Technical Report Documentation Page

1. Report No. TX-00/4933-S	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle METHODS FOR MEETING THE INTENT OF THE ADA IN SIDEWALK CROSS-SLOPE DESIGN		5. Report Date August 1999, Revised January 2000
7. Author(s) Kara Kockelman, Yong Zhao, and Chessalay Blanchard-Zimmerman		6. Performing Organization Code
		8. Performing Organization Report No. 4933-S
9. Performing Organization Name and Address Center for Transportation Research The University of Texas at Austin 3208 Red River, Suite 200 Austin, TX 78705-2650		10. Work Unit No. (TRAIS)
		11. Contract or Grant No. 7-4933
12. Sponsoring Agency Name and Address Texas Department of Transportation Research and Technology Transfer Section/Construction Division P.O. Box 5080 Austin, TX 78763-5080		13. Type of Report and Period Covered Project Summary Report (11/13/99 to 8/31/99)
		14. Sponsoring Agency Code

15. Supplementary Notes
Project conducted in cooperation with the Texas Department of Transportation.

16. Abstract
This summary report is a review of research undertaken to determine appropriate sidewalk cross-slope design in accordance with the Americans with Disabilities Act (ADA). The research methods used are described and specific recommendations are provided. This summary report also provides a summarized review of works on related topics; the full review is available in the previously submitted research report.

To ensure sidewalk accessibility to persons with ambulatory disabilities, the research results suggest the following: (1) sidewalk cross-slope should be limited to 4 percent where feasible, and should not exceed 10 percent; and (2) where feasible and cost-effective, sidewalk design should minimize primary grade and cross-slope and increase width.

This research was conducted with the support of the Texas Department of Transportation (TxDOT) and, as such, supports that agency's desire to achieve compliance with the intent of the ADA and the associated ADAAG. Information derived from this research should be submitted to the Access Board for inclusion in proposed rule making and eventual law.

17. Key Words: ADA, Americans with Disabilities Act, cross-slope, sidewalk, wheelchair, disabled, persons with disabilities, ADAAG, accessibility		18. Distribution Statement No restrictions. This document is available to the public through the National Technical Information Service, Springfield, Virginia 22161.	
19. Security Classif. (of report) Unclassified	20. Security Classif. (of this page) Unclassified	21. No. of pages 128	22. Price

Form DOT F 1700.7 (8-72) Reproduction of completed page authorized

METHODS FOR MEETING THE INTENT OF THE ADA IN SIDEWALK CROSS-SLOPE DESIGN

by

Kara Kockelman, Yong Zhao, and Chessalay Blanchard-Zimmerman

Project Summary Report Number 4933-S

Research Project 7-4933
Sidewalk Slope Variability with Respect to the
Americans with Disabilities Act Accessibility Guidelines

Conducted for the

TEXAS DEPARTMENT OF TRANSPORTATION

by the

CENTER FOR TRANSPORTATION RESEARCH
Bureau of Engineering Research
THE UNIVERSITY OF TEXAS AT AUSTIN

August 1999

DISCLAIMERS

ACKNOWLEDGMENTS

The authors would like to thank the following individuals for supporting the work undertaken here: Robert R. Kovar (DES-DDO), program coordinator; Fred D. Woodall (DES-FCIII), project director; and the other members of the project monitoring committee, which included Robert L. Stuard (AUS-TP&D), Gilbert G. Gavia (SAT-DES), Paul Douglas (TPP-MMO), John Mack (FHWA), Mark A. Marek (DES-GD), and Elizabeth Hilton (DES-FCII).

In addition, the authors would like to recognize the following persons and organizations for their contributions to this work:

- Dr. Chandra Bhat, UT Austin, who supplied the original program code for the ordered probit model
- Dean Taylor, Lydia Heard, and Beth Taylor, UT Austin, who conducted the first phase of this project and authored the Review of Methods
- Capitol Metro, Austin, Texas
- Beneficial Designs, Santa Cruz, California
- The Access Board, Washington, D.C.

IMPLEMENTATION RECOMMENDATIONS

1. Sidewalk cross-slope should be limited to 4 percent where feasible, and should not exceed 10 percent.
2. Where feasible and cost effective, sidewalk design should minimize primary grade and cross-slope and increase width to ensure the greatest accessibility.

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CHAPTER 1. INTRODUCTION AND OBJECTIVES

This project was undertaken in order to assist the Texas Department of Transportation (TxDOT) enhance its accessible-sidewalk program with regard to the Americans with Disabilities Act (ADA). The ADA is divided into five titles. Title I prohibits discrimination against individuals with disabilities in employment by private businesses with fifteen or more employees. Title II prohibits discrimination by state and local governments in provision of services, including employment. Title III prohibits discrimination by public accommodations covered by twelve categories of private entities and commercial businesses, and includes regulations and specifications for accessible construction and design that also apply to Title II. Title IV concerns telecommunications, while Title V is a miscellaneous catchall provision that covers Congress, the legislative branch, and federal wilderness areas. In support of the ADA, the Architectural and Transportation Barriers Compliance Board (Access Board) developed a set of standards for accessible design in 1994. Known as the ADAAG, these guidelines, which cover new construction and alterations, acquire force of law when adopted by the Department of Justice (DOJ) into the regulations that govern the ADA*(1)*.

Currently, the Department of Justice has adopted ADAAG sections 1 through 10, concerning public accommodations and commercial facilities. Sections 11 through 14 of the ADAAG apply to Title II entities and were developed to cover such programs and services as judicial facilities, correctional facilities, accessible public housing, and public right-of-ways. Sections 11 and 12 have been incorporated into the ADAAG as final guidelines. Section 13 is held in reserve while further guidelines are developed, and Section 14 is being held in reserve in favor of a campaign to focus on education and outreach regarding pedestrian facility design.

As a state agency, TxDOT falls under ADA Title II regulations, which apply to state and local governments. Sidewalks are considered to be pedestrian facilities covered under Title II, Part A, and are addressed in some detail in the proposed Section 14 of the ADAAG regarding public right-of-ways.

In general, all facilities designed, constructed, or altered by, on behalf of, or for the use of a public entity must be readily accessible and usable by individuals with disabilities, if the construction or alteration begins after January 26, 1992 (28 CFR 35.151). This means that the facility must be designed, constructed, or altered in strict compliance with a design standard that is certified by the DOJ as ADA-equivalent.

In addition to and apart from construction standards, Title II entities subject to Part A fall under the "program accessibility" requirement, which states: "A public entity may not deny the benefits of its programs, activities, and services to individuals with disabilities because its facilities are inaccessible." A public entity's services, programs, or activities, when viewed in their entirety, must be readily accessible to and usable by individuals with disabilities (28 CFR 35.149–35.150). However, an important limitation of the program accessibility requirement is that a public entity does not have to take any action if that action would result in either (1) a fundamental alteration in the nature of its program or activity, or (2) an "undue burden," meaning undue financial or administrative burdens*(1)*.

In the case of sidewalks, the benefit being provided by the agency is that pedestrians have access to places that provide employment or services to the public. People with disabilities must also have access to these services and benefits. If the same sidewalk used by other pedestrians does not provide this access, then it must be provided by some other means.

The proposed Section 14 of the ADAAG, which concerns public right-of-ways, provides detailed specifications and guidelines on continuous passage, sidewalks, and other accessible elements of the right-of-way (ROW). Although this section was issued as interim guidelines in 1994, it was eventually withdrawn and held in reserve for later proposed rulemaking. Comments from public works agencies, transportation departments, and traffic consultants on Section 14 guidelines showed a disparate understanding of pedestrian accessibility criteria in general, and of the application of the Section 14 provisions for new construction in particular. Based on these comments, the Access Board decided to reserve the guidelines in favor of working with other governmental and private sector organizations in the transportation industry to promote the incorporation of pedestrian accessibility criteria into industry guidelines, standards, and recommended practices (63 FR 2000, January 13, 1998).

The ADA and the associated ADAAG make it clear that accessible sidewalks require limited cross sloping. It is TxDOT's desire and intent to be in compliance with the ADA when designing and constructing roadway projects that include pedestrian facilities. However, variable terrain conditions, restricted right-of-ways, city codes, and existing infrastructure often inhibit efforts to provide a cross slope of less than or equal to the required 2 percent at all points along an accessible route. TxDOT's primary area of concern is the intersection of sidewalks with driveways, because maintaining the prescribed cross slope along an entire sidewalk that crosses numerous driveways, as is often found in urban areas, can be extremely difficult or impossible within the existing right-of-ways.

TxDOT's goals are to design and construct sidewalks that are (1) consistent with the intent of the ADA, (2) responsive to individuals with disabilities, and (3) observant of various constraints. Specifically, in locations where the agency cannot meet the prescribed cross-slope limits, TxDOT wants to know the limiting values for the majority of disabled users so that better support for requesting variances to ADA can be made and so that engineers can provide as high a level of accommodation as the location allows.

Findings submitted in this team's earlier 1999 report, 4933-1,"A Review of Methods for Meeting the Americans with Disabilities Act Sidewalk Cross-Slope Requirement," indicated that prior research is insufficient to support the ADA's 2 percent cross-slope requirement *(2)*. In addition, prior research does not offer a maximum limit for cross slope in situations where the 2 percent requirement may be relaxed. Related studies have used fairly homogeneous populations of young males with good upper body strength and stamina*(3, 4)*. Because of these two findings, the validity of existing requirements for less physically capable users and users with different mobility aids has been questioned. A reasonable maximum slope standard is urgently needed for design standards and construction cost estimation.

The design-related methods found in Phase I (mentioned above) of this project do not adequately address TxDOT's concerns for meeting the intent of the ADA at driveway crossings. In the absence of an accepted standard for this type of design and construction, transportation agencies have often followed a "do-the-best-you-can" approach. Accessibility is a civil right, and ADA court history has established a high standard of "undue burden" when it comes to noncompliance *(5)*. Phase II of this project was conducted to provide a scientific basis for constructing sidewalks with cross slopes that provide the safest slopes possible within design constraints while meeting the intent of ADA. In carrying out this research, the team's goals were to determine a range of acceptable cross slopes and to provide TxDOT with implementation recommendations.

CHAPTER 2. SURVEY METHODOLOGY

Scientific evidence sufficient to either support or oppose the 2 percent sidewalk cross-slope requirement does not exist. The conclusion from the reviewed works was that a 2 percent cross slope is acceptable from the perspective of the wheelchair user, but that a higher slope may also be acceptable. The studies reviewed show that the propulsion (in terms of force), the net energy cost, and the work per meter on a 2 percent cross slope are greater than those values associated with a level surface. However, the single study that investigated these values suggests that the difference in wheelchair user effort between traversing cross slopes in the range of 2 percent to 5 percent may not be very large (about 20 percent) and that this effort may only double when the cross slope is increased from 2 percent to about 16 percent *(4)*.

Based upon these findings, the research team designed and administered a study to evaluate the usable range of sidewalk cross slopes under the current ADA accessibility guidelines with regard to user perception and effort. This phase of the project, administered to volunteers through on-site and Internet-based surveys, used 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 sidewalk users with various disabilities.

2.1 SURVEY AND SAMPLE DESCRIPTION

Data for this study were collected using three types of survey instruments: a Web-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.

2.1.1 Survey Population

The greatest obstacle to the completion of this research was the difficulty in recruiting participants. In soliciting participants, the researchers contacted sixteen different agencies and organizations, gave five public presentations (including one televised presentation), and distributed 2,000 pieces of literature, both through direct mail and through more general marketing methods. While the targeted community seemed to be supportive of the research effort, few of its members participated in the survey process. Table 2.1 briefly describes the types of persons who did participate in one or more of the surveys (a list of contact organizations can be found in Appendix 1).

Respondents to the field survey ranged in age from 27 to 59, and included ten women and nine men. The on-site perception surveys were held at two locations, so as to encourage participation. Some participants volunteered for both perception locations and the heart rate survey, providing twenty-two on-site perception surveys and ten heart rate surveys. All sampled persons were Caucasian.

Table 2.1 Participant distribution by type of disability and mobility aid and by age

Type of Disability and Mobility Aid	Number of Respondents*		Age	Number of Respondents
Blind, Seeing Eye Dog	2		27	1
Cerebral Palsy, Manual Chair	1		28	1
Cerebral Palsy, No Aid	1		32	1
Congenital Heart Disease, Manual Chair	1		35	1
Head Injury, Electric Wheelchair	2		41	1
Head Injury, Scooter	1		42	1
Muscular Dystrophy, Electric Wheelchair	2		43	2
Cerebral Palsy, Electric Wheelchair	1		44	1
Neural MD, Cane	1		45	2
Paraplegic, Manual Wheelchair	1		46	2
Polio, electric Wheelchair	2		49	3
Polio, Manual Wheelchair	1		50	1
Single Amputee, Crutches	1		52	1
Spinal Cord Injury, Electric Wheelchair	1		59	1
Visually Impaired, Cane	1			

*One respondent participated using both a manual and an electric wheelchair, bringing this total to 20.

2.1.2 Field Surveys

Sidewalk-crossing comfort perception surveys were held at locations along bus routes identified as having high numbers of riders with disabilities, based on information provided by the local public transportation agency. Furthermore, the sites chosen were those where participants could traverse the greatest number of different cross slopes between two bus stops. Using bus stops as boundaries for the surveys allowed participants ease of transportation to and from the sites. The field surveys required the participants to traverse a series of delineated sections with varying cross slopes and other attributes. In order to estimate and account for biases between Web-based visual and on-site perceptions, several field-survey sections were also used in the Web-based visual survey. Participants were instructed to traverse the sidewalk sections at a comfortable pace, pausing as needed and simulating the way they would typically use a sidewalk. Before and after each section, the participants' difficulty rank assessments and pulses were recorded.

Seven variables were observed for each sidewalk section: cross slope, primary slope, width, distance, setback from road, pulse rate, and difficulty assessment. Each participant's age, gender, fitness level, type of disability and mobility aid, and resting pulse rate were also recorded as explanatory variables. Table 2.2 provides definitions for the recorded variables.

Because ease of sidewalk use is the objective of ADAAG design standards in this area, the surveys focused on participants' perceived comfort in traversing the sections. However, the research team also hoped to establish a link between perceived comfort (or lack thereof) and physical effort. According to Kirkpatrick and Birnbaum, the most reliable indication of physical effort is heart rate measurement *(6)*. 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 *(7)*. Athletic-type pulsemeters, which measure the blood flow rate in the earlobe and display the rate in beats per minute, were used to record heart rates.

Table 2.2 Definitions for exogenous variable

Variable	Definition
Facility-related variables	
Cross slope	The vertical slope to the direction of a sidewalk (%)
Primary slope	The main slope along the guideline of a sidewalk (%)
Length	The length of a sidewalk section (m)
Width	The width of a sidewalk section (m)
Set-back	The set-back distance of a sidewalk section (100 m)
Transition	The transition distance between cross slopes (m)
Traffic volume	The average measured traffic volume of parallel street(veh/hour)
Speed	The average traffic speed of parallel street (km/hour)
Flare	1 if the sidewalk section has a flare, 0 otherwise
Personal variables	
Age	The age of the survey participant
Gender	1 if the participant is a male, 0 otherwise
Manual wheelchair	1 if the participant uses a manual wheelchair, 0 otherwise
Electrical wheelchair	1 if the participant uses an electrical wheelchair, 0 otherwise
Cane	1 if the participant uses a cane, 0 otherwise
Crutch	1 if the participant uses a crutch, 0 otherwise
Walker	1 if the participant uses a walker, 0 otherwise
Scooter	1 if the participant uses a scooter, 0 otherwise
Leg brace	1 if the participant uses a leg brace , 0 otherwise
Foot brace	1 if the participant uses a foot brace, 0 otherwise
Artificial leg	1 if the participant uses a artificial leg, 0 otherwise
Low audition	1 if the participant has low audition, 0 otherwise
Physical fitness level	Participant's self-assessed physical fitness level (5-point scale, from 1=very out of shape to 5=in great shape)
Frequency	The sidewalk travel frequency of the participant in a week
Travel length	The regular sidewalk travel distance of the participant in a day (km)

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 *(8)*. Because the perception surveys were designed along actual sidewalks, the individual sections — and the time spent by the participants traversing them — were fairly short in length. While heart rate data were gathered on participants in these surveys, the data are not as conclusive as had been anticipated.

In order to more accurately measure the physical effort associated with various cross slopes, the research team developed a second type of field survey. This heart rate survey was specifically designed to measure the participants' change in physical effort as a response to cross slope. Necessarily, this survey required participants to travel for some distance to allow for accurate measurement of the change in heart rate. The second major obstacle of this project involved locating an easily accessible survey area sufficient to accommodate long sections and having enough surface change to provide varied cross slopes. This proved to be quite difficult, as large, paved lots must be constructed in such a way as to be accessible to disabled users. Ultimately, the site used for this survey was selected because it was adjacent to a perception survey site, it provided some variety of grades and cross slopes, and it was the site most conveniently located to the group of volunteers. The site is a church parking lot situated uphill from the sidewalk location. The steepest surface of this section was the driveway, but its grade limited participants' ability to traverse a series of multidirectional paths. The parking area provided a surface with an average grade of 3 percent, where four tridirectional sections were monitored.

The heart rate survey consisted of thirteen separate sections with varying lengths, grades, and cross slopes. Data gathered during this survey included resting heart rates, age, gender, type of disability and mobility aid, fitness level, and working heart rates. While one's resting heart rate is most accurately measured upon waking, a reasonably close measurement can be taken after having the participant sit quietly for a few minutes *(6)*. It is important to note that the temperature was quite warm on the day of the heart rate survey (in excess of 85 °F). Weather characteristics contribute to the comfort or discomfort of sidewalk users, especially in a state such as Texas where extreme heat is not uncommon.

2.1.3 Web-Based Survey

Finally, remote visual assessments of sidewalk cross slopes were collected via a Web-based survey. This survey featured pictures of twenty-five different sidewalk sections, together with facility information about each section, including cross slope, primary slope, width, length, set-back distance, and traffic volume and speed on the adjacent street. The participants appraised the difficulty of traversing each section based on the information provided and on their individual experiences. Each participant's age, gender, sidewalk travel experiences, mobility aid type or disability, and other attitudes about sidewalks were also recorded. In total, forty-eight persons ranging in age from 19 to 62 and using seven different types of mobility aids responded to this survey.

Some respondents to the Web-based survey regularly use more than one type of mobility aid. To avoid bias, these respondents selected and were assigned only one mobility aid type when they responded to the survey.

Several of the sections used for the remote visual assessments were also used for the on-site surveys to allow for direct comparisons of perception for participants who responded to both survey instruments. However, in examining both data sets, it became apparent that the information provided in the Web-based survey was insufficient, since cross slope was very difficult to assess from the photographs. Thus, the visual perception responses suggested that respondents were more comfortable than they actually were, and these data were disregarded.

CHAPTER 3. ANALYTICAL METHODOLOGY

The methodology used in this study is based on the use of linear and nonlinear regression procedures to estimate the boundaries of sidewalk cross slope. The linear regression model studies the heart rate changes of subjects traversing sidewalk sections having distinct cross slopes. The nonlinear model is examined to analyze the ordered cross-slope assessment both from the remote visual survey and the on-site field survey. The ordinal assessment involves a five-point scale, with categories ranging from "easy to cross" to "impossible to cross."

3.1 LINEAR REGRESSION WITH WEIGHTED LEAST SQUARE ESTIMATION

The change in heart rate is an important indicator of energy consumption as a result of crossing a sidewalk section *(4, 9)*. The basic principle involved in regression is that heart rate change (the difference between post-test heart rate and resting heart rate) is linearly affected by the variation in relevant exogenous variables (see Appendix 6 for related equations). The resting heart rate is the weighting factor used in the weighted least square (WLS) analysis.

3.2 ORDERED RESPONSE PROBIT ANALYSIS

In this analysis, the categorized assessment of a sidewalk section with a particular cross slope is modeled using an ordered response probit structure. The procedure, popularized by McKelvey and Zavoina *(10)*, enables one to include a set of additional parameters representing the unobserved thresholds between assessment categories. This analysis allows the determination of successive thresholds of difficulty, such that more than 20 percent of the sidewalk users will feel uncomfortable when they traverse specific cross slopes (the third threshold indicates a shift from the "requires-some-effort-to-cross" to the "difficult-to-cross" response, and the fourththreshold indicates a shift from the "difficult-to-cross" response to the "impossible-to-cross" response).

Data provided by the 1990 National Health Interview Survey's (NHIS) Assistive Devices Supplement indicate that, of the 6.4 million persons using assistive devices for "getting around," 79 percent use crutches or canes, 26 percent use walkers, 21 percent use manual wheelchairs, 2 percent use electric wheelchairs, and less than 1 percent use scooters *(11)*. Some persons use multiple devices, though at different times. In addition, the data indicate that "73 percent of people who use assistive devices are 55 and older"*(12)*. Bearing this figure in mind, it seems appropriate to advocate a cross-slope value that would be traversible by 80 percent of the assistive-device-using population (see Appendix 6 for related equations).

3.3 RESULTS

3.3.1 Linear Regression Model with WLS Estimation

As shown in Table 3.1, the weighted and adjusted R^2 value is rather high, indicating that the explanatory variables in the model explain much of the variation in recorded heart rate changes. The coefficient of distance suggests that the average heart rate change will increase if the sidewalk section distance increases. The coefficient of age suggests that older users may experience greater change in heart rate than will younger users. The effect of physical fitness level suggests that the higher the level of physical fitness, the less the heart rate increases in response to cross slopes.

Table 3.1 WLS regression model results

Variable	Coefficients	Standard Error	t-statistic
Primary slope (%)	1.42	6.04	0.23
Cross slope (%)	3.41	7.75	0.44
Distance	0.51	0.12	4.17*
Age	0.58	1.02	0.57
Physical fitness level (1 to 5; 5 = great shape)	-29.34	5.29	-5.54*
Electric wheelchair	-35.49	24.16	-1.47
Cane or crutch	62.12	18.65	3.33*
Scooter	-23.82	23.58	-1.01

N = 126, Weighted and Adjusted R^2 =0.780

**Statistically significant at 0.05 level.*

Note: Reference disability is "manual wheelchair" and weighting factor is "resting heart rate."

The coefficients of mobility aid types describe the average heart rate change for each kind of mobility aid without considering the effects of sidewalk characteristics. The related magnitudes of the parameters imply that people using canes/crutches consume more energy than do people using other aid types. Finally, as anticipated, the effects of cross slope and primary slope are positive, suggesting that higher cross slopes increase heart rates. The relative magnitudes of the coefficients suggest that the effect of the primary slope is smaller than that of the cross slope.

Because the site used for the heart rate surveys was less than ideal, participants were required to travel along some paths that were perpendicular to the main grade of the area, and along some paths that were parallel to the main grade. Additionally, the limited dimensions of this particular site necessitated that they travel out from and back to a point of origin for each section. In such situations, the measured main grades and cross slopes are highly correlated; thus, the model suffered from multicollinearity. However, because it is believed that the main grade and cross slope play important roles in producing change in heart rates, these two explanatory variables were retained in the final model and their coefficient estimates should not be biased.

3.3.2 Ordered Response Model

The goodness-of-fit measure, the pseudo-R^2 value, for this model is 0.10. Thus, the effects of the exogenous variables in the model specification are statistically significant. Table 3.2 shows the ordered response probit model results.

