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# PUBLIC PERCEPTION OF PAVEMENT RIDEABILITY

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16. Abstract


To evaluate the public perception of pavements in Colorado, 24 individuals were driven over 69 pavement sections in the Denver Metro area. These individuals were asked to rate the pavement based on rideability and to determine whether that ride was acceptable or unacceptable. The 69 pavement sections that were rated include: 51 bituminous and 18 concrete sections, urban and rural roads, and 35 and 55 mph speed limits.

These ratings were then scaled from 0 to 5, with 5 being the best ride. Using regression analysis, the scaled ratings were compared to the roughness of the pavement. The pavement roughness was measured by the CDOH using a Mays Index.

The conclusions are:

- for bituminous pavements 10 percent of the public is unhappy at a present serviceability index of 2.50
- for concrete pavements 10 percent of the public is unhappy at a present serviceability index of 2.21
- the public will tolerate rougher roads at slower speeds.


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# PUBLIC PERCEPTION OF PAVEMENT RIDEABILITY

## EXECUTIVE SUMMARY


**INTRODUCTION**

The purpose of this study, funded by the Colorado Department of Highways (CDOH), is to develop a correlation between the present serviceability rating (PSR) and the Mays Index (MI) values. The public's perception of pavement serviceability versus CDOH current serviceability standards are also analyzed.

**RESEARCH SIGNIFICANCE**

Due to the limited state funds available, road rehabilitation must often be prioritized, that is funding must be optimized to achieve the best result for the dollar. Determining when a road needs repair, and which roads are the worst, are difficult but yearly tasks for every state highway department. Since CDOH must compete for state tax dollars, it is imperative that they present the relevant facts to the legislature.

CDOH must prove what money is necessary to satisfy the public, the Legislature's constituents. In a true business enterprise, the market acceptance of the product is of primary importance. Incorporating the public user into a highway's pavement serviceability requirement establishes a market acceptance of a product --- the pavement. Establishing what the market (public) wants, and will accept, is a primary step in developing a strategic plan to satisfy that market.

If the strategic plan is underfinanced, CDOH can indicate to the legislature what percent of the public will be unsatisfied with the pavement serviceability (ride). Incorporating the public users into the budgeting process should help the highway department compete for the limited state funds. Also, if underfunded, CDOH can indicate the approximate number of dissatisfied constituents that the Legislature can expect.

**RESEARCH PROGRAM**

Twenty-four raters, three in a vehicle, were driven over 69 pavement sections in the Denver Metro area. All vehicles were provided by the CDOH and were the same make and model. The pavement sections represented were; concrete and bituminous materials, rural and urban locations, and 35 mph and 55 mph speed zones. The raters were asked to subjectively evaluate pavement rideability by marking an x on a rating card. Their ratings were then evaluated on a scale from 0 to 5, with 5 being a perfect road. Additionally, the raters also had to determine whether the pavement was acceptable or unacceptable.

**RATER RESPONSE ANALYSIS**

Over 1600 rater responses were analyzed. This analysis involved a five step process. First, the ratings between the back seat raters were analyzed, then the ratings between the back seat and front seat were analyzed, and finally the ratings between cars were analyzed. This analysis indicated that there was no significant statistical difference between the rater responses regardless of where the rater was sitting in the car or in which car the rater rode.

Rater responses were grouped into different categories and regression analyses were performed to relate the panel ratings to the pavement roughness, Mays Index values. The following equations provide the various linear and transformed regression models that estimate the public's perception of pavement serviceability ratings (PSR) for a given roughness (MI);

**Concrete Pavements**

$1/PSR = 0.000642 * MI + 0.236668$ (Correlation = .49)

$\ln (PSR) = -0.001902 * MI + 1.395860$ (Correlation = .46)

**Bituminous Pavements**

$1/PSR = 0.001530 * MI + 0.180514$ (Correlation = .90)

$\ln (PSR) = -0.003678 * MI + 1.494468$ (Correlation = .79)

Also analyzed were the initial and terminal pavement serviceability ratings. Very few new (6 months after construction) pavements were rated thus making an estimate of an initial pavement serviceability rating difficult. However, many raters found a number of pavement sections unacceptable and a terminal pavement serviceability rating was established. Most state highway agencies design sections, including CDOH, consider 2.5 as the terminal serviceability index for major highways and 2.0 as the terminal serviceability index for minor highways. The following two tables indicate how the public feels about the established terminal serviceability index.

| Bituminous Pavement | | Concrete Pavement | |
|---|---|---|---|
| Percent Public Dissatisfied | CDOH Rating | Percent Public Dissatisfied | CDOH Rating |
| 10 | 2.51 | 10 | 2.21 |
| 20 | 2.25 | 20 | 1.82 |
| 30 | 2.07 | 30 | 1.53 |
| 40 | 1.91 | 40 | 1.29 |
| 50 | 1.77 | 50 | 1.09 |

This table indicates for the 51 bituminous test pavement sections rated on major highways 10% of the public is dissatisfied with the highway at the rating at which CDOH considers repair. For the 18 concrete test pavement sections rated, 10% of the public is dissatisfied when the pavement serviceability is 2.21. However, CDOH considers repairing concrete pavements at 2.5, when a very small percentage of the public is dissatisfied.

If the strategic repair plan is underfinanced, this table provides an estimate of the percent of dissatisfied public that will be traveling on the road. For instance, if funding did not allow repair for bituminous pavements at 2.5 but instead at 2.0, then approximately 35% of the public would be dissatisfied with the pavement ride.

**CONCLUSIONS**

Based on the study described, the conclusions are:

1. There was no significant statistical difference between rater responses due to seating position in a car or to the car that was used.
2. Statistically significant regression models were developed to relate panel ratings to roughness. The correlation coefficient for the bituminous regression equation was 0.90 and the for concrete regression equation was 0.50. This means that the regression for the bituminous ratings fit the data reasonably well, whereas the regression equation for the concrete data does not match the data.
3. The public views the ride on bituminous pavements to be rougher than the CDOH believes it is. Also, the public feels that the ride on concrete pavements is better (smoother) than CDOH would consider it to be.
4. For concrete pavement virtually all of the public is satisfied with the ride at a terminal serviceability index of 2.5. However, for bituminous pavement 10% of the public is dissatisfied with the ride at a terminal serviceability index of 2.5.

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# CHAPTER I

## INTRODUCTION TO PAVEMENT PERFORMANCE

Highways deteriorate with age. As they deteriorate, designers, administrators and users contemplate the point at which renovation or reconstruction is necessary. Due to the limited funds available, road reconstruction must often be prioritized, that is, funding must be optimized. Determining when a road needs reconstruction and then which roads are the worst is a difficult but yearly task for every state highway department.

State highway departments are often criticized by the travelling public for their lack of road maintenance. This criticism may be focused in the wrong direction. The travelling public occasionally forgets that CDOH competes with others for a portion of the state tax dollars. The Department's ability to prove what they must do, and the money they need to satisfy the public user, is quite often a missing link in their budget request. Tieing the public users, the Legislature's constituents, into the budgeting process should help the highway department compete for limited state funds.

Determining the serviceability, ie. ride quality, of a road and when it needs repair is a necessary function of a highway agency. Pavement serviceability is measured by road roughness and physical distress (cracking, potholes, etc.). Typically, highway departments set minimum levels of roughness and physical distress that require repair. These minimums should reflect the comfort of the public user. Most state highway departments, however, have not considered the opinion of the public user in establishing minimum pavement serviceability requirements.

In a true business enterprise, the market acceptance of the product is of primary importance. Incorporating the public user into a highway's pavement serviceability requirements establishes a market acceptance view of a product --- the pavement. Establishing what the market (public) wants and will accept is a primary step in developing a strategic plan to satisfy the market. Also, if the strategic business plan is underfinanced, the highway department can determine the percentage of unsatisfied customers.

## Serviceability-Performance Concepts

The serviceability-performance concept is based on five fundamental assumptions (1), summarized as follows:

1. Highways are for the comfort and convenience of the travelling public (User).

2. Comfort, or riding quality, is a matter of subjective response and is the opinion of the User.

3. Serviceability can be expressed by the mean of the ratings given by all highway users and is termed the serviceability rating.

4. There are physical characteristics of a pavement which can be measured objectively and which can be related to subjective evaluations. This procedure generates an objective serviceability index.

5. Performance can be represented by the serviceability history of a pavement.

Pavement serviceability is expressed by a present serviceability index (PSI). The PSI is obtained from measurements of roughness at a particular time during the service life of the pavement.

Equations for the PSI developed by the AASHTO Road Test (1), have been modified by most state highway departments. These modifications reflect local experiences but the PSI values still represent ride quality. Typically, physical distress only slightly influences PSI, ie. ride quality. Because of this relatively small effect on ride quality, many highway agencies rely only on roughness to estimate ride quality. While physical distress may only have a slight effect on ride quality, it is likely to influence the decision to initiate maintenance or rehabilitation.

The CDOH obtains their roughness values from pavement measurements that are then converted to a present serviceability index. The percent of pavement cracking is combined with the present serviceability index to give a subjective rating of good, fair, and poor. The good, fair, and poor represent the CDOH Condition States.

## Initial and Terminal Serviceability Index

The most common scale for the present serviceability index (PSI) ranges from 0 to 5, with a value of 5 representing a perfect road. The initial serviceability index represents the user's estimate of ride quality immediately after road construction. The terminal serviceability index is the lowest acceptable value before resurfacing or reconstruction is necessary.

The AASHTO Road Test established an initial serviceability index of 4.2 for flexible pavements (bituminous) and 4.5 for rigid pavements (concrete). Although the Road Test did not establish a terminal serviceability index, an index of 2.5 or 3.0 is often suggested for major highways and 2.0 for other roads.

Achieving high quality control during construction will provide a higher initial serviceability index and therefore a longer life cycle. A longer life cycle is also achieved by defining a lower terminal serviceability index. The major factors that influence the loss of serviceability, ie. the change from initial to terminal serviceability, are traffic loadings, age and environment.

## Colorado Department of Highways Present Serviceability Index

The Colorado Department of Highways (CDOH) uses a "Condition States" chart (Figure 1., p. 8) to classify pavement serviceability as good, fair or poor. This matrix combines both the percent cracking/patching and the Mays Index (MI) values to determine the pavement's overall condtion of good, fair, and poor. The MI values provide a measure of the pavement's roughness.

The CDOH currently does not use the Condition States methodology to determine when a road needs repair. There is no correlation between condition states and a pavement's terminal serviceability index. Also, the public is not an integral part of the decision process for the selection of roads in need of repair. In the design process, CDOH does consider 2.0 to 2.5 as the terminal pavement serviceability, ie. an unacceptable pavement. The 2.5 value relates to major highways and the 2.0 to secondary roads. Also, CDOH expects new pavements to be built to an initial serviceability index of 4.5.

## Project Objectives

The Colorado Department of Highways requested a research study to investigate the public opinion of pavement serviceability and to suggest possible methods of incorporating public opinion into current procedures. The primary objectives are stated below:

1. Correlate public ratings to CDOH's present serviceability index.
2. Establish the public's terminal serviceability index.

In addition to these primary objectives, the project will also provide a preliminary estimate of the public's perception of initial pavement serviceability, suggestions for incorporating the results of this study into current CDOH procedures, and recommendations for future study.

Figure 1.1 - Colorado Department of Highways Condition States

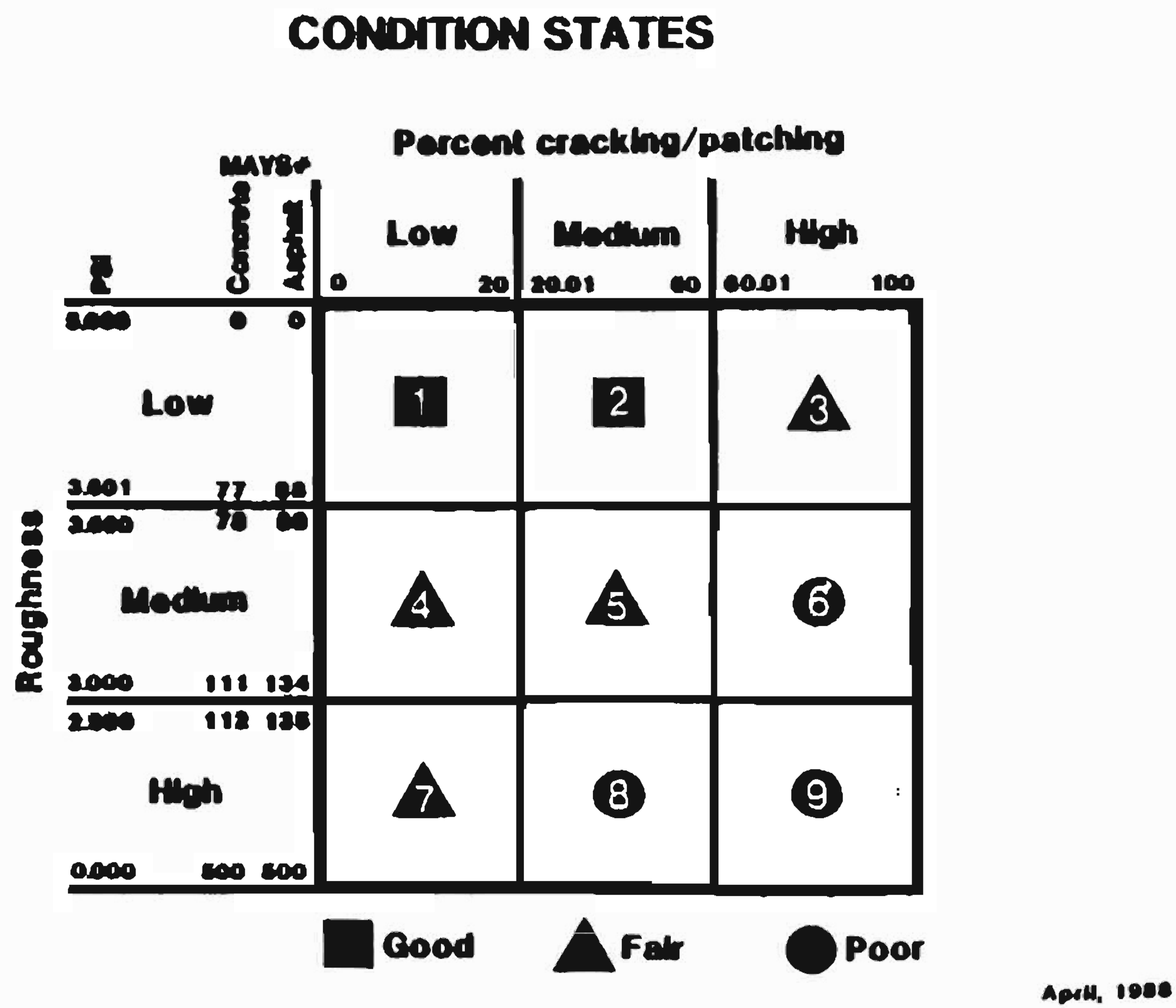


Figure 1. Colorado Department of Highways Condition States

# CHAPTER II

# BACKGROUND AND LITERATURE REVIEW

The National Cooperative Highway Research Program Report #275, "Pavement Roughness and Rideability" (2) summarizes the majority of research completed up to 1985. Thirty-four papers are referenced which detail many aspects of pavement serviceability and rideability. Some of that work applies to this project study. This work, and other work since 1985 that relates directly to the study undertaken for the Colorado Department of Highways by the University of Colorado - Boulder, is presented here.

