    = 1- e'*W*e/( (y-meanc(y))'*W*(y-meanc(y)) );
  wtadjR2 = 1-( e'*W*e )*(N-1) / ( ((y-meanc(y))'*W*(y-meanc(y)) )* (N-k) );

  retp( b,stdb,sigma2,t,pvt,R2,wtR2,wtadjR2 );
endp;


/*******************************************************
vcx

Purpose:    Computes a variance-covariance matrix from a data matrix.
Format:     vc = vcx(x);
Input:      x    NxK matrix of data.
Output:     vc   KxK var-covar matrix.
Source:     corr.src
********************************************************
corrvc

Purpose:    Computes a correlation matrix from a
            variance-covariance matrix.
```

```
Format:     cx = corrvc(vc);
Input:      vc    KxK variance-covariance matrix (of data or parameters).
Output:     cx    KxK correlation matrix.
Source:     corr.src
*****************************************************/

output off;
```

### ***Weighted Least Square Model (One-wayRandom Effect between individuals)***

```
/*********************************************************************/
/*    WLS(Weighted Least Square)MODEL                                 */
/*    Written by Yong Zhao(1999)                                      */
/*    Modified for sidewalk project by Young-Jun Kweon (August 2001)  */
/*********************************************************************/


external proc indices2;
@clearg _weight;@

/* dataset for analysis ==For sidewalk project, it's "HRDIFF" */

dataset = "E:\\Sidewalk\\9901\\R081201\\HRDIFF1\\HRD1b.DAT" ;

/******** Variable List ********* ...........................................................................
/* HRDIFF1 MSlope CSlope Length lnlnth SHAPE AGE lnage MALE
  RHAND AIDMWC AIDEWC AIDCRUT AIDCANE AIDBRAC AIDWALK
AIDSCTR
  BLIND AIDCACRBR AIDEWCSC HRREST HRTURN
  HRTIME HREND weight UNO ;
*/

/* Independent varibles */
ivname = { CSlope LNAGE SHAPE MALE HRREST HRTIME
        AIDWALK BLIND AIDCACRBR AIDEWCSC } ;
/* Base group is AIDMWC */

/* Dependent variable   */
dvname= { HRDIFF1 } ;

/* At this moment, Two-way W matrix is not prepared */
switch = 1 ; /* 1=One-way RE & 2=Two-way RE */

/* Load weight matrix   */
if switch == 1;
                /* One-way WLS */
                load w1[200,100] = E:\Sidewalk\9901\R081201\HRDIFF1\W11b-1.txt;
                load w2[200,100] = E:\Sidewalk\9901\R081201\HRDIFF1\W11b-2.txt;
elseif switch == 2;
                /* Two-way WLS */
                load w1[200,100] = E:\Sidewalk\9901\R081201\HRDIFF1\W12b-1.txt;
                load w2[200,100] = E:\Sidewalk\9901\R081201\HRDIFF1\W12b-2.txt;
else;
   errorlog "ERROR: Choose the weight matrix";
```

```
    end;
endif;

w = w1[.,.]~w2[.,.];
/* Since the weight matrix is too big for a one file in a correct form, */
/* W matrix is split into two files and combined in GAUSS              */