Table 3.2 Ordered response probit model result

Variable	Coefficients	Standard Error	t-statistic
Primary Slope	0.15	0.03	4.99*
Cross slope	0.11	0.02	5.84*
Logarithm of Age	1.91	1.57	2.00*
Gender	-0.98	0.17	-5.64*
Physical Fitness Level	-0.20	0.10	-1.93*
Manual wheelchair	0.19	0.16	1.19
Threshold 1	3.71	2.32	1.60
Threshold 2	4.32	2.32	1.86*
Threshold 3	4.82	2.33	2.07*
Threshold 4	5.82	2.34	2.49*

**Statistically significant at 0.05 level.*
Reference disability is cane/crutch.

Among the facility-related variables, the effects of primary slope and cross slope are positive, suggesting an increase in traversing difficulty as the primary slope and/or cross slope increase. The relative magnitudes of the coefficients suggest that the effect of the primary slope is a little larger than that of the cross slope.

The negative coefficient of gender suggests that a male will feel more comfortable crossing a sidewalk section than will a female. The negative coefficient of physical ability suggests that people in good shape will feel more comfortable crossing sidewalks than will those who are less physically fit. The mobility-aid indicator variables have positive coefficients, suggesting that traversing sidewalks will be more difficult for people with manual wheelchairs than for people with the default mobility aid type cane/crutch. This implication differs from the result of the WLS model. However, other aid types like scooter and electric wheelchairs do not have significant effects with regard to traversing sidewalks. This finding suggests that the main user groups that should be considered in sidewalk design are people using manual wheelchairs or canes/crutches.

CHAPTER 4. MODEL APPLICATION

Model estimation is used to extrapolate real-world guidelines based on available data. Studying the effects of different sidewalk variables on the sampled population allows for the derivation of maximum allowable limits for those variables. The research conducted here focuses on sidewalk cross slope; thus, model estimates were used to gauge maximum allowable cross slopes considering a variety of factors.

4.1 WLS MODEL APPLICATION

The WLS regression model can be used to estimate average heart rate changes for sidewalk users with different disabilities as a function of cross slope. Since heart rate changes are highly related to energy consumption and therefore indicate the difficulty that people with mobility impairments will face, a maximum desirable cross slope may be estimated by assuming some critical heart rate change. While there is no medically proven method for determining this critical range, the accepted method of ascertaining the maximum heart rate is 226-age for females and 220-age for males (6, 13).

The heart rate target zone for physical training is defined as between 60 percent and 80 percent of one's maximum heart rate *(12, 13)*. Based on the test sample (age and resting heart rate) and using 80 percent of the age-adjusted maximum heart rate as the critical upper level of heart rate change, the average critical heart rate change— as a response to traversing varying cross slopes — is about 75 percent. Similarly, use of 75 percent of the maximum heart rate as the critical upper level results in an average critical heart rate change of about 60 percent for the test-sample subjects.

Table 4.1 illustrates several different cases that were calculated by inputting these 75 percent and 60 percent heart rate changes. As Case 8 illustrates, for a person who uses a cane or a crutch, who is in the middle category of physical fitness, and who traverses a 15-m (50-ft) sidewalk section with a 5 percent primary slope, the critical cross slope is about 5.3 percent. This percentage is greater than that of the current ADAAG requirement. If the sidewalk section is as long as 45 m (150 ft), the maximum cross slope for a manual wheelchair user in the middle fitness category is estimated to be 8.5 percent.

Table 4.1 Case study of the WLS model

Variables	**Case 1**	**Case 2**	**Case 3**	**Case 4**	**Case 5**	**Case 6**	**Case 7**	**Case 8**
Primary slope (%)	0	5	0	5	0	5	0	5
Distance	15 m	15 m	30 m	30 m	45 m	45 m	15 m	15 m
Physical fitness level	3	3	3	3	3	3	3	3
Electric wheelchair	0	0	0	0	0	0	0	0
Manual wheelchair	1	1	1	1	1	1	0	0
Cane or crutch	0	0	0	0	0	0	1	1
Scooter	0	0	0	0	0	0	0	0
Critical cross slope (%)	25.7	23.6	18.1	16.0	10.5	8.5	7.4	5.3

It is important to note that, while crutch and cane users constitute the largest group of the disabled population, their devices are often used as secondary and/or temporary aids. The crutch user in this survey commented that she would be obtaining a prosthetic device in the near future and would then no longer use crutches. Another respondent, who would fall into the NHIS crutch and cane category, explained that he uses a cane occasionally, but prefers to go without it. When researching sidewalk accessibility issues, it may be most appropriate to consider those who use a specific aid on a consistent, long-term basis *and* who desire to use sidewalks. Anecdotal and analytical evidence suggests that manual wheelchair users may best fit this description.

4.2 ORDERED PROBIT MODEL APPLICATION

The ordered response model of sidewalk assessments can be used to examine how changes in sidewalk facility characteristics impact sidewalk users with disabilities. This section demonstrates the application of this model by estimating the maximum cross slope that can be applied to sidewalk construction standards for use by people with mobility impairments.

Assuming that the critical slope can be calculated as a threshold measurement at which 20 percent of sidewalk users will feel uncomfortable, inputting different personal and facility characteristics yields maximum cross-slope values for each situation. The emphasized characteristics for this comparison are primary slope and age. Female users were considered here because they tend to experience more difficulty than male users when traversing sidewalks. Manual wheelchair users were assumed in this application of the model. Other variables were assigned the average value in the sample.

Table 4.2 shows eight cases involving several age variables and sidewalk primary slopes of 0 percent and 5 percent.

Table 4.2 Case study of the ordered probit mode

Variables	**Case 1**	**Case 2**	**Case 3**	**Case 4**	**Case 5**	**Case 6**	**Case 7**	**Case 8**
Primary Slope (%)	0	5	0	5	0	5	0	5
Age	30	30	40	40	50	50	60	60
Gender	Female	Female	Female	Female	Female	Female	Female	Female
Physical Fitness Level	3	3	3	3	3	3	3	3
Manual wheelchair	1	1	1	1	1	1	1	1
Cane & Crutch	0	0	0	0	0	0	0	0
Critical Cross slope (%)	14.3	7.4	12.1	5.3	10.4	3.6	9.0	2.2

Inputting these data in the ordered model reveals that the critical cross slope for 60-year-old manual wheelchair users is about 2.2 percent when the primary slope (i.e., main grade) of the sidewalk is 5.0 percent (Case 8), and 9.0 percent when the main grade of the sidewalk is 0 percent (Case 7). However, anecdotal evidence from this research suggests that the number of 60-year-old female manual wheelchair users who rely on self-propulsion is low, perhaps largely because these individuals lack sufficient upper-body strength to move across even flat, low-friction surfaces. Thus, using the average age of the test sample (40 years), the resulting critical cross slopes for 5.0 percent and 0 percent main grades are 12.1 percent and 5.3 percent, respectively (Cases 3 and 4). These thresholds are significantly higher than the ADAAG cross-slope standard of 2 percent.

4.3 MODEL COMPARISONS

A 1996 study by Chesney and Axelson *(2)* showed that the work-per-meter value on a 2 percent primary grade hardly changes for marginally different cross slopes, as shown in Table 4.3.

Table 4.3 Average work-per-meter required to propel wheelchair across a plywood ramp (Chesney and Axelson, 1996)

Grade	Cross slope	Average Work per Meter (newton meters)	Standard Deviation (newton meters)
2%	0%	26.32	1.39
8%	0%	71.48	1.43
2%	2%	31.54	0.48
2%	3%	33.81	0.41
2%	5%	37.91	0.50
2%	8%	45.25	0.77
2%	12%	55.46	0.95
2%	14%	58.76	0.61
2%	16%	62.23	1.88
2%	20%	75.04	3.08

At a primary slope of 8 percent (the ADA maximum is 8.33 percent), the "break point" of average work per meter would occur at about 70 newton meters. This break point suggests a maximum cross-slope bound in the neighborhood of 16 to 20 percent. However, because the researchers used in their experiments relatively young, male wheelchair-racing athletes, the actual threshold is likely to be lower when older sidewalk users are considered.

Using the test results provided in Table 4.3, a linear regression model was estimated to reveal the relationship between the average work per meter and main grades and cross slopes, such that work per meter is equivalent to 11.42+(7.51*main grade)+(2.355*cross slope). Therefore, the predicted work per meter for a 5 percent grade and 2 percent cross-slope situation is 53.68 newton meters. This situation is the "worst" presently allowed by ADAAG. Assuming the critical effort of 53.68 newton meters, the maximum allowable cross slope would be 17.9 percent with 0 percent main grade.

To compare the results of Chesney and Axelson's (1996) study with the ordered probit model presented here, one can input similar user attributes (young, male, manual wheelchair user). The 5 percent grade and 2 percent cross-slope situation yields a latent "disutility" value of 2.65 (which is less than the "easy-to-cross" threshold value). The latent assessment for this situation implies that people (especially younger persons) will not feel uncomfortable even if they expend a relatively high effort in crossing the sidewalk.

Table 4.4 compares the prediction values of Chesney and Axelson's (1996) data and our ordered probit model for a series of sidewalk situations. A graphical illustration is given in Figure 4.1.

Table 4.4 Prediction value comparison between two models

Primary Slope (%)	Cross slope (%)	Average Work per Meter (newton meters)	Latent Disutility
0	0	11.42	1.04
5	0	48.97	1.79
10	0	86.52	2.54
0	5	23.20	1.59
5	5	60.75	2.34
10	5	98.30	3.09
0	10	34.97	2.14
5	10	72.52	2.89
10	10	110.07	3.64
0	15	46.75	2.69
5	15	84.30	3.44
10	15	121.85	4.19
0	20	58.52	3.24
5	20	96.07	3.99
10	20	133.62	4.74

Note: Table results based on 30-year-old male subject in good shape in manual wheelchair

Regressing the predicted effort from Chesney and Axelson's (1996) data and the latent disutility from the ordered response model builds the relationship between the effort and the ordered models.

If the work-per-meter value of 56.38 newton meters (arising from a 5 percent primary slope and 2 percent cross slope) is assumed as the critical value for all predictions, then the latent disutility value is about 2.31. Obviously, the latent disutility value of 4.82, which corresponds to threshold 3 (i.e., "will take significant effort"), will result in a higher measurement of newton meters or effort. Thus, the situation discussed in this report is more conservative than that described by Chesney and Axelson (1996), lending support to the reasonableness of this analysis.

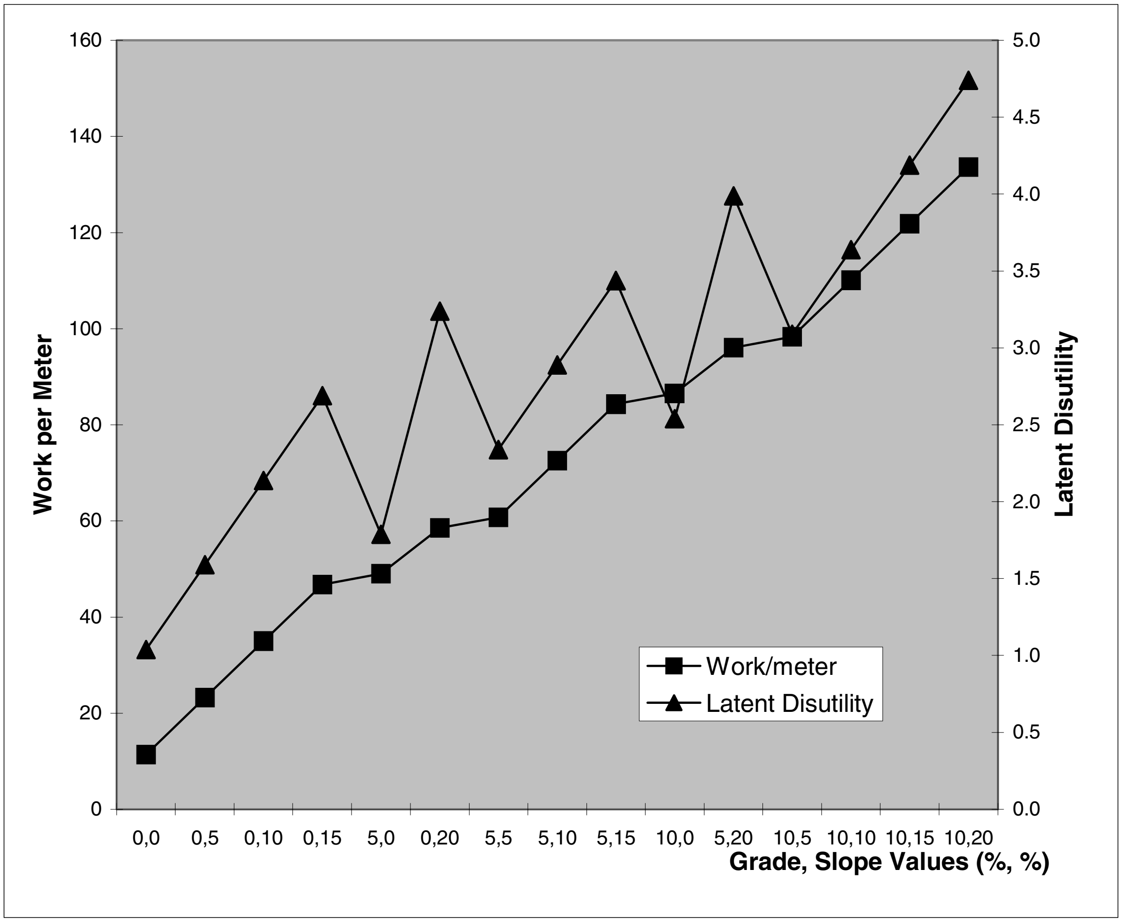

Figure 4.1 Plot of prediction value comparison between two models

CHAPTER 5. IMPLEMENTATION RECOMMENDATIONS

5.1 ALLOWABLE RANGE OF CROSS SLOPE

Persons using different types of mobility aids and having different levels of functional ability are capable of traversing a range of cross slopes. While many of those with disabilities who were sampled here are able to traverse sidewalks having up to a 20 percent cross slope, many are not. In recognition of the trade-off between construction feasibility and user comfort, a 10 percent maximum cross slope is recommended, based on this research. Such a slope is estimated to preclude use by those who describe themselves as being in very poor physical shape. However, anecdotal evidence gathered in this study suggests that persons in this category either do not rely on sidewalks to meet their daily travel needs or do not normally rely on their own propulsion when traveling on sidewalks. In order to accommodate the largest number of possible users, a 4 percent maximum cross slope is recommended.

In order to be reasonably confident (i.e., with 80 percent probability) that a disabled user in the critical-aid category and in moderate shape could traverse a sidewalk section without finding it very difficult, the results suggest that an upper cross-slope bound may be set at 5.7 percent (see Table 4.1) for a 49.5-ft (15-m) length with a 5 percent upgrade. For manual wheelchair users and/or shorter, flatter, or otherwise less severe sections, the bound lies closer to 12 percent. This outcome is further supported by recognizing user perceptions, rather than simply heart-rate data (see Table 4.2). Based on these results, it is recommended that the maximum allowable cross slope be set at 4 percent where feasible, and at 10 percent where mitigating factors exist and where primary slope does not exceed 5 percent.

In all situations, it is recommended that the maximum allowable cross slope be set at 4 percent. However, where the 4 percent maximum is not feasible and the primary slope is less than 5 percent, a 10 percent maximum cross slope is allowable.

5.2 DESIGN GUIDELINES

In addition to maximum accessible cross slopes, this research yields design guidelines as well. As is illustrated by the ordered response probit model results (Table 3.2), the most easily accessible sidewalks are those where cross slope is minimized and width is maximized. The demonstrated relationship between the increase in heart rate and the increase in cross slope (Table 3.1) further supports the recommendation that sidewalk design should minimize primary slope and cross slope and should maximize width to ensure the greatest accessibility.

Examples of practical sidewalk design that exemplify this recommendation can be found in guidelines issued by the Oregon Department of Transportation (ODOT) *(14)*. ODOT provides techniques for facilitating wheelchair movements at driveways that "prevent an exaggerated warp and cross slope." The first of these techniques is the construction of a wide sidewalk, as indicated in Figure 5.1. The appropriate width would be one that avoids an abrupt driveway slope. Figure 5.2 illustrates the use of a planting strip to reduce sidewalk cross slope. If a planting strip is not available, a jogged driveway crossing, as depicted in Figure 5.3, could be used. A caution here is that this arrangement may prove difficult for vision-impaired pedestrians who follow the curb line for guidance. In cases where a minimal sidewalk is provided directly behind the curb, the sidewalk can be dipped with construction of parallel ramps, as shown in Figure 5.4. Possible problems with this technique include drainage behind the sidewalk and discomfort for pedestrians.

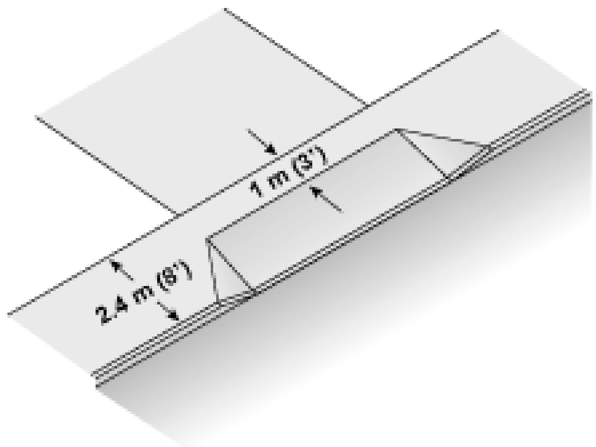

Figure 5.1 Wide sidewalk at driveway (ODOT, 1995)

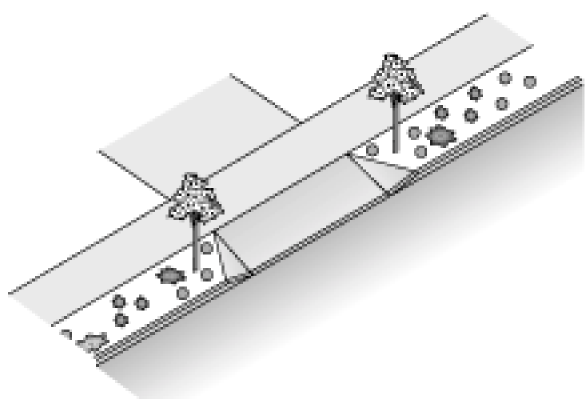

Figure 5.2 Driveway with planting strip (ODOT, 1995)

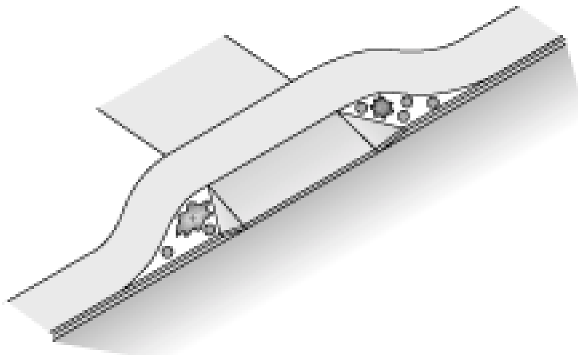

Figure 5.3 Sidewalk wrapped around driveway (ODOT, 1995)

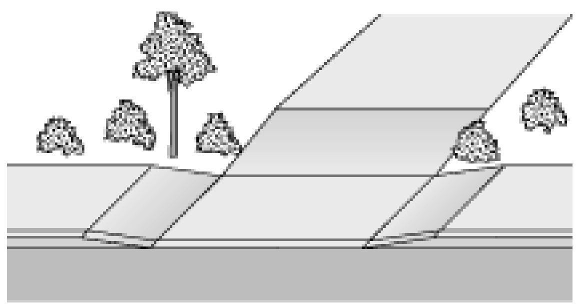

Figure 5.4 Entire sidewalk dips at driveway (ODOT, 1995)

Other sidewalk users, such as bicyclists and pedestrians without disabilities, must also be considered. For example, the design treatment in Figure 5.3 lengthens the trip for these users. A similar design (such as that in Figure 5.1) that replaces the planting areas with sidewalk paving would allow other users to proceed straight if they wished.

The Access Board states that "several design approaches are possible to achieve a complying apron, including a retrofit treatment for existing driveways that ensures a passageway across the opening that does not exceed cross-slope limits" *(15)*. In addition to the design approaches described above, one may use rolled-curb sections or a lip at the gutter for minimizing the vertical distance to be ramped. In these cases, a bridgeplate at the gutter may be required for vehicle use, street crossing, or picking up mail. Further guidance states that a 1:10 apron can be cleared with a setback of 48 inches. Also, a 1:8 apron can be retrofitted to achieve a 1:48 cross-slope for a 3-ft-wide section by constructing two steeper ramps on either side of the accessible section. For this technique, illustrated in Figure 5.5, it is stated that the steeper ramps will not cause cars to "bottom out." This design might increase motorist yield compliance (to pedestrians), but will probably also decrease motorist comfort.

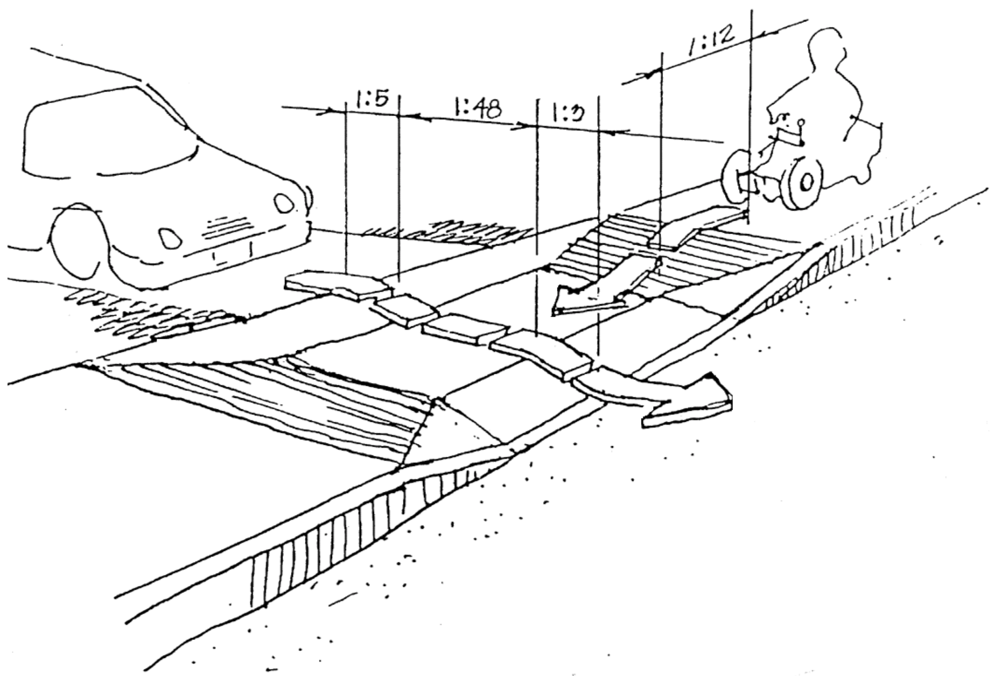

Figure 5.5 Driveway/sidewalk retrofit (Access Board, 1998)

5.3 COMMUNITY PARTICIPATION

Historically, research of the type documented in this report has been significantly hampered by a lack of response by the user community, as is evidenced in this research by the small sample size. An Austin, Texas, public transportation provider (Capitol Metro) effectively circumvents this situation by relying on a mobility impaired services advisory council (MISAC). MISAC members are appointed by the agency's board of directors and hold monthly meetings whereby they recommend service enhancements to the board. Meeting topics include critiques of new or changed services and facilities, commendations to agency employees for meritorious service, and reports from subcommittees that address particular issues. This council encourages dialogue between the agency and its service community and alerts the agency to problems.

It is recommended that a forum be established to encourage participation from the community of persons with disabilities in order to demonstrate the agency's goal of compliance and to ensure implementation of practical designs.