## Establishment of Definitions

The concept of pavement serviceability was first addressed in a 1960 study for the Highway Research Board by Carey and Irick (3). The research described a system where the serviceability of pavements could be measured and rated by a panel of experts and a mathematical correlation drawn between this subjective rating and an objective (physical) measurement. The following definitions were presented by

Carey and Irick and are also applicable to this study:

1. **Present Serviceability:** The ability of a specific section of pavement to serve high-speed, high-volume, mixed (truck and automobile) traffic in its existing condition.

2. **Individual Present Serviceability Rating:** An independent rating of the present serviceability of a specific section of roadway made by marking the appropriate point on a scale.

3. **Present Serviceability Rating (PSR):** The mean of the individual ratings of the present serviceability of a specific section of roadway.

4. **Present Serviceability Index (PSI):** A mathematical combination of values obtained from certain physical measurements (cracking, rutting depth, etc.) that predicts the pavement's PSR.

Carey and Irick (3) also presented ten general steps to be used to establish, derive, and validate a Present Serviceability Index. These are stated below.

1. **Establish Definitions:** What is to be rated, what is included and what is excluded from consideration? Define the project scope.

2. **Establish a Rating Panel:** Serviceability is an opinion of this group and care should be taken in selecting

its members.

3. **Orient and Train the Rating Panel:** All panel members must be instructed. Ratings are kept confidential during the rating process.

4. **Select Pavements for Rating:** A minimum pavement section length of 1200 feet is desireable. All types and qualities of roads should be included in the rating process.

5. **Field Rating:** Panel members are taken in small groups to rate the pavement sections. They then mark their rating card, independent of the other raters.

6. **Replicate Ratings:** Determine the consistency of the panelists' ratings by having them rate the same pavement sections on different days.

7. **Validate Rating Panel:** Select other groups of users and have them rate the same pavement sections which the panel rated.

8. **Physical Measurements:** Measure roughness and physical distress.

9. **Summarize Measurements:** Summarize roughness and physical distress for each section.

10. **Derive Present Serviceability Index:** Determine a statistical correlation between the present serviceability

ratings (PSR's) and the roughness measurement summary.

Future research has modified and altered some aspects of this study by Carey and Irick, but the main concepts presented in 1960 are still valid today.

## Establishment of Rating Panel

In 1960, Carey and Irick (3) felt strongly that panel selection was very important. Since 1960, other studies have found that although panel selection is important, many members of the public sector could be used as viable raters. Nick and Janoff (4) determined in their 1982 study that neither sex, age, vehicle type normally driven, nor average miles driven per year significantly altered the results of the rating panel.

Weaver (5) decided that raters should be selected based on their ability to make sincere, independent judgments and follow simple instructions. This research also suggested that nondrivers and pavement experts not be allowed to participate in the rating process.

Janoff and Nick (6) also examined the effects of residence and training of the rating panel for their effect on the subjective evaluation of road roughness.

Five panels of 21 people each rated 34 pavement sections in Pennsylvania and 31 sections in Florida using two different vehicle types and two vehicle speeds. They determined that the difference between trained (engineering background in pavement analysis) and untrained (layman) raters had no statistically significant effect on the ratings, thus refuting Weaver's (5) suggestion that experts will bias the rating results and should not be used as panelists. The residence of the rater did have a small effect when rating rough pavements. Therefore, Janoff and Nick suggest that the raters all live in the same general area of the country.

Besides selecting the individual raters, determining the appropriate number of raters is required. Moore, Clark and Plumb's (7) study for the Kansas Department of Transportation (KDOT), used 24 member rating panels. This number was arrived at by assuming a standard deviation of 0.60 scale units with a maximum allowable error of 0.25 scale units and a confidence interval of 95 percent. Janoff and Nick's (6) pavement roughness and rideability study used 21 raters. A sample size of 21 was required to detect a minimum difference of 0.5 scale units between the two treatment groups with a 90 percent probability and a 5 percent error.

## Orientation and Training of Panelists

In previous research (7), the raters were instructed to concentrate only on ride quality, ignoring pavement appearance, cracking, patching and spalling. The drivers instructed the panelists when the new sections began and ended and collected the forms after each rating, but did not rate the pavement sections themselves.

The instructions to raters used by Nick and Janoff (4) were also used in the KDOT (7) study and seem to be the accepted standard.

## Selection of Pavements

Weaver's (5) pavement rating study used a maximum of 90 test sections and 80 raters. He determined that each test section should be a minimum of 0.25 miles and a maximum of 0.5 miles long and have uniform roughness. There should be a rapid transition between pavement sections so the rater's mind would not wander from the task at hand. Atypical surroundings should be avoided to minimize rater distractions.

In the KDOT study (7), three test circuits were designed to reflect the maximum pavement design, traffic, and environmental differences found in the state of Kansas.

Each circuit contained 36 - 0.5-mile test sections, including each possible variation of pavement type. Four pavement types were evaluated: full-design bituminous, partial-design bituminous, portland cement concrete and composite pavement. The design included at least 24 test sections of each pavement type.

Research by Nick and Janoff (4) suggested that the length of each section could vary, but the total exposure time to the section should remain approximately the same (ie. longer sections for faster speeds, shorter for slower speeds). The median exposure time was 27.5 seconds with a range from 18 to 34 seconds over all pavement sections. The circuit took 2.75 hours to complete and had a median time between sections of 3.5 minutes. To achieve this medium time, dummy sections were used to fill in gaps between sections.

## Field Ratings

In 1982 Nick and Janoff (4) analyzed the preferred scaling method for obtaining panel ratings of pavement ride quality. The goal of this research was to determine if there was a significant difference between outcomes using different rating scales.

Three rating scales were considered for evaluation: the Weaver-AASHO Scale, the Holbrook Scale, and the Nonsegmented Scale. These three rating scales along with the KDOT Three Point scale are shown in Figure 2, page 18.

Nick and Janoff chose the Weaver-AASHO Scale as a baseline for comparison to other scales. This scale is subdivided into five segments, from "Impassable" (0 scale points) to "Perfect" (5 scale points). The segments between 0 and 5 use the adjectives "Very Poor", "Poor", "Fair", "Good" and "Very Good" and are evenly spaced along the scale.

Holbrook (8) suggested that the systematic errors of leniency (tendency of the rater to rate too high or low), the halo effect (non-subjective ratings due to outside stimuli), and central tendency (raters reluctant to rate very high or very low) were not taken into account in the design of the Weaver-AASHO scale. Holbrook also stated that the raters must be given clear definitions to help them define the anchors, thereby allowing a more accurate evaluation of the pavement roughness and corresponding 0-5 value assigned to that roughness.

The Holbrook Scale also uses five segments and anchors, "Unbearable" and "Excellent", but the other adjectives along the scale are not evenly spaced. Holbrook felt these changes would eliminate systematic errors of leniency and central tendency which were found in the Weaver-AASHO Scale.

The Nonsegmented Scale merely identifies the anchors at each end of the scale without additional descriptive adjectives. The rater is thus unaided, allowing the subject to place a rating mark anywhere on the scale.

From their comparison of the three scales, Nick and Janoff (4) concluded that as long as the raters' instructions were clear, the type of rating scale used had no bearing on the outcome of the study. Other analyses from this study determined that neither the effect of starting point on the circuit nor seating position within the rating vehicle had a statistically significant impact on the rater values.

The KDOT study (7) examined two rating scales, Weaver-AASHO and KDOT Three Point, to determine a statistical correlation between the public's pavement perception and actual Mays Index values. The KDOT Three Point Scale (see Figure 2, p. 18) uses a 0 to 3 scale with

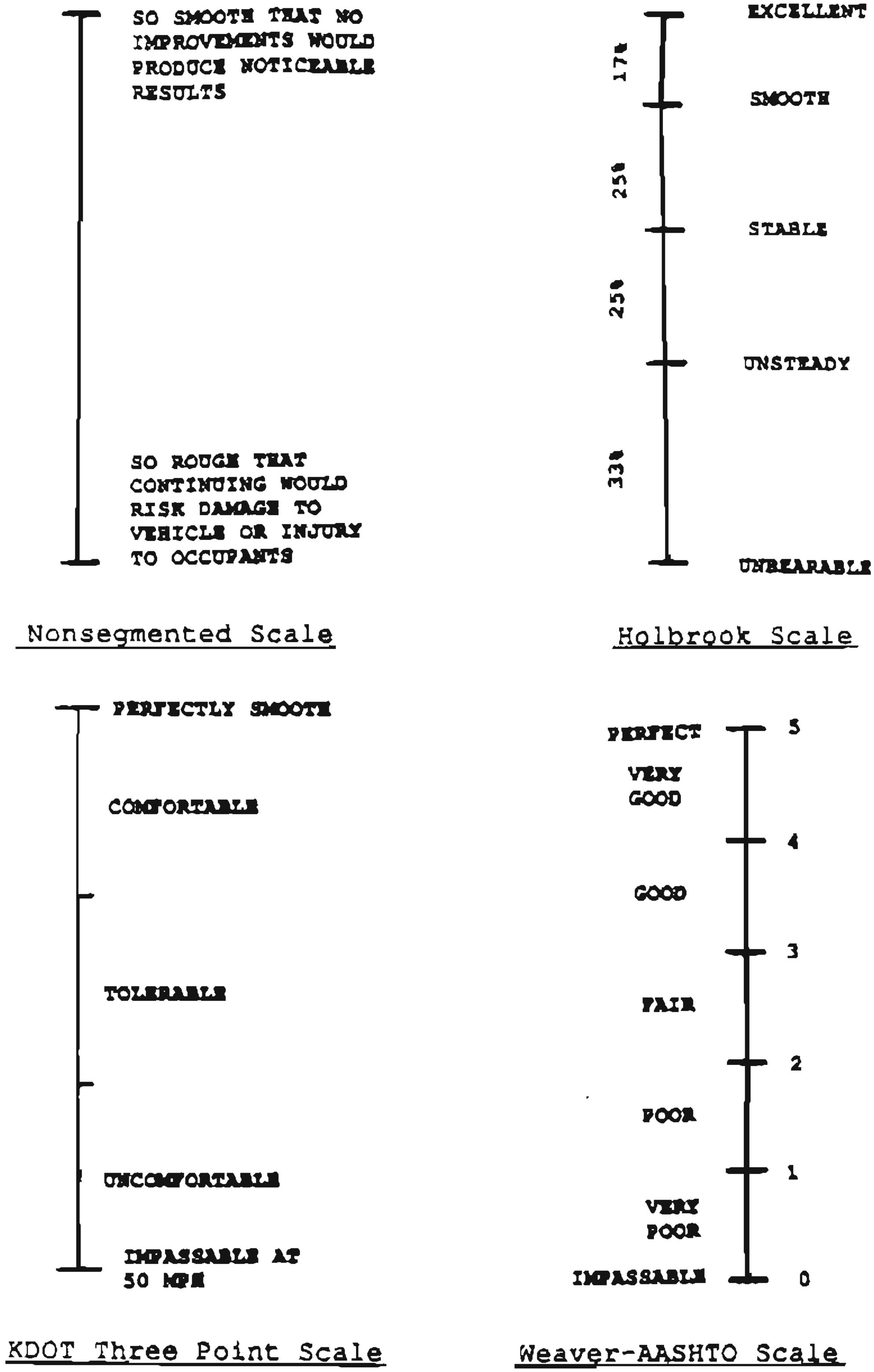


Figure 2. Rating Scales

the ends of the scale anchored by the words "Perfectly Smooth" (a scale value of 3) and "Impassable at 50 mph" (a scale value of 0). The three divisions were equally spaced along the continuum, just as on the Weaver-AASHO Scale. However, the descriptive adjectives along the scale were "Comfortable", "Tolerable" and "Uncomfortable", differing slightly from the Weaver-AASHO Scale. KDOT calculated a statistical correlation between their Three-Point scale and the Weaver-AASHO scale.

## Replication of Field Ratings

Although recommended by Carey and Irick (3), no studies were found which had raters evaluate the same pavement sections more than once and then compare these two ratings to determine statistical variances.

## Validation (Replication) of Panel

The only research found to have addressed the validation of the panel is that of Carey and Irick (3) in their 1960 study. Two professional truck drivers and a group of ordinary automobile drivers rated the pavement sections along with the original test panels. The mean panel results of all three groups were quite similar.

## **Physical Measurements**

For the KDOT (7) research, Mays Roughness data was collected within two days of the panel rating, to insure consistency, and represented the average of three runs over each 0.5-mile test section. No other research was found which detailed the objective data collection techniques or time frame in which the measurements were taken.

## **Derivation of Present Serviceability Index**

Results of the KDOT study (7) showed: the average standard deviation over all pavement types for panel sizes of 24 is approximately 12 percent of the maximum scale value (using either the 3-point (0.36) or 5-point (0.60) scale); the standard deviation of individual panel ratings is independent of the mean panel rating for a given pavement section; linear, log-log linear, and exponential linear models are not completely satisfactory for predicting PSI given MI roughness values; and a statistically significant correlation can be established between the Weaver-AASHO five-point scale and the KDOT three-point scale.

The accepted methods for analysis and correlation of PSR to MI values are regression equations and analyses of variance (ANOVA). These have been used repeatedly throughout previous research (3,4,5,6,7,9).

# CHAPTER III

## CDOH PAVEMENT RIDEABILITY STUDY

The research process was developed after considering the relevant literature and the Colorado Department of Highways' needs. This research program is a modified version of the recent study completed by the Kansas Department of Transportation (7). The research program is described in a 10-step process.

### <u>1. Establishment of Definitions</u>

The definitions pertinent to this study are: present, initial and terminal serviceability; individual present serviceability rating; present serviceability rating (mean panel rating); and present serviceability index. These were defined in Chapters I and II.

### <u>2. Establishment of Rating Panel</u>

Previous research by the KDOT (7) and Janiewski and Hudson (10) determined that 24 panelists were a sufficient sample size for statistical reliability. The panel size of

24 was arrived at by assuming a standard deviation of 0.60 for all pavement sections with a maximum allowable error of 0.25. This results in a minimum sample size of 23 raters required to be 95 percent confident that the population mean falls within the allowable error (0.25) relative to the mean panel rating.

Twenty-four raters were chosen for this study, placing 3 raters per vehicle, one in the front and two in the back. Although raters could have been selected from a large data base, it was more pragmatic to select raters that were employed by the CDOH. First, according to insurance regulations, only state employees could ride in the state vehicles. Second, because of the possibility of snow or other unforeseen problems, raters should be easy to notify for cancellations and also easy to summon for rating on another date. Since previous research (12) indicated no statistical difference in mean ratings of state highway department personnel and other rating groups, employees of the CDOH were selected as raters.

The CDOH posted a volunteer notice and approximately 30 volunteer raters were retained to participate in the study. The raters were to have at least 5 years of driving experience within the state of Colorado.

These 24 panelists were divided into groups of 3 and conducted the pavement ratings in 8 vehicles. Six raters were chosen as alternates in the event that some of the raters could not participate.

No professionals involved in pavement design, maintenance, or other pavement activities were included as raters. The raters, for the most part, represented the secretarial and administrative staff of the CDOH.