/* The title of the the output */
if switch == 1;
                title = "HEARTRATE CHANGE: HRDIFF1 (WLS ESTIMATION: One-
way Random Effect)";
elseif switch == 2;
                title = "HEART RATE CHANGE: HRDIFF1 (WLS ESTIMATION: Two-
way Random Effect)";
endif;
```

**< The coding that then follows below this point is the same as the previous WLS model >**

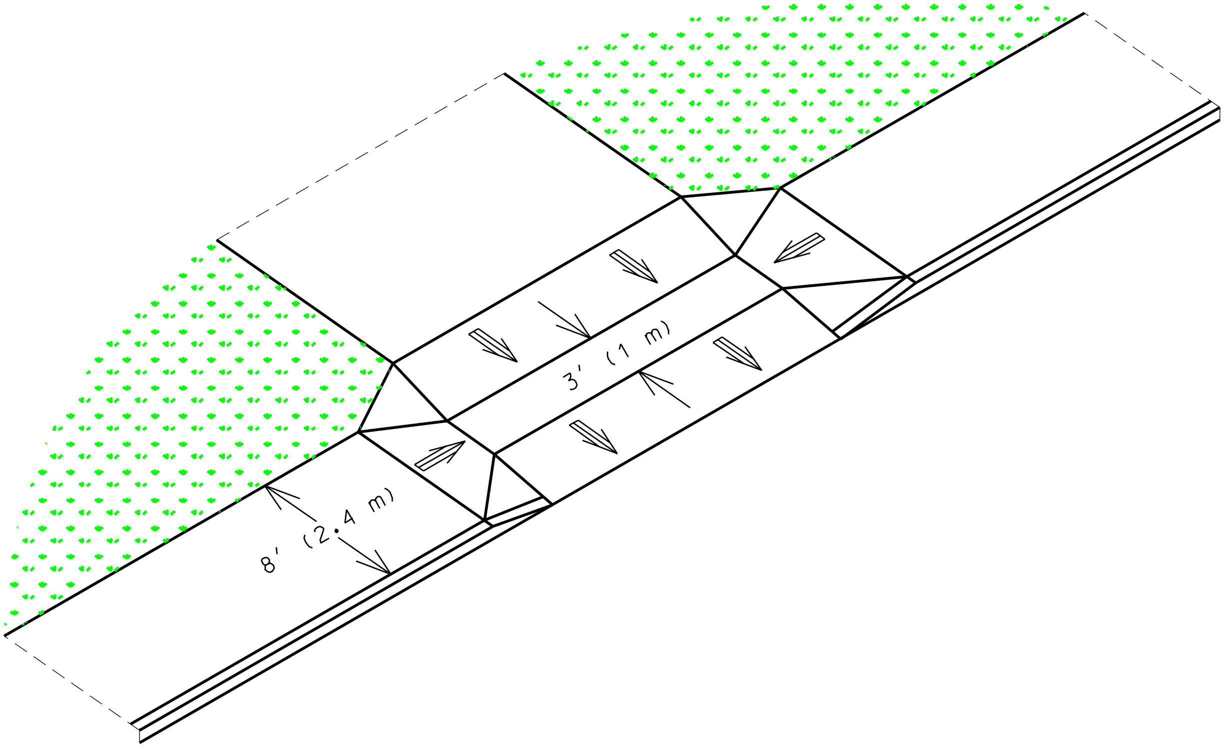
Computation of Measures of Goodness of Fit:

```
e = y -x*b ;
R2 = 1 - e'*e/( (y-meanc(y))'*(y-meanc(y)) );
adjR2 = 1-( e'*e )*(N-1) / ( ((y-meanc(y))'*(y-meanc(y)) )* (N-k) );
wtR2 = 1- e'*W*e/( (y-meanc(y))'*W*(y-meanc(y)) );
wtadjR2 = 1-( e'*W*e )*(N-1) / ( ((y-meanc(y))'*W*(y-meanc(y)) )* (N-k) );
```

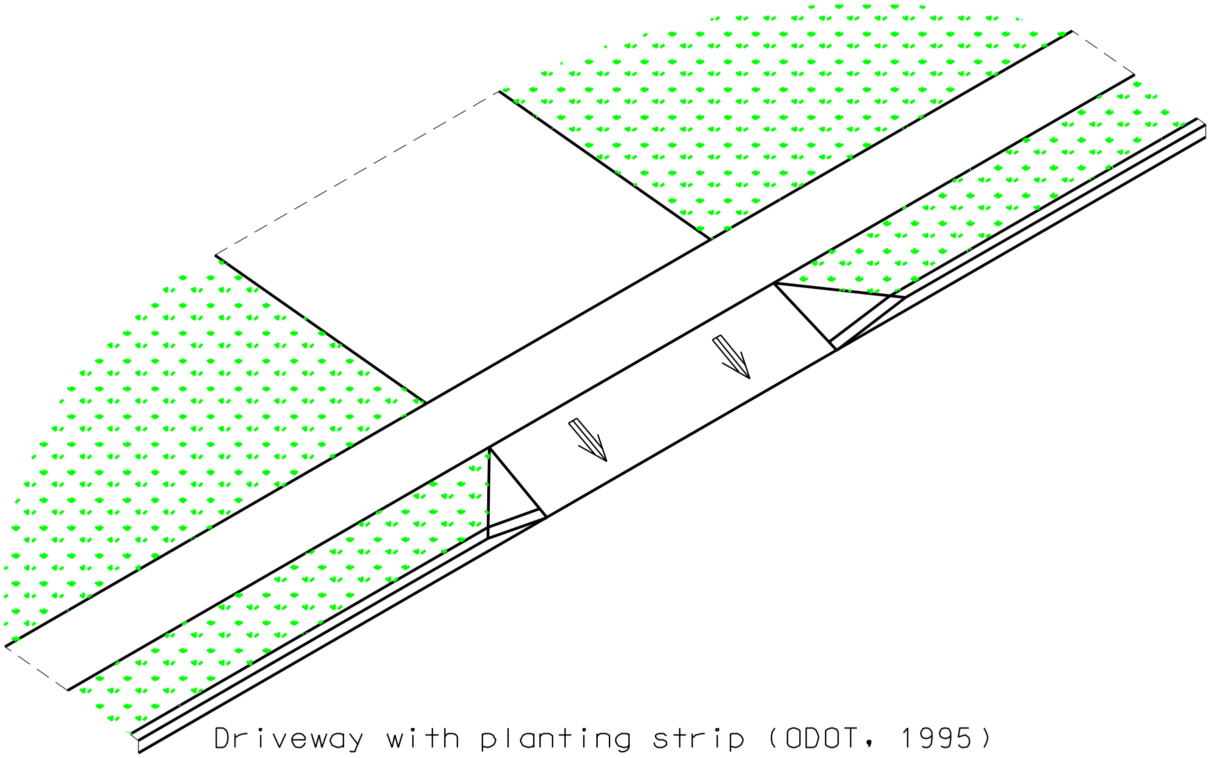
# APPENDIX E: GRAPHICS FOR THE TXDOT HIGHWAY DESIGN DIVISION OPERATIONS AND PROCEDURES MANUAL

Some graphics that TxDOT may wish to include in its *Design Manual* are shown here. These images were originally contained in the ODOT (1995) and ADAAG (1998) documents. They have been generated as MicroStation dgn files and delivered as a product under this project. (The following images are stored as eps files, for insertion in this Word2000 document.)

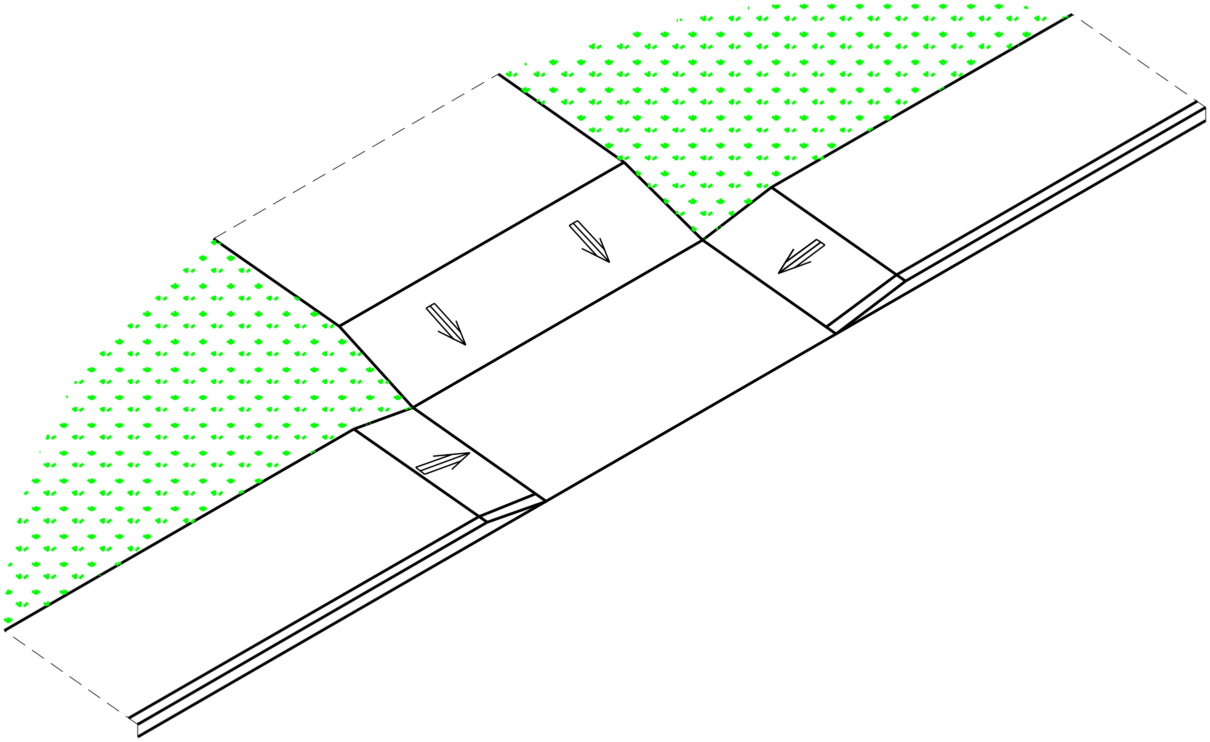