CHAPTER 6. CONCLUDING COMMENTS

This research was conducted using an ordered probit model for analysis of disabled-user response to sidewalk characteristics and using weighted least square regression for analysis of assessment and of heart rate data, permitting determination of maximum sidewalk cross slope consistent with the intent and spirit of the ADA. It is recommended that the maximum allowable cross slope be set at 4 percent where feasible, and at 10 percent where mitigating factors exist and where primary slope does not exceed 5 percent. The analysis performed in this research yielded additional general sidewalk design guidelines as well.

The experimental research detailed in this report was conducted in order to develop maximum and desirable limits for sidewalk cross slope at driveway crossings. As such, recommendations from this work will be submitted to the Access Board for inclusion in proposed rule making. Public provision of transportation facilities that will be used by people with disabilities is challenging in terms of access and costs. Information gained from this work will allow TxDOT to contribute to the evolving guidelines governing pedestrian accessibility and to provide greater access to its service community.

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APPENDIX 1. LIST OF CONTACTS

The team contacted these organizations to solicit volunteers for the field and Web surveys. Fliers were distributed to their offices and members, announcements and/or links to our Web survey were posted on their electric bulletin boards, and team members spoke at organizational meetings when invited.

- ADAPT, Bob Kafka, 442-0522, adapt@adapt.org
- Advocacy Inc., Sally Parker at 454-4816, http://www.advocacyinc.org
- ARCIL — Austin Resource Center for Independent Living, Jack Stratton at 467-0744
- Austin Mayor's Committee for People with Disabilities, Dolores Gonzalez at 499-2292
- Capital Metro — Nancy Crowther, nancy.crowther@capmetro.austin.tx.us
- City of Austin, David Gerard at 499-7022
- CTD — Coalition of Texans with Disabilities, http://www.cotwd.org/ Maria Tamez at 478-3366
- Disability Policy Consortium, Lee Redmond at 478-3366, ctd@io.com
- Governor's Committee on People with Disabilities, Pat Pound, Dir. at 463-5739
- MISAC, Mobility Impaired Services Advisory Committee, Marilyn Rogers at snm@io.com or 451-9335
- Momentum, Glenn Gadbois at 424-6545 (mornings), 451-5396 (afternoons), 451-3667 (fax) or gadbois@ccsi.com
- Texas Commission for the Blind, Ron Lucey at 459-2577
- Texas Rehabilitation Commission, Mike Brevell at mike.brevell@rehab.state.tx.us

  Field Offices:

Austin East	800 Brazos #410	478-6161
Austin South	2416-A South Lamar	448-2333
Austin North	5203-A Cameron Rd	458-9121

- UC Berkeley Office for Disabled Students, http://dsp.berkeley.edu/
- UCPA/CA — United Cerebral Palsy Association of the Capitol Area, Inc.
- http://www.main.org/UCPA/index.html, Norman Kieke at 834-1827
- UT Services for Students with Disabilities, http://www.utexas.edu/depts/dos/ssd, Michael Gearhart at dsmag@utxdp.dp.utexas.edu, 471-6259

APPENDIX 2. SURVEY FLIER

SIDEWALK SURVEY

If you have any type of mobility impairment
AND you have ever used a sidewalk, then

We Want to Hear From You!!!

The Center for Transportation Research at UT-Austin is conducting a survey to determine appropriate cross-slope for sidewalks with regard to users with mobility impairments. New road and sidewalk construction is required to meet ADA guidelines, and your input will help to ensure that our pedestrian network will provide accessibility in the future. We are seeking participants with all types of mobility impairments to participate in this survey.

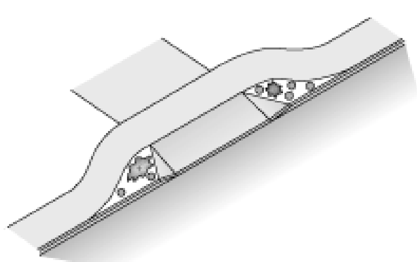
Yes!! I want to be part of this unique opportunity!

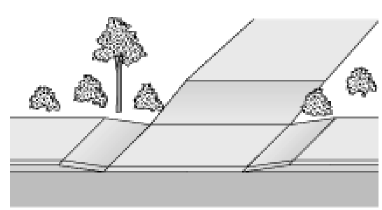
Go to http://sidewalksurvey.hypermart.net and take the Web survey.
Then, if you would like to participate in the on-site survey, fill out the requested information and submit the form.

On-site surveys are scheduled for June 19th, 26th & 27th.

You will be contacted with more information.

If you have questions, e-mail Chessie Blanchard-Zimmerman at vegetariyum@hotmail.com or call her at 512.929.5092.





"Sidewalk Slope Variability with respect to the Americans with Disabilities Accessibility Guidelines" is conducted for the Texas Department of Transportation by the Center for Transportation Research, Bureau of Engineering Research, at The University of Texas at Austin. Primary researcher is Dr. Kara Kockelman, Assistant Professor of Civil Engineering, UT Austin.

APPENDIX 3. SITE DESCRIPTIONS

3.1 SIDEWALK SECTIONS

Both field sites were located parallel to four-lane roads with average traffic speeds of 35 mph and average traffic volume of 2,000 cars per hour. The sites were selected for the variety of cross-slopes they offered, and for their location along convenient bus routes. The sites were locates at 38th St and Guadalupe, and at Manchaca and Lamar. Characteristics for each section are described in Table 3.1.

Table 3.1 Sidewalk section characteristics

ID	Part	AssNo	CrsSlp	MainSlp	Trs	Setback	Length (ft)	Width (ft)	Volume	Speed
1	1	1	0.06	0.05	9	0	34	9	2000	30
2	1	2	0.02	0.02	0	10	20	5	200	30
3	1	3	0.15	0.03	5	0	16	6	2000	30
4	1	4	0.1	0.01	3	0	13	10	2000	30
5	1	5	0.01	0	5	0	77	5	2000	15
6	1	6	0.01	0.07	0	50	120	6	2000	35
7	1	7	0.12	0.02	2	0	21	10	2000	35
8	1	8	0.02	0.01	6	3	31	6	2000	35
9	1	9	0.11	0	0	3	51	6	2000	35
10	1	10	0.01	0.01	0	16	28	5.5	2000	35
11	2	11	0.08	0.02	4	0	35	30	2000	35
12	2	12	0.05	0.02	6	0	38	35	2000	35
13	2	13	0.06	0.05	2	2	46	35	2000	35
14	2	14	0.02	0.01	2	6	200	4.5	2000	35
15	2	15	0.07	0.01	1	0	50	30	2000	35
16	2	16	0.04	0.01	2	6	90	4.5	2000	35
17	2	17	0.03	0.01	5	8	76	4	1500	30
18	2	18	0.10	0.02	1	0	10	5	100	15
19	2	19	0.03	0.02	3	0	50	13	100	15
20	2	20	0.12	0	6	0	20	11	100	15
21	2	21	0.01	0	0	50	30	16	2000	30
22	2	22	0.03	0.015	0	0	70	5	2000	30
23	2	23	0.03	0.01	0	30	42	7	2000	30
24	2	24	0.02	0.01	0	50	200	6	2000	30
25	2	25	0.01	0	0	50	30	6	2000	30

3.2 HEART RATE SECTIONS

The heart rate surveys were performed in a church parking lot adjacent to one of the survey sites. The site provided some variety of cross-slope and primary slope, but did not quite meet the team's goals for this particular type of survey. However, a group of volunteers had previously scheduled a meeting near this site, so choosing it ensured a certain number of participants. In addition, this site is located along a popular bus line and is within walking distance of many of the participants' homes. The characteristics of the heart rate sections are described in Table 3.2.

Table 3.2 Heart rate section characteristics

Section	Main Slope (%)	Cross-Slope (%)	Distance (ft, in.)
1A	2.97	0.50	220
1B	2.74	2.00	148,4
1C	2.10	1.90	133,4
2A	3.90	1.20	132
2B	3.60	2.20	164
2C	2.76	1.50	210,2
3A	0.95	3.10	178
3B	0.88	2.50	223,4
3C	0.67	2.50	256
4A	0.57	3.60	242,8
4B	0.53	2.50	292,6
4C	0.40	1.90	220
5A	3.64	0.50	125

APPENDIX 4. SURVEY INSTRUMENTS

4.1 INTERNET-BASED SURVEY FORM

(http://sidewalksurvey.hypermart.net/)

4.2 SIDEWALK SURVEY FORM

Date:

Sidewalk Cross-Slope Study **Proctor:**

Site Survey from: Manchaca at Lamar

Participant Information

Name: ____

Address: ____

Phone: ____

E-mail: ____

Heart monitor? ____ Yes ______ No

Ask these questions on the test site before the test begins.

1. What is your disability and mobility aid? ________________________________

2. What kind of shape do you consider yourself to be in?

very out of shape				in great shape
1	2	3	4	5

3. What is your age? ____________

4. What is your gender? _______Male ______Female

5. Are you right- or left-handed? ______Right ______Left

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

7. On a day when you travel on sidewalks, what is the distance you normally travel? ______Miles or Blocks

8. Pre-test heart rate: ______bpm
(If participant agrees to heart-rate monitoring)

Ask these questions before and after each section during the test.

Section No. ________

1. Heart rate before section: ______bpm

2. Heart rate during section: ______bpm

3. How difficult does this section appear to be? 1 2 3 4 5
   Very hard (1) … Easy (5)

4. How comfortable were you in traversing the last section?
   very uncomfortable … very comfortable
   1 2 3 4 5

5. If 3 or less, then what was the main reason for your discomfort? ____
   (examples: traffic, pavement surface, cross-slope)

6. If 3 or less, how many of these sections would you be comfortable negotiating in one trip?
   ______0 ______1
   ______2 ______1/block
   ______2/block ______infinite

Ask these questions after completion of the test.

1. How comfortable was the overall test for you?
   very uncomfortable … very comfortable
   1 2 3 4 5

2. How many such trips could you make in one day?
   ______zero ______one
   ______two ______three to five
   ______six to ten ______infinite

3. Is this enough to satisfy your travel needs? ______yes ______no

4. When traveling on a sidewalk, how do you feel most motorists react to you?

   very hostile 1 2 3 4 5 very considerate

5. How would you rate the automobile traffic during the test?

   very heavy 1 2 3 4 5 very light

6. How much do you know about ADA's sidewalk requirements?

   a lot 1 2 3 4 5 none

7. How important are sidewalks in providing for you access to public transportation
?

   very important 1 2 3 4 5 not important

4.3 HEART RATE SURVEY FORM

Heart-Rate Study — South Lamar

Resting heart rate: ________

Section	Heart rate before A	Heart rate before B	Heart rate before C	Heart rate after A	Heart rate after B	Heart rate after C
1						
2						
3						
4						
5		n/a	n/a		n/a	n/a

APPENDIX 5. DATASETS

5.1 INTERNET SURVEY DATA

Tables 5.1 and 5.2 list data collected from the Internet-based remote visual assessment survey. The data are separated into those collected on the basic portion and those collected on the advanced portion.

Table 5.1 Basic Internet survey data

ID	1	2	3	4	5	6	7	8
Wear-Monitor		1	0				0	0
Aid_MWC	1							
Aid_EWC							1	1
Aid_Crutch	1		1	1				
Aid_Cane					1	1	1	
Aid_Walker						1		
Aid_Scooter				1		1		
Aid_LegBrace								
Aid_FtBrace				1				
Aid_AtfLeg								
Aid_LowAud	1	1						
Aid_Deaf								
Aid_LowVision								
Aid_Blind								
Length	1	1	1	0	0	1	2	2
Gender	0	1	0	0	0	1	0	1
Assess1.1	0	1	0	3	3	1	1	2
Assess1.2	2	1	0	2	2	2	2	1
Assess2.1	0	1	0	2	2	2	0	0
Assess2.2	1	1	1	3	2	2	2	0
Assess3.1	2	1	0	4	4	2	2	3
Assess3.2	2	1	1	4	1	2	2	3
Assess4.1	2	1	0	3	3	1	1	1
Assess4.2	2	1	0	4	2	1	1	2
Assess5.1	0	1	0	4	2	2	4	1
Assess5.2	3	1	2	4	2	3	4	1
Assess6.1	0	0	0	4	1	1	1	0
Assess6.2	0	1	0	4	2	1	1	0
Assess7.1	0	1	0	1	1	0	1	0
Assess8.1	1	1	1	2	1	0	1	0
Assess9.1	2	1	0	3	3	2	2	3
Assess9.2		1	0	4	2	2	2	3
Age	46	35	50	62	48	57	41	43
Freg	1	2	1		6	3	0	1
Assess10.1		1	0	2	1	1	1	0
Assess10.2		1	0	3	1	2	1	0
Participate						2	0	0

ID	9	10	11	12	13	14	15	16
Wear-Monitor	0	0		0	0			0
Aid_MWC	1			1				1
Aid_EWC		1	1		1	1	1	
Aid_Crutch							1	
Aid_Cane								
Aid_Walker								
Aid_Scooter								
Aid_LegBrace								
Aid_FtBrace								
Aid_AtfLeg								
Aid_LowAud								
Aid_Deaf								
Aid_LowVision								
Aid_Blind								
Length	0	4	0	1	3	0	1	1
Gender	0	0	1	1	1	0	1	0
Assess1.1	1	0	0	0	1	1	2	3
Assess1.2	3	0	1	2	1	1	2	2
Assess2.1	1	0	1	4	0	0	1	1
Assess2.2	3	3	1	4	2	1	1	2
Assess3.1	2	1	1	2	2	1	2	4
Assess3.2	3	1	2	2	1	2	2	3
Assess4.1	1	1	2	0	1	2	1	3
Assess4.2	2	0	3	0	1	0	1	1
Assess5.1	2	1	2	2	1	1	1	1
Assess5.2	2	1	3	2	2	3	2	4
Assess6.1	1	0	0	2	0	0	2	3
Assess6.2	1	0	0	2	0	0	1	2
Assess7.1	1	0	0	0	0	0	1	1
Assess8.1	1	0	0	0	1	0	1	1
Assess9.1	1	0	0	2	1	0	2	3
Assess9.2	1	0	1	2	1	1	2	2
Age	22	29	19	41	25	50	49	32
Freg	1	0	4	1	3	3	1	3
Assess10.1	1	0	0	1	0	0	0	1
Assess10.2	1	0	0	0	0	0	1	0
Participate	2	0	1	2	0		1	0

ID	17	18	19	20	21	22	23	24
Wear-Monitor	0	0	0	0	0	0	0	
Aid_MWC					1			
Aid_EWC			1		1		1	
Aid_Crutch	1	1		1	1	1		
Aid_Cane				1	1	1		
Aid_Walker						1		
Aid_Scooter								
Aid_LegBrace				1	1			
Aid_FtBrace								
Aid_AtfLeg		1		1				
Aid_LowAud								
Aid_Deaf								
Aid_LowVision								1
Aid_Blind								
Length	1	1	1	1	4	3	2	0
Gender	1	1	1	1	0	0	0	1
Assess1.1	1	2	0	2	0	0	0	0
Assess1.2	1	1	0	2	0	0	1	0
Assess2.1	1	1	0	0	1	0	0	0
Assess2.2	2	3	0	0	1	0	0	0
Assess3.1	3	3	1	2	1	0	2	0
Assess3.2	3	1	1	1	2	0	2	0
Assess4.1	2	3	0	2	1	0	1	0
Assess4.2	2	1	0	2	1	0	1	0
Assess5.1	3	1	0	2	0	0	0	0
Assess5.2	3	0	2	2	0	0	4	0
Assess6.1	1	2	0	2	0	0	0	0
Assess6.2	1	0	0	2	0	0	0	0
Assess7.1	1	1	0	1	0	0	0	0
Assess8.1	1	1	0	1	0	0	0	0
Assess9.1	1	0	0	2	1	0	0	0
Assess9.2	1	0	0	2	2	0	1	0
Age	43	52	25	48	44	40	46	51
Freg	2	2	3	1	3	1	1	1
Assess10.1	1	1	0	1	1	0	0	0
Assess10.2	1	0	0	0	1	0	0	0
Participate	0	0	2	0	0	0	0	1

ID	25	26	27	28	29	30	31
Wear-Monitor	2		0	2		0	
Aid_MWC		1		1	1	1	1
Aid_EWC	1	1					
Aid_Crutch			1				
Aid_Cane							
Aid_Walker							
Aid_Scooter			1	1			
Aid_LegBrace							
Aid_FtBrace							
Aid_AtfLeg							
Aid_LowAud							
Aid_Deaf							
Aid_LowVision							
Aid_Blind							
Length	3	2	4	1	3	0	0
Gender	1	0	0	0	0	0	1
Assess1.1	0	1	0	1	2	1	0
Assess1.2	1	2	0	1	1	1	1
Assess2.1	0	1	0	1	1	1	0
Assess2.2	2	1	1	2	2	1	1
Assess3.1	2	2	1	3	3	3	2
Assess3.2	2	2	2	3	3	2	3
Assess4.1	1	2	0	2	3	2	1
Assess4.2	2	1	1	2	2	2	1
Assess5.1	0	1	0	0	0	1	0
Assess5.2	4	2	4	3	3	0	2
Assess6.1	0	1	1	3	0	2	1
Assess6.2	0	1	2	3	0	1	1
Assess7.1	0	0	1	1	1	0	0
Assess8.1	0	1	0	0	1	1	0
Assess9.1	0	2	1	2	2	1	1
Assess9.2	1	2	1	3	2	1	2
Age	43	36	34	30	41	27	62
Freg	1	0	0	1	1	3	1
Assess10.1	0	0	0	0	1	0	0
Assess10.2	0	0	0	1	0	0	0
Participate	0	1	0	0	1	0	1

ID	32	33	34	35	36	37	38
Wear-Monitor	0	0					
Aid_MWC		1		1			1
Aid_EWC			1		1	1	
Aid_Crutch							
Aid_Cane							
Aid_Walker	1						
Aid_Scooter	1						
Aid_LegBrace							
Aid_FtBrace							
Aid_AtfLeg							
Aid_LowAud							
Aid_Deaf							
Aid_LowVision							
Aid_Blind							
Length	2	2	2	3	4	4	2
Gender	0	1	0	1	1	1	0
Assess1.1	0	1	0	4	0	2	3
Assess1.2	0	2	2	3	2	2	2
Assess2.1	1	1	0	2	1	2	1
Assess2.2	1	2	2	4	2	2	2
Assess3.1	1	1	3	3	3	3	3
Assess3.2	1	3	3	3	4	3	3
Assess4.1	0	1	2	2	1	4	1
Assess4.2	1	2	3	4	1	4	1
Assess5.1	0	1	0	1	4	4	4
Assess5.2	1	3	4	3	4	4	4
Assess6.1	0	1	0	1	0	1	1
Assess6.2	1	1	2	2	0	1	1
Assess7.1	0	1	2	2	0	2	1
Assess8.1	1	1	0	1	0	1	2
Assess9.1	1	1	2	2	1	2	2
Assess9.2	1	2	1	2	1	2	2
Age	36	44	52	54	36	41	48
Freg	1	3	6	0	1	1	4
Assess10.1	0	1	0	1	0	1	1
Assess10.2	1	1	1	2	0	1	1
Participate	0	0	1	1	1	2	1

ID	39	40	41	42	43	44	45	46
Wear-Monitor	0		0					
Aid_MWC	1		1		1	1		
Aid_EWC		1					1	1
Aid_Crutch								
Aid_Cane								
Aid_Walker								
Aid_Scooter								
Aid_LegBrace								
Aid_FtBrace								
Aid_AtfLeg								
Aid_LowAud								
Aid_Deaf								
Aid_LowVision								
Aid_Blind								
Length	1	2	4	1	2	3	5	1
Gender	0	1	0	0	1	1	1	0
Assess1.1	3	0	1	2	3	2	2	0
Assess1.2	3	0	1	1	3	2	1	2
Assess2.1	2	0	1	1	2	2	2	0
Assess2.2	2	2	2	1	3	3	2	0
Assess3.1	3	3	2	3	4	3	4	1
Assess3.2	3	2	3	3	4	3	2	4
Assess4.1	4	3	3	2	3	3	4	1
Assess4.2	4	3	3	2	3	3	4	3
Assess5.1	3	2	1	2	4	1	4	0
Assess5.2	3	2	1	2	4	1	4	4
Assess6.1	1	0	1	1	3	1	0	0
Assess6.2	1	0	1	1	3	1	0	0
Assess7.1	1	0	0	2	0	2	0	0
Assess8.1	1	0	1	1	0	1	1	0
Assess9.1	2	2	3	2	2	3	4	0
Assess9.2	3	2	3	2	2	3	4	3
Age	49	43	44	44	62	55	41	35
Freg	0	1	1	1	2	0	0	1
Assess10.1	1	1	0	1	0	1	1	0
Assess10.2	1	1	0	1	1	1	1	0
Participate	2	1	1	0	0	1	2	1

ID	47	48
Wear-Monitor		
Aid_MWC		
Aid_EWC	1	1
Aid_Crutch		
Aid_Cane		
Aid_Walker		
Aid_Scooter		
Aid_LegBrace		
Aid_FtBrace		
Aid_AtfLeg		
Aid_LowAud		
Aid_Deaf		
Aid_LowVision		
Aid_Blind		
Length	1	1
Gender	0	1
Assess1.1	1	0
Assess1.2	2	0
Assess2.1	0	0
Assess2.2	2	0
Assess3.1	3	0
Assess3.2	3	0
Assess4.1	3	1
Assess4.2	3	1
Assess5.1	0	1
Assess5.2	4	3
Assess6.1	1	0
Assess6.2	2	0
Assess7.1	1	0
Assess8.1	0	0
Assess9.1	3	0
Assess9.2	3	0
Age	57	36
Freg	1	4
Assess10.1	0	0
Assess10.2	1	0
Participate	1	1

Table 5.2 Advanced Internet survey data

Id	1	2	3	4	5	6	7	8	10	13	15	16
injury		4	2	1	4	0		2		4	3	2
diff_expr	3	0	3	3	2	2	2	2	1	2	2	2
access_surface			1				1			1	1	
fallen_surface			1		1							1
fallen_self			1		1					1		
diff_slope	1		0	1	1		1				1	1
diff_surface			1		1					1		
diff_transitoin			1				1	1		1		
fallen		0						0				
assess10.1	1	1	1	4	3		2	3	2	2	2	2
fallen_sdwk											1	1
travel_diff	0	3	0	0	2	2	0	1	0	2	0	1
fallen#	2	0	6	3	5		1	1	1	5	10	35
fallen_grade					1				1		1	1
fallen_faclty				1	1						1	1
diff_volume			1									
diff_setbk						1			1			
damage	0	3	3		2			2	3	3	2	
assess1.1	0	1	0	3	3	1	1	0	0	1	2	2
assess1.2	0	1	0	3	2	1	1	0	4	1	2	1
assess2.1	0	1	0	3	2	0	1	0	0	1	2	2
assess2.2	1	1	0	3	2	1	1	0	2	1	2	1
assess3.1	0	1	0	4	2	0	1	0	0	1	2	1
knowAda	2	0	0	3	1	1	3	1	1	2	0	3
sdwk%	5	0	0	50	0	15	5	20	5	50	95	80
assess3.2	1	1	0	4	1	0	1	0	0	1	2	1
assess4.1	0	1	0	4	1	2	1	1	0	1	1	1
access_bldng	1		1	1	0		0	0	1	1		1
diff_width										1		
assess4.2	1	1	0	4	1	1	1	0	0	1	2	1
assess5.1	0	1	1	4	2	1	1	0	0	1	2	2
assess5.2	0	1	0	3	1	1	1	0	0	1	2	1
assess6.1	0	1	0	4	1	1	1	0	2	1	1	0
assess7.1	0	1	1	4	2	2	1	2	2	1	1	0
assess6.2	0	1	0	3	1	2	1	0	2	1	1	0
assess8.1	2	1	0	4	3	2	1	3	2	1	2	3
diff_grade						1			1			
access_cross				1			1	1	1	1		1
assess9.1	0	1	0	4	3	1	1	0	0	1	2	0
assess9.2	1	1	0	4	2	1	1	0	2	1	2	0
fallen_path										1	1	
fallenOutside	0	0	3		3	0	0	1	1	5	7	15
alter_choice	0	0	0	0		0	0	0	1	0		0
assess11.1	0	1	0	1	1		1	0	0	0	1	0
assess12.1	0	1	0	2	1		1	0	0	0	1	0
assess11.2	0	1	1	11	1		1	0	0	0	1	0
assess13.1	0	1	0	2	2		2	0	0	1	2	0
assess12.2	0	1	0	2	1		1	0	0	0	1	0
assess14.1	0	1	0	2	2	1	1	0	0	0	0	0
assess13.2	0	1	1	2	2		1	4	2	1	2	0
assess15.1	0	1	0	4	1		1	0	0	0	1	0
assess14.2	0	1	1	2	1	1	1	0	0	0	1	0
assess15.2	0	1	0	4	1		1	0	0	0	1	0
fallen_design												