### 3. Orientation and Training of Panelists

The Instructions to Raters presented were a slightly modified version of those used by the KDOT (7), as first presented by Nick and Janoff in 1982 (4). The Instructions to Raters were presented during a half-hour training session that was given just prior to the pavement rating. Every effort was made to ensure that the raters were completely familiar with the task ahead. The raters were asked to provide a mark on a scale of 0 to 5 that represented the pavement's rideability and also to mark a box to indicate whether that pavement's ride was acceptable or unacceptable.

A copy of the Instructions to Raters used in this study is provided in Appendix E. A copy of the CDOH rater sheet used for this study is also included (Figure 5, p. 35).

The drivers of the vehicles were also in need of some training. To familiarize the drivers with the two test circuits, a dry run was conducted one week prior to the actual testing. Both circuits were driven, noting the beginning and ending of each test section. Test sections were typically marked with flagging tape; yellow flagging marked the start and red flagging marked the end.

The drivers had to locate each test section, notify the raters when to start rating the test section, and then direct the raters to mark their answers on the rating sheet when the test section ended.

## 4. Criteria for Selection of Test Circuits

The CDOH provided five main criteria to be used in selecting the test circuits for pavement rideability testing. They are:

1. Two circuits; one circuit to be travelled at approximately 35 mph and the second to be travelled at approximately 55 mph.
2. Both urban and rural roads should be included.

3. Test pavement sections within each test circuit should include the three categories of roads as classified by the CDOH "Condition States": good, fair, and poor.

4. The 35 mph and the 55 mph test circuits should include a mixture of both bituminous and concrete pavements.

5. Pavement sections should be between 0.25 and 0.50 miles in length.

Based upon these 5 criteria, previous studies described in Chapter 2, and practical considerations, two test circuits were chosen and submitted to the CDOH for review. The 55 mph circuit included 33 pavement sections, 11 concrete and 22 bituminous. The 35 mile per hour circuit included 36 pavement sections, 7 concrete and 29 bituminous. Most of the pavements within the Denver Region are bituminous, making it difficult to find sufficient concrete test sections to rate.

The 55 mph circuit included both Federal Aid Interstate and Federal Aid Primary roadways. The 35 mph circuit included roads classified as Federal Aid Primary, Federal Aid Secondary and Federal Aid Urban. The two circuits are shown in Figures 3 and 4 (p. 28-29) and described in Appendix A.

After the circuits were established, the CDOH performed a condition survey on the pavement. This survey included roughness measurements at 0.1 mile increments. This condition survey was performed at the posted speed limits.

Part of the selection criteria was to find test pavement sections which have uniform roughness over 0.25 to 0.50 mile intervals. This allows the rater to think about his/her decision while experiencing the same ride for the entire test section. Because pavement roughness varies, the length of each test section varied to represent a single roughness value. For the 55 mph circuit, test pavement sections varied in length from 0.33 to 0.56 miles. For the 35 mph circuit, test pavement sections varied in length from 0.21 to 0.73 miles.

For the 55 mph circuit, the average roughness values (MI) for the bituminous test sections varied from 37.8 to 171.5. Roughness values for the concrete test sections varied from 82.2 to 158.6. For the 35 mph

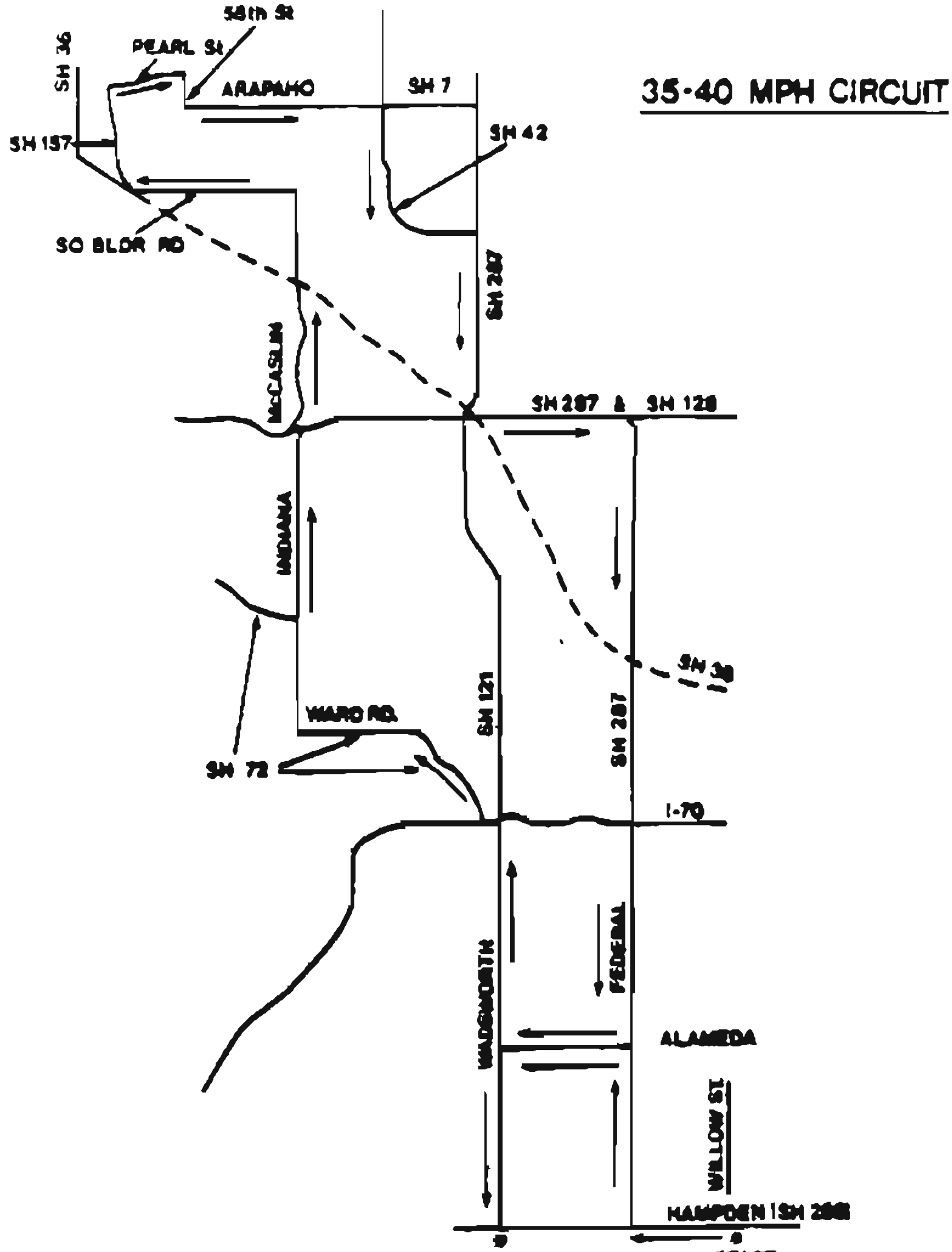


Figure 3. 35 Mile Per Hour Circuit

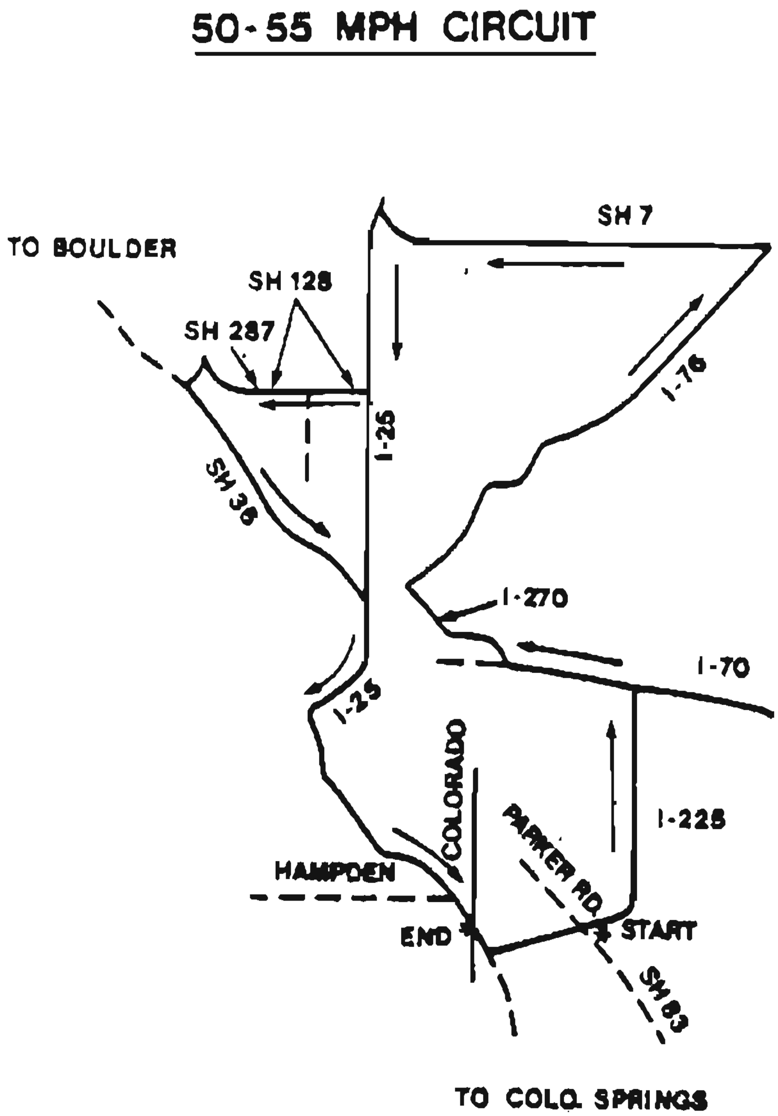


Figure 4. 55 Mile Per Hour Circuit

circuit, roughness values for bituminous sections varied from 37.4 to 281.0. Roughness values for the concrete test sections varied from 96.0 to 136.0.

## 5. Field Ratings

Although previous research (4) had shown that, if administered correctly, all rating scales could be used with equal satisfaction, the Weaver-AASHO Scale was chosen for this study. This scale was selected, in part, because of its previous use in Virginia (11), Indiana (12), Minnesota, Indiana, and Illinois (2), Pennsylvania (13), and others (14), thereby providing the opportunity for comparison and replication between studies. Also, since the CDOH's "roughness levels" use a 5-point serviceability index, a 5-point rating scale would be easier to correlate with their existing pavement rating methodology.

Field ratings were completed on March 16, 1990. The 35 mile per hour route was rated in the morning and the 55 mile per hour route was rated in the afternoon. Rater number 15 was absent for the 55 mph rating. Rater number 4 did not fill out the rater card correctly for the 35 mph route and those scores were disregarded. Therefore, only 23 raters were used in the evaluation process for each route.

The raters had two jobs to perform; determine the appropriate scale between 0 and 5 and decide whether the ride was acceptable or unacceptable. The rating sheets were collected from the raters at the end of each circuit. The raters' responses for each test section are listed in Appendix B.

Eight vehicles provided by the CDOH were used to transport the raters over the test sections. All vehicles were Dodge Aries type K cars with approximately the same number of miles. Data for each vehicle is also shown in Appendix B.

## 6. Replication of Field Ratings

Carey and Irick (3) suggested that each rater should be required to rate the same pavement sections more than once to insure replication of ratings. Only Carey and Irick have implemented this into their pavement rideability studies. They found that panelists did not vary their ratings significantly enough to alter the overall results. The CDOH study therefore accepted this finding and did not attempt to replicate the Carey and Irick study.

However, because of the test circuit set-up, it was possible to rate one section twice. These sections were the 7th and 33rd sections rated on the 35 mph circuit. The mean panel ratings for these test sections are discussed in Chapter IV.

## 7. Validation (Replication) of Panel

The concern here is that the panelists' views are the same as those of the general public. Carey and Irick (3) suggested selecting other groups of users and have them rate the same sections which had been rated by the original panel. They did not, however, find a statistical difference between these groups and the rating panel. No other studies have attempted to replicate this finding.

For the CDOH study, it was not economically feasible to accomplish a validation of the panel. This is probably why other state-funded research projects have not attempted to validate the panel.

## 8. Physical Measurements

Physical measurements of pavement roughness for the given test sections were taken with a Model 8300A Roughness Surveyor (15) on January 9 and 10, 1990 and are shown in Appendix C.

The Surveyor is owned by the CDOH and was purchased from K.J. Law Engineers, Inc., Novi, Michigan. Model 8300A provides a repeatable, non-contact pavement roughness measurement system. It is unaffected by variations in vehicle type, speed, or temperature above 40 degrees Fahrenheit. The system is based on the principles of a patented device, the Inertial Profilometer, which uses an accelerometer to measure vehicle motion and an ultrasonic probe to measure the displacement between the vehicle frame and the road surface. These two readings are then input into the system's on-board computer and used to calculate the roughness index.

The Surveyor's computer calculates the root mean square acceleration (RMSA) index of the road surface and then converts that index to a secondary roughness index based on the Mays Index (MI). In this study, MI values were used as requested by the CDOH.

The surveyor takes a continuous roughness measurment and prints out an average value over the interval specified by the operator. The recommended distance is 0.1 miles, which was used in this study. The average 0.1 mile values were then summed over the section length and divided by the number of tenths of miles contained within the pavement section. These section averages were then used in the CDOH analysis.

## 9. Summaries of Roughness Measurements

Composite Mays Index values for the two test circuits are shown in Appendix C.

## 10. Derivation of Present Serviceability Index

Derivation and discussion of the correlation between panel ratings and roughness values are presented in Chapter IV. Results of the statistical analyses are shown in Appendix D.