To illustrate slopes on these images, ADAAG standards are helpful. Under these standards, maximum sidewalk ramp slopes are 8.3% (1:12) and maximum sidewalk cross slopes are 2% (1:48).



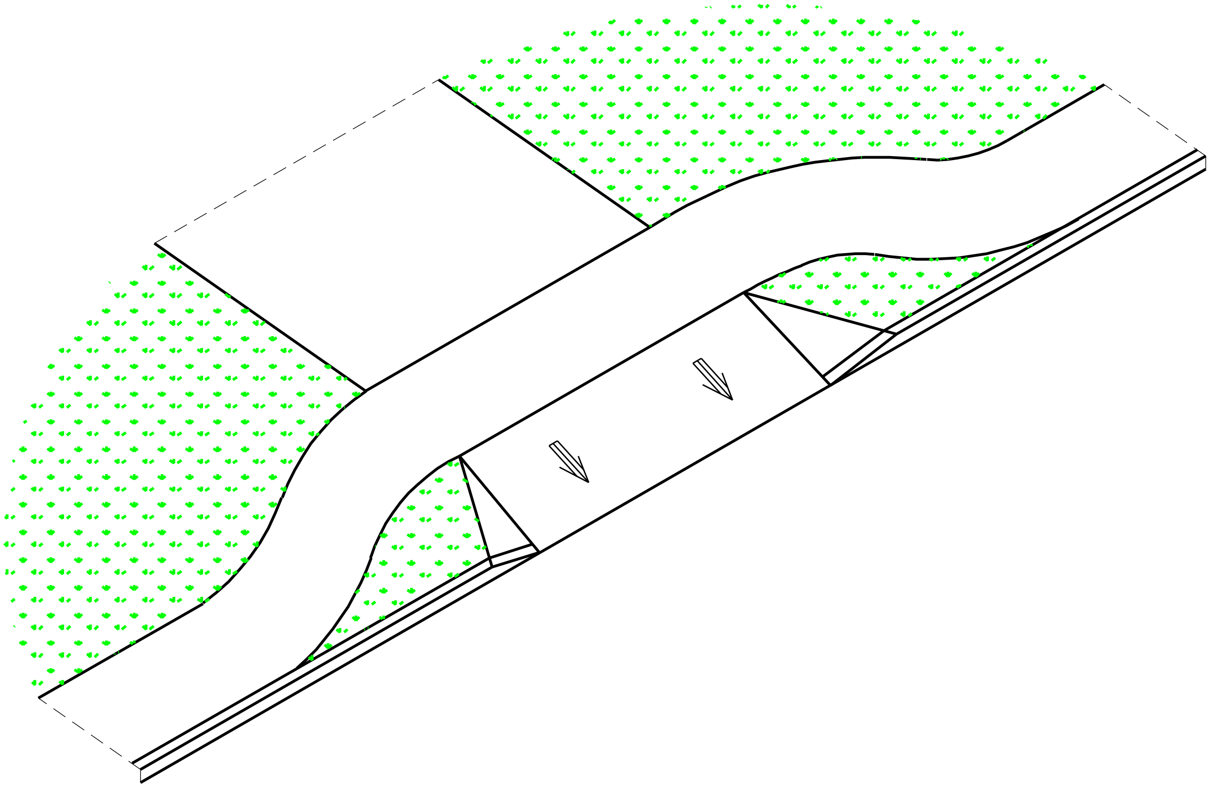
Driveway/sidewalk retrofit (Access Board, 1998)



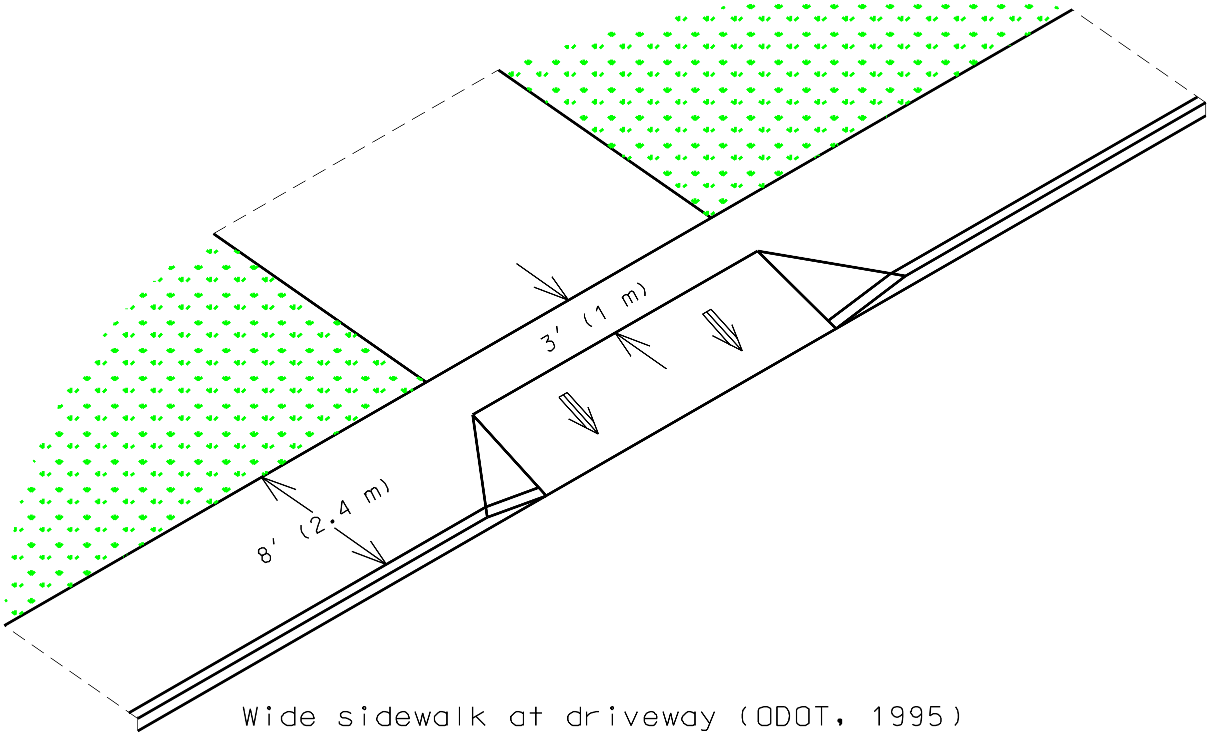
Driveway with planting strip (ODOT, 1995)



Entire sidewalk dips at driveway (ODOT, 1995)



Sidewalk wrapped around driveway (ODOT, 1995)



Wide sidewalk at driveway (ODOT, 1995)

## APPENDIX F: SITE DATA UPDATE TO 1999 SUMMARY REPORT

In undertaking this new, more extensive data collection, test sites along Lamar and Guadalupe sites were revisited and their cross slopes re-measured. Slope differences were noted on several of the sections. In many cases these were simply due to choosing different spots along the path for measurement. In other cases, differences lay outside the range of normal sidewalk variation. In several instances