Id	17	18	19	20	21	24	25	26	28	29	30	31
injury	3	4	4	3	1		3	2	4	1	4	2
diff_expr	2	2	2		2	0	4	2	2	3	2	3
access_surface	1			1	1							
fallen_surface		1										
fallen_self	1				1						1	
diff_slope	1		1							1	1	
diff_surface	1									1		
diff_transitoin	1			1						1		1
fallen												
assess10.1		2	0	2	2	0	1	2	3	2	1	1
fallen_sdwk										1		
travel_diff	0	2	0	1	0		0	1	0	0	0	0
fallen#	15	3	0		3	0	1	1		##	6	1
fallen_grade		1		1				1	1		1	
fallen_faclty								1				
diff_volume												
diff_setbk				1	1							
damage	3	2	3		3		1	2	3	2	3	2
assess1.1	1	3	0	1	0	0	1	1	0	3	1	1
assess1.2	1	1	0	1	0	0	1	0	1	3	1	1
assess2.1	1	2	0	1	0	0	0	1	0	2	1	1
assess2.2	1	0	0	1	0	0	0	0	1	1	1	1
assess3.1	1	2	0	1	0	0	0	1	1	2	1	0
knowAda	1	2	1	2	1	3	2	2	1	2	1	0
sdwk%	8	10	10	10	16	0	30	30	75	25	25	15
assess3.2	1	0	0	1	0	0	0	1	1	1	1	0
assess4.1	1	2	0	2	2	0	2	2	1		1	0
access_bldng		1	1				1					
diff_width	1				1							
assess4.2	1	1	0	2	2	0	0	2	1		1	0
assess5.1	1	2	0	1	0	0	0	1	1		1	1
assess5.2	1	1	0	1	0	0	1	1	1		1	1
assess6.1	1	1	0	1	0	0	0	1	1	1	0	0
assess7.1	1	1	0		1	0	0	0	2	2	0	0
assess6.2	1	0	0	1	0	0	1	1	1	1	0	0
assess8.1		2	0	2	2	0	1	2	2	3	2	2
diff_grade	1							1	1			
access_cross	1			1							1	1
assess9.1		2	0	1	0	0	0	2	1	2	1	0
assess9.2		1	0	1	0	0	0	1	1	2	1	0
fallen_path												
fallenOutside		2	0	10	1		1	1	1	30	2	1
alter_choice			0	0	0						1	0
assess11.1		2	0	1	0	0	0	0	0	0	1	0
assess12.1		2	0	1	0	0	0	0	0	0	1	0
assess11.2		0	0	1	0	0	0	0	0	0	1	0
assess13.1		3	0	2	0	0	0	1	1	0	0	0
assess12.2		1	0	1	0	0	0	0	0		1	0
assess14.1	1	3	0	1	0	0	0	0	0	2	0	0
assess13.2		2	0	2	0	0	0	1	1	0	0	0
assess15.1		3	0	2	0	0	0	1	0	0	0	0
assess14.2	1	1	0	1	0	0	0	0	0	0	0	0
assess15.2		2	0	2	0	0	0	0	0	0	0	0
fallen_design				1	1		1		1	1		

5.2 FIELD SURVEY DATA

Tables 5.3 and 5.4 list data collected from the sidewalk section surveys. The data are separated based on the location of the survey.

Table 5.3 38th and Guadalupe data

ID	1	1	2	3	4	5	6	7	8	9	10
aid_ewc	1		1	1					1		1
aid_mwc		1						1			
aid_blind						1	1				
aid_cane					1					1	
shape	2	2	3	4	4	4	4	2.5	5	3	5
age	44	44	46	41	43	49	52	50	32	45	49
gender	0	0	0	0	1	0	1	1	0	0	1
handed	0	0	0	0	0	0	0	0	0	0	0
trvl_freq	3	3									
trvl_len	2	2	1	0.25	0.2	0.2	0.5	2	2	0.5	0.1
pre_hrt			NA	108	75	87	99	105	n/a	85	78
hrt1.0				110	79	88	102	102	n/a	82	83
hrt1.1				112	81	90	105	105	n/a	86	85
sec1.0	4	2	4	4	4	n/a	n/a	4	5	n/a	4
sec1.1	4	1	4	4	3	4	4	4	5	5	4
hrt2.0				115	87	87	107	101	n/a	82	82
hrt2.1				116	88	90	109	103	n/a	84	84
sec2.0	5	4	5	3	4.5	n/a	n/a	4	5	n/a	5
sec2.1	5	4	5	4	5	3	5	4	5	5	5
hrt3.0				116	89	93	107	105	n/a	83	85
hrt3.1				118	87	95	110	107	n/a	87	87
sec3.0	2	2	4	4	3	n/a	n/a	4	5	n/a	3
sec3.1	3	2	4	4	2	4	3	3	5	4	2
hrt4.0				117	87	95	108	103	n/a	80	84
hrt4.1				117	90	97	109	104	n/a	82	86
sec4.0	4	4	5	3	4	n/a	n/a	4	5	n/a	5
sec4.1	4	4	5	4	5	4	4	4	5	5	5
hrt5.0				117	85	94	105	100	n/a	82	86
hrt5.1				117	95	101	107	102	n/a	84	83
sec5.0	3	2	4	3	3	n/a	n/a	4	4	n/a	5
sec5.1	3	1	4	3	3	5	4	4	4	4	5
hrt6.0				113	87	104	104	106	n/a	87	85
hrt6.1				112	90	106	106	105	n/a	88	86
sec6.0	5	4	5	5	5	n/a	n/a	5	5	n/a	5
sec6.1	4	4	5	5	5	5	3	5	5	4	5
hrt7.0				112	88	110	105	103	n/a	84	86
hrt7.1				109	90	114	107	105	n/a	87	91
sec7.0	2	1	5	5	4	n/a	n/a	5	5	n/a	4
sec7.1	2	1	5	5	4	5	5	5	5	5	4
hrt8.0				117	84	108	108	100	n/a	86	89
hrt8.1				117	92	112	106	101	n/a	86	84
sec8.0	5	5	5	5	5	n/a	n/a	5	5	n/a	5
sec8.1	5	5	5	5	5	5	5	5	5	5	5
overall_dff	5	3	4	5	4	5	5	5	5	5	5
trp/day	2	0	19	19	8	8	8	19	8	19	19
satify	0	0	1	1	1	1	1	1	0	1	1
motorist	4	4	3	3	3.5	5	4	4	5	4	5
traffic_rt	3	3	3	3	2	4	4	4	3	4	5
knowAda	4	4	2	1	3	3	3	3	4	4	1
imptnt	1	1	1	1	1	1	1	1	1	5	5

Table 5.4 Manchaca and Lamar data

ID	11	12	13	7	8	14	15	16	9	10	17
aid_ewc	1	1			1			1		1	
aid_mwc				1		1	1				
aid_blind									1		
aid_cane									1		
aid_scooter			1								
shape	4	2	3	3	5	5	1	1	3	5	2
age	41	43	35	50	32	27	49	46	45	49	59
gender	0	1	0	1	0	0	1	0	0	1	1
handed	0	1	0	0	0	1	0	0	0	0	0
trvl_freq	7	7	7	7	2	7	7	0	5	7	7
trvl_len	0.25	1	0.5	2.5	2.5	1.5	1.5		0.5	0.1	0.2
pre_hrt						82					
hrt1.0											
hrt1.1											
sec1.0	5	5	5	5	5		4	5	5	5	5
sec1.1	5	5	5	5	5		4	5	5	5	5
hrt2.0											
hrt2.1											
sec2.0	5	5	5	5	5		3	4	5	5	3
sec2.1	5	5	5	5	5		4	5	5	5	3
hrt3.0						88					
hrt3.1						94					
sec3.0	4	5	5	5	5	5	4	5	5	5	4
sec3.1	4	5	5	5	5	3	3	5	5	5	3
hrt4.0						95					
hrt4.1						98					
sec4.0	4	4	5	5	5	5	4	5	5	5	5
sec4.1	4	4	5	5	5	5	4	5	5	5	5
hrt5.0						95					
hrt5.1						99					
sec5.0	5	5	5	5	5	5	4	5	5	5	5
sec5.1	5	5	5	5	5	5	4	5	5	5	5
hrt6.0						98					
hrt6.1						112					
sec6.0	5	4	5	5	5	3	2	5	5	5	3
sec6.1	5	4	5	5	5	2	2	5	5	5	2
hrt7.0						101					
hrt7.1						104					
sec7.0	5	5	5	5	5	5	4	5	5	5	5
sec7.1	5	5	5	5	5	5	4	5	5	5	5
overall_dff	5	5	5	5	5	4	3	5	5	5	4
trp/day	0	0	0	19	8	4	4	19	19	19	4
satify	1	1	1	1	0	1	0	1	1	1	1
motorist	3	5	2	4	5	4	4	4	4	5	4
traffic_rt	2	3	5	4	3	3	3	3	4	5	3
knowAda	1	2	3	3	4	2	3	2	4	1	4
imptnt	1	1	1	1	1	1	2	4	5	5	2

5.3 HEART RATE SURVEY DATA

Table 5.5 lists data collected during the heart rate surveys.

Table 5.5 Heart rate survey data

	Other	**1a**	**1b**	**1c**	**2a**	**2b**	**2c**	**3a**	**3b**	**3c**	**4a**	**4b**	**4c**	**5**
ID	9													
Aid Type	blind													
Rest	80													
Before		105	99	89	103	100	95	107	110	120				
After		113	105	99	106	107	107	113	117	113				
ID	16													
Aid Type	ewc													
Rest	123													
Before		128	127	132	138	137	137	135	137	137	137	137	138	143
After		131	132	132	135	138	137	137	137	137	138	138	143	140
ID	14													
Aid Type	mwc													
Rest	82													
Before		131	132	82	132	140	142	95	105	164	151	119	110	95
After		165	164	165	164	180	180	132	165	145	123	137	120	180
ID	12													
Aid Type	ewc													
Rest	102													
Before		109	109	109	113	113	114	114	112	114	117	117	114	119
After		109	109	113	113	114	114	114	114	114	117	114	115	117
ID	13													
Aid Type	scooter													
Rest	84													
Before		103	107	108	104	111	108	103	105	106	110	106	110	104
After		109	109	110	112	109	108	106	108	109	106	109	109	105
ID	4													
Aid Type	cane													
Rest	85													
Before		79	98	110	108	117	122	105	114	120	110	115	127	110
After		103	115	113	120	135	138	112	123	137	118	128	148	184
ID	18													
Aid Type	ewc													
Rest	70													
Before		76	76	76	74	75	73	75	77	77	78	76	75	75
After		76	76	78	75	74	74	78	79	76	78	79	75	74
ID	10													
Aid Type	ewc													
Rest	90													
Before		90	88	85	84	86	87	91	94	91	90	89	92	94
After		84	85	87	86	87	89	91	92	91	89	92	93	96
ID	19													
Aid Type	mwc													
Rest	79													
Before		82	88	95	103	108	122	110	112	118	112	110	116	109
After		90	95	104	110	121	135	115	118	121	115	118	123	168
ID	20													
Aid Type	crutches													
Rest	78													
Before		81	138	135	128	137	122	95	120	122	99	130	135	95
After		132	146	152	135	152	145	121	145	138	128	139	146	180

APPENDIX 6. STATISTICAL METHODS

6.1 METHODS DESCRIPTIONS AND EQUATIONS

6.1.1 Linear Regression with Weighted Least Square Estimation

The change in heart rate is an important indicator of energy consumed when crossing a sidewalk section. The basic principle involved in regression is that the variation of the heart rate changes Y_i (the difference between the post-test heart rate and the resting heart rate on test *i*) is linearly affected by the variation in relevant exogenous variables.

$$Y_i = \vec{X}'_i \vec{\beta} + \varepsilon_i \tag{1}$$

where X_i is a row vector of exogenous variables, β is a corresponding column vector of coefficients to be estimated, and ε_i is an error term representing the random variation about the heart rate changes in each test *i*. The distribution of the error ε_i is assumed to be normal and to have an average magnitude of zero and a constant variation, i.e. $E(\varepsilon_i) = 0$ *and* $V(\varepsilon_i) = \sigma^2.0$

Normally, the ordinary least squares (OLS) estimation can minimize the sum of squared residuals/unexplained errors between the observed and predicted values of the dependent variable and achieve consistent and unbiased results. However, the OLS estimation will suffer from heteroscedasticity when the variance of error terms is not constant. In the present case, because all subjects participated in multiple tests, there are correlationships across the error terms for each individual. Thus, the error terms are actually composed of two parts: individual-specific biases and purely random error.

$$\begin{aligned} Y_{in} &= \vec{X}'_{in} \vec{\beta} + u_{in} \\ \textit{where } u_{in} &= \varepsilon_n + \varepsilon_{in} \end{aligned} \tag{2}$$

Y_{in} is the heart rate change of individual *n* on *i*'th experiment. μ_{in} is the observed error term. ε_n is the error specific to individual *n* and ε_{in} is the purely random error.

A weighted least squares estimation can accommodate the heteroscedasticity, where the weights are estimates of the variances associated with each observation's error term. This technique is called "feasible generalized least squares" and is asympototically as efficient as maximum likelihood estimation (when error terms are normal). If it is assumed that the variance of each individual's error term and the variance of each experiment's error term are constants, i.e., $\text{var}(\varepsilon_{in}) = \sigma_i^{\ 2}$, $\text{var}(\varepsilon_n) = \sigma_n^{\ 2}$, and the correlation of error terms that individual *n* took in two tests *p* and *q* is

$$corr(u_{pn}, u_{qn}) = \rho_{pq} = \frac{\text{cov}(u_p, u_q)}{\sigma_p \cdot \sigma_q} \quad \forall p, q \in I; \tag{3}$$

then a weight matrix "W" can be constructed as follows:

$$W = \begin{bmatrix} \Omega_1 & 0 & 0 \\ 0 & \ddots & 0 \\ 0 & 0 & \Omega_N \end{bmatrix}, where\ \Omega_n = \begin{bmatrix} 1 & \rho_{1q} & \rho_{1I} \\ \rho_{p1} & \ddots & \rho_{pI} \\ \rho_{I1} & \rho_{Iq} & 1 \end{bmatrix} \quad (4)$$

The WLS estimate of the parameter vector $\vec{\beta}$ is the following:

$$\hat{\beta}_{WLS} = \left(X'WX\right)^{-1} X'WY \quad (5)$$

where X is the matrix of the explanatory information and Y is a column vector of the heart rate *c* difference.

6.1.2 Ordered Response Probit Analysis

In this analysis, the categorized assessment of a sidewalk section with a particular cross-slope is modeled using an ordered response probit structure. The procedure enables one to include a set of additional parameters representing the unobserved thresholds between assessment categories.

The ordered-response mechanism is based on the hypothesis that a continuous variable Y_i^* represents the unobserved or "latent" response for an individual on a sidewalk section *i*. The latent response is assumed to be a linear function of relevant exogenous variables and a standard normally distributed random error term ε_i. The variance of ε is assumed to be 1.0 since Y_i^* is unobserved (hence its scale is unidentifiable). Given a respondent's ranking or assessment, Y_i, of a sidewalk section *I,* the latent response (Y_i^*) and threshold bounds (μ_k) are as follows:

$$\begin{aligned} & Y_i^* = \vec{X}_i'\vec{\beta} + \varepsilon_i \\ & Y_i = k \ \ if \ \ \mu_{k-1} < Y_i^* \le \mu_k \quad (k = 0,1,\ldots K) \end{aligned} \quad (6)$$

where $\vec{X}_i$ is a column vector of exogenous variables, $\vec{\beta}$ is a corresponding column vector of coefficients to be estimated, and the μ's are threshold bounds (with $\mu_1 = -\infty, \mu_k = +\infty$). The probability associated with each term is determined by the threshold bounds and the latent response Y_i^*; in equation form:

$$P(Y_i = k) = \Phi(\mu_k - Y_i^*) - \Phi(\mu_{k-1} - Y_i^*) \quad (7)$$

where Φ is the cumulative standard normal distribution function.

The estimation maximizes the log likelihood function given by:

$$\ln L = \sum_i \ln L_i = \sum_i \ln[P(Y_i = k)] \tag{8}$$

Since the objective is to find the maximum reasonable cross-slope, this variable is included in the exogenous variables. Having estimated the threshold bounds (Y_i^*), the maximum cross-slope can be calculated, such that

$$P(\vec{X}_i'\vec{\beta} + \mu_i \geq Y_3^*) \geq 0.20 \tag{9}$$

i.e., more than 20 percent of the sidewalk users will feel uncomfortable when they traverse such a cross-slope (the 3rd threshold indicates the difficult response, and the 4th indicates the "impossible-to-access" response).

6.2 ORDERED PROBIT MODEL

```
/**************************************************************
*****************
 *    ORDERED PROBIT MODEL
 *    Written by Dr. Chandra Bhat (1999)
 *    Modified for sidewalk project by Yong Zhao
**************************************************************
****************/

/*= Include MaxLik library =*/

library maxlik;
#include maxlik.ext;

/*= Reset global variables =*/

maxset;

/*= Clear the globle variables =*/

clearg ncon,_indep,threlbl,inf,minf,_weight;

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

dataset = "slopenew";
```

```
/***************************************************************
****************
                    Specification of variables area
***************************************************************
***************/

/* definition of independent variables (exclude constant
because program
   is set up to estimate all boundary thresholds; some other
programs
   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) */

ivname = { CRSSLP   MAINSLP STBK100 LGWIDTH  LGAGE Gender
Freg Trvlen
 AidMWC AidEWC  AidCrtch AidCane AidSctr AidLowA } ;

/*- Variables list -----
  { CRSSLP MAINSLP TRS  SETBACK STBK100 LENGTH LGLEN  WIDTH
LGWIDTH  VOLUME LGVOL  SPEED LGSPD  Flare
 Age AGE2 LGAGE Gender  Uno  Freg Trvlen
 AidMWC AidEWC  AidCrtch AidCane AidWlkr AidSctr AidLgBr
AidFtBr AidAtfL AidLowA AidLowV };*/

/* 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,"uno");

{ varnam, iv1 } = indices (dataset, ivname');

/* Output file name for "dumping" results */

output file = c:\gauss\out\ordered.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 = { -0.7165,0.1586,1.19558,-0.002,0.013,0.12587,0.17175
};
   ncon=2;
else;
    b=(init(dataset))|zeros(rows(iv1),1);
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;

/* Procedure to determine start values 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=1;
 do until j == n+1;
   p=p|s[j]+p[rows(p)];
   j=j+1;
 endo;
 p=trimr(p,1,1)/p[rows(p)];
 st = cdfni(p);
 retp(st);
```

```
endp;

/* 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_GradProc=&lgd;

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

__row = 1000;

_max_Options = { bfgs stepbt };

_max_CovPar = 1;


/* Maxlik procedure call */

{ 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 " The Log likelihood function:    ";;
log1=f*_max_NumObs;
print log1;

/*- Maxlik procedure call for restriced log-likelihood
extimation-*/

ivname = { uno } ;
{ varnam, iv1 } = indices (dataset, ivname’);

if _stols == 0;
```

```
   b = { -0.7165,0.1586,1.19558,-0.002,0.013,0.12587,0.17175
};
   ncon=2;
else;
    b=(init(dataset))|zeros(rows(iv1),1);
endif;

_max_ParNames= threlbl|varnam;
{ x,f,g,cov,retcode } = maxlik(dataset,0,&lpr,b);

/*- Print the restricted log-likelihood -*/
log0=f*_max_NumObs;
print " The restricted log-likelihood:  ";;
print log0;

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


/* 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;

proc lgd(x,dta);
  local
newv,y,tu,tl,pcfu,pcfl,cdfu,cdfl,cdfd,pcfd,tempy,g,z9,mask,mas
k1,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);
  cdfu = cdfn(tu);
  cdfl = cdfn(tl);
  cdfd = cdfu-cdfl;
  pcfd = pcfu-pcfl;
  if cdfd > 0;
    z9= (cdfd);
    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;
```

6.3 WLS MODEL

```
/*--------------------------------------------------------------
----------------------
**  WLS.gau
**
**  Porpose: Weighted regression using weight matrix.
**  Author: Yong Zhao (yzhao@mail.utexas.edu)
**  Last modified: 7/13/1999
**  Note: Originally developed for Sidewalk project
**
--------------------------------------------------------------
--------------------*/
external proc indices2;

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

```
dataset = "hrtrate3";

/* definition of independent variables */

/* variable list: PlsChg  TstChg  MainSlp CrsSlp Distanc
logdis Gender Age logage Shape aidewc aidmwc aidcrtch aidcane
aidsctr */

ivname = {   MainSlp CrsSlp  logdis logage aidewc aidmwc
aidcane aidsctr } ;

/* Dependent variable (dv) */

dvname= { PlsChg } ;

/* Provide  weight matrix  */
        open f1 = "weight" ;
        w=readr( f1,rowsf(f1) );
       close(f1);

/* Output file name for "dumping" results */
output file = c:\gauss\out\WLS.out on;

/*- The title of the printout -*/
title = "SIDEWALK HEART RATE CHANGE WLS ESTIMATION";

/*--------------------------------------------------------------
-----------------------------------------------------
                       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 ] ;
        closeall;

/* WLS procedure call */

{ b,stdb,sigma2, t, pvt, r2, wtR2, adjR2 } = wlsPs( y, x, w );

/*- Print the output -*/

        print "-----------------------------------------------------
-----------------------";
        print title;
        print "-----------------------------------------------------
-----------------------";
        print ftos(nobs,"Valid cases:  %*.*lf",12,0);;
        print ftos(depvar,"   Dependent variable:
%*.*s",12,8);

        print ftos(R2 ,"R-squared:    %*.*lf",12,3);;
        print ftos(wtR2,"   Weighted R-squared: %*.*lf",12,3);
        print ftos(adjR2,"Weighted AdjR-2: %*.*lf",9,3);;
        print ftos(sqrt(sigma2) ,"   Std. Err of Est:
%*.*lf",12,3);
        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);


/*--------------------------------------------------------------
------------------
```

```
**  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, adjR2 } =
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
**             adjR2    scalar, Weighted adjusted R2
--------------------------------------------------------------
----------------*/

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

  local N,k,df, b,e,sigma2,varb,stdb,t, pvt, R2, wtR2, adjR2;

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

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

```
/* R2 and adjR2 should be weighted by the w matrix */

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

  retp( b,stdb,sigma2,t, pvt, R2, wtR2, adjR2 );

endp;
/*-------------------------------------------------------------
----------------*/
```

APPENDIX 7

Technical Report Documentation Page

1. Report No. 4933-1	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle A REVIEW OF METHODS FOR MEETING THE AMERICANS WITH DISABILITIES ACT (ADA) SIDEWALK CROSS-SLOPE REQUIREMENT		5. Report Date March 1999 6. Performing Organization Code
7. Author(s) Dean Taylor, Kara Kockelman, Lydia Heard, Beth Taylor, and Yong Zhao		8. Performing Organization Report No. 4933-1
9. Performing Organization Name and Address Center for Transportation Research The University of Texas at Austin 3208 Red River, Suite 200 Austin, TX 78705-2650		10. Work Unit No. (TRAIS) 11. Contract or Grant No. 7-4933
12. Sponsoring Agency Name and Address Texas Department of Transportation Research and Technology Transfer Section/Construction Division P.O. Box 5080 Austin, TX 78763-5080		13. Type of Report and Period Covered Research Report (11/13/98 8/31/99) 14. Sponsoring Agency Code
15. Supplementary Notes Project conducted in cooperation with the Texas Department of Transportation.		