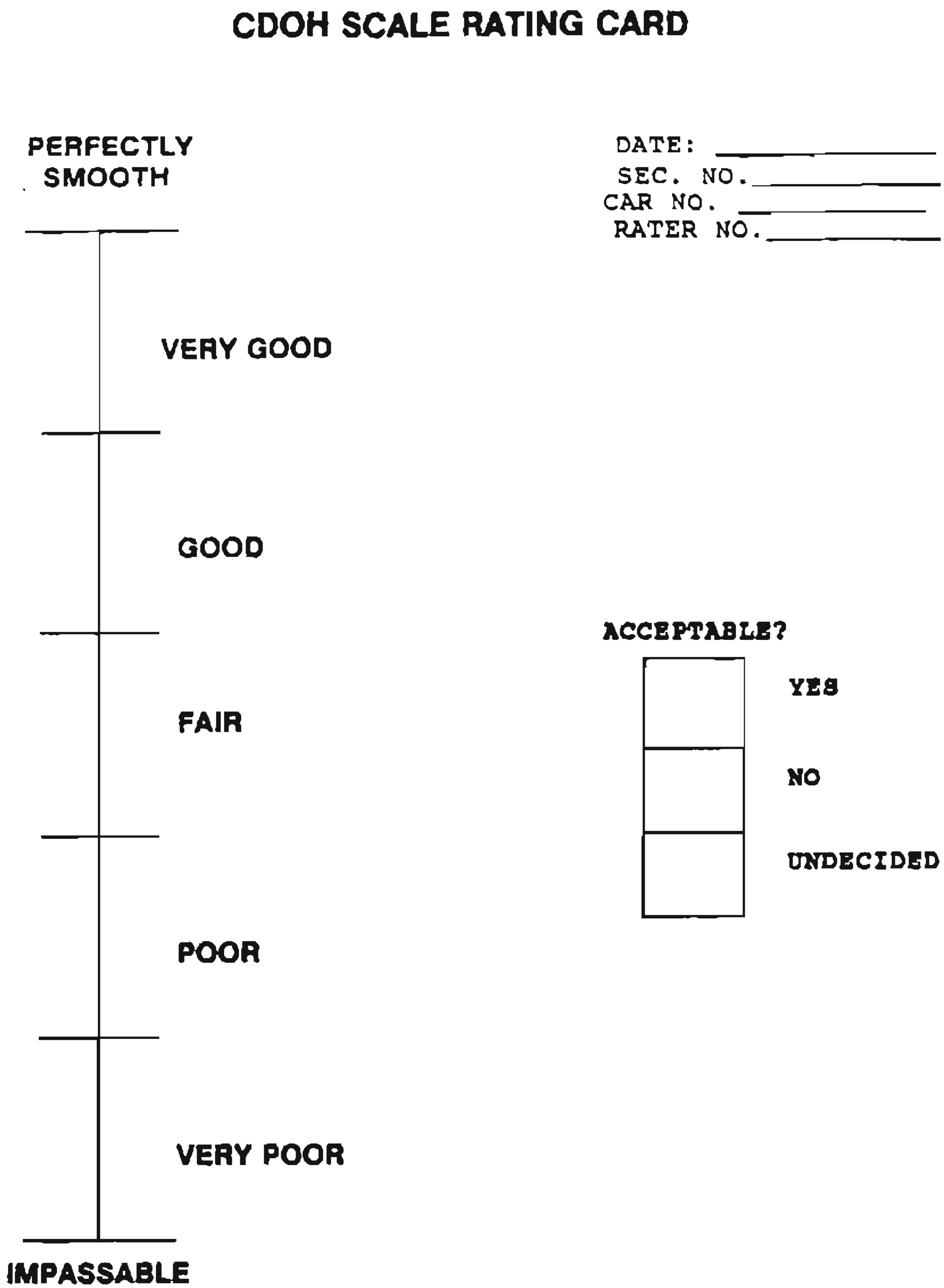


Figure 5. CDOH Rating Card

# CHAPTER IV

# DATA ANALYSIS AND VARIABLE CORRELATION

The objective of this analysis is to correlate the mean panel serviceability ratings with the roughness values (MI number) for each test section. Regression analyses will be performed to determine the best correlation. From raters' responses for 4 pavement sections along the 35 mph route, an initial serviceability value will be determined for concrete pavement. Also, from the raters' responses of unacceptable pavement test sections, a terminal pavement serviceability value will be determined.

However, before either analysis can be undertaken, a separate investigation must be completed to determine which test sections can be grouped together. That is, can all test sections for the 35 mph and 55 mph circuits be grouped as one set of data? Can all the concrete and bituminous pavement sections be grouped? Do the front seat raters give the same rating as the back seat raters, in the same car, or between cars?

To correlate the present serviceability ratings (PSR) and the roughness values (MI numbers), a five step analysis was performed. First, the two back seat rater's PSR's were evaluated to determine if they were statistically different. Next, the back seat ratings were compared with the front seat ratings to determine if all the raters in the same car could be grouped together. Third, an analysis of the variance (ANOVA) was completed to determine if the average ratings from each vehicle were the same. Fourth, regression analyses were performed to correlate PSR values with MI values. Finally, pavement test sections that the raters considered unacceptable were evaluated to determine the public's value of terminal serviceability for different pavements.

Research (4) has shown that there is no statistical difference between ratings due to the rater's seating position within the test vehicle. An analysis was completed to determine if there was a statistical difference among raters within each vehicle for this study. The back right rater's values were compared to the back left rater's values. The average of the means for the back seat were then compared to those of the front seat of each vehicle using a t-test.

Also, the rater values for each vehicle for each pavement section were compared to those of the other vehicles using analysis of variance (ANOVA) to determine if there was a statistical difference between raters in different vehicles.

Next, regardless of seat position or vehicle in which the rating was conducted, raters' responses were grouped into 4 subsets. These subsets are:

- o mean ratings at 35 mph on bituminous test sections
- o mean ratings at 35 mph on concrete test sections
- o mean ratings at 55 mph on bituminous test sections
- o mean ratings at 55 mph on concrete test sections

Regression analyses were used to compare raters' values (PSR's) to the corresponding MI values. Correlations in ratings for bituminous and concrete pavements at both 35 and 55 miles per hour could then be established.

Finally, unacceptable pavement sections, as determined by the raters, were evaluated for the 4 subset categories as defined above for the scale ratings, to determine the raters' perception of terminal pavement serviceability.

**Back Seat Comparison**

To determine if the variations found between back seat left and back seat right ratings were significant, an analysis was done using paired data for each vehicle at 35 mph and at 55 mph. The data for these analyses are shown in Appendix D.

The differences between back right- and left-side rater values and their corresponding standard deviations were calculated. Using the paired data, a hypothesis test was performed to determine, at the 1% significance level, if the data was from two different populations. The numerical value from a t-equation, with 35 degrees of freedom for the 35 mph circuit and 32 degrees of freedom for the 55 mph circuit, was compared to the two-sided critical value obtained from tables for the 99% confidence interval and given degrees of freedom.

If the numerical value calculated from the t-equation was less than the critical value, then the data could be grouped into one population. If, however, the t-equation yielded a value greater than the critical value, then each group of data is from a separate population.

Tables 4.1 and 4.2 show the results of the t-test for each vehicle. The critical t values are 2.73 for 35 mph and 2.74 for 55 mph. As can be seen, 3 of the results for the t-tests exceeded these values. In spite of this, the PSR's for the back seat raters were grouped together for future analysis.

The calculated values which exceeded the critical t-values will be addressed later in this chapter.

**TABLE 4.1 BACK SEAT RATING - 35 MPH CIRCUIT**

35 MPH ROUTE

| CAR # | 10 | 117 | 73 | 127 | 123 | 153 | 114 | 16 |
|---|---|---|---|---|---|---|---|---|
| t VALUE | 2.28 | 1.96 | 2.89 | 2.73 | 2.03 | 3.53 | 1.78 | 0.18 |
| t CRIT | 2.73 | 2.73 | 2.73 | 2.73 | 2.73 | 2.73 | 2.73 | 2.73 |
| | | | * | | | * | | |

* = Critical t-value exceeded

**TABLE 4.2 BACK SEAT RATING - 55 MPH CIRCUIT**

55 MPH ROUTE

| CAR # | 10 | 117 | 73 | 127 | 123 | 153 | 114 | 16 |
|---|---|---|---|---|---|---|---|---|
| t VALUE | 2.12 | 0.00 | 0.46 | 1.29 | | 2.60 | 0.15 | 3.01 |
| t CRIT | 2.74 | 2.74 | 2.74 | 2.74 | 2.74 | 2.74 | 2.74 | 2.74 |
| | | | | | | | | * |

* = Critical t-value exceeded

## Front Seat to Back Seat Comparison

Using the same procedure as outlined in the previous section, an analysis was completed comparing the front seat PSR's to those of the back seat.

The critical values to be used for comparison purposes were arrived at using 35 degrees of freedom for the 35 mph route, 32 degrees of freedom for the 55 mph route and a 99% confidence interval for both routes. As shown in Tables 4.3 and 4.4, 5 of the results of the t tests for the vehicles exceed the critical value determined from tables. In spite of this, all of the PSR's from each of the vehicles were be grouped together for further analysis.

The calculated values which exceeded the critical t-values will be addressed at the end of the next section.

**TABLE 4.3 BACK SEAT VS. FRONT SEAT - 35 MPH CIRCUIT**

| CAR # | 10 | 117 | 73 | 127 | 123 | 153 | 114 | 16 |
|---|---|---|---|---|---|---|---|---|
| t VALUE | 2.35 | | 9.28 | 0.06 | 0.70 | 3.08 | 3.54 | 1.19 |
| t CRIT | 2.73 | 2.73 | 2.73 | 2.73 | 2.73 | 2.73 | 2.73 | 2.73 |
| | | | * | | | * | * | |

* = Critical t-value exceeded

**TABLE 4.4 BACK VS. FRONT SEAT - 55 MPH CIRCUIT**

| CAR # | 10 | 117 | 73 | 127 | 123 | 153 | 114 | 16 |
|---|---|---|---|---|---|---|---|---|
| t VALUE | 1.14 | 6.96 | 2.35 | 10.3 | | 2.56 | 1.85 | 1.78 |
| t CRIT | 2.74 | 2.74 | 2.74 | 2.74 | 2.74 | 2.74 | 2.74 | 2.74 |
| | | * | | * | | | | |

* = Critical t-value exceeded

## Comparison Between Vehicles

The next step was to determine if there was a significant statistical difference among PSR's for different vehicles. The three PSR's for each vehicle were used as inputs for the ANOVA analysis. Each section was taken as a separate case, thus 69 trials were run.

The output of these trials were 69 F-ratios. These ratios were compared to critical F-ratios obtained from tables to determine if the variances between vehicles were statistically significant. If the ANOVA F-ratios exceeded the critical F-values obtained from the tables, then the variances between vehicles were significant. However, if the ANOVA F-ratios were less than the critical F-values, then the differences were insignificant and all of the data could be grouped as one population. The results of the ANOVA analyses are shown in Table 4.5.

The critical F-ratio value from tables, using 7 and 15 degrees of freedom, is 6.31. This value is not exceeded by any of the calculated F-ratios in Table 4.5. Therefore, the PSR variances between cars are not statistically significant and the PSR's may be grouped together as one population.

**TABLE 4.5 - F-RATIOS FOR ANOVA ANALYSES**

| SECTION | F-RATIO | SECTION | F-RATIO | SECTION | F-RATIO |
|---|---|---|---|---|---|
| 1 | 1.48 | 24 | 1.84 | 47 | 0.68 |
| 2 | 3.90 | 25 | 2.08 | 48 | 1.11 |
| 3 | 0.88 | 26 | 0.59 | 49 | 1.65 |
| 4 | 2.45 | 27 | 1.68 | 50 | 0.29 |
| 5 | 2.25 | 28 | 0.62 | 51 | 0.97 |
| 6 | 0.52 | 29 | 0.66 | 52 | 1.35 |
| 7 | 0.56 | 30 | 1.04 | 53 | 0.82 |
| 8 | 1.47 | 31 | 0.98 | 54 | 0.91 |
| 9 | 1.49 | 32 | 1.65 | 55 | 1.46 |
| 10 | 2.78 | 33 | 1.99 | 56 | 1.98 |
| 11 | 1.49 | 34 | 1.72 | 57 | 1.57 |
| 12 | 0.34 | 35 | 0.82 | 58 | 4.00 |
| 13 | 1.19 | 36 | 0.42 | 59 | 1.21 |
| 14 | 2.03 | 37 | 4.21 | 60 | 1.99 |
| 15 | 1.21 | 38 | 2.02 | 61 | 0.77 |
| 16 | 0.34 | 39 | 2.04 | 62 | 1.98 |
| 17 | 0.89 | 40 | 1.37 | 63 | 0.67 |
| 18 | 0.77 | 41 | 1.39 | 64 | 4.79 |
| 19 | 0.29 | 42 | 2.40 | 65 | 1.07 |
| 20 | 1.82 | 43 | 2.58 | 66 | 0.97 |
| 21 | 1.03 | 44 | 5.80 | 67 | 0.89 |
| 22 | 1.99 | 45 | 2.01 | 68 | 0.95 |
| 23 | 1.02 | 46 | 0.61 | 69 | 1.74 |

In the previous sections, 8 critical t-values were exceeded leading to the assumption that there was an effect of seating position on the ratings. However, the remainder of the analysis assumes that there are no statistically significant differences between seat positions within the test vehicle.

The assumption that there is no difference in ratings due to seating position is based on information obtained during the data analysis. The data suggests that a few of the raters may have "check each others answer" during the ratings. That is, they may have looked at other raters' sheets and adjusted their own pavement ratings. This would affect the front seat to back seat analysis by statistically skewing the results toward the back seat ratings. Also, it was noted that a few of the panelists rated the sections consistently lower than others. This would affect the back seat comparison. These "quirks" between ratings leads to the assumption that although 8 of the 29 analyses completed exceed the critical values stated, this was due to incorrect or inconsistent rating techniques, not statistical differences due to seating position. Also, these "quirks" are minor and do not affect the validity of the study.

This assumption is solidified by the fact that the ANOVA analysis between vehicles shows no F-ratio values exceeding the critical F-ratio value. The ANOVA analysis used all data obtained from all pavement sections whereas the seating analysis addressed each vehicle independently. Therefore, all data is considered to be from the same population, whether obtained from a front seat or back seat rater or from different vehicles.

## Concrete and Bituminous PSR VS. MI

Using the ratings from the 35 mph and 55 mph routes separately, four curve fit analyses were completed to determine a correlation between rater PSR's and MRM values. The combined (35 mph and 55 mph) bituminous and concrete ratings were then each analyzed.

The equations used in the analysis included: linear, exponential, power function, logarithmic, inverse dependent and inverse independent.

In general, the equations underestimate the serviceability for smooth pavements. A perfectly smooth pavement (MI = 0 in./mile) should yield a value approaching 5.0. The power functions presented do not have this characteristic. Also, as the MI value approaches infinity, some of the equations do not return a value that approaches 0.0 for PSR. In fact, the linear equations return a negative value. However, these equations are the best fit for the given data.

### Concrete PSR VS. MI Values at 35 MPH

The following equations provide the various linear and transformed models that estimate the Present Serviceability Ratings given MI roughness values (in inches per mile) for concrete pavement at 35 miles per hour.

$$1/PSR = 0.000721 * MI + 0.201451 \quad (r = -0.675)$$

$$\ln (PSR) = -0.002205 * MI + 1.514448 \quad (r = -0.636)$$

**Bituminous PSR VS. MI Values at 35 MPH**

The following equations provide the various linear and transformed models that estimate the PSR given MI roughness values (in inches per mile) for bituminous pavement at 35 miles per hour.

$$\ln (PSR) = -0.003887 * MI + 1.543228 \quad (r = -0.909)$$

$$1/PSR = -0.009820 * MI + 4.222287 \quad (r = -0.904)$$

**Concrete PSR VS. MI Values at 55 MPH**

The following equations provide the various linear and transformed models that estimate the PSR given MI roughness values (in inches per mile) for concrete pavement at 55 miles per hour.

$$1/PSR = 0.001030 * MI + 0.216748 \quad (r = -0.756)$$

$$\ln (PSR) = -0.003047 * MI + 1.449079 \quad (r = -0.749)$$

**Bituminous PSR VS. MI Values at 55 MPH**

The following equations provide the various linear and transformed models that estimate the PSR given MI roughness values (in inches per mile) for bituminous pavement at 55 miles per hour.

$$1/PSR = 0.001204 * MI + 0.215673 \quad (r = -0.873)$$

$$\ln (PSR) = -0.003586 * MI + 1.461337 \quad (r = -0.864)$$

**Combined Concrete and Bituminous Equations**

The following equations provide the various linear and transformed models that estimate the PSR given MI roughness values for all concrete ratings (35 mph and 55 mph), all bituminous ratings (35 mph and 55 mph), all ratings at 35 mph, all ratings at 55 mph, and then all ratings combined for the entire survey.