these differences arose because the original, 1999 participants had actually chosen to negotiate slightly easier paths than the shortest-distance central-path locations would have suggested. And, in several other cases, the test proctor for the 1999 data set, Chessalay Blanchard-Zimmerman, had modified the test site locations, after measuring the cross slopes. The current project team conducted several visits to the test sites with Chessalay Blanchard-Zimmerman, and new, more correct cross slopes were obtained (via an averaging of several slopes taken along each section). The following table represents an update to the site data used in the original project's summary report, titled "Methods For Meeting the Intent of the ADA in Sidewalk Cross-Slope Design" (Research Report 4933-S).

On page 31 of Appendix 3 of Report 4933-S, Table 3.1 should be replaced by the following:

*Table 3.1 (As labeled in Report 4933-S) Sidewalk section characteristics*

| ID | Site | Cross Slope | Main Slope | Transition Length (ft) | Setback (ft) | Length (ft) | Width (ft) | Traffic Volume (veh/hr) | Speed (mph) |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 1 | 8.33% | 1.80% | 6 | 6.75 | 41 | 3.5 | 2000 | 35 |
| 2 | 1 | 4.07% | 1.37% | 9.5 | 0 | 21 | 2 | 2000 | 35 |
| 3 | 1 | 5.12% | 1.78% | 9 | 5 | 37.5 | 4 | 2000 | 35 |
| 4 | 1 | 5.40% | 8.30% | 0 | 5 | 12 | 4 | 2000 | 35 |
| 5 | 1 | 9.00% | 0.60% | 0 | 5.5 | 13 | 4.5 | 2000 | 35 |
| 6 | 1 | 2.50% | 1.94% | 0 | 4.5 | 33 | 4 | 2000 | 35 |
| 7 | 1 | 5.70% | 10.70% | 3.5 | 4.5 | 17.3 | 4 | 2000 | 35 |
| 8 | 1 | 2.67% | 2.47% | 6 | 3 | 31 | 6 | 2000 | 35 |
| 9 | 2 | 0.67% | 1.00% | 0 | 16 | 28 | 5.5 | 2000 | 35 |
| 10 | 2 | 2.58% | 2.43% | 2 | 0 | 21 | 10 | 2000 | 35 |