16. Abstract

This review of methods for meeting the sidewalk cross-slope requirement in the Americans with Disabilities Act (ADA) is intended to help the Texas Department of Transportation (TxDOT) enhance its accessible-sidewalk program. Specifically, the review is targeted toward providing TxDOT with enough information to determine whether or not its concerns regarding sidewalk cross slope at driveway crossings have been sufficiently addressed by others. The review can be broken down into the following four areas: (1) **research and science** related to how people with disabilities perceive travel across sidewalk cross slopes of various magnitudes, (2) **design-related methods** for providing accessible cross slope at driveway crossings, (3) **programmatic methods** for meeting the intent of ADA at driveway crossings within the constraints of the situation at hand, and (4) **expert opinions** on meeting the intent of ADA at sidewalk-driveway crossings.

Prior to this study, TxDOT had done significant internal review in the latter three areas. The main focus of this review is, therefore, on the research and science area. The review presented herein for the latter three areas can be used to determine if something important was missed, to identify any new information that has become available, and to provide a comprehensive look at these areas. TxDOT will use this review to decide whether or not to continue to Phase II of this project, which is to determine cross-slope accessibility needs and operational ranges so that the design and construction of pedestrian facilities are responsive to the needs of people with disabilities.

17. Key Words Sidewalk design, Americans with Disabilities Act, sidewalk accessibility, sidewalk cross slopes	18. Distribution Statement No restrictions. This document is available to the public through the National Technical Information Service, Springfield, Virginia 22161.		
19. Security Classif. (of report) Unclassified	20. Security Classif. (of this page) Unclassified	21. No. of pages 56	22. Price

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A REVIEW OF METHODS FOR MEETING THE AMERICANS WITH DISABILITIES ACT (ADA) SIDEWALK CROSS-SLOPE REQUIREMENT

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RESEARCH REPORT 4933-1

CENTER FOR TRANSPORTATION RESEARCH
BUREAU OF ENGINEERING RESEARCH
THE UNIVERSITY OF TEXAS AT AUSTIN

MARCH 1999

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IMPLEMENTATION RECOMMENDATIONS

There are no implementation recommendations based on this report.

NOT INTENDED FOR CONSTRUCTION,
BIDDING, OR PERMIT PURPOSES

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ACKNOWLEDGMENTS

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Research performed in cooperation with the Texas Department of Transportation.

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CHAPTER 1. INTRODUCTION

This review of methods for meeting the sidewalk cross-slope requirement in the Americans with Disabilities Act (ADA) is intended to help the Texas Department of Transportation (TxDOT) enhance its accessible-sidewalk program. Specifically, the review is targeted toward providing TxDOT with information sufficient to determine whether its concerns regarding sidewalk cross slope at driveway crossings have been adequately addressed by others. The review can be broken down into the following four areas:

(1) **research and science** related to how people with disabilities perceive travel across sidewalk cross slopes of various magnitudes,

(2) **design-related methods** for providing accessible cross slope at driveway crossings,

(3) **programmatic methods** for meeting the intent of ADA at driveway crossings within the constraints of the situation at hand, and

(4) **expert opinions** on meeting the intent of ADA at sidewalk-driveway crossings.

Prior to this study, TxDOT had undertaken significant internal review in the latter three areas. The main focus of this review is, therefore, on the research and science area. The review presented herein for the latter three areas can be used to determine if something important was missed, to identify new information that has become available, and to provide a comprehensive look at these areas. TxDOT will use this review to decide whether to continue to Phase II of this project, which is to determine cross-slope accessibility needs and operational ranges so that the design and construction of pedestrian facilities are responsive to the needs of people with disabilities.

The next chapter provides a broad and general overview of the ADA. In the third chapter, stakeholder concerns are articulated and discussed, especially those of people with disabilities and those of agencies similar to TxDOT. Next, a background to ADA is provided in terms of (1) the history and spirit of the legislation, (2) prior research and science related to the sidewalk cross-slope requirement, and (3) relevant court decisions. The fifth chapter contains a discussion of possible programmatic methods for meeting the intent of the ADA with respect to cross slope. Key ADA cross slope-related requirements are identified and discussed, as are any caveats applying to situations under which those requirements do not have to be met. The fifth chapter also presents and discusses various design-related methods reported in the literature for meeting the ADA cross-slope requirement at driveway crossings. In the final chapter, key findings are summarized in a way that is intended to help TxDOT decide whether its concerns for providing accessible sidewalk cross slopes at driveway crossings have been sufficiently addressed by others. In addition, we comment on Phase II of this project (i.e., conducting further research).

CHAPTER 2. A BROAD OVERVIEW OF THE AMERICANS WITH DISABILITIES ACT

The Americans with Disabilities Act (ADA) of 1990 embodies civil rights legislation that extends to individuals with disabilities comprehensive protections similar to those provided to persons on the basis of race, sex, national origin, and religion under the Civil Rights Act of 1964. The ADA consists of five titles. Title I prohibits discrimination against individuals with disabilities in employment by private businesses with fifteen or more employees. Title II, the primary focus of this review, prohibits discrimination by state and local governments in the provision of services, including employment. Title III prohibits discrimination by public accommodations covered by twelve categories of private entities and commercial businesses, and includes regulations and specifications for accessible construction and design that also apply to Title II. Title IV concerns telecommunications, and Title V is a miscellaneous catchall provision that covers Congress, the legislative branch, and federal wilderness areas.

The following is an overview of the ADA Accessibility Guidelines (ADAAG). Although general in nature, the overview begins to focus on the Texas Department of Transportation (TxDOT) and sidewalks. This is followed by short overviews of the other accessibility guidelines that may be applicable to TxDOT, i.e., the Uniform Federal Accessibility Standards (UFAS) and the Texas Accessibility Standard (TAS).

2.1 ADA ACCESSIBILITY GUIDELINES

The ADA Accessibility Guidelines (ADAAG) (1994) are a set of standards for accessible design developed by the Architectural and Transportation Barriers Compliance Board (Access Board). These guidelines, covering new construction and alterations, acquire force of law when adopted into regulations established by the Department of Justice. Currently, the Department of Justice (DOJ) has adopted ADAAG Sections 1 through 10, concerning public accommodations and commercial facilities, into the Title III regulations.

The DOJ also certifies state laws and local building codes for equivalency, meaning they meet or exceed the minimum requirements of the ADA for accessibility and usability of facilities. The Texas Accessibility Standards (TAS) have received certification of equivalency from the DOJ and are applicable to all new construction and alterations in the state of Texas.

It is important to remember that the ADA is civil rights legislation, not a building code. The federal government does not perform plan reviews or inspections for ADA compliance. Covered entities are considered to be in compliance until a complaint is received, and an ensuing investigation by the DOJ or a judgment in a court of law finds the entity to be in noncompliance.

2.1.1 Guidelines for Title II Entities

Sections 11 through 14 of the ADAAG apply to Title II entities. They were developed to cover such programs and services as judicial facilities, correctional facilities, accessible public housing, and public right-of-ways. Notices of Proposed Rule Making (NPRMs) were issued and comments were received. Interim final accessibility guidelines were issued with revisions in response to the initial comments. On the basis of further comments, Sections 11 and 12 were incorporated into the ADAAG as final guidelines, but have not yet been adopted into the regulations by the Department of Justice. Section 13 is held in reserve while further guidelines are developed. Section 14 is being held in reserve by the Access Board in favor of a campaign to focus on education and outreach regarding pedestrian facility design. All the guidelines will be reissued for public comment under NPRM before final rules are issued. Until then, Title II entities have the option of using ADAAG, the Uniform Federal Accessibility Standards (UFAS), or DOJ-certified equivalent standards as guidelines for new construction and alterations. The complete ADAAG is expected to be ready for public comment by July 2000.

2.1.2 Applicability to the Texas Department of Transportation (TxDOT)

As a state agency, TxDOT falls under Title II regulations applicable to state and local governments. Part B of Title II concerns transportation facilities for which TxDOT may have responsibility; these requirements will not be addressed here. Sidewalks are regarded as pedestrian facilities covered under Title II, Part A, and are addressed in some detail in the proposed Section 14 of the ADAAG pertaining to public right-of-ways.

In general, all facilities designed, constructed, or altered on behalf of or for the use of a public entity must be readily accessible and usable by individuals with disabilities, if the construction or alterations begin after January 26, 1992 (28 CFR 35.151). This means that the facility must be designed, constructed, or altered in strict compliance with a design standard that is certified by the DOJ as ADA equivalent, such as the existing UFAS (as long as it is applicable), or the ADAAG.

In addition to and apart from construction standards, Title II entities subject to Part A fall under the "program accessibility" requirement, which states: "A public entity may not deny the benefits of its programs, activities, and services to individuals with disabilities because its facilities are inaccessible." A public entity's services, programs, or activities, when viewed in their entirety, must be readily accessible to and usable by individuals with disabilities (28 CFR 35.149 - 35.150).

An important limitation of the program's accessibility requirement is that a public entity does not have to take any action that it can demonstrate would result in either (1) a fundamental alteration in the nature of its program or activity, or (2) an "undue burden," meaning undue financial or administrative burdens. This determination can be made only by the head of the public entity (or his or her designee) and must be accompanied by a written statement of the reasons for reaching that conclusion. The determination that undue burdens would result must be based on all resources available for use in the program. If an action would result in such an alteration or such burdens, the public entity must take any other action that would not result in such burdens, but would nevertheless ensure that individuals with disabilities receive the benefits and services of the program or activity. In the case of sidewalks, the benefit is that pedestrians have access to places that provide employment or services to the public. People with disabilities must also have access to these services and benefits. If the same sidewalk used by other pedestrians does not provide this access, then it must be provided by some other means.

2.1.3 Applicability to Sidewalks

As previously stated, Sections 1 through 10 of the ADAAG were adopted into the Title III regulations by the DOJ and carry the force of law. These guidelines contain specifications for pedestrian routes in general, including such sidewalk elements as running slope, landings, cross slope, width, overhead obstructions, and curb ramps. The adopted ADAAG (1994) currently addresses sidewalk slope in Section 4.3.7. In addition, changes in levels on an accessible route will apply and are addressed in Section 4.3.8. Specifications for curb ramps must also be considered in driveway crossings and are addressed in Section 4.7. The final ADAAG will contain guidelines for Title II entities that are consistent with guidelines for Title III entities, unless there is a compelling reason for them to be different; therefore, Title II entities should observe requirements in the Title III regulations, where applicable.

The proposed Section 14 of the ADAAG, concerning public right-of-ways, gives more detailed specifications and guidelines on continuous passage, sidewalks, and other accessible elements of the right-of-way (ROW). This section was issued as interim guidelines in 1994, but withdrawn and held in reserve for later proposed rulemaking. The Access Board received a large number of comments on the Section 14 guidelines from public works agencies, transportation departments, and traffic consultants. The comments showed a disparate understanding of pedestrian accessibility criteria in general, and the application of the ADAAG Section 14 provisions for new construction contained in the interim rule in particular. Based on the comments, the Access Board decided to reserve the guidelines in favor of working with other governmental and private sector organizations in the transportation industry to promote the incorporation of pedestrian accessibility criteria into industry guidelines, standards, and recommended practices (63 FR 2000, January 13, 1998).

The guidelines contained in Section 14 of the interim rule have been adopted by the State of Alabama and are being used to guide policies on pedestrian accessibility in California, New Jersey, and Florida. Several cities, including Portland, Oregon, and Seattle, Washington, have pedestrian-planning requirements that are substantially similar to those contained in the interim rule. In future rulemaking, the Access Board will review its education and outreach program and the impact of the regulatory efforts by states and localities in this area, and will consider publication of requirements for accessibility in public right-of-ways. Any significant information obtained by TxDOT as a result of this research project may be submitted for potential inclusion in final rulemaking.

2.2 UNIFORM FEDERAL ACCESSIBILITY STANDARDS

Title II entities may use either the Uniform Federal Accessibility Standards (UFAS) or ADAAG, until a final version of the ADAAG is issued and adopted into the regulations. Since the ADAAG will eventually become the single federal standard, it seems prudent to use the ADAAG exclusively. There are no significant differences between the UFAS and ADAAG that would make one preferable over the other, with the following exceptions:

(1) **Exemption from application of standards in new construction**

ADAAG contains a structural impracticability exception for new construction. Full compliance with the new construction standards is not required in the rare case where the terrain prevents compliance (28 CFR 35.151{4.1.1(5)(a)).

UFAS does not contain a structural impracticability exception (or any other exception) for new construction.

(2) **Exemption from application of standards in alterations**

ADAAG: For alterations, application of standards is not required where it would be “technically infeasible” (i.e., where application of the standards would involve removal of a load-bearing structural member or where existing physical or site restraints prevent compliance). Cost is not a factor (28 CFR 35.151{4.1.6(1)(j)).

UFAS: Application of standards is not required for alterations where “structurally impracticable,” i.e., where removal of a load-bearing structural member is involved or where the result would be an increased cost of 50 percent or more of the value of the element involved. Cost is a factor (USDOJ, 1992). (Note that the similar term, “structural impracticability,” is used in ADAAG, but in relation to new construction. In UFAS, it is used in relation to alterations and has a different meaning.)

In summary, the ADAAG allows for structural impracticability in new construction; the UFAS does not. The UFAS allows for a cost factor in making alterations accessible; the ADAAG does not.

2.3 TEXAS ACCESSIBILITY STANDARD

The Texas Accessibility Standard (TAS) is based on the ADAAG and has been certified for ADAAG equivalency by the Department of Justice. There are no differences between the TAS and the ADAAG involving public sidewalks. Using the TAS involves an administrative burden and added costs in plan reviews and project inspections. TxDOT has indicated it is attempting administrative removal of this requirement for TxDOT projects.

CHAPTER 3. STAKEHOLDER CONCERNS

Those primarily impacted by ADA sidewalk cross-slope requirements are divided here into four stakeholder groups: the Texas Department of Transportation (TxDOT), other similar agencies (e.g., cities and other state DOTs), people with disabilities, and property owners. The concerns of these stakeholders are discussed below. These discussions are meant primarily to present the various concerns, not to determine (or support) the impact of each concern relative to the problem at hand.

3.1 TEXAS DEPARTMENT OF TRANSPORTATION (TXDOT) CONCERNS

The ADA and the associated ADAAG make it clear that accessible sidewalks require limited cross sloping. It is TxDOT's desire and intent to be in compliance with the ADA when designing and constructing roadway projects that include pedestrian facilities. However, TxDOT has observed that when constructing sidewalks, variable terrain conditions, restricted right-of-ways (ROWs), city codes, and existing infrastructure often inhibit efforts to provide a cross slope of less than or equal to the required 2 percent at all points along an accessible route. TxDOT's primary area of concern is where a sidewalk crosses a driveway, given that maintaining the prescribed cross slope along an entire sidewalk that crosses numerous driveways, as is often found in urban areas, can be extremely difficult under some conditions (e.g., hilly terrain).

In general, TxDOT must consider the provision of accessible sidewalks from the point of view of all stakeholders. As such, TxDOT wants to design and construct sidewalks that are (1) consistent with the intent of the ADA, (2) responsive to individuals with disabilities, and (3) observant of various constraints. In specific, for locations that do not meet the prescribed cross-slope limits of the ADA, TxDOT wants the definition of accessibility needs described so that engineers can provide as high a level of accommodation as the specific project location practically allows.

Among several related cross-slope concerns, TxDOT believes that engineers are fearful of losing their licenses if their designs do not comply with the ADA, even if TxDOT's ADA Variance Committee grants a waiver. TxDOT is concerned with complying with the ADA, while Section 14 of the ADAAG, which speaks to public right-of-ways, has not yet been adopted into regulations by the Department of Justice and, therefore, does not carry the force of law. Many now want TxDOT to construct sidewalks along existing roadways that the cities had directed TxDOT not to build sidewalks on when the roadway was originally constructed. TxDOT thought that ADA changes were not required when a street was resurfaced. However, a victory by a plaintiff in a court case regarding this issue may indicate the opposite. TxDOT also has expressed uncertainty as to whether the entire width of the sidewalk — or just a 3-ft contiguous width — must meet the cross-slope requirement. Finally, since Texas is topographically diverse, some districts, such as Houston and Corpus Christi, naturally will have fewer problems than the more hilly districts, such as Austin and San Antonio.

TxDOT believes that sidewalk drainage may not be a significant issue, so cross slopes of 2, 0, or even -2 percent may be reasonable. Also, contractors seem to exert little control over sidewalk cross slope during construction, since it has not historically been a primary concern. It is believed that the main construction control is simply "eyeballing" the cross slope. Similarly, inspectors historically have not inspected sidewalk cross slope to the level of detail now implied by the ADA. Such inspection represents a significant change in routine. Without drainage as an issue, it appears that the construction and inspection concerns can be minimized (though they still remain) by designing to 0 percent (or flat) whenever feasible. In addition, the construction and inspection concerns justify the need for an acceptable *range* of cross slopes.

TxDOT has not seen any substantive, nonanecdotal evidence on which the 2 percent requirement might be based. It is possible that 2 percent was a negotiated settlement and may not need to be strictly observed to achieve the intent of the ADA. The latter is more probable if the requirement is relaxed only in isolated instances, such as driveway crossings with limiting terrain conditions, with the backing of scientific evidence to be provided by Phase II of this study. The savings gained by constructing cross slopes to meet the intent of the ADA, but not always the strict 2 percent requirement, may be used to enhance other features of an accessible pedestrian circulation network.

The above discussion highlights the fact that, to effectively consider the provision of accessible sidewalks, TxDOT must trade off the cost and feasibility of (always) meeting the 2 percent cross-slope requirement with the accessibility concerns of people with disabilities (and possible defense and liability costs). To do this, TxDOT desires a sidewalk cross-slope requirement that is based on scientific evidence. This is to be the primary result of any research conducted for this project. TxDOT's initial idea for this requirement was to determine a range of acceptable cross slopes from 0 to *X* percent; whether *X* is 2 percent or something greater should be based on scientific evidence. TxDOT also thinks the above concerns (most specifically, those related to driveway crossings) may justify a "gray area" bounded below by *X* and above by *Y*. Use of cross slopes in this gray area would be contingent on other factors, such as the cost and feasibility of meeting the *X* boundary, the length of the section, the traffic volume, the locations of alternate routes, and type of disability. Any research conducted during Phase II of this study will focus on establishing the *X* and *Y* bounds while identifying the factors that might justify designing to the gray-area boundaries, or establishing some similar system of meeting the intent of the ADA while remaining observant of the various constraints.

TxDOT has other ADA-related concerns (besides cross slope) pertaining to constructing and reconstructing sidewalks and other pedestrian facilities (e.g., trails), but does not want these concerns specifically addressed in this project. TxDOT also does not want any process-oriented solutions (e.g., participation by people with disabilities in the design/waiver process) considered in this project. Such concerns and potential solutions may be documented (listed), but not pursued in any detail.

3.2 OTHER SIMILAR AGENCIES

Other transportation agencies charged with constructing and operating roadways in the public right-of-way, such as cities and other state DOTs, are likely to have cross-slope concerns similar to those of TxDOT. In fact, Lois Thibault of the Architectural and Transportation Barriers Compliance Board (Access Board) stated (personal communication, January 1999) that cross slope was one of the most controversial portions of the Draft ADAAG Section 14 on Public Right-of-Ways.

To determine whether other agencies had similar concerns and, if they did, to identify how they had addressed them, we contacted 27 state DOT pedestrian coordinators (many of whom are also bicycle coordinators) via e-mail. (The Federal Highway Administration maintains a Webpage with the contact information for all state DOT pedestrian coordinators; of those listed, e-mail addresses were provided for 27.) It must be note that many state DOT pedestrian/bicycle coordinators are advocates for these "minority" modes. Their answers and comments should be considered with this in mind. Because of this focus, their ideas, conclusions, and experiences may differ from those of other DOT personnel within the same state. The message sent read as follows:

> **I am a member of a University of Texas research team that is helping the Texas Department of Transportation (TxDOT) enhance their accessible sidewalk program. TxDOT's primary concern is meeting the ADA requirement of no greater than a 2 percent sidewalk cross slope at driveway crossings.**
>
> **(1) Has your DOT had similar concerns?**
> **(2) If so, how have you addressed them? For example, has your DOT set up any guidelines for how to handle sidewalk-driveway crossings where various constraints inhibit efforts to meet the required 2 percent cross slope?**
> **(3) Are you aware of any hard scientific studies that support the 2 percent requirement?**
>
> **Thank you for your consideration and help.**

Fourteen of these e-mail messages never made it to their destinations because of incorrect addresses. Of the thirteen that apparently received the e-mail, six answered (Arizona, Florida, Iowa, New York, Oregon, and South Carolina). Iowa has "not really gotten involved in the pedestrian issues, yet." Of the others, none reported any remaining significant problems in meeting the 2 percent cross-slope requirement. Quotations taken from the e-mail responses to this effect include:

Oregon: "There is rarely an excuse to not provide the 3-ft, 2% passage at driveways."

Arizona: "We've almost uniformly stuck to the 2% side-slope standard with no complaints from driveway owners or the disabled."

New York: "We have used the 2% cross slope for years without too much difficulty, even in hilly terrain. It may require tinkering with both the sidewalk and the driveway profiles (and maybe even with the sidewalk width and alignment) to get it right in some difficult locations. However, it's a rare case (I can't think of one) where we can't get a 2% cross slope along an accessible route across a driveway."

South Carolina: "We fail to see any constraints to the 2% cross slope. Yes, it will cost more money and perhaps require getting encroachment permission to regrade some driveways, but nothing significant."

Florida: "You ask – '(1) Has your DOT had similar concerns?' Absolutely. After all, ADA is the law."

These comments must be considered with appropriate caution owing to both the potential advocacy focus (discussed above) and the biased survey response phenomenon.. In addition, there are organizational philosophy differences between each state DOT and different social cultures in each state that must be considered. In other words, reasonable and rational experts can disagree as a result of differences in the environment in which they are making their decisions.