**Combined 35 MPH and 55 MPH Concrete**

$$1/PSR = 0.000642 * MI + 0.236668 \quad (r = -0.489)$$

$$\ln (PSR) = -0.001902 * MI + 1.395860 \quad (r = -0.459)$$

**Combined 35 MPH and 55 MPH Bituminous**

$$\ln (PSR) = -0.003678 * MI + 1.494468 \quad (r = -0.899)$$

$$1/PSR = 0.001530 * MI + 0.180514 \quad (r = -0.785)$$

**Combined Concrete and Bituminous at 35 MPH**

$$\ln (PSR) = -0.003696 * MI + 1.571731 \quad (r = -0.842)$$

$$1/PSR = -0.009448 * MI + 4.311743 \quad (r = -0.830)$$

**Combined Concrete and Bituminous at 55 MPH**

$$1/PSR = 0.001079 * MI + 0.221763 \quad (r = -0.840)$$

$$\ln (PSR) = -0.003243 * MI + 1.444030 \quad (r = -0.837)$$

**Combined Concrete and Bituminous for all Sections**

$$\ln (PSR) = -0.003362 * MI + 1.493912 \quad (r = -0.823)$$

$$1/PSR = 0.001380 * MI + 0.181907 \quad (r = -0.817)$$

Figures 6 - 11, shown on pages 59-64, illustrate the equations above combined with a scatter plot of the data used to calculate the equations.

## Initial and Terminal Serviceability

Initial and terminal serviceability are important factors in roadway design. They determine how smooth the road should be immediately after construction and how much the road will be allowed to deteriorate prior to renovation. AASHTO (1) recommends the initial serviceability of a pavement be 4.5 and a terminal