| 11 | 2 | 4.86% | 1.64% | 0 | 0 | 70 | 5 | 2000 | 30 |
| 12 | 2 | 2.63% | 1.34% | 0 | 30 | 42 | 7 | 2000 | 30 |
| 13 | 2 | 1.80% | 0.70% | 0 | 50 | 30 | 16 | 2000 | 30 |
| 14 | 2 | 1.25% | 6.28% | 0 | 50 | 120 | 6 | 2000 | 35 |
| 15 | 2 | 0.41% | 1.74% | 0 | 4.5 | 40 | 4 | 2000 | 30 |

For purposes of comparison, the previous sidewalk section characteristics had been taken to be the following:

| ID | Site | Cross Slope | Main Slope | Transition Length (ft) | Setback (ft) | Length (ft) | Width (ft) | Traffic Volume (veh/hr) | Speed (mph) |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 1 | 4.77% | 0.90% | 6 | 6.75 | 41 | 3.5 | 2000 | 35 |
| 2 | 1 | 12.00% | 2.00% | 9.5 | 0 | 21 | 2 | 2000 | 35 |
| 3 | 1 | 5.53% | 1.13% | 9 | 5 | 37.5 | 4 | 2000 | 35 |
| 4 | 1 | 3.33% | 4.95% | 0 | 5 | 12 | 4 | 2000 | 35 |
| 5 | 1 | 3.10% | 1.20% | 0 | 5.5 | 13 | 4.5 | 2000 | 35 |