Two respondents noted that additional costs are incurred to meet the required 2 percent. Several gave advice on where to go for technical drawings and guidance on providing the required 2 percent cross slope. These include the following:

(1) Florida DOT: Document set titled "Roadway and Traffic Design Standards"

(2) South Carolina DOT:
http://www.dot.state.sc.us/RoadDesign/pdf/standard/english/std720d.pdf
http://www.dot.state.sc.us/RoadDesign/pdf/standard/english/std720e.pdf

(3) New York DOT: The Access Board's proposed accessible-ROW design manual (Access Board, 1998), especially Section 3.3.3, titled "Cross slope"

(Note: Design-related methods are addressed in more detail in Section 5.2.)

We also believe that the City of Seattle, Washington, is a good agency to contact. Peter Lagerwey, Seattle's bicycle/pedestrian coordinator, is a nationally recognized leader in the bicycle and pedestrian transportation field.

3.3 PEOPLE WITH DISABILITIES

Obviously, people with disabilities have concerns related to sidewalk cross slope. These concerns contributed to the ADA cross-slope requirement in the first place. To discuss these concerns, it is important to consider people with different types of disabilities, including those who:

(1) have auditory impairments (including deafness),
(2) have visual impairments (including low vision and blindness),
(3) have gait or balance impairments,
(4) have ambulatory impairments that require walking aids, such as walkers, crutches, canes, and braces, and/or
(5) use wheelchairs (including a variety of motorized and nonmotorized designs).

No documentation of cross slope-related concerns was found for auditory and visually impaired pedestrians. However, it would seem that increased cross slope might increase the possibility that the visually impaired would be led off the sidewalk (in the direction of the cross slope) if a proper texture/color border is not provided to distinguish the sidewalk boundary and provide lateral orientation.

In a draft document, the Access Board (1998) states that “excessive cross slope is the single greatest barrier to travel along sidewalks and shared-use paths for pedestrians who use wheelchairs and scooters, pedestrians who use walkers and crutches, pedestrians who have braces or lower-limb prostheses, and those with gait, balance, and stamina impairments.” This statement seems a little strong. It seems that primary slope may be a much greater barrier to those with stamina impairments, that primary slope or pavement smoothness would be a greater barrier to manual wheelchair users, and that insufficient sidewalk width would represent a greater barrier to crutch users.

Sidewalk cross slopes can impact those with ambulatory impairments. Kathy Johnson (Access Board, 1997) states that (1) the chance for lower crutch slippage is increased and (2) turning is more difficult on nonlevel surfaces, the latter being of most importance at intersections with other sidewalks or walkways used to access buildings (possibly including driveways). Also, crutch users appear to be especially susceptible to cross slope when travelling downgrade (Access Board, 1998).

Dennis Cannon (Access Board, 1997) states that 50 percent more effort is required for a wheelchair user to traverse a 3 percent cross slope relative to a 2 percent cross slope, though he does not provide a reference for this statement. (It is important to note that it is not the relative effort that is of primary importance; it is the point at which the increased effort becomes “too much” over “some length” of travel that is most important. For example, if it were 50 percent more difficult to traverse a 3 percent cross slope [which research does not support], it still may be fairly easy.) Cannon goes on to point out that there is increased difficulty in traversing a cross slope in combination with a primary grade, such as that on a ramp, when using a wheelchair. He also points out that slipping is more apt to occur the greater the cross slope, especially under wet or icy conditions. Finally, he illustrates some of the differences in motorized and manual wheelchairs, though not specifically in the context of cross slope.

It is important to note that any wheelchair/crutch slippage or loss of balance will typically project the pedestrian towards the street, and it is reported that children with disabilities may be less able than adults to compensate for cross slope (Access Board, 1998). Also, driveway aprons constructed like ramps, with steep short side flares, may cause wheelchair, walker, and crutch users to tip or fall (Access Board, 1998).

Although no detailed discussions were found in the literature, many other factors in conjunction with cross slope may impact the perception of comfort and level of service (for people with disabilities) when traveling on a sidewalk. These other factors include:

(1) length of continuous sidewalk route sections exceeding 2 percent cross slope,
(2) proportion of entire sidewalk route exceeding 2 percent cross slope,
(3) adjacent automobile traffic volume and the separation distance from such traffic,
(4) sidewalk pavement condition (type, texture, state of repair, iced over or wet, etc.),
(5) primary sidewalk slope (note: downgrade and upgrade effects differ) (Axelson, 1998),
(6) weather,
(7) sidewalk width, and
(8) degree of accessibility of the entire route (including curb cuts, street crossings, etc.).

3.4 PROPERTY OWNERS

Property owners are concerned with access to their residences or businesses during roadway reconstruction. Their primary concerns, relative to modifying the sidewalk-driveway cross slope, probably include the degree of accessibility during the modification and the length of time that access will be limited, in addition to ROW or easement changes, and how changes in driveway slope might impact their customers. Examples of the latter would be if the modification makes the driveway uncomfortable to drivers or causes some cars to "bottom out." In addition, regardless of the fact that the sidewalk is in the public ROW, they probably should be concerned about potential negative publicity that would result should the sidewalk crossing their driveway access be involved in a lawsuit or other newsworthy controversy over access for people with disabilities. A final consideration is whether people with disabilities need to access property through the driveway or through a walkway adjacent to it. Because it was determined that identifying property owners' concerns in detail would have little bearing on TxDOT's decision to implement Phase II of this study, we interviewed no property owners and made little effort to identify such documentation in the literature.

3.5 CONCLUDING COMMENTS

Several sidewalk route elements are of concern relative to cross slope, including driveway crossings, street crossings, and curb ramps. However, driveway crossings seem to be the primary sidewalk section where the 2 percent ADA cross slope requirement is difficult to meet. TxDOT and other agencies must trade off the cost and feasibility of meeting this requirement in conjunction with meeting the needs of people with disabilities. Since driveway crossings are relatively short, it seems possible that people with disabilities could negotiate greater cross slopes over some driveway crossings that are difficult to construct below 2 percent. The constraining or "design disability" factor would seem to be the effort required (or comfort) of manual wheelchair users when traversing a cross sloped section. However, it is also possible that slippage (either crutch or wheelchair) could be the constraining factor in some situations. The design disability might differ for different routes if the latent/unobserved demand for the facility can be estimated in terms of people with different disabilities, or if the section is often wet or icy.

CHAPTER 4. BACKDROP TO ADA'S CROSS-SLOPE REQUIREMENT

In analyzing how TxDOT, as a public transportation agency, can meet the intent (or "spirit") of ADA's sidewalk cross-slope requirement, it is necessary to understand the environment in which the legislation was drafted and in which it is currently being enforced. Thus, this chapter presents the contextual background. First, the history behind the legislation and the subsequent accessibility guidelines (e.g., ADAAG) is explored with the goal of getting to the spirit of the legislation. Next, we review any published research or science either supporting or contradicting the 2 percent cross-slope requirement. Finally, relevant court decisions are discussed.

4.1 HISTORY

In drafting the Americans with Disabilities Act (ADA) in the late 1980s, Congress found that a significant proportion of Americans (an estimated 20 percent) have one or more physical or mental disabilities, and that this percentage increases as the population ages. Historically, society has tended to isolate and segregate individuals with disabilities, with such discrimination continuing to be a serious and pervasive social problem. Unlike individuals in other protected classes, individuals who experience discrimination on the basis of disability had no legal recourse to redress such discrimination (Section 2 Findings and Purposes. 42 USC 12101).

Census and other study data indicate that people with disabilities, as a group, are severely disadvantaged socially, vocationally, economically, and educationally. This group represents a discrete and insular minority occupying a powerless position in society as a result of stereotypical assumptions about the abilities of such individuals to participate in and contribute to society. Such discrimination denies people with disabilities the opportunity to pursue equal opportunity, full participation, independent living, and economic self-sufficiency; in addition, it costs the United States billions of dollars in expenses resulting from dependency and nonproductivity (Section 2 Findings and Purposes. 42 USC 12101).

The National Council on Disability (NCOD), an independent federal agency that reviews and makes recommendations concerning federal laws, programs, and policies affecting individuals with disabilities, originally developed the ADA legislation. In its 1986 study, "Toward Independence," the NCOD recognized the inadequacy of the existing, limited patchwork of protections for individuals with disabilities, and recommended the enactment of a comprehensive civil rights law for individuals with disabilities (NCOD, 1986). The legislation was first introduced in 1988. Although the Congress did not act on the legislation at that time, then-Vice-President George Bush endorsed the concept of comprehensive disability rights legislation during his presidential campaign and, as president, signed the Act into law on July 26, 1990.

Elements of the ADA were drawn principally from two key civil rights statutes — the Civil Rights Act of 1964 and Title V of the Rehabilitation Act of 1973. The ADA generally employs the framework of Titles II (42 USC 2000a to 2000a-6) and VII (42 USC 2000e to

2000e-16) of the Civil Rights Act of 1964 for coverage and enforcement and the terms and concepts of Section 504 of the Rehabilitation Act of 1973 (29 USC 794) for what constitutes discrimination.

Most programs and activities of state and local governments are recipients of financial assistance from one or more federal funding agencies. Therefore, they are already covered by Section 504 of the Rehabilitation Act of 1973, as amended, which prohibits discrimination on the basis of disability in federally assisted programs and activities. The ADA closely follows the provisions of existing Section 504 regulations, with major portions of the ADA regulations taken directly from the 504 regulations.

The ADAAG was primarily derived from the Uniform Federal Accessibility Standards (UFAS), which was published in 1984. The intent of the UFAS was to present uniform standards in accordance with the Architectural Barriers Act, minimizing the differences between the standards previously in use by four agencies covered by the act (the General Services Administration, Housing and Urban Development, the Department of Defense, and the U.S. Postal Service). Congress established the Architectural and Transportation Barriers Compliance Board (ATBCB), which is now the Access Board, to ensure compliance with the standards by issuing minimum guidelines and requirements.

The four standard-setting agencies determined that the standards adopted by the ATBCB should be consistent with the standards published by the American National Standards Institute (ANSI) for general use. ANSI is a nongovernmental national organization that publishes a wide variety of recommended standards. The ANSI standards for barrier-free design were developed by a committee that included representatives from 52 organizations, such as associations representing people with disabilities, rehabilitation professionals, design professionals, builders, and manufacturers. The standards, which were called ANSI A117.1, "Specifications for Making Buildings and Facilities Accessible to, and Usable by, Physically Handicapped People," were developed using a consensus process (rather than using scientific research exclusively). The original ASNI A117.1 was adopted in 1961. The current edition, ANSI A117.1 – 1980, is also somewhat based on research funded by the Office of Housing and Urban Development (HUD, 1979). This edition has generally been accepted by the private sector and has been recommended for use in model state and local building codes by the Council of American Building Officials (UFAS, 1988).

Anecdotal comments from several ADA "experts" were inconsistent with respect to the precise origin of the 2 percent sidewalk cross-slope requirement. Some said it was based on scientific research, others said it was not. One remembered something about a HUD study, another thought that a Veterans Administration study had some say in it. One said that it probably arose from a combination of prior guidelines, such as architectural building guidelines and roadway/sidewalk drainage guidelines. Another said it was most likely a negotiated settlement, as are many of the individual requirements of the ADA, with perhaps some original basis in science and prior guidelines. The latter opinion seems to be the most likely, as it incorporates all the other comments into one plausible theory. No matter how it got there, one question still remains: Is there any research and science to back it up? This is explored in the next section.

4.2 RESEARCH AND SCIENCE

This report reviews prior research into the science that deals with perception of effort by people with disabilities when traversing cross-sloped sections. Much of this work is found in the medical rehabilitation research literature. Such studies usually are designed to explore the control and design of wheelchairs, not the perceptions of users while traveling on sidewalks. Therefore, these studies are only partially applicable to the problem at hand. In addition, there are few articles that directly study the effects of cross slope. Most focus on the directional stability of wheelchairs.

That no studies were found pertaining to the effects of cross slope on people who use other walking aids, such as crutches and walkers, supports the assumption that manual-wheelchair users will most often be the design population. The relative ease of "propelling a wheelchair with handrims is dependent on several factors, namely, the weight, physical dimensions, and materials of the wheelchair, the physical dimensions and capacities of the user, the compatibility of wheelchair and user dimensions, and such external factors as the texture, hardness, and slope of the surface on which the wheelchair is operated" (Brubaker et al., 1986). As stated earlier, because traveling on a sidewalk is the focus of this study, other external factors may also be quite significant, such as the length and frequency of driveway crossings and the volume of adjacent auto traffic. No studies exploring these factors appear to exist.

Papers that are in some way applicable to the sidewalk cross-slope problem are reviewed here first. Next, papers of ancillary applicability, such as those dealing only with primary slope, those dealing with estimating demand, or those that may be of help with an experimental design, are reviewed. Finally, papers of only minor applicability, such as those that deal with wheelchair dynamics, are reviewed.

4.2.1 Directly Applicable Studies

There is not nearly enough scientific evidence to either support or oppose the 2 percent sidewalk cross-slope requirement. The preliminary conclusion from the reviewed works is that a 2 percent cross slope is acceptable from the perspective of the wheelchair user, but a higher slope also may be acceptable. The studies show, as expected, that the propulsion (in terms of force), the net energy cost, and the work per meter on a 2 percent cross slope is greater than that required for a level surface. However, one study suggests that the difference in wheelchair-user effort between traversing cross slopes in the range of 2 percent to 5 percent may not be very large (about 20 percent), and that this effort may only double when increased from 2 percent to about 16 percent (Chesney and Axelson, 1996). However, no study attempted to find the cross slope at which wheelchair-user effort becomes "too high" when traversing a cross-sloped section. Besides this, all studies have major weaknesses that prevent one from drawing strong inferences relative to the design of sidewalk cross slopes for people with disabilities. These weaknesses include small sample sizes, lack of diversity in the samples, lack of realism in experimental design relative to traversing actual sidewalks, and lack of consideration of other factors that might impact perception (e.g., length of traversed section, adjacent traffic volume).

The most applicable study is that provided by Chesney and Axelson (1996), who focused on developing a method to objectively measure the effort of wheelchair users on a variety of surfaces. Perhaps most important is their conclusion that the work required to negotiate a specific ramp angle may be viable as a pass/fail criterion for short-distance wheelchair travel. This might include the short distance required to traverse a driveway.

However, 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. Broadly interpreting their ideas, one could consider developing a *performance measure* for sidewalk accessibility by first dividing a route into various sections, with the boundaries defined by cross-slope and main-grade changes. Multiplying the length of distinct sidewalk sections by their respective work-per-meter value, summing over all sections on a route, and then normalizing to a work-per-mile value could be a very effective accessibility performance measure. Such a measure explicitly considers driveway crossings that have cross slopes in excess of 2 percent. The measure could be compared to a threshold or "break point" criterion obtained by survey and experimentation on a sample of wheelchair users selected to reflect the general population and used in conjunction with short-distance bounds for individual driveway crossings. This methodology should be considered for use in Phase II of this study, with the research targeted to (1) finding the appropriate work-per-meter values for various sidewalk designs used by TxDOT, and (2) finding the appropriate pass/fail criteria by experimentation.

Also of note is Chesney and Axelson's use of the SMART^{wheel} to measure pushrim forces. This equipment can be useful as a supplement to oxygen-uptake and heart-rate monitors in measuring effort. Measurements were taken on an adjustable plywood ramp set at different grades, cross slopes, and grade/cross-slope combinations. Comparisons between the measurements made on level surfaces and on various ramp angles demonstrate the feasibility of using the work-per-meter value for a specific ramp grade as a pass/fail performance criterion for short distances of accessible surfaces. One primary weakness of the study, with respect to TxDOT's problem, is the lack of diversity in wheelchair user/chair interactive dynamics: Only one 166 lb test subject and one wheelchair were used. Another weakness is that the test surface was plywood, not sidewalk paving material. Rolling resistances are typically 1.5 times greater on concrete relative to treadmills (Brubaker, 1986), and treadmills probably have a surface whose smoothness more closely approximates that of plywood than it does that of concrete. In addition, the studies by Chesney and Axelson, among others, were conducted exclusively in laboratory settings, leaving experimentation in actual sidewalk environments unexamined. Thus, there is a significant and clear need to go beyond the lab environment — to actual sidewalks and pathways — in order to obtain a realistic measure of actual effort on typical TxDOT and local pedestrian facilities.

One interesting result of the Chesney and Axelson (1996) study is that the work-per-meter value on a 2 percent primary grade does not change immensely for different cross slopes, as shown in Table 4.1. This is in clear contrast to Cannon's remark (Access Board, 1997)[1] and supports the possibility that a cross-slope range wider than 0 to 2 percent might be acceptable by wheelchair users when traversing short distances. However, the researchers make no explicit attempt to assess a user "break point" or threshold for distances similar to driveway crossing widths, except to suggest using the work-per-meter for some (undetermined) primary ramp slope as the "break point."

Table 4.1 Average work-per-meter required to propel a wheelchair across a plywood ramp (Chesney and Axelson, 1996)

Grade	Cross Slope	Average Work per Meter (newton meters)	Standard Deviation (newton meters)
2%	0%	26.32	1.39
8%	0%	71.48	1.43
2%	2%	31.54	0.48
2%	3%	33.81	0.41
2%	5%	37.91	0.50
2%	8%	45.25	0.77
2%	12%	55.46	0.95
2%	14%	58.76	0.61
2%	16%	62.23	1.88
2%	20%	75.04	3.08

At a primary ramp slope of 8 percent (the ADA maximum is 8.33 percent), the "break point" would be at about 70 newton meters. This suggests a maximum bound in the neighborhood of 16 to 20 percent. However, ramp slopes are of a much shorter duration than driveway crossings, so this "break point" would probably be lower. In addition, their research does not address whether this bound is suitable for the general population of interest. Nor do they assess differences in user perceptions of sidewalk cross slope, especially variances in perception across the population and across sidewalk environments. Finally, the study does not investigate a 0 percent grade with different cross slopes. Nonetheless, our research team has had some preliminary discussions with the researchers of that study: In an effort to strengthen our experimental design and sampling strategies, we will coordinate our Phase II efforts with any related research they might be conducting.

In a related area of work, Brubaker et al. (1986) attempt to identify and quantify several factors affecting directional stability of manual wheelchairs on uneven and 2-degree (3.5 percent) cross-sloped surfaces. They state that, even though a major national report has identified cross slope as the *most* significant problem in wheelchair mobility, this point is debatable. However, they also state that most users and experts in the field would likely agree that it is a problem of significance and that very little has been accomplished beyond identifying this as a problem.

[1] Cannon states that 50 percent more effort is required for a wheelchair user to traverse a 3 percent cross slope relative to a 2 percent cross slope (see Chapter 3) (Access Board, 1997).

Brubaker et al. test the drag and propulsion for a standard and a sport wheelchair using one athletic young male paraplegic on a motorized treadmill, not on sidewalk paving material. They measure the subject's oxygen consumption, heart rate, and stroke rate. Their findings indicate that the compensation for the downhill turning moment of a wheelchair on a 2-degree (3.5 percent) cross slope results in a retarding force approximately equal to the rolling drag of a wheelchair on a level surface. The total drag *force* on the wheelchair is, therefore, roughly double the rolling drag. They establish this both experimentally and by using a static analysis.

However, they estimate that the net *energy* cost (oxygen consumption) of propulsion on a 2-degree (3.5 percent) cross slope to be only 30 percent greater than that for a level surface. (This is in general agreement with Chesney and Axelson's [1996] results, which indicate a 28 percent work increase between 0 and 3 percent cross slopes [on a primary grade of 2 percent].) The mechanical efficiency (defined as the ratio of power required to energy cost) of propulsion on the slope is higher than that on the level surface. They attribute this to the "more favorable conditions with respect to the force-velocity relationship of the muscles" and also to the fact that only one arm is used for propulsion, meaning only one arm is active in the recovery phase that uses energy, but does not produce any work. However, as expected, the efficiency of travel on the slope is less efficient, based on the ratio of net oxygen consumption to distance traveled.

They do not explore cross slopes greater than 2 degrees (3.5 percent) or how a variety of users would perceive this increased effort in actual sidewalk travel environments. Therefore, one cannot draw from their results very strong inferences regarding the design of sidewalk-driveway crossings.

In a different paper, Brubaker (1986) analyzes factors that impact wheelchair mobility and performance. He states that "the nearly ubiquitous cross slope of improved outdoor surfaces produces a downhill turning tendency." As shown by Brubaker et al. (1986), this downhill turning tendency causes the total drag force to roughly double for a 2-degree (3.5 percent) cross slope relative to a level surface. Brubaker (1986) concludes that "minimization of downhill turning tendency is most effectively and practically achieved by moving the center of mass toward the main wheel axis."

Cooper (1989) investigates the directional stability of racing wheelchairs on crown roads and concludes that crown compensation mechanisms appear to solve most of the directional instability problems induced by roadway crowns. He derives the equations necessary to specify the minimum spring force required to compensate for the downhill turning moment and compares these to the actual preset forces for various compensators. The force required for maintaining directional stability is found to be less than that needed to deflect the crown compensator. This study used an extremely small (nondiverse) sample (three athletes), which the author notes is a common problem in rehabilitation research. The wheelchairs used are of a racing design that is probably not common in sidewalk travel. Most importantly, the study does not address the range of cross slopes that ordinary wheelchair users might find acceptable for short distances at sidewalk-driveway crossings, unless one wants to make some (strong) assumptions regarding possible future wheelchair technology improvements.

4.2.2 Studies of Ancillary Applicability

Many have studied the static and dynamic stability of wheelchairs on various ramp grades. These studies support an upper bound on wheelchair-accessible primary ramp slope of 5 to almost 13 percent, and the static stability of wheelchairs seems to be maintained in situations with larger than 10 percent forward and backward slope. Also supported is the fact that sideways static stability of wheelchairs can be achieved on at least a 5-degree (8.7 percent) cross slope. There is also some research on the demand for transportation of people with ambulatory impairments.

Researchers at Syracuse University have studied maximum primary ramp slopes and the relationship between cross slope and length using a plywood ramp surface in a laboratory environment (HUD, 1979). In this work they measure heart rate to assess overexertion. If an excessive amount of time is needed, or if after a 2-minute rest following the trial the user's heart rate has not returned to within 10 beats of the resting rate, the ramp negotiation is termed "unsuccessful." Almost half the wheelchair users did not successfully negotiate a 40-ft ramp sloped at 8.33 percent. About one-third did not complete even 5 ft. Of those unable to manage the 8.33 percent cross slope, 67 percent were able to travel at least 30 ft on a 6.25 percent cross slope. All wheelchair users completed the full 40-ft length of a ramp sloped at 5 percent.

Sanford et al. (1996) studied 171 subjects of all ages using different types of mobility aids as they traversed a 30-ft ramp whose cross slope varied from 5 percent to 12.5 percent. Pulse rate, energy expenditure, speed, distance traveled, and resting locations were recorded. Of all the subjects, only a few manual wheelchair users had difficulty traversing the 30-ft ascent.

Canale et al. (1991) tested the criteria for ramp construction for wheelchair users using a sample of 140 individuals having different levels of impairment. They concluded 15 percent to be the maximum allowable cross slope for a 1-meter ramp and 10 percent to be the maximum for a 3-meter ramp.

Kirby et al. (1992) tested the static and dynamic forward stability of occupied wheelchairs by using a down ramp and a 5-cm obstruction. No cross-slope stability tests were considered. Gaal et al. (1996) conducted a similar test and neglected any cross-slope effects. Kirby et al. (1996) examined the rear stability of occupied wheelchairs, using a positively tilted platform. No consideration of cross slope was made.

Guerette et al. (1995) pointed out that current standards for ramp slope and length generally have been established based on performance of young, strong, male wheelchair users, and that evidence suggests that current standards may not be appropriate for a wide range of older users and users having severe functional limitations. They conducted a literature review of previous ramp evaluations and government standards to examine recommended ramp specifications, previous populations evaluated, and methodologies used to evaluate ramp performance. Their paper does not provide any evidence regarding cross slopes.