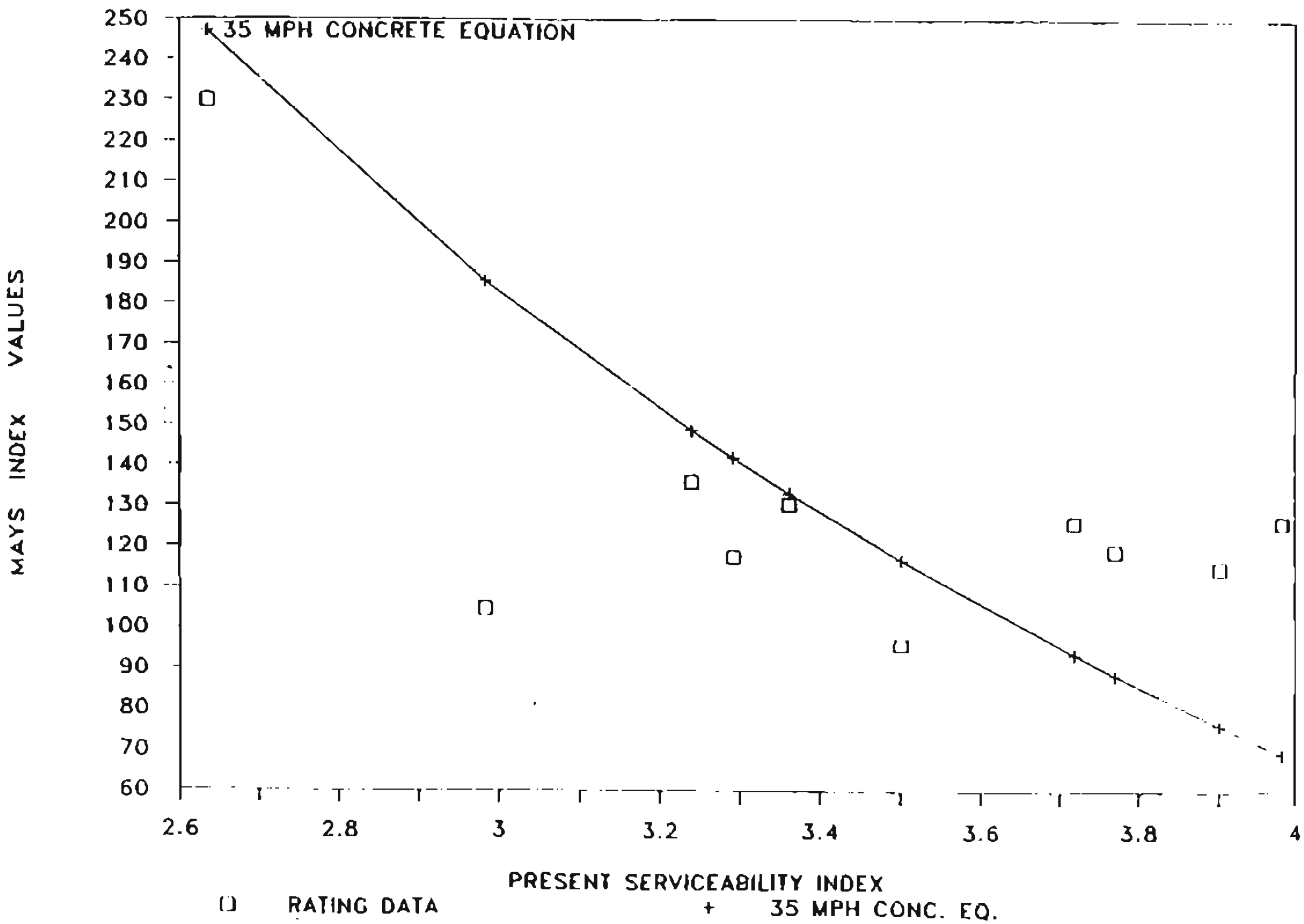


Figure 6. Scatter Diagram - Concrete @ 35 Miles Per Hour

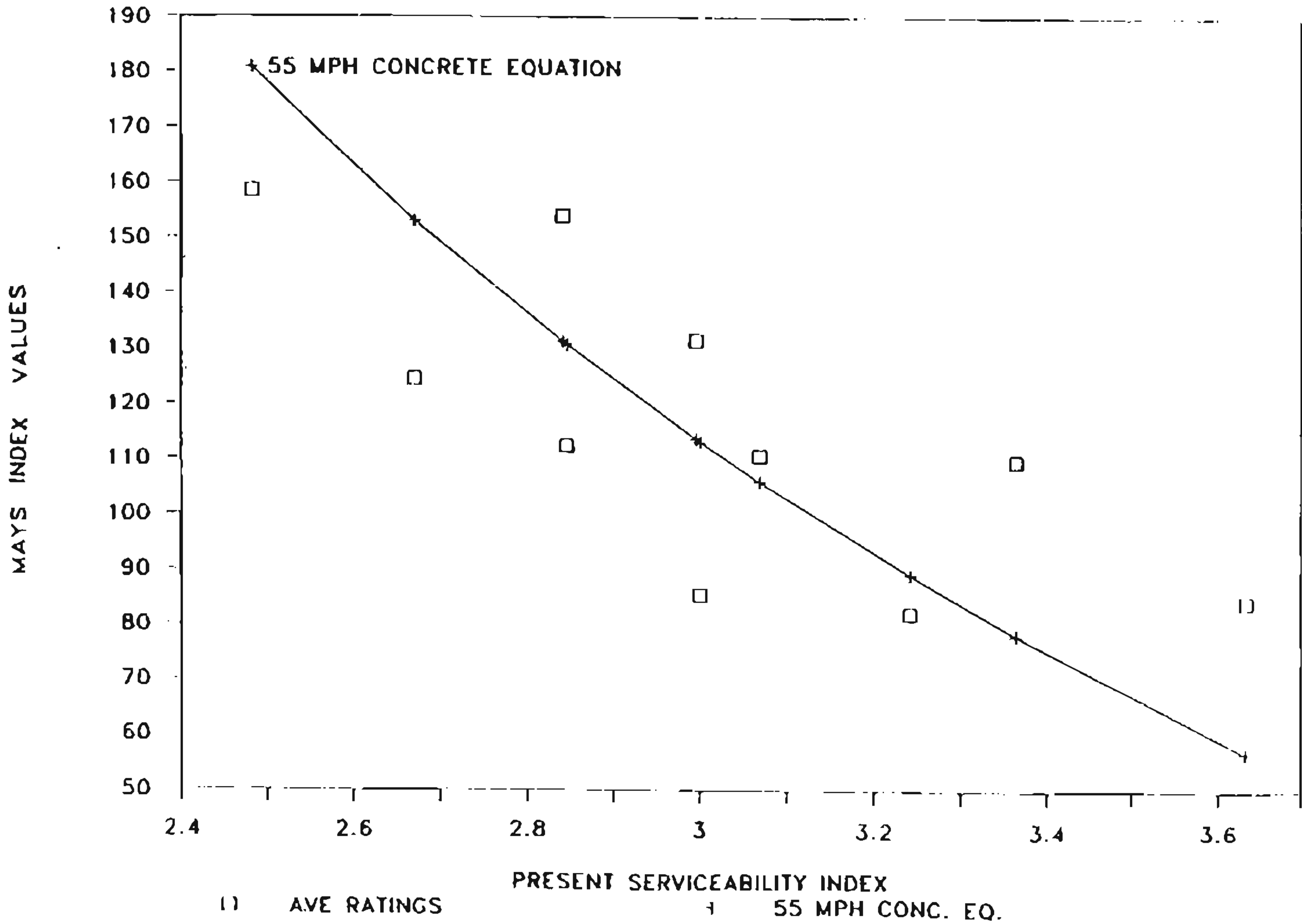


Figure 7. Scatter Diagram - Concrete @ 55 Miles Per Hour

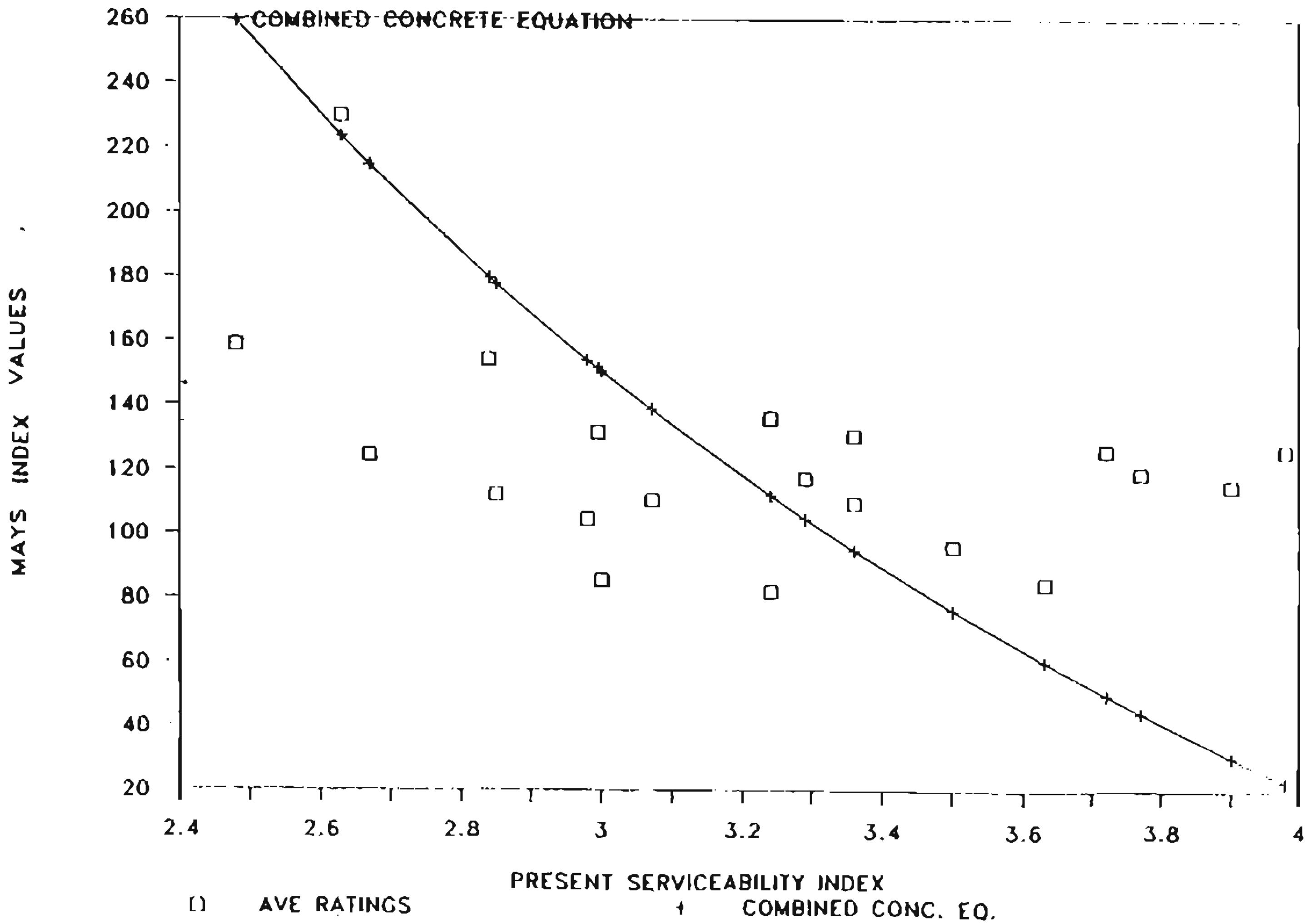


Figure 8. Scatter Diagram - Combined Concrete

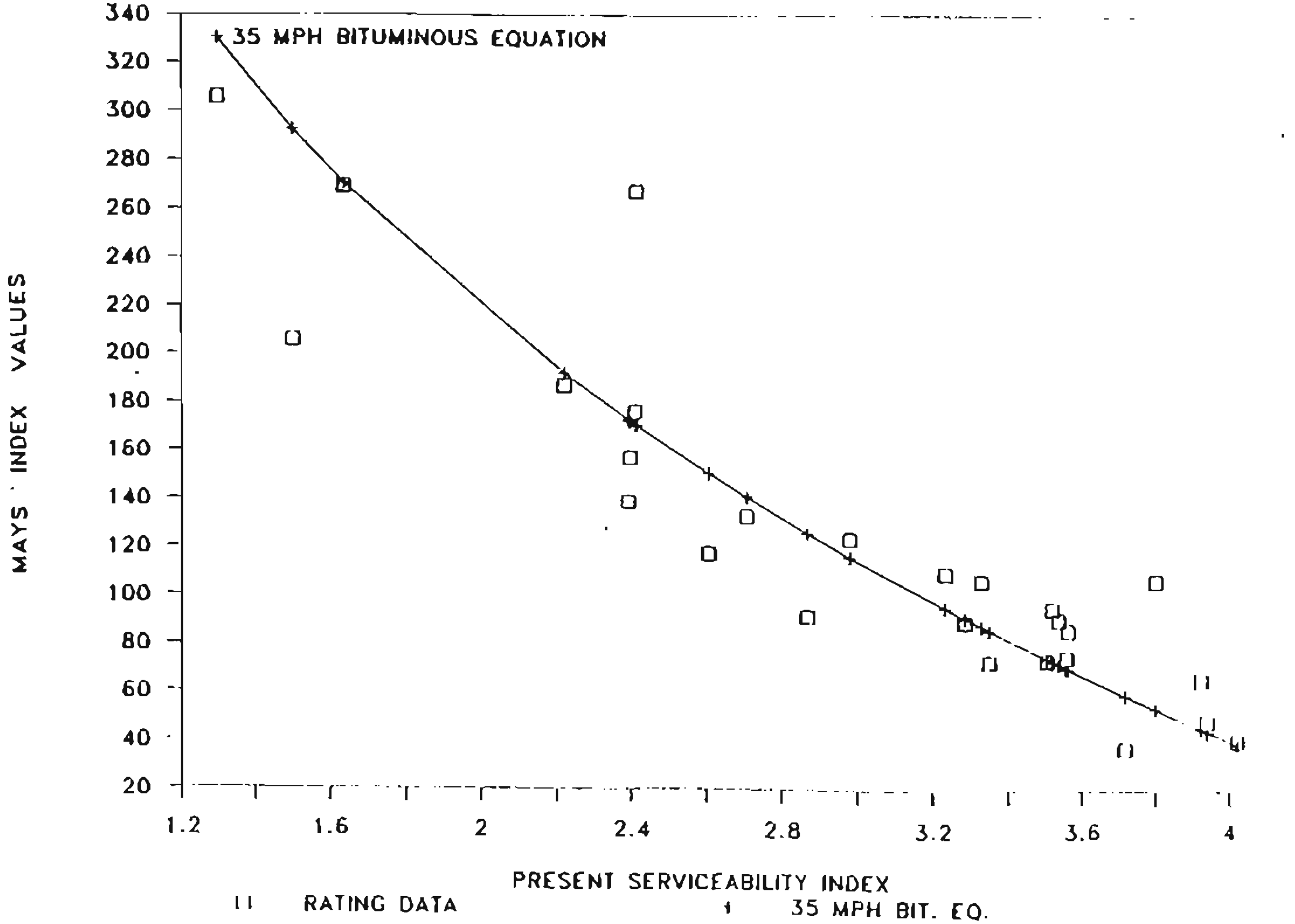


Figure 9. Scatter Diagram - Bituminous @ 35 Miles Per Hour

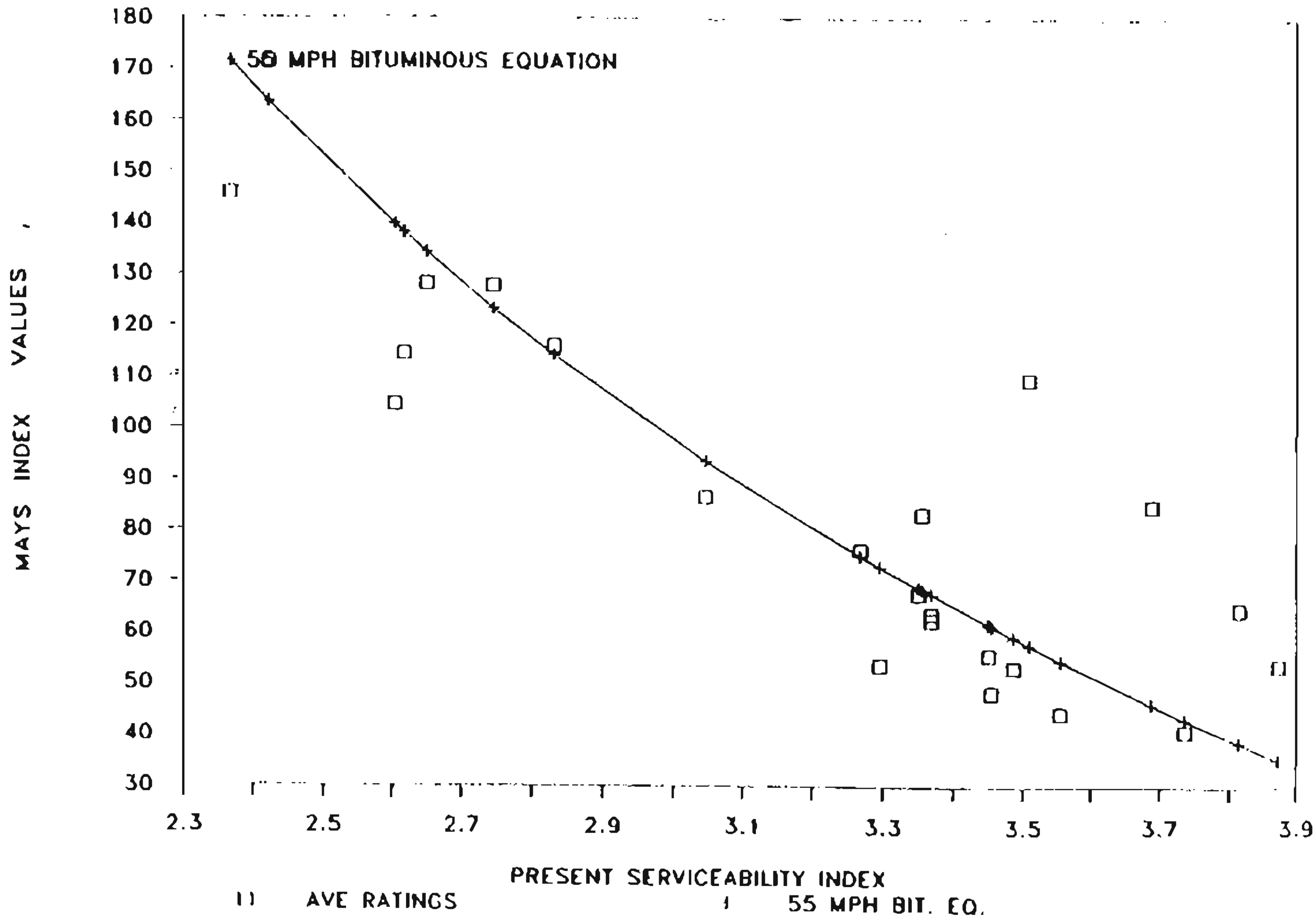


Figure 10. Scatter Diagram - Bituminous @ 55 Miles Per Hour

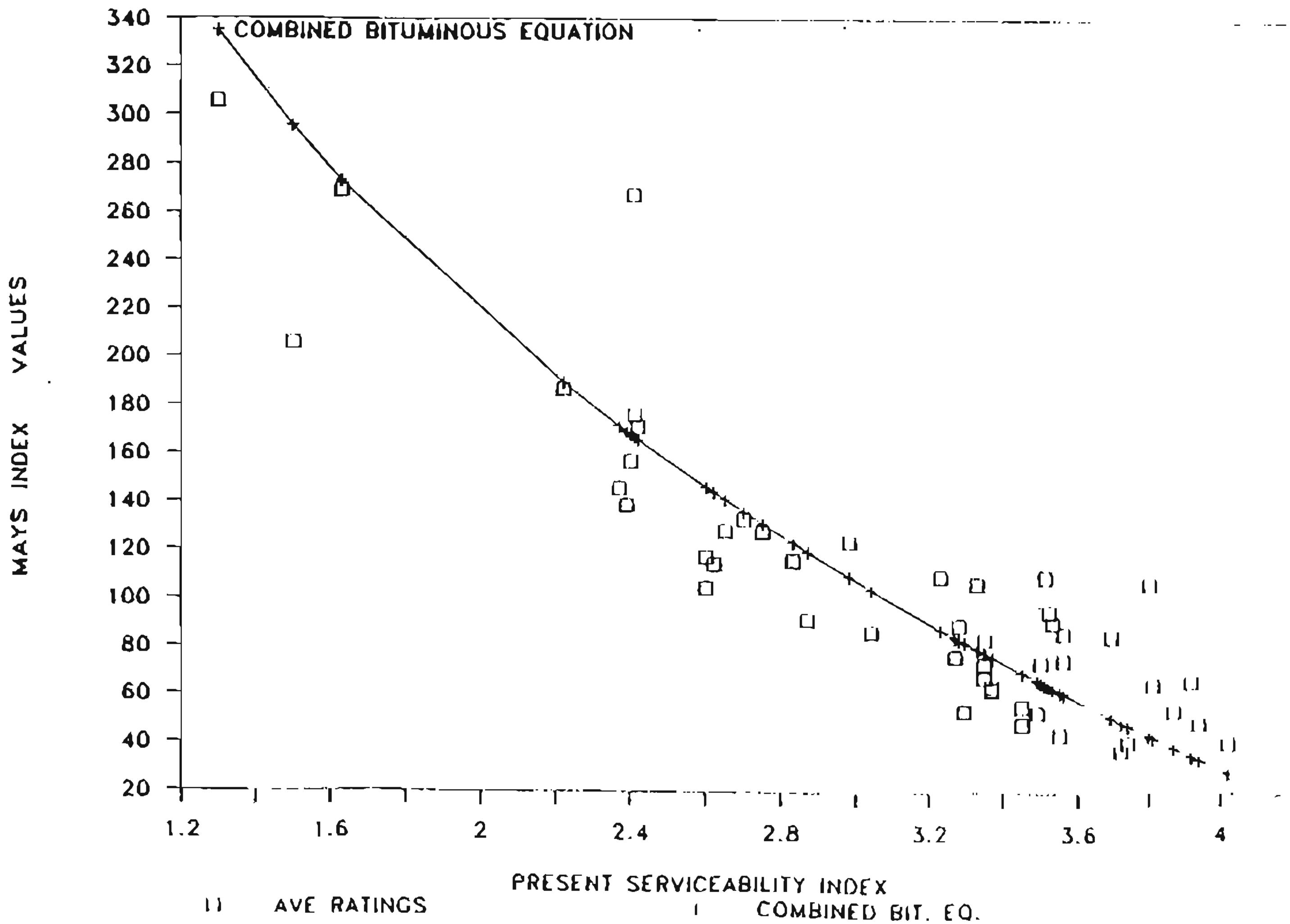


Figure 11. Scatter Diagram - Combined Bituminous

serviceability between 2.0 and 2.5. Major highways should use the 2.5 value and secondary roads the 2.0. The CDOH design staff uses these same values for serviceability.

The CDOH uses a chart to determine levels of rougness from Mays Index (MI) values (Figure 1, p. 8). Currently, this chart does not establish a corrleation between roughness and terminal pavement serviceability. Roughness is broken down into three sections: low, medium, and high. These are determined by their respective MI values which is converted to a PSI values. Table 4.6 shows their current breakdown of MI and PSI values.

**TABLE 4.6 - CDOH ROUGHNESS LEVELS: PSI AND MI VALUES**

| | | MAYS NUMBER | |
|---|---|---|---|
| ROUGHNESS | PSI | CONCRETE | ASPHALT |
| LOW | 5.000-3.601 | 0-77 | 0-88 |
| MEDIUM | 3.600-3.000 | 78-111 | 89-134 |
| HIGH | 2.999-0.000 | 112-500 | 135-500 |

These values correspond to the following transformed models.

$$\ln(PSI) = -0.003801 * MI + 1.611043 \qquad (r = -1.000)$$

$$\ln(PSI) = -0.434240 * \ln(MI) + 3.225451 \qquad (r = -1.000)$$

## Initial Serviceability

As recommended by AASHTO (1), the CDOH design staff currently attempts to provide an initial serviceability of

4.5 for all new pavements. "New" for this study included pavements less than 6 months old. Four pavement sections fell into this category, all constructed of concrete and on the 35 mph circuit. No bituminous sections on either circuit were resurfaced or reconstructed within the past 6 months. Therefore no initial serviceability value for bituminous pavement can be provided.

Two sections on Alameda (#7 and #33) and two on South Boulder Road (#19 and #20) were analyzed. The ratings for these sections were evaluated using the Kolmogorov-Smirnov (KS) test for normal distribution and a 99% confidence interval.

As Table 4.7 shows, all 4 of the pavement section's maximum differences are less than the critical values determined from tables. Therefore, the ratings may be analyzed as a normally distributed population.

**TABLE 4.7 - NORMAL DISTRIBUTION ANALYSIS USING KS TEST INITIAL SERVICEABILITY**

| SECTION | CASES | MAX DIFF | CRIT VALUE |
|---|---|---|---|
| 7 | 23 | 0.170 | 0.33 |
| 19 | 21 | 0.134 | 0.35 |
| 20 | 23 | 0.156 | 0.33 |
| 33 | 23 | 0.177 | 0.33 |

The CDOH is interested in what the public perceives as the initial serviceability of roads. Using a normal curve and calculating the mean, standard deviation, and maximum and minimum values for the sections shown above (7,19,20,and 33), it was possible to prepare Table 4.8. This shows the public's perceived PSR value for initial serviceability, and what percent of the public agrees this value is valid.

**TABLE 4.8 - INITIAL SERVICEABILITY FOR CONCRETE PAVEMENT**

| % OF PUBLIC | INITIAL PSR |
|---|---|
| 10 | 4.48 |
| 20 | 4.26 |
| 30 | 4.11 |
| 40 | 3.97 |
| 50 | 3.85 |

This table shows that 50 percent of the public perceives the initial serviceability index to be 3.85, while only 10 percent of the public perceives the initial serviceability to be 4.48, nearly the value the CDOH strives for in their pavement design. Therefore, the initial serviceability index goal of 4.5 is only perceived as such by 10 percent of the public.

**Terminal Serviceability**

As stated, the CDOH design staff strives to maintain a terminal serviceability value of 2.0 for secondary roads and 2.5 for major highways. The question arises as to whether or not this corresponds to the public's perception of roughness. Repairs should meet the public needs. The following analysis addresses that question.

Unacceptable pavement sections, used to determine terminal serviceability, were tabulated for the following categories: bituminous at 35 mph; bituminous at 55 mph; combined 35 mph and 55 mph bituminous; and combined 35 mph and 55 mph concrete sections. There is only one category for concrete pavement because of the lack of sufficient concrete sections in the test circuits and, correspondingly, the lack of concrete sections rated as unacceptable.

The mean, minimum value, maximum value, standard deviation and number of cases were calculated for each of the groups listed above. Using the Kolmogorov-Smirnov (KS) test for distribution, these groups were analyzed for goodness of fit against a normal distribution. The rating values in each group were standardized to obtain a mean value of 0.0. The maximum difference between these standardized values and an assumed normal cumulative density function were then calculated. If this maximum difference was greater than the critical value (at the 99%

confidence level) as obtained from tables, then the data was not adequately represented by a normal distribution. If, however, these values were less than the critical value (at the 99% confidence level) from tables, then a normal distribution was considered a good representation of the data. The results of the tests are shown in Table 4.9.

This table shows that all of the groups are represented sufficiently by a normal distribution (ie. no

**TABLE 4.9 - NORMAL DISTRIBUTION ANALYSIS USING KS TEST TERMINAL SERVICEABILITY**

| GROUP | # CASES | MAX DIFF | CRIT VALUE |
|---|---|---|---|
| BIT @ 35 MPH | 70 | 0.109 | 0.146 |
| BIT @ 55 MPH | 18 | 0.132 | 0.370 |
| COMB. BIT | 88 | 0.112 | 0.174 |
| COMB. CONC | 13 | 0.129 | 0.420 |

maximum difference was greater than the critical value). Therefore, terminal PSR values will be calculated using various areas under a normal curve.

To be of use to the CDOH, the percent of public which is dissatisfied must be calculated. This was done using a standard normal curve (ie. using various areas under the normal curve). Assuming 50% of the public is satisfied with the pavement roughness at the mean value for each of the above categories, calculations were made to determine the 40%, 30%, 20% and 10% dissatisfaction values for PSR. Tables 4.10 - 4.13 summarize the percent of the public which is dissatisfied at given PSR values.

To derive the 60% to 90% dissatisfied values would not be of use to the highway department. If 50% of the travelling public is dissatisfied with a pavement, the highway department should already be aware the pavement is in need of repair and data supporting this would not be significant.