| 6 | 1 | 1.30% | 1.03% | 0 | 4.5 | 33 | 4 | 2000 | 35 |
| 7 | 1 | 6.10% | 6.33% | 3.5 | 4.5 | 17.3 | 4 | 2000 | 35 |
| 8 | 1 | 2.00% | 1.00% | 6 | 3 | 31 | 6 | 2000 | 35 |
| 9 | 2 | 1.00% | 1.00% | 0 | 16 | 28 | 5.5 | 2000 | 35 |
| 10 | 2 | 12.00% | 2.00% | 2 | 0 | 21 | 10 | 2000 | 35 |
| 11 | 2 | 3.00% | 1.50% | 0 | 0 | 70 | 5 | 2000 | 30 |
| 12 | 2 | 3.00% | 1.00% | 0 | 30 | 42 | 7 | 2000 | 30 |
| 13 | 2 | 1.00% | 0.00% | 0 | 50 | 30 | 16 | 2000 | 30 |
| 14 | 2 | 1.00% | 7.00% | 0 | 50 | 120 | 6 | 2000 | 35 |
| 15 | 2 | 1.30% | 0.90% | 0 | 4.5 | 40 | 4 | 2000 | 30 |

## APPENDIX G: FLOW CHARTS OF DATA PREPARATION PROCESS AND MODELING

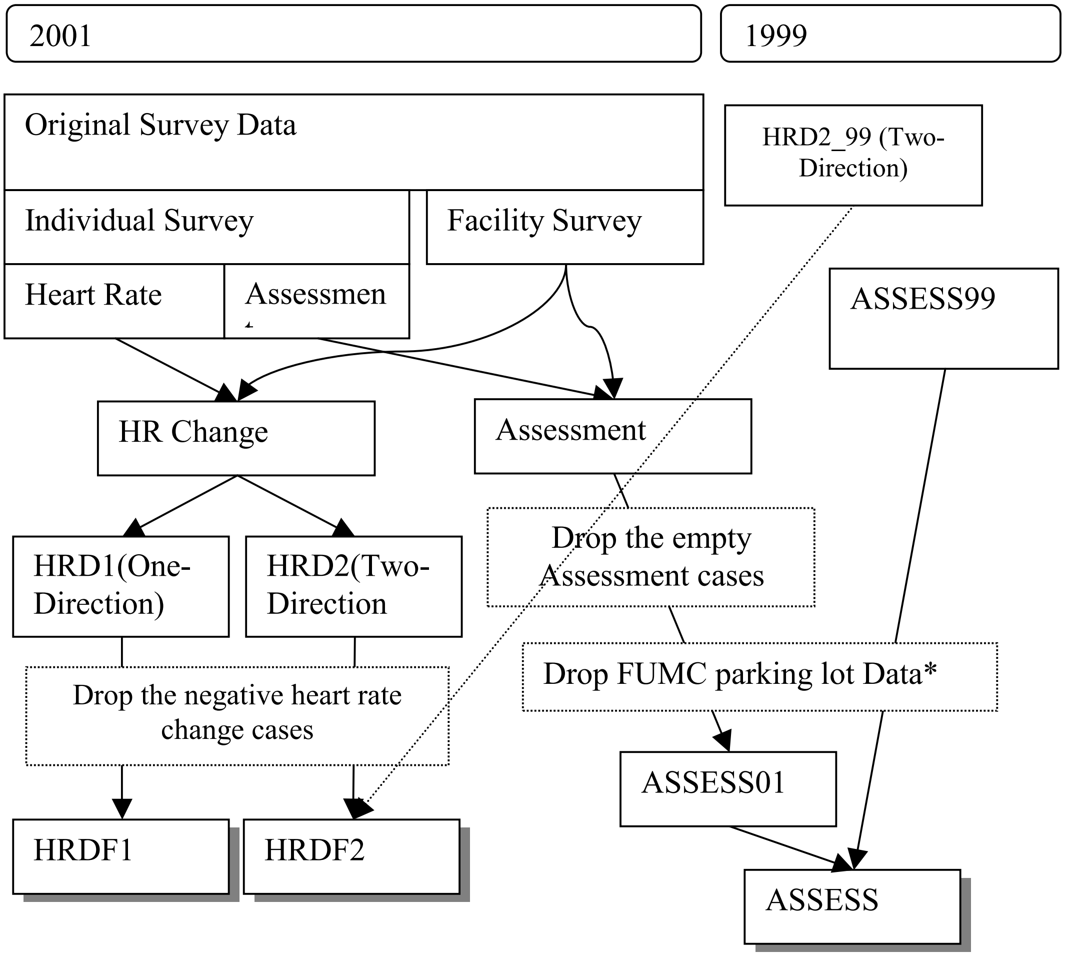


Figure G1. Flow of Data Preparation for model estimation for sidewalk.

* Due to back and forth main slopes

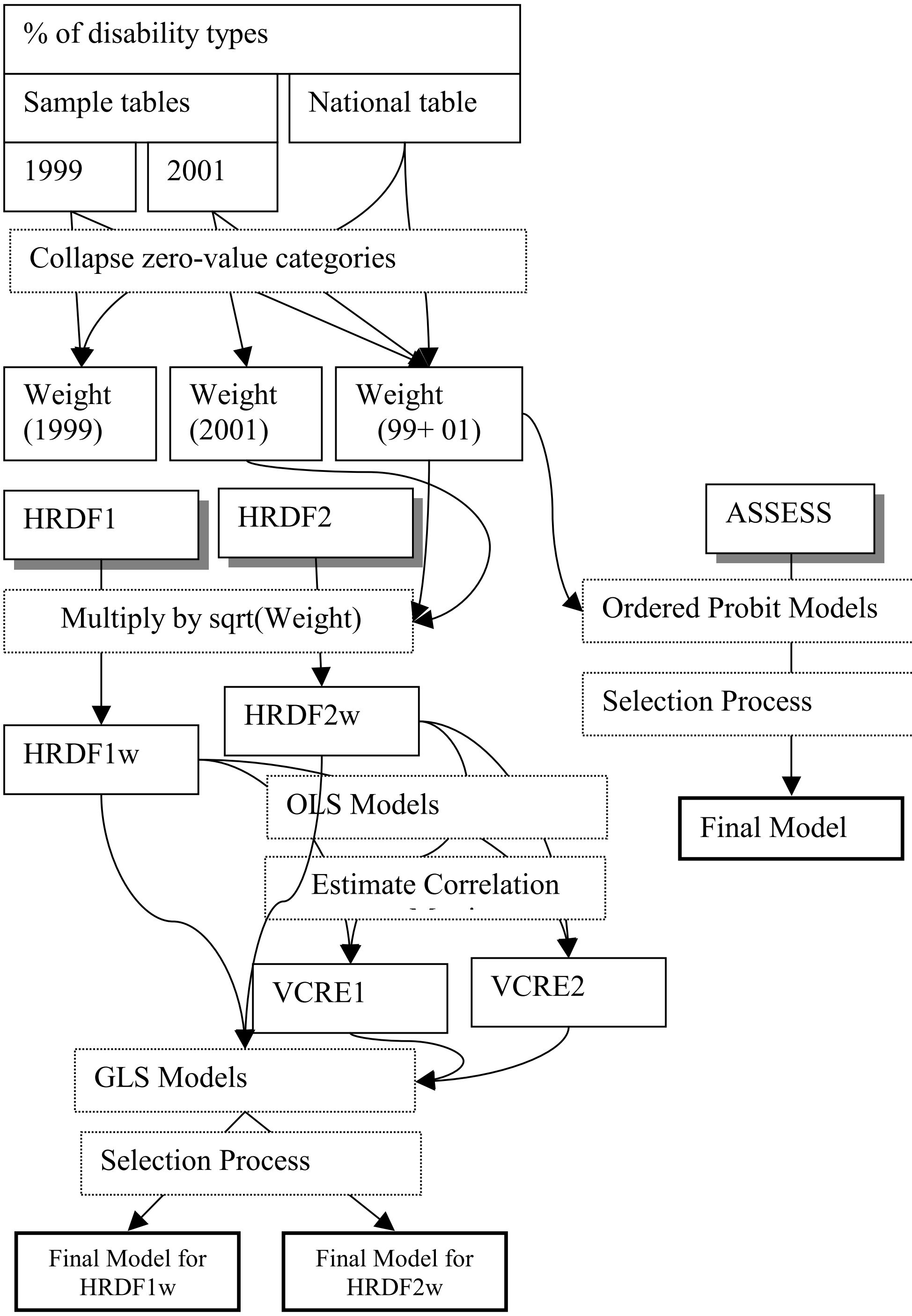


Figure G2. Flow of modeling process with sidewalk survey data