Via a survey, Linden et al. (1996) asked individuals with disabilities to report their travel modes and frequencies, as well as provide information on fatigue, seat belt use, driving frequency, and accident rates. Half of the 87 respondents regularly used a manual wheelchair during transportation, while 29 percent used power wheelchairs, 15 percent used scooters, and 7 percent used another type of mobility aid. (Note: Only 1.5 percent of their 5,000 mail surveys were answered and returned.)

Kirby et al. (1994) reported that 57.4 percent of their 577 respondents had completely tipped or fallen from their wheelchairs at least once. Of these, 24.2 percent were in the sideways direction. Results also indicated that 16 percent of such accidents were serious (i.e., resulting in fractures) and many of these accidents occurred outdoors or on ramps.

4.2.3 Studies of Only Minor Applicability

Finally, there are other, less applicable studies that may provide additional ideas for designing and conducting the experimental research in Phase II of this study. These studies include the following:

(1) Cappozzo et al. (1991) sought a reliable prediction of length and grade limits for ramps that can be traversed by any special category of wheelchair-dependent individuals by measuring the maximal voluntary force.

(2) Lawrence et al. (1996) considered wheelchair ride comfort via subjective response by wheelchair users.

(3) O'Connor et al. (1996) studied three-dimensional kinematic variables of racing wheelchair propulsion to improve the efficiency of racing wheelchairs.

(4) Brubaker et al. (1984) estimate wheelchair propulsion efficiency for various combinations of speed and technology. They found that wheelchair-use efficiency was higher over 1-degree (1.7 percent) and 2-degree (3.5 percent) slopes than over a level section.

(5) Woude et al. (1988) studied how changes in grade and speed impact mechanical efficiency and effort. They found that a low-speed/high-slope combination is more efficient than the reverse (for the same energy input). They used several cardio-respiratory measures, including gross mechanical efficiency, ventilation, oxygen consumption, and heart rate.

4.3 COURT DECISIONS

In this section, court cases with some relevance to the ADA sidewalk cross-slope problem are briefly reviewed. No cases were found that relate directly to sidewalk cross slope. However, there is one case that directly relates to sidewalk accessibility, and certain other cases provide some guidance in relation to the "program accessibility" requirements for Title II entities.

In a case involving sidewalk accessibility, the court held that Title II of the ADA requires the City of Philadelphia to install curb ramps when it resurfaces any street on which a resurfacing contract bid was let. Rejecting the city's "undue burden" defense, the appeals court said that resurfacing a street is an "alteration" within the meaning of the rules implementing Title II, thereby triggering the city's responsibilities to install curb ramps (*Kinney v. Yerusalim* [CA 3 1993], cert. Denied; *Hoskins v. Kinney*, No. 93-1439 [US SupCt 4/18/94]). This case reaffirms existing language in the ADAAG, as "resurfacing" is mentioned as triggering alteration requirements. It also points out the high standard for "undue burden." The implications of this ruling on other aspects of sidewalk accessibility, such as cross slope, are unclear. Recent draft guidance states "agencies should plan to incorporate curb ramps on all resurfacing projects where pedestrian routes exist," but says nothing about other sidewalk route elements (Access Board, 1998). It also states that "only surface projects of limited scope, such as spot patching, thincoat sealing, reseating of disturbed curbing, restriping of existing markings in place, and similar efforts would be exempted as maintenance" (Access Board, 1998).

Two cases involve the "program accessibility" requirement to provide services "in the most integrated setting possible." In one, the court held that the Pennsylvania Department of Public Welfare must provide home attendant care services to a woman who uses a wheelchair and who qualifies for the state's home attendant care program (the agency was requiring that the woman remain in a nursing home). The court said the state agency violated the ADA by denying the woman the opportunity to receive state services "in the most integrated setting possible," as required by the Justice Department regulations implementing Title II (*Helen L. v. DiDario* [CA 3 1995]).

In the other case, the court held that Georgia state mental health officials violated Title II of the ADA by continuing to institutionalize two mentally retarded individuals in a state mental hospital instead of providing community-based treatment. The court held that unnecessary institutional segregation of people with disabilities "constitutes discrimination per se, which cannot be justified by a lack of funding" (*L.C. v. Olmstead,* No. 1:95-CV-1210-MHS [DC NGa 3/26/97]). This case also points to the high standard for "undue burden" by refusing to acknowledge lack of funding as a justification for segregation.

In the third case affecting "program accessibility," a federal district court found in favor of the City of Johnson City, Tennessee, saying that the city is not liable under Title II of the ADA, even though its transition plan was almost 2 years late, since its services "when viewed in their entirety," were made accessible to the plaintiff, a wheelchair user, "as expeditiously as possible." Although the transition plan was "inadequate in many ways," the court said the plaintiff was not unlawfully excluded from participation in city services (*Miller v. City of Johnson City, Tenn*. [DC ETenn 1996]). This decision makes a case for "good faith effort" on the part of public entities to make their programs and services accessible.

4.4 CONCLUDING COMMENTS

The ADA represents powerful legislation that attempts to prevent discrimination and prejudice from denying people with disabilities the opportunity to pursue equal opportunity, full participation, independent living, and economic self-sufficiency. The exact history of the 2 percent sidewalk cross-slope requirement was not ascertained, and no research and science supporting a unilateral 2 percent requirement was found. For short distances, such as those for crossing driveways, a reliable upper bound could not be determined from the research.

One study, conducted using plywood ramps, can be interpreted to indicate a maximum "short-distance" cross-slope upper bound in the neighborhood of 16 to 20 percent (Chesney and Axelson, 1996). This supports the idea that the ADA's 2 percent limit might be too strict for relatively infrequent short-distance sidewalk sections, such as driveway crossings, when considered in combination with the various constraints. However, the actual short-distance upper bound suitable for the general population of interest probably will be significantly less than 20 percent, since there are anecdotal opinions, substantive reasons, and other preliminary research indications that point to a lower bound. Further research is required to determine such bounds and to identify under what conditions they would apply (e.g., the maximum length of an individual section). In addition, a route performance measure was suggested for use in conjunction with the short-distance bound.

Finally, the ADA court rulings indicate that there is a high standard for "undue burden" exemptions from ADA, but "good faith effort" by public agencies has been used successfully as a defense. It seems that conducting research to determine maximum bounds on cross slopes for various situations and users could be considered a "good faith effort."

CHAPTER 5. METHODS FOR MEETING THE INTENT OF ADA

In this chapter, two primary methods for meeting the intent of the ADA with respect to sidewalk cross slope at driveway crossings are reviewed. The first is a programmatic method that relies on various caveats in existing and proposed ADA regulations and guidelines that define conditions and constraints under which the strict 2 percent requirement does not have to be met. The second consists of a group of design-related methods that have been developed by various agencies to meet the 2 percent cross-slope requirement at driveway crossings. Finally, a short discussion directed towards satisfying the concerns of property owners, contractors, and public agency inspectors is given.

5.1 PROGRAMMATIC METHOD

The key requirement of the ADA relative to pathway cross slope is that a 36-inch width must be provided at no more than a 2 percent cross slope in order to be considered part of a pedestrian circulation network for people with disabilities. This includes the sidewalk, curb ramps, driveway crossings, street crossings, locations where two sidewalks meet, etc. There are several caveats included in the legislation that allow public agencies some leeway in this requirement. These will be discussed in the following subsections. It should be made clear that this section does not constitute legal advice, but is more aptly termed "suggestions and ideas" for agencies to consider in their efforts to meet the spirit and intent of the ADA.

5.1.1 Continuous Passage/Pedestrian Circulation Network (Program Accessibility)

The proposed Section 14 of the ADAAG recognizes that modifications and specific requirements respond to the unique nature and function of public right-of-ways (ROWs). For example, natural terrain, constrained width, the number and complexity of services that must be accommodated within and along the ROW, and the demands of adjacent development may offer little opportunity for the creation of accessible routes as required by Title III guidelines. Section 14 is based on the concept of a *continuous passage* to connect public sidewalks, curb ramps, and street crossings into a pedestrian network that serves both adjacent sites and elements intended for pedestrian use on and along the public sidewalk (36 CFR Part 1191). *Continuous passage* is analogous to the *program accessibility* requirement for Title II entities. The TxDOT program or service in question is pedestrian access in the public ROW; continuous passage constitutes accessibility to this program or service.

In Section 14, continuous passage is defined as "…a continuous unobstructed pedestrian circulation path within a public sidewalk connecting pedestrian areas, elements, and facilities in the public right-of-way to accessible routes on adjacent sites. A continuous passage is provided in lieu of an accessible route in a public right-of-way." An *accessible route* is an unobstructed path connecting all accessible elements of a building or facility. Although public sidewalks are subject to technical provisions similar to those that apply to accessible routes, public sidewalks are not required to meet guidelines for accessible routes unless the public sidewalk is used to provide the required accessible route connecting accessible elements on a site.

The ADA does not require construction of sidewalks where none previously existed, unless other work of a significant enough nature is being done to the adjacent street (e.g., reconstruction). Comments received in response to the Notice of Proposed Rule Making (NPRM) indicated a belief that "continuous passage" required the construction of new sidewalks in order to connect other accessible sidewalk segments. The response by the Access Board was that the ADAAG does not require construction of new public sidewalks. New public sidewalk construction is typically initiated at the local level, by individual or neighborhood request, or as part of a public improvement project (including street modification and reconstruction projects). If no such project is underway at any given location, new sidewalk construction is not required. However, under the program accessibility requirement of Title II, construction of a pedestrian walkway where none existed previously may be necessary to ensure that individuals with disabilities have access to a particular state or local program, such as a school (USDOJ, 1996).

To conclude, it is the intent of the ADA that, in the long term, all addresses that provide services to the public (e.g., businesses, places of employment, government agencies) along a public street should be made accessible to people with disabilities via a continuous unobstructed pedestrian circulation network (i.e., continuous passage). Therefore, almost all streets, with the exception of rural roads and highways, will (when altered) need to provide an accessible sidewalk wherever feasible. A major question is how direct must the path be from any point A to any point B in the network. In the law (for alterations), these paths must be direct to the "maximum extent feasible." Whenever a street alteration is performed and some sections of the sidewalk are not made accessible, TxDOT should document its evaluation of how it determined that access to all addresses on the altered street section were made as direct as possible. Such documentation would help immensely should that street's accessibility ever be challenged.

5.1.2 Site Infeasibility

Site infeasibility relates to "structural impracticability" owing to unique characteristics of terrain as defined in the adopted Title III regulations concerning accessibility. As public sidewalks are permitted to take the running slope of adjacent roadways without invoking an exception, steeply sloping terrain is not in itself grounds for a finding of site infeasibility.[2] Adjacent development and constrained ROW width give rise to

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[2] "Site infeasibility is intended to be the basis for exceptions to new construction guidelines for additions and alterations in the public right-of-way. This definition has been clarified by substituting the phrase 'site development conditions' for 'physical or site constraints' in the MPRM. Extremes of terrain are recognized in both new construction and alterations provisions by permitting public sidewalks to take the running slope of adjacent roadways without invoking an exception. Thus, steeply sloping terrain is not in itself grounds for a finding of site infeasibility. Rather, it is adjacent development and constrained right-of-way width that give rise to exceptions for site infeasibility. Where newly constructed bridges and tunnels are intended to carry pedestrian traffic, they must incorporate public sidewalks that meet Section 14 provisions. This is further

exceptions for site infeasibility. A site infeasibility exception for cross slope is allowed under ADAAG Section A14.3, where minimum cross slope may be exceeded owing to differences in grade from curb to building entrances at the back of a sidewalk. This is the only actual stated exception to meeting minimum cross-slope requirements.

Where site infeasibility precludes full compliance with provisions for new construction, public entities must provide accessibility to the maximum extent feasible, regardless of the accessibility of adjacent areas or other features. If site infeasibility precludes meeting the minimum requirements for cross slope, requirements must still be met for width, surface, separation, etc., if feasible.

The initial proposed rule allowed exceptions in new construction for site infeasibility. Based on comments received, the interim final rule made a greater distinction between the requirements for new construction and alterations. *New construction* generally means a newly planned town, subdivision, street, or roadway where none existed before. A high degree of accessibility is required for new construction and there are no exceptions for site infeasibility. Strong uniform accessibility requirements have been provided, with few exceptions allowed. Most persons commenting on the rules felt that cross-slope requirements could be met in new construction.

Most of the construction in the ROW will be considered *alterations* as addressed in ADAAG Section 14.3. Alterations must meet the requirements for new construction when feasible; there are exceptions for site infeasibility and disproportionate cost. The guidelines recognize that minimum cross-slope requirements cannot be met in every alteration. Entities making alterations will be able to craft an alternative that best fits existing conditions. Consistent with the adopted ADAAG 4.1.6 (Accessible Buildings: Alterations), alterations in the ROW must meet the following requirements: (1) reductions in the accessibility of existing pedestrian facilities are prohibited; (2) full accessibility to public sidewalks, curb ramps, and pedestrian street crossings within a project area is required if a series of small alterations has the overall effect of a reconstruction; and (3) alteration projects involving public sidewalks, curb ramps, and street crossings must include alterations necessary to connect to adjacent portions of the continuous passage, to the extent these are not disproportionate in cost and scope.

5.1.2.1 Disproportionate Cost. The disproportionate cost requirement is based upon ADAAG 4.1.6(2) (Alterations to an Area Containing a Primary Function), which requires that alterations affecting usability of or access to an area of primary function be made readily accessible to and usable by individuals with disabilities to the maximum extent feasible. If the connections to other accessible elements in the pedestrian network cost more than 20 percent of the cost of the actual alteration (for instance, the addition of a curb ramp), the cost is disproportionate and a lesser standard can be allowed. The 20 percent requirement is only a guideline and does not have the force of law, as a final determination of disproportionate cost has not been made by the U.S. Attorney General. The disproportionate cost requirement will

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discussed at ADAAG 14.1.5 (4)." This proposed ADAAG Section 14 was withdrawn and reissued as a technical assistance manual. The actual guidelines are currently under review again for reissue.

affect design elements such as the "warping" and "blending" required to meet minimum cross slope where sidewalks cross driveways.

5.1.2.2 Performance Standards vs. Specific Requirements. Some comments on the proposed rule, including comments from the Institute of Traffic Engineers, suggested that a set of fixed requirements could not be applied or enforced under the variety of site constraints commonly encountered along the ROW. Instead, they advocated a performance standard that would allow more flexibility in responding to local conditions. A performance standard generally describes a desired goal for new construction (such as accessible continuous passage), but does not prescribe a methodology. The Access Board concedes that a performance standard might be useful in ADAAG Section 14, but that a detailed specification will be useful to agencies evaluating alternatives, particularly where site constraints may appear to limit options. The Board also feels that it will be more difficult to determine compliance with a performance standard. If a suitable performance standard for accessible continuous passage can be developed as a result of this research project, it may be submitted to the Access Board for inclusion in proposed rule making.

5.1.2.3 Summary. The Access Board, in developing proposed guidelines, recognizes that there are instances where alterations cannot meet new construction specifications. While trying to state that alternative ways of providing access are acceptable under the law, the proposed guidelines do not clearly state specific alternatives that will satisfy the legal requirements of equal access. This is in part why the proposed guidelines were withdrawn. The concept of "continuous passage" meets the spirit of the law, but is a nebulous term when dealing with specific issues such as sidewalk cross slope. Such generalized goals require well-researched and well-documented decisions on the part of designated TxDOT officials.

5.1.3 Community Outreach

There is no requirement that the continuous passage be designated or marked, but entities may do so if desired. If there are many instances where cross slope has been exceeded, some public outreach may be desirable, employing methods such as those suggested here.

First, the public agency may designate a pedestrian coordinator to coordinate with local entities' pedestrian coordinators where available, or with equivalent personnel, or with the district engineer if no equivalent person is available within the local government. This pedestrian coordinator can be responsible for determining that continuous passage exists within the local pedestrian circulation network. This may be delegated to the current TxDOT Variance Committee, who would not only determine where variances are necessary, but would also determine alternatives to meet the requirement for continuous passage.

Another suggestion is to publish pedestrian circulation network maps for people with disabilities, with information on whom to contact if there is a problem. Agencies could also consider installing signage to denote the pedestrian circulation network and notifying pedestrians of potential hazards or difficulties in the continuous passage, such as extreme or frequent driveway cross-slope problems. Notification of potential hazard signs might also direct the pedestrian to the nearest alternative route that is accessible (Axelson et al., 1998). In the longer term, an application of ITS technology to pedestrian facilities might also be considered; such technology could include computer information kiosks or pedestrian circulation network maps on Webpages. These applications could provide pedestrian circulation network information in sufficient detail to meet the needs of a large variety of people with differing disabilities. A sidewalk assessment process has been developed to obtain objective access information about sidewalks to use in developing signs, maps, and other community outreach information (Axelson et al., 1998).

5.1.4 Equivalent Facilitation

The adopted ADAAG Section 2.2 allows for “Equivalent Facilitation.” It states that “departures from particular technical and scoping requirements of this guideline by the use of other designs and technologies are permitted where the alternative designs and technologies used will provide substantially equivalent or greater access to and usability of the facility.” The appendix gives the example of equivalent facilitation provided for elevators in the Alterations Section 4.1.6 (3)(c). For example, if technical infeasibility prohibits compliance with minimum elevator-car plan dimensions for new construction, a smaller absolute minimum is provided. Different dimensions may also be provided when usability can be demonstrated.

This is relevant to TxDOT’s desire to establish a range of accessible sidewalk cross slopes. It seems that such a range would be acceptable as an equivalent facilitation in alterations if “usability can be demonstrated.” This provides good reason for further research into the “usability” of sidewalks with different cross slopes. Any equivalent facilitation that research can show to be “usable” could then be submitted for inclusion in the final guidelines.

5.1.5 Requirement to Purchase Greater Right-of-Way

Right-of-way (ROW) requirements are also differentiated between new construction and alterations. The appendix to the proposed ADAAG (1994) Section 14 (A14.2) states that when undeveloped land is incorporated for new construction and new right-of-ways are established, sufficient width should be allotted to comply with minimum requirements for new construction. Further guidance in the appendix encourages state and local governments to acquire sufficient ROW, but states that “jurisdictions are not required to provide a greater right-of-way width than would otherwise be planned under regulations, guidelines, or practices normally applied to new development. Right-of-way width may be based on zoning, land use, pedestrian volume or population densities, transportation master plans, or similar factors. Since these guidelines prohibit decreasing the accessibility of the public pedestrian network, jurisdictions should anticipate the need for future roadway widenings by establishing an initial right-of-way that can accommodate future growth and development” (ADAAG, 1994).

This anticipation of future ROW needs should also take into account the need to plan for future sidewalks. For instance, if TxDOT is constructing, reconstructing, or altering a roadway in a municipality's jurisdiction, and the municipality states that they do not want sidewalks constructed at that time, TxDOT has a potential responsibility to plan for future sidewalk needs in the ROW. This may involve universal design methodologies for driveway aprons in the ROW so that when sidewalks are later constructed, the driveways already meet guidelines and do not have to be reconstructed. This entails front-end cost savings that will be accounted for in consideration of "undue burden" when sidewalks are later added.

The above ADAAG statements were offered as guidance and do not carry force of law. However, Title II regulations require public entities to modify policies and procedures when necessary to ensure program accessibility, unless such modification causes an "undue burden," a fundamental alteration to the program in question, or the way in which services or provided. Therefore, the fact that current TxDOT policies may not require greater ROW acquisition does not in itself excuse inadequate ROW for minimum accessibility. As an example, if adding an accessible sidewalk along an existing roadway during an alteration would require purchasing additional ROW, but TxDOT policy is not to purchase additional ROW, that policy may need to be modified, or a modification at least considered by the agency head or designee. If modifying ROW policy would involve an act of the legislature to adjust budget allocation, and the legislature meets only once every 2 years, this would probably be considered an "undue burden."

5.1.6 Alternative Routes

The ADAAG allows for temporary "alternate routes" at construction sites, where pedestrian passage on the roadway is allowed if safely barricaded from traffic. Installation of more permanent "alternate routes," similar to a dedicated on-road bicycle lane, might also be considered to achieve continuous passage along an accessible route. However, these on-road options have limitations because (1) driveway crossings cannot be barricaded, and (2) roadway crowning might exceed the minimum cross-slope requirement. If feasible, off-road options should be considered first.

5.1.7 Potential Department of Justice Revisions to Title II Regulations

When the final ADAAG is issued, the Department of Justice (DOJ) will revise Title II regulations to ensure greater uniformity with the ADAAG and relevant provisions of Title III. A likely result will be that accessible elements will be prioritized in an order of importance when making alterations. This is analogous to the Title III requirement for an accessible path of travel to "areas of primary function" (36 CFR Part 1191). In relation to sidewalks, the priority elements are likely to be access to (1) state and local government offices and facilities, (2) public transportation (i.e., bus stops), (3) places of public accommodation and employment, and (4) anywhere else (BNA, 1992).

In the preamble to the ADA Title III regulations, Section 36.402(c) also states that alterations shall provide the maximum physical accessibility feasible, meaning that any features of a facility that are being altered shall be made accessible unless it is technically infeasible to do so. For example, if it is technically infeasible to make a sidewalk accessible to persons who use wheelchairs, or a certain type of wheelchair, the sidewalk must still be made accessible to people with other types of disabilities (e.g., those who use crutches), to the maximum extent feasible.

This distinction in the regulations between different types of disability and mobility aids makes a case for more research on actual accessibility for persons with different disabilities, since the existing guidelines make no such distinction. This could be a point to consider in the experimental design for Phase II of this project.

5.1.8 Focus on Education and Outreach

As stated in Chapter 2, ADAAG Section 14 is being held in reserve by the Access Board in favor of a campaign to focus on education and outreach regarding pedestrian facility design. The many comments received from public agencies on Section 14, including comments on cross-slope requirements, demonstrated to the Access Board that public agencies did not entirely understand the intent of ADA nor all of its caveats (discussed above). Innovative or "do the best you can" engineering solutions (for difficult ADA-related design problems) are being encouraged by this public outreach campaign.

Lois Thibault of the Access Board (personal conversation, January 1999) and others have stated that "do the best you can" is a realistic answer to how to handle difficult cross-slope situations. However, the definition of "do the best you can" is obviously rather vague and does not provide as much protection to public agencies as design guidance based on research. Nevertheless, Oregon's department of transportation design guide for sidewalk cross slope contains a similar statement (ODOT, 1995). Thibault also said that the Access Board, through this public outreach, was to some extent relying on engineers to come up with innovative/"do the best they can" solutions. It seems reasonable to conclude that determining (through research) a "gray area" cross-slope range that is acceptable in certain circumstances could be considered one of these solutions.

5.1.9 Section Concluding Comments

There are several caveats in the ADA that are designed to allow public agencies to relax their strict adherence to ADA requirements, including sidewalk cross slope, for good reasons. It would seem important that public agencies document these reasons to use for defense in lawsuits. Combining these with other programmatic caveats, such as outreach to the community of people with disabilities and the "do the best you can" message of the Access Board's public outreach campaign, one can partly understand why some departments of transportation might feel that they are adequately covered. However, until the ADAAG becomes law, public agencies can be challenged in court on their "do the best you can" solutions and on their interpretations of the ADA caveats. As shown in the court cases reviewed in Chapter 4, agencies have sometimes interpreted correctly and sometimes incorrectly.