**TABLE 4.10 - TERMINAL SERVICEABILITY FOR BIT. AT 35 MPH**

| % DISSATISFIED | % SATISFIED | TERMINAL PSR |
|---|---|---|
| 10 | 90 | 2.19 |
| 20 | 80 | 1.97 |
| 30 | 70 | 1.82 |
| 40 | 60 | 1.68 |
| 50 | 50 | 1.55 |

**TABLE 4.11 - TERMINAL SERVICEABILITY FOR BIT. AT 55 MPH**

| % DISSATISFIED | % SATISFIED | TERMINAL PSR |
|---|---|---|
| 10 | 90 | 2.50 |
| 20 | 80 | 2.31 |
| 30 | 70 | 2.18 |
| 40 | 60 | 2.06 |
| 50 | 50 | 1.95 |

**TABLE 4.12 - TERMINAL SERVICEABILITY FOR COMBINED BIT.**

| % DISSATISFIED | % SATISFIED | TERMINAL PSR |
|---|---|---|
| 10 | 90 | 2.28 |
| 20 | 80 | 2.06 |
| 30 | 70 | 1.90 |
| 40 | 60 | 1.76 |
| 50 | 50 | 1.63 |

**TABLE 4.13 - TERMINAL SERVICEABILITY FOR COMBINED CONC.**

| % DISSATISFIED | % SATISFIED | TERMINAL PSR |
|---|---|---|
| 10 | 90 | 2.67 |
| 20 | 80 | 2.45 |
| 30 | 70 | 2.29 |
| 40 | 60 | 2.15 |
| 50 | 50 | 2.02 |

It should be noted that the public's perception of terminal serviceability for bituminous pavements at 35 mph (50% terminal PSR of 1.55) and at 55 mph (50% terminal PSR of 1.95) differ significantly. This coincides with the idea that the public wants the 55 mph ride to be smoother than that of the 35 mph ride and should be taken into account in the design and reconstruction of all roadways.

These terminal PSR values were obtained using the data from the ratings conducted for this study. The next step is to relate these calculated values to those currently in use by the CDOH. As stated previously, the CDOH uses roughness levels to indicate the present serviceability index. PSI and corresponding MI values for the CDOH roughness levels are explained on page 55 of this study. To relate the terminal serviceability values shown above to those in use by the CDOH requires the following steps.

1. Convert the calculated PSR values shown above to MI values using the regression equations given on pages 46-48.

2. Using the MI values obtained in step 1 and the CDOH equation shown on page 55, calculate the corresponding CDOH PSI values.

3. Compare these PSI's with those shown on the CDOH roughness levels.

Since the CDOH roughness levels do not differentiate between 35 mph and 55 mph, only the combined concrete and combined bituminous pavement analyses were conducted. These calculations are summarized in Tables 4.14 and 4.15.

**TABLE 4.14 - PUBLIC PERCEPT. VS. CONDITION STATES VALUES BITUMINOUS PAVEMENT**

| % DISSATISFIED | PUBLIC PERCEPTION | CDOH PSI |
|---|---|---|
| 10 | 2.28 | 2.51 |
| 20 | 2.06 | 2.25 |
| 30 | 1.90 | 2.07 |
| 40 | 1.76 | 1.91 |
| 50 | 1.63 | 1.77 |

**TABLE 4.15 - PUBLIC PERCEPT. VS. CONDITION STATES VALUES CONCRETE PAVEMENT**

| % DISSATISFIED | PUBLIC PERCEPTION | CDOH PSI |
|---|---|---|
| 10 | 2.67 | 2.21 |
| 20 | 2.45 | 1.82 |
| 30 | 2.29 | 1.53 |
| 40 | 2.15 | 1.29 |
| 50 | 2.02 | 1.09 |

All of the public perception terminal PSR values for bituminous pavement are lower than the PSI values currently used by the CDOH. This would indicate that bituminous roads and highways are repaired and/or reconstructed prior to the time when the public feels it is necessary.

All of the public perception terminal PSR values for concrete pavement are higher than the PSI values used by the CDOH. This indicates that the concrete pavements are reconstructed when approximately 5 percent of the travelling public is dissatisfied.

Graphs of the CDOH roughness levels versus the calculated combined bituminous and combined concrete PSR's are shown on pages 64-65 (Figures 12 and 13).

## Replication of Panel Ratings

Carey and Irick (3) suggested that panelists evaluate the same test sections more than once to ensure replication of ratings. Due to the circuit layout and the limited funding available for the CDOH study, only one pavement section (#7 and #35 along the 35 mph circuit) was rated twice. Section #7 was the first section rated and section #35 was the last section rated.

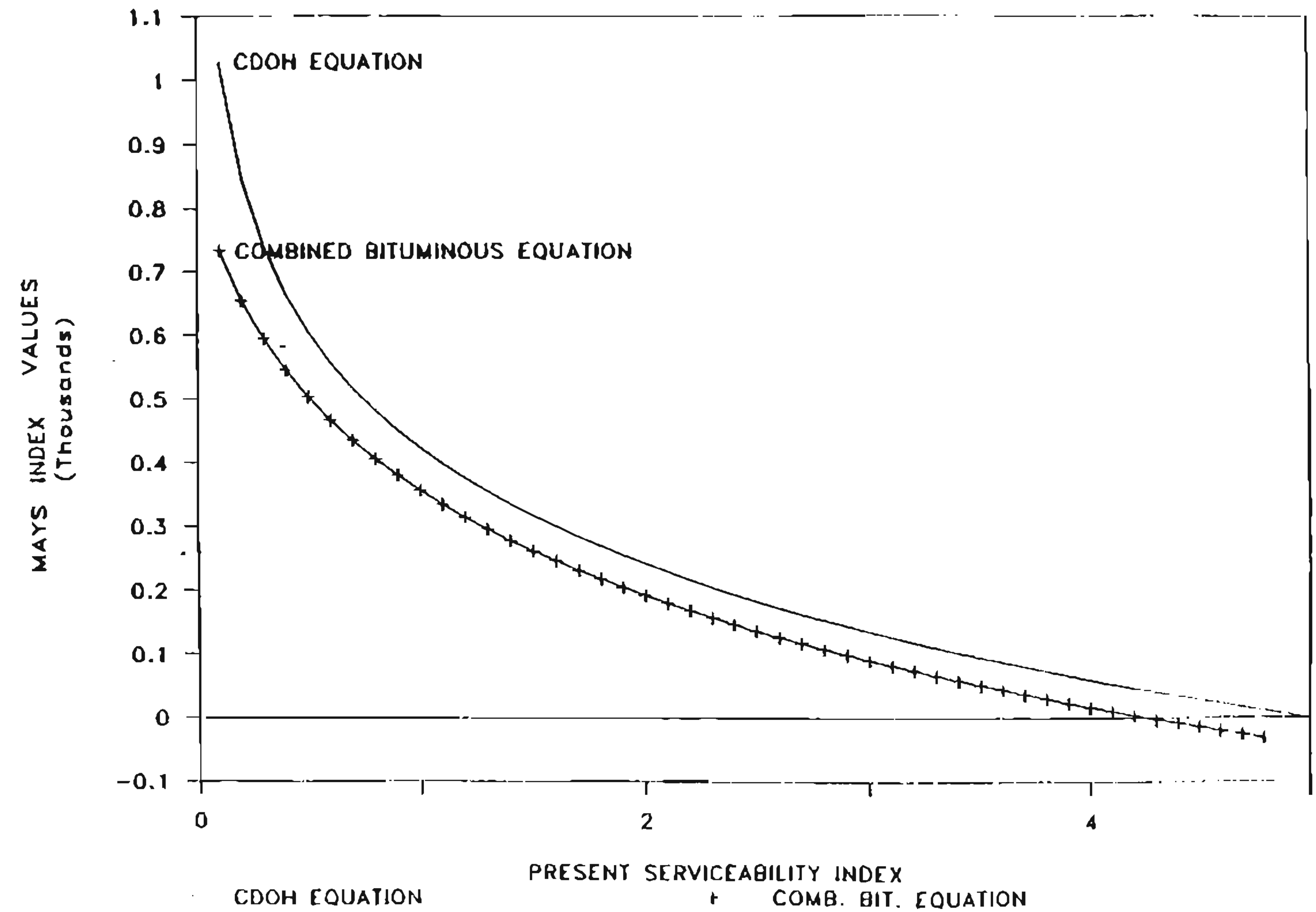


Figure 12. Graph of Condition States Equation vs. Combined Bituminous Pavement

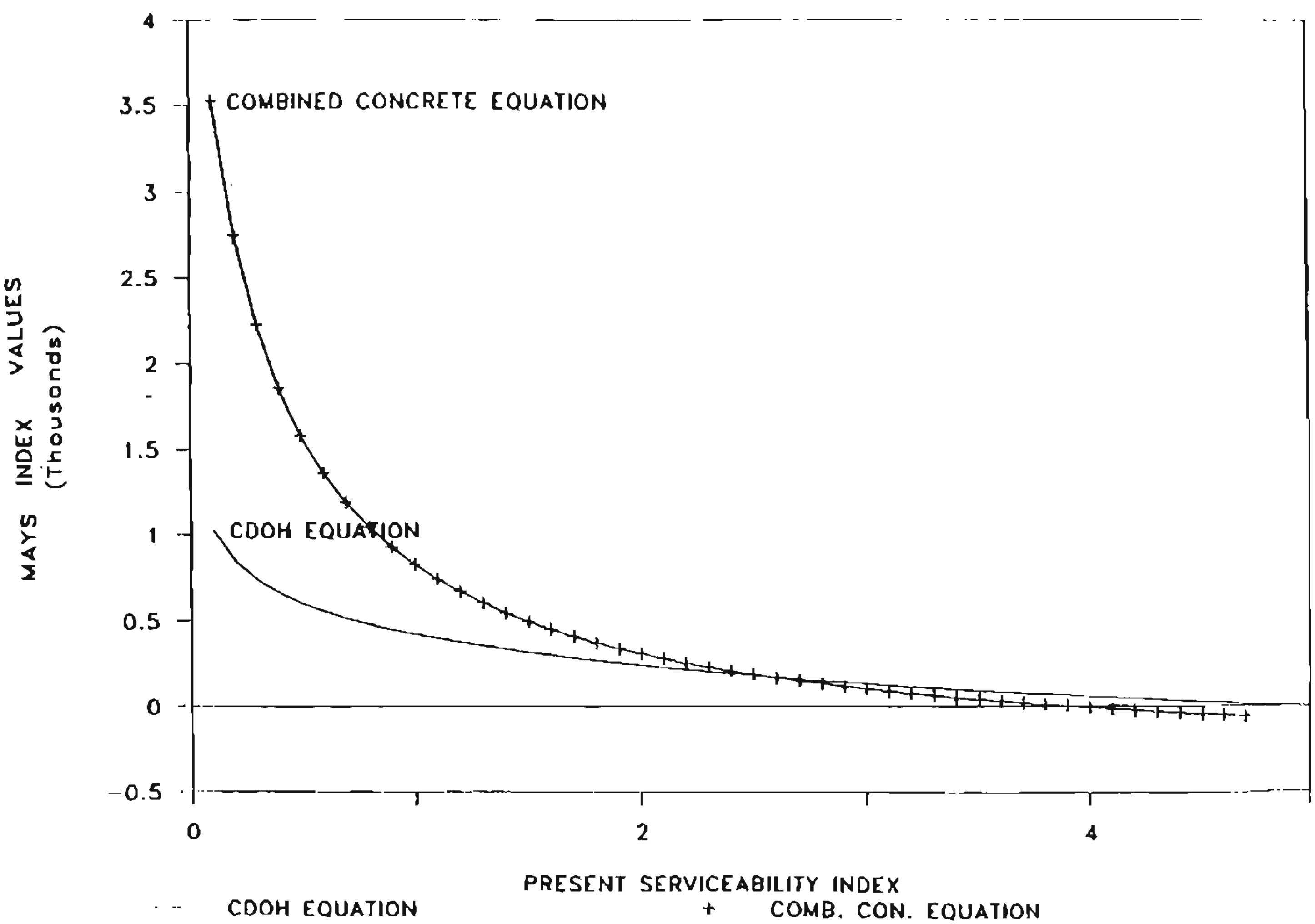


Figure 13. Graph of Condition States Equation vs. Combined Concrete Pavement

The mean value for each rating was calculated along with the standard deviation. Table 4.16 shows the results of this analysis.

**TABLE 4.16 - REPLICATION OF RATINGS**

| SECTION | RATINGS | MIN | MAX | MEAN | STD DEV |
|---|---|---|---|---|---|
| 7 | 23 | 2.9 | 4.7 | 4.03 | 0.467 |
| 33 | 23 | 2.6 | 4.8 | 3.72 | 0.587 |

To determine if the difference in the means of sections 7 and 33 was statistically significant, a double-sided t-test was used. The t-value calculated for this test was 2.785. There were 23 ratings which were evaluated. Therefore, 22 degrees of freedom and a 99% confidence interval were used to obtain a critical t-value of 2.81 from the tables.

Since the calculated t-value is less than that of the critical value obtained from tables, the variance in the means of sections 7 and 33 is not statistically significant. The difference in mean values (0.31 scale units) does raise the question of whether or not the raters learn and adjust their ratings as they continue to rate sections. There is the possibility that 3 to 5 dummy sections should be placed at the start of each circuit to familiarize the raters with the task at hand. This is outside the scope of this study but is addressed further in Chapter VI, Recommendations for Future Studies.

# CHAPTER V

# DISCUSSION

The Kansas Department of Transportation (KDOT) completed a study similar to this in 1985 (6). Regression equations were presented in that paper which relates PSR to MI for various pavement types. Although the KDOT study did not attempt to provide equations for different speeds, much of their work dealt with the same aspects of pavement serviceability as the study just completed for the Colorado Department of Highways. Due to the geographical proximity, a brief comparison of the results of the two studies is warranted.

The analysis completed by KDOT included regression equations for full-design bituminous pavement and portland cement concrete pavement, just as the CDOH study. The equation types and corresponding correlation coefficients (r values) for the KDOT study and the CDOH study are shown in Table 5.1.

The correlation coefficients for bituminous pavements are very similar between the two studies.

However, the KDOT developed a much better regression equation to represent the concrete pavements. This is most likely due to the fact that between 24 and 30

**TABLE 5.1 - REGRESSION EQUATIONS AND R VALUES**

| STUDY | PVMT TYPE | EQUATION | R VALUE |
|---|---|---|---|
| CDOH | BITUMINOUS | EXPONENTIAL | -0.899 |
| | BITUMINOUS | INVERSE | -0.785 |
| KDOT | BITUMINOUS | LINEAR | -0.820 |
| | BITUMINOUS | POWER FUNC. | -0.820 |
| CDOH | CONCRETE | INVERSE | -0.489 |
| | CONCRETE | EXPONENTIAL | -0.459 |
| KDOT | CONCRETE | POWER FUNC. | -0.820 |
| | CONCRETE | LINEAR | -0.770 |

concrete sections were rated versus 18 in the CDOH study.

The KDOT equations had high correlation coefficients but had problems representing the data when the pavements were smooth. A perfectly smooth pavement (MI = 0) should return a PSR value of 5.0. None of the KDOT equations had this characteristic but many of the CDOH equations do satisfy this constraint.

The KDOT study concluded that for panel sizes of 24, the average standard deviation of individual panel ratings over all pavement types is approximately 12 percent of the maximum scale value (0.60 on a scale of 5). The CDOH study had a panel size of 24 and a standard deviation over all pavement types of 0.80, corresponding to 16 percent of the maximum scale value. The CDOH study's statistics for various pavement groupings are shown in Table 5.2.