To reduce liability risk, it may be prudent for TxDOT to perform the primary research it is considering in Phase II of this study. Such research (1) would be targeted to develop design guidance for individual driveway crossings that would be acceptable as equivalent facilitation in alterations (e.g., a gray-area range), and (2) might even begin to establish a suitable performance standard for an accessible pedestrian circulation network. Either research result could be submitted to the Access Board for inclusion in proposed rule making. (Note: A framework for a performance standard was suggested in Chapter 4 and TxDOT directly suggested the gray-area range.) Furthermore, it seems that any distinctions this research could make between the cross-slope needs of persons with different disabilities might also have a good chance of being incorporated into law, since the existing guidelines make no such distinction.

5.2 DESIGN-RELATED METHODS

Guidelines issued by the Oregon Department of Transportation (ODOT) indicate that cross slope should be reduced as much as possible whenever the ADA 2 percent minimum cannot be achieved (i.e., "do the best you can") (ODOT, 1995). ODOT recommends pursuing a strategy of reducing the number of accesses, since this limits the need for special provisions. In addition, ODOT provides techniques for facilitation of wheelchair movement at driveways that "prevent an exaggerated warp and cross slope." The first of these techniques is the construction of a wide sidewalk, as indicated in Figure 5.1. An appropriate width should be chosen to avoid an abrupt driveway slope. Figure 5.2 illustrates the use of a planting strip to reduce sidewalk cross slope. If a planting strip is not available, a jogged driveway crossing, as depicted in Figure 5.3, could be used. A caution here is that this arrangement may prove difficult for vision-impaired pedestrians who follow the curb line for guidance. In cases where a minimal sidewalk is provided directly behind the curb, the sidewalk can be dipped with construction of parallel ramps, as shown in Figure 5.4. Possible problems with this technique include drainage behind the sidewalk and discomfort for pedestrians.

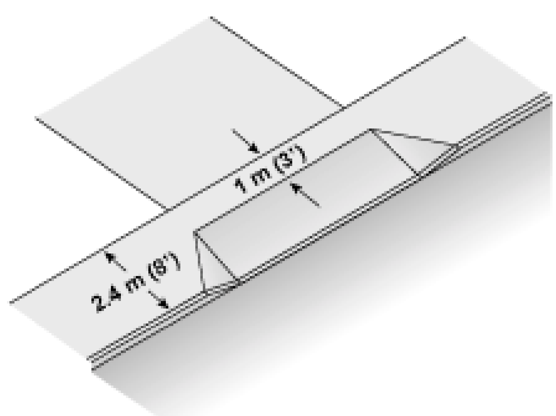

Figure 5.1 Wide sidewalk at driveway (ODOT, 1995)

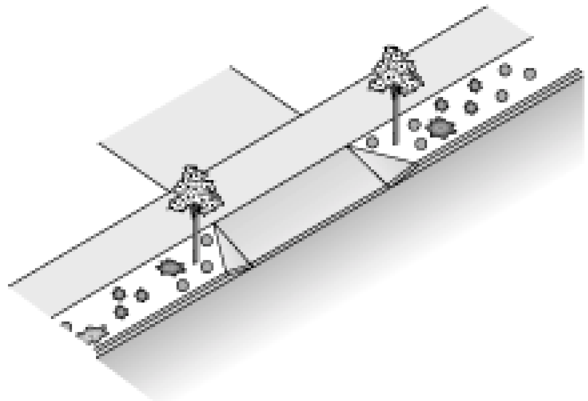

Figure 5.2 Driveway with planting strip (ODOT, 1995)

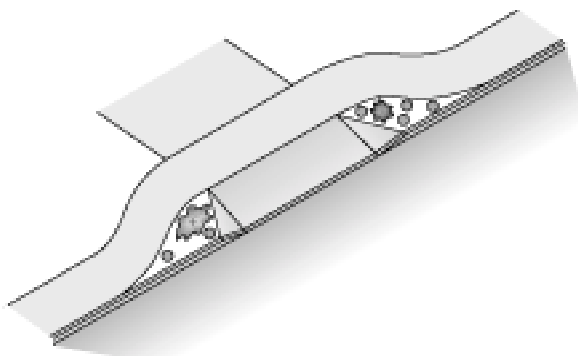

Figure 5.3 Sidewalk wrapped around driveway (ODOT, 1995)

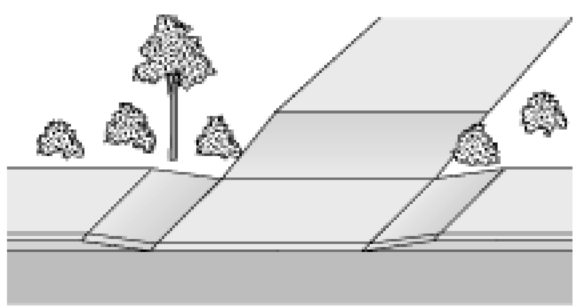

Figure 5.4 Entire sidewalk dips at driveway (ODOT, 1995)

Other sidewalk users, such as pedestrians without disabilities and bicyclists, must also be considered. For example, the design treatment in Figure 5.3 lengthens the trip for these users. A similar design (see Figure 5.1) that replaces the planting areas with sidewalk paving would allow other users to proceed straight if they wished.

The Access Board (1998) states that "several design approaches are possible to achieve a complying apron, including a retrofit treatment for existing driveways that ensures a passageway across the opening that does not exceed cross-slope limits." Several of these design approaches were described above. Other approaches include the use of rolled curb sections or a lip at the gutter for minimizing the vertical distance to be ramped. In these cases, a bridgeplate at the gutter may be required for vehicle use, street crossing, or for picking up mail. Further guidance states that a 1:10 apron can be cleared with a setback of 48 inches. Also, a 1:8 apron can be retrofitted to achieve a 1:48 cross slope for a 3-ft-wide section by constructing two steeper ramps on either side of the accessible section. For this technique, illustrated in Figure 5.5, it is stated that the steeper ramps will not cause cars to "bottom out." This design might increase motorist yield compliance (to pedestrians), but will probably also decrease motorist comfort.

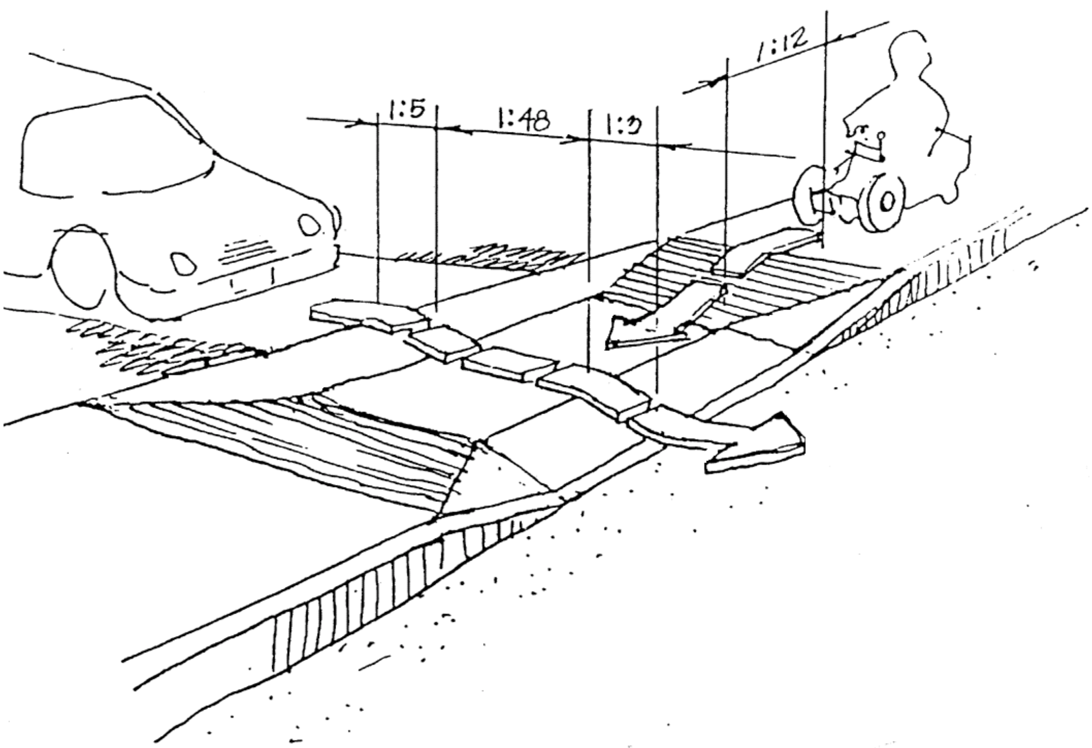

Figure 5.5 Driveway/sidewalk retrofit (Access Board, 1998)

The policy guide published by the American Association of State Highway and Transportation Officials (AASHTO) provides no examples of design techniques that may be used to solve the driveway-crossing problem (AASHTO, 1990). The Institute of Transportation Engineers (ITE, 1994) states that "a setback of 6 ft prevents driveway ramp slopes protruding into the sidewalk, which are a problem for the elderly and people with disabilities." Although perhaps not particularly applicable to most situations encountered by TxDOT, the Access Board (1998) indicates that in cases where additional sidewalk width is needed to meet cross-slope requirements, traffic calming techniques that borrow width from the street may be useful. For example, bulbouts and curb extensions can produce extra sidewalk width.

It is generally agreed that elimination of short flares (in the pedestrian path) is best (as illustrated in Figures 5.1, 5.2, and 5.3), followed by replacement of flares with ramps or long transition (warped) sections (as illustrated in Figures 5.4 and 5.5) (Access Board, 1998; FHWA, 1998). Rapid changes in cross slope can create safety hazards because one wheel of a wheelchair or one leg of a walker can lose contact with the ground (FHWA, 1998).

Design guidance provided in several sources described above indicates that a 2 percent cross slope can be achieved in some sidewalk-driveway crossing situations. However, there are obvious limits to these methods. These limits are controlled by such factors as the current driveway grade, the distance from curb to ROW boundary or easement boundary, car "bottoming out," driver comfort, and moments that may cause motor vehicles to overturn in run-off-the-road accidents. Simple "back of the envelope" computations show this quite clearly. For example, providing a 3-ft, 2 percent section for the sidewalk crossing when reconstructing a roadway with 8 ft between curb and ROW boundary at a driveway with a current slope of 10 percent would require a 15 percent driveway slope over the remaining 5 ft. Most engineering rules of thumb and judgment would probably agree that a 15 percent slope would be excessive. The 13 percent grade break is also probably excessive. The City of Arlington, Texas, recommends a maximum 9 percent driveway slope and a maximum 6 percent grade break (Arlington, 1995). ITE (1974) recommends a maximum 15 percent slope for residential driveways and 5 to 8 percent for commercial/industrial driveways, with a maximum 6 percent grade break for low volume driveways on major or collector streets (3 percent for high volumes).

One could analytically determine the upper limits of original driveway slope for which each of these techniques would suffice. However, TxDOT has performed this analysis to a significant extent and has determined that such techniques are not adequate for solving its overall driveway-crossing problem. These techniques are presented here for completeness and so that TxDOT may reevaluate, if it wishes, that initial analysis in the presence of an array of suggested design-related methods found in the literature.

5.3 SATISFYING THE CONCERNS OF PROPERTY OWNERS, CONTRACTORS, AND INSPECTORS

Information uncovered during this review that may help TxDOT satisfy the concerns of property owners, contractors, and inspectors is presented in this section. However, this was not a primary focus of the review.

Some detailed information related to satisfying the concerns of property owners came via several e-mail discussions with ODOT's bicycle and pedestrian program manager and an assistant project manager. The bicycle and pedestrian program manager writes the following:

> Construction always disrupts businesses, it's a cost that society has to absorb if we want to "improve" roads. There are many ways to provide a level area (across driveways) that do not involve easements or right-of-way. What we do is we build half of a commercial driveway at a time. That still allows enough width for one car to enter or exit at a time. For narrower residential driveways, it shuts it down for about a day. Both businesses and residents are given plenty of warning. Since the whole area is under construction, it's usually not an undue burden.

An ODOT assistant project manager, who has worked on several urban projects where driveways were retrofitted, writes the following:

> Disruptions happen. Virtually every business whose driveway has been rebuilt has complained, but the bottom line is that I don't know of any that have suffered long-term damage. In fact, they all benefit disproportionately from the transportation improvement. While the bulk of the cost is borne by taxpayers in general — the vast majority of which will never frequent that business — the business owners realize the greatest long-term economic benefit. Most business and property owners realize this, but will not admit it. It's interesting to talk to them 3–6 months after the project is complete.
>
> The most important thing to do is limit the duration of the disruption to their access. Temporary signs that help their customers find the temporary driveway go a long way in gaining good will. Also, talking to each business owner and explaining their options (total closure for a shorter period of time, etc.) and allowing them some control in the situation eases their tension. Sometimes, they just want someone to complain to. Bottom line, though, they all understand that you cannot drive through wet concrete — they just might not want to admit that they know that.
>
> Any time limitations for construction of driveways must be in the specs. The contractor generally doesn't share our level of concern for the health of the businesses. Strict limits with $$$ attached help to speed the process.

Regarding contractors and inspectors, recent draft guidance (Access Board, 1998) states that the 2 percent cross-slope requirement should not be considered a design dimension: "To be sure that field tolerances result in usable construction, notes and dimensions in construction documents should identify and incorporate expected tolerances so that a required dimension is not exceeded by the addition of a finish or a variation in construction practice. Plans that reflect such considerations also provide a better basis for decision making in the field." The guidance goes on to say that field construction based on a specification of the maximum permissible slope (2 percent) "may fail to achieve the access that is required, leading to liability for changes that may be costly" (Access Board, 1998).

For example, to be sure that the 2 percent maximum cross slope is not exceeded, the City of Roseville, California, sets extruding machines and forms to less than 2 percent. In general, a 1.5 percent cross slope is used except in the case of steep longitudinal grades where a 1 percent cross slope is used (Access Board, 1998). It seems that specifying, in construction plans, a sidewalk cross slope of less than 2 percent and working with contractors (and inspectors) to ensure they are constructed in this manner will help reduce liability-for-changes risk to TxDOT.

5.4 CONCLUDING COMMENTS

Primarily owing to ROW constraints and existing driveway grades, it does not appear that the design-related methods found in the literature will adequately address TxDOT's concerns for meeting the intent of ADA at driveway crossings. Programmatic methods, such as relying on ADA caveats, outreach to the community of people with disabilities, and the "do the best you can" approach may pose too much risk to be adequate in and among themselves. Public agencies can be (and have been) challenged in court for "do the best you can" solutions and interpretations of the ADA caveats. To reduce risk of liability for (costly) changes, it may be prudent for TxDOT to perform the primary research it is considering in Phase II of this study. A further argument for such research is that its results, including any distinctions made between the cross-slope needs of persons with different disabilities, could be submitted to the Access Board for inclusion in proposed rulemaking (i.e., incorporation into law).

Finally, it should be noted that the Access Board, along with the Federal Highway Administration and the Department of Justice, has created a draft document entitled *Accessible Rights-of-Way: A Design Manual* (Access Board, 1998). Although broader in scope, this document contains information of a nature similar to that documented in this chapter and provides a nice complement to this chapter (and this report).

CHAPTER 6. CONCLUSIONS AND SUMMARY

This review has been conducted primarily to aid TxDOT in deciding whether or not enough information and design guidance currently exist to address its concerns regarding meeting the intent of ADA at sidewalk-driveway crossings. The review was conducted in four main areas:

(1) **research and science** related to how people with disabilities perceive travel across sidewalk cross slopes of various magnitudes,

(2) **design-related methods** for providing accessible cross slope at driveway crossings,

(3) **programmatic methods** for meeting the intent of ADA at driveway crossings within the constraints of the situation at hand, and

(4) **expert opinions** on meeting the intent of ADA at sidewalk-driveway crossings.

With regard to the first area, there definitely has not been enough research performed to develop the type of design guidelines that TxDOT desires. In addition, prior research findings are notably insufficient to support the 2 percent ADA requirement, especially when relaxed for short distances (e.g., some driveway crossings) and/or in special circumstances. Regarding the second area, several design-related methods have been developed. While these methods are solid, available ROW and existing driveway grade limit their use when reconstructing roadways. Because of this, they do not completely address TxDOT's concerns.

The third area — programmatic methods (which includes caveats in the ADA and the "do the best you can" approach) — provides further options for TxDOT, while the fourth area of review — expert opinions — suggests that some state DOTs are placing confidence in a combination of programmatic and design-related methods. However, the extent to which these DOTs have internally examined the driveway-crossing problem could not be adequately determined within the resources allocated for this review. In addition, no determination could be made of (1) the number of driveway accesses under the jurisdiction of each state DOT, (2) the existing grades of these driveways, or (3) the ROW available for modifications at these sites. Perhaps other DOTs do not often face the same issues as TxDOT or perhaps the attitudes and goals of those agencies and the associated state's citizenry allow other DOTs more latitude in purchasing easements and additional ROW for driveway-crossing improvements. Furthermore, additional examination of the policies and actions of other state DOTs is unlikely to help quantify or address the risk of legal liability for changes, whenever the 2 percent requirement is not met.

This review has highlighted the major trade-offs involved in the design of sidewalk cross slope. It has been organized in a manner intended to aid TxDOT in determining whether specific design concerns have been sufficiently met via existing sources. The research team makes no direct recommendation, but does point out key factors for TxDOT to consider when making this determination.

In making a decision on whether to adhere to the ADA's 2 percent cross-slope requirement under unfavorable site conditions, transportation agencies face a trade-off involving the risk of costly lawsuits. Lawsuits carry defense costs, damage costs, costs associated with a loss in good public relations, and costs of the design/construction solution. Construction costs range from high (for always reconstructing driveway crossings at 2 percent) to low (for "do the best you can" solutions or solutions based on design methodologies developed from research). Liability should be lowest when one designs and constructs roadways according to guidance that is based on solid scientific research. One decision presently before TxDOT is whether or not to enter the research phase of this project to develop such guidance and, thus, help lower the risk of lawsuit costs.

Unfortunately, neither the research team nor TxDOT is able to reliably put a dollar value on the potential liability-change costs; nor can we reliably estimate the probability of a lawsuit for each of the potential design/construction solutions. Therefore, TxDOT must make a decision based on somewhat limited information. In making this decision, TxDOT should consider the following:

(1) Verify that a combination of programmatic and design-related methods does not sufficiently satisfy TxDOT's concerns. In addition to this review, the review drafts of the documents *Designing Sidewalks and Trails for Access: A Review of Existing Guidelines and Practices* (FHWA, 1998) and *Accessible Rights-of-Way: A Design Manual*, a joint publication of the Access Board, FHWA, and USDOT, with assistance from the DOJ (Access Board, 1998) may be helpful. The latter document presents ADA sidewalk-related issues and information in a similar manner to this review. However, it addresses public right-of-ways in their entirety, rather than focusing on sidewalk cross slope. In addition, one can contact the Access Board directly. Lois Thibault is the board's coordinator of research. She can be reached at (202) 272-5434 ext. 32.

(2) Experimental research will permit submission of the resulting design methodologies and recommendations to the Access Board for inclusion in proposed rule making (law). Allowing the Access Board to comment on and aid in developing the experimental design may facilitate this process.

(3) Furthermore, any distinctions that experimental research finds between the cross-slope needs of persons with different disabilities may also be incorporated into law.

(4) Experimental research could be interpreted as a demonstration of TxDOT's "good faith" or "best one can do" effort to meet the intent and spirit of the ADA. As such, research would emphasize TxDOT's positive role while facilitating eventual legal adoption of the results.

(5) The ADA indicates that construction of sidewalks is required in some instances when constructing new streets or reconstructing existing streets Because of this, it seems imperative that TxDOT, and other agencies of its kind, have compliant

design practices, especially considering the uncertainty surrounding what constitutes accessibility and good faith.

In preparation for the second phase of this research effort (should TxDOT decide that this project will continue), the research team has begun to craft the research design. The current thinking on this design is as follows:

(1) By making reasonable assumptions to narrow the number of factors for which different limits might apply, one can reasonably expect to accomplish the research objective of developing maximum and desirable limits for cross slope at driveway crossings. In addition, it may be feasible to gather some information that might be supplemented in the future to develop a performance measure to capture the accessibility of an entire route or street with multiple driveway crossings.

(2) The few prior experimental studies performed to assess wheelchair-user effort when traversing cross-sloped sections are inadequate for TxDOT's use, not only because they use extremely small samples on surfaces other than concrete in a laboratory environment, but also because they did not attempt to assess user perception. For sidewalk design purposes, user perception seems best addressed by assessing user comfort when the person is traversing an actual sidewalk under actual traffic conditions.

(3) Because comfort is the best measure on which to base design guidance, the experimental design will rely primarily on a sample of persons with different disabilities participating in field tests to assess their perceptions of comfort when traversing driveway cross slopes of varying degrees in actual (and different) on-street environments. Efforts will be made to recruit and process as many participants as resources allow. However, owing to the problems other studies of people with disabilities have had in recruiting participants (Cooper, 1989), a sample of between 25 to 75 subjects will be considered a success. A heart rate monitor will be used on a subset of this population during the field tests to supplement the comfort assessments with physical measurements. The field tests will be supplemented with a remote, purely visual, Web-based survey of a larger population of people with disabilities. Potential biases in this survey will be controlled based on field test results. Laboratory tests will not be performed because they cannot capture the potential effects (on pedestrian comfort) that are related to an on-street traffic environment.

(4) Manual wheelchair users will be the primary target population for the field tests. Attempts will be made to test several different types of wheelchair designs, including motorized wheelchairs and scooters. In addition, attempts will be made to test crutch and walker users and possibly even a few persons with visual impairments.

(5) The most important explanatory factors (e.g., adjacent traffic volume, pavement surface smoothness, length of driveway crossings, and frequency of driveway

crossings) are still to be determined in conjunction with the constraints of the field and visual survey assessment procedures and the project resources.

(6) The potential limitations of the resulting design methodologies are still to be determined. Full determination is not possible until the actual sample sizes and variations are known.

(7) Integration of this research with other current and planned research is also to be determined. However, three organizations/individuals to contact in this regard have been identified and some preliminary discussion has begun. These organizations/individuals are the Access Board (primary contact: Lois Thibault), Beneficial Designs, Inc. (primary contacts: Denise Chesney, Peter Axelson, and Julie Kirschbaum), and Rory A. Cooper (Cooper, 1989).

There are a few miscellaneous, but important, items that should be listed here for emphasis. These are:

(1) The 2 percent sidewalk cross-slope requirement is intended to be an in-place, finished-product construction standard, rather than simply a design standard (which is subject to deviations owing to actual construction practices) (Access Board, 1998). (See the end of section 5.3 for more detail.)

(2) A 5-ft width is suggested for sidewalks adjacent to the curb (Access Board, 1998).

(3) Community outreach might be a wise strategy. Such outreach could consist (in part) in partnering with cities to develop pedestrian circulation networks that are accessible to people with disabilities and to provide information (through signs, maps, etc.) on what portions of the network are accessible to people with different disabilities. (See Chapter 4 for more detail.)

(4) Developing a method for assessing the performance of a pedestrian circulation network in providing access for people with disabilities appears to be of great importance, as is the development of a performance standard. A method based on average effort per meter traveled appears to hold promise in this area. (See Chapter 4 for more detail.)

In summary, public provision of transportation facilities for use by people with disabilities offers challenges in terms of access and costs. Current practices rely on a combination of limited physical solutions for strictly meeting ADAAG and programmatic solutions that contain much uncertainty as to how and when they should be applied. Very little existing work allows one to appreciate the effort and other access differences that result from changes in cross slope; research is certainly needed here. TxDOT is in a position to do this, and the results are likely to support national and international efforts to ensure access to all users of transportation facilities.

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