There were many similarities between the two studies including rating panel size (24), rating scale used (Weaver-AASHO), number of sections per circuit

**TABLE 5.2 - STATISTICS FOR VARIOUS PAVEMENT GROUPINGS**

| GROUPING | MEAN | MIN | MAX | STD DEV |
|---|---|---|---|---|
| BIT @ 35 | 2.99 | 0.4 | 4.9 | 0.92 |
| BIT @ 55 | 3.21 | 1.0 | 4.7 | 0.70 |
| COMB BIT | 3.09 | 0.4 | 4.9 | 0.84 |
| CONC @ 35 | 3.43 | 1.4 | 4.8 | 0.66 |
| CONC @ 55 | 3.02 | 1.3 | 4.8 | 0.67 |
| COMB CONC | 3.23 | 1.3 | 4.8 | 0.70 |
| ALL SECTS | 3.13 | 0.4 | 4.9 | 0.80 |

(approximately 36), and the instructions to raters used. The instructions used by the CDOH study were modified slightly to accommodate other information found in the literature review.

The issues of initial and terminal pavement serviceability were addressed in the CDOH study but not included by the KDOT. These are critical serviceability values and should be included in the analysis when raters are asked to determine which pavement sections are unacceptable.

Overall, the two studies returned similar results for the correlation between PSR and MI data. However, the regression equations developed in each study do not exhibit all of the same qualities.

# CHAPTER VI

## CONCLUSIONS AND RECOMMENDATIONS

Based on the two circuits used for ratings (35 mph and 55 mph), a 24 member rating panel, 1700 data points, 69 pavement sections, literature research, and the previous discussions and analyses, the following conclusions can be drawn.

1. The seating position within a vehicle did not influence the raters' ability to subjectively rate a pavement section. There was also no statistical significant difference in ratings between the different vehicles in this study.

2. Statistical significant linear, exponential and power function models were developed to determine PSR given MI data. However, some of these equations are conceptually incorrect for extreme values, ie. MI values approaching 0 or infinity.

3. The public's perception of pavement serviceability (PSR) for bituminous pavements is lower than the PSI

equation in use by the CDOH roughness levels. The public views bituminous pavements as being rougher than the CDOH believes they are.

4. The public's perception of pavement serviceability (PSR) for concrete pavements is higher than the PSI currently in use by the CDOH at the high end of the rating scale, ie. very smooth pavements, and lower than the CDOH values on the low end of the scale, ie. very rough pavements (see Figure 13, page 65).

5. Public perception of initial serviceability (PSR) values for concrete pavements is less than that which the CDOH strives for in design.

6. Public perception of the terminal serviceability (PSR) values for bituminous pavements is lower than those currently in use by the CDOH. Perception of the terminal serviceability values for concrete values is higher than those currently in use by CDOH staff design.

The public's perception of the terminal serviceability value in relation to the value used by the CDOH is best illustrated by an example.

The terminal serviceability value used by the CDOH design staff is 2.5 for major highways. Table 4.14 shows that, for bituminous pavements, only 10 percent of the travelling public is dissatisfied when a pavement has a PSI value of 2.51. Therefore, bituminous pavement highways are reconstructed when only 10 percent of the public is dissatisfied.

The CDOH design staff uses a terminal serviceability index for secondary highways of 2.0. Table 4.14 shows that 30 percent of the public is dissatisfied at this PSI value. This is probably the appropriate time to renovate a road.

For concrete pavements, Table 4.15 shows that a terminal serviceability index of 2.5 corresponds to approximately 5 percent of the public dissatisfied. A terminal serviceability index of 2.0 corresponds to about 15 percent of the public dissatisfied. Therefore, major concrete highways are reconstructed when only 5 percent of the public is upset with the ride. Secondary roads are reconstructed when approximately 15 percent of the public is dissatisfied.

## Implementation of Results

The authors recommend the overall terminal serviceability index for bituminous pavements to be 2.5 and for concrete pavements to be 2.2. At these recommended values, 90% of the public would be satisfied with the ride.

An overall terminal serviceability index for bituminous pavements can be misleading. Raters expressed a significant preference for a smoother ride at 55 mph than while traveling at 35 mph. Although the recommended combined terminal serviceability index is 2.5, the recommended terminal serviceability index for bituminous pavements at 35 mph is 1.9 and at 55 mph is 2.8. This indicates the riders definite preference for a smoother ride at faster speeds. The recommended terminal serviceability index at 35 mph and 55 mph is based on 90% of the public being satisfied with the ride.

The recommended terminal serviceability index for concrete can't be refined any further. The data base for these sections was minimal when compared to that of bituminous pavement. Therefore, these concrete values do not carry the same weight and/or statistical significance as the bituminous values.

Due to the limited database, recommendations can't be made regarding initial serviceability index for either concrete or bituminous pavements. The initial serviceability index determined for concrete pavement is based upon only 4 pavement sections. Without further investigation, these values should not be used except for discussion purposes. There was not enough data obtained in this study to alter the design and/or construction criteria currently used for new pavements.

For studies on pavement rideability raters determine when a pavement is acceptable or unacceptable. Unfortunately, the rating system does not differentiate between higher ratings. A PSR of 3.2 is better than 3.0 but this rating is difficult to translate into a good, fair, or poor category. This study can't be used to determine if the current 3.6 or 3.0 thresholds set by the CDOH are reasonable or acceptable.

## Recommendations for Future Studies

The following recommendations for future study are suggested.

1. This study did not find a statistical difference between the two ratings of the same pavement section. However, there was a difference in the means of the ratings. Possible future studies could analyze the learning curve effect on panelists during the rating of sections. By this it is meant that 5 to 6 dummy sections

could be included at the start of the rating session to prepare the raters for the task at hand, then rate the same 5 to 6 sections at the end of the circuit to determine if the ratings change substantially.

2. Although there are a minimum number of studies which address the question of terminal serviceability, this should be included in future research to aid the highway departments in determining the public's perception.

3. Initial serviceability should be studied further. Perhaps ratings of new pavements could take place at the end of the paving season to determine the public's perception of initial serviceability.

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# APPENDIX A.

# DESCRIPTIONS OF 35 MPH AND 55 MPH CIRCUITS

35 - 40 MILE PER HOUR ROUTE

Start at the intersection of Willow Street and State Highway 285 (Hampden Avenue), go west on SH 285 to SH 287 (Federal Boulevard), go north on SH 287 to Alameda, go west on Alameda to SH 121 (Wadsworth), go north on SH 121 to I-70, go west on I-70 to SH 72, go north on SH 72 to Indiana Street, go north on Indiana to SH 128, go west on SH 128 to McCaslin, go north on McCaslin to South Boulder Road, go west on South Boulder Road to SH 157 (Foothills Parkway), go north on SH 157 to Pearl Street, go east on Pearl Street to 55th Street, go south on 55th Street to SH 7 (Arapaho Road), go east on SH 7 to SH 42, go south on SH 42 to SH 287, go south on SH 287 to Alameda, go west on Alameda to SH 121, go south on SH 121 to SH 285.

This route is approximately 85 miles long and took approximately 3 hours to complete the ratings along these roads.

55 MILE PER HOUR ROUTE

Start at the intersection of State Highway 83 (Parker Road) and Interstate 225, go northeast on I-225 to I-70, go west on I-70 to I-270, go northwest on I-270 to I-76, go north on I-76 to SH 7, go west on SH 7 to I-25, go south on I-25 to SH 128, go west on SH 128 to SH 36, go southeast on SH 36 to I-25, and go south on I-25 to Colorado Boulevard.

This route is approximately 80 miles long and took approximately 2 hours to complete the ratings along these roads.

# APPENDIX B.

# PANELISTS' COMPOSITE RATINGS

**PANELIST RATINGS FOR 35 MILE PER HOUR ROUTE**

| RATER # | CAR # | SEAT # | SECTION # 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 10 | 1 | 3.5 | 2.0 | 3.8 | 3.5 | 2.4 | 2.5 | 4.0 |
| 2 | 10 | 2 | 2.7 | 1.8 | 3.8 | 2.9 | 1.9 | 1.9 | 4.5 |
| 3 | 10 | 3 | 3.5 | 3.1 | 3.7 | 3.4 | 2.2 | 2.5 | 4.4 |
| 4 | 117 | 1 | | | | | | | |
| 5 | 117 | 2 | 3.2 | 2.3 | 3.4 | 2.7 | 2.6 | 2.1 | 3.4 |
| 6 | 117 | 3 | 3.2 | 1.7 | 3.8 | 1.8 | 4.1 | 2.8 | 3.8 |
| 7 | 73 | 1 | 3.2 | 2.2 | 3.8 | 1.6 | 3.2 | 1.9 | 3.5 |
| 8 | 73 | 2 | 3.5 | 3.2 | 4.0 | 2.9 | 3.4 | 4.2 | 4.4 |
| 9 | 73 | 3 | 4.0 | 2.6 | 3.9 | 2.6 | 3.2 | 2.5 | 4.5 |
| 10 | 127 | 1 | 4.0 | 2.6 | 3.9 | 2.6 | 3.2 | 2.5 | 4.5 |
| 11 | 127 | 2 | 3.7 | 2.9 | 3.2 | 2.9 | 3.1 | 2.9 | 3.8 |
| 12 | 127 | 3 | 3.4 | 1.3 | 3.3 | 2.4 | 3.2 | 1.4 | 4.4 |
| 13 | 123 | 1 | 2.2 | 1.5 | 4.0 | 2.0 | 3.6 | 3.5 | 4.4 |
| 14 | 123 | 2 | 3.8 | 1.8 | 3.5 | 2.0 | 2.8 | 2.3 | 3.7 |
| 15 | 123 | 3 | 2.2 | 2.1 | 4.3 | 1.9 | 2.7 | 2.7 | 4.1 |
| 16 | 153 | 1 | 4.1 | 3.7 | 3.2 | 2.2 | 3.2 | 3.4 | 4.1 |
| 17 | 153 | 2 | 3.6 | 2.4 | 3.3 | 2.1 | 3.0 | 2.8 | 4.2 |
| 18 | 153 | 3 | 3.5 | 2.5 | 3.5 | 3.4 | 3.4 | 2.5 | 3.4 |
| 19 | 114 | 1 | 3.1 | 2.1 | 3.1 | 2.2 | 3.1 | 2.2 | 4.1 |
| 20 | 114 | 2 | 3.1 | 2.4 | 3.5 | 2.2 | 2.6 | 3.0 | 3.4 |
| 21 | 114 | 3 | 3.7 | 2.7 | 3.3 | 2.1 | 2.9 | 2.8 | 4.0 |
| 22 | 16 | 1 | 3.8 | 1.1 | 2.5 | 2.1 | 3.1 | 3.1 | 4.7 |
| 23 | 16 | 2 | 3.0 | 2.0 | 3.5 | 2.0 | 3.1 | 3.0 | 4.4 |
| 24 | 16 | 3 | 3.5 | 2.1 | 3.7 | 2.8 | 3.4 | 3.2 | 2.9 |
| PAVEMENT TYPE: | | | BIT | BIT | BIT | BIT | BIT | BIT | CON |

BIT: BITUMINOUS
CON: CONCRETE
SEAT NUMBER 1: FRONT RIGHT
SEAT NUMBER 2: BACK LEFT
SEAT NUMBER 3: BACK RIGHT

**DATA FOR 35 MILE PER HOUR ROUTE**

| | | | SECTION # | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| RATER # | CAR # | SEAT # | 8 | 9 | 10 | 11 | 12 | 13 | 14 |
| 1 | 10 | 1 | 2.5 | 2.7 | 2.2 | 3.7 | 2.8 | 3.8 | 3.9 |
| 2 | 10 | 2 | 3.4 | 2.4 | 3.0 | 3.2 | 3.3 | 3.5 | 3.2 |
| 3 | 10 | 3 | 3.8 | 2.8 | 2.8 | 3.0 | 2.8 | 3.9 | 3.9 |
| 4 | 117 | 1 | | | | | | | |
| 5 | 117 | 2 | 3.5 | 3.9 | 4.3 | 4.3 | 3.0 | 3.5 | 4.6 |
| 6 | 117 | 3 | 2.4 | 1.3 | 4.1 | 4.2 | 3.1 | 4.3 | 3.8 |
| 7 | 73 | 1 | 2.2 | 1.7 | 3.5 | 2.9 | 2.0 | 3.2 | 3.5 |
| 8 | 73 | 2 | 3.6 | 3.1 | 3.9 | 4.0 | 3.8 | 4.0 | 4.0 |
| 9 | 73 | 3 | 2.6 | 1.4 | 4.3 | 3.4 | 2.5 | 3.4 | 3.5 |
| 10 | 127 | 1 | 3.7 | 1.9 | 3.4 | 2.0 | 2.0 | 3.1 | 3.6 |
| 11 | 127 | 2 | 3.6 | 2.9 | 3.6 | 3.4 | 3.0 | 3.6 | 3.2 |
| 12 | 127 | 3 | 3.4 | 2.4 | 2.3 | 2.4 | 3.1 | 4.2 | 3.8 |
| 13 | 123 | 1 | 3.5 | 2.0 | 4.2 | 3.9 | 2.5 | 4.0 | 3.6 |
| 14 | 123 | 2 | 2.2 | 1.9 | 3.2 | 2.0 | 2.5 | 4.2 | 3.0 |
| 15 | 123 | 3 | 2.5 | 3.7 | 4.8 | 3.8 | 2.8 | 3.8 | 3.8 |
| 16 | 153 | 1 | 3.2 | 2.8 | 3.3 | 2.9 | 1.8 | 2.9 | 3.1 |
| 17 | 153 | 2 | 3.2 | 2.3 | 3.3 | 3.0 | 2.2 | 3.7 | 2.7 |
| 18 | 153 | 3 | 3.4 | 2.5 | 3.5 | 3.3 | 3.3 | 3.4 | 3.3 |
| 19 | 114 | 1 | 4.1 | 2.2 | 3.1 | 2.7 | 2.2 | 3.2 | 3.2 |
| 20 | 114 | 2 | 3.2 | 1.8 | 3.6 | 3.3 | 2.4 | 3.6 | 3.3 |
| 21 | 114 | 3 | 4.2 | 3.0 | 4.0 | 3.8 | 3.2 | 2.8 | 3.5 |
| 22 | 16 | 1 | 3.2 | 2.3 | 2.8 | 3.1 | 2.2 | 2.5 | 3.2 |
| 23 | 16 | 2 | 3.2 | 2.0 | 3.5 | 3.5 | 2.7 | 3.4 | 3.5 |
| 24 | 16 | 3 | 3.7 | 2.0 | 3.8 | 3.9 | 3.0 | 3.9 | 4.1 |
| | PAVEMENT TYPE: | | BIT | BIT | CON | CON | BIT | BIT | BIT |

BIT: BITUMINOUS
CON: CONCRETE
SEAT NUMBER 1: FRONT RIGHT
SEAT NUMBER 2: BACK LEFT
SEAT NUMBER 3: BACK RIGHT

# DATA FOR 35 MILE PER HOUR ROUTE

| RATER # | CAR # | SEAT # | SECTION # 15 | 16 | 17 | 18 | 19 | 20 | 21 |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 10 | 1 | 3.8 | 1.8 | 1.4 | 4.2 | 4.2 | 4.1 | 3.9 |
| 2 | 10 | 2 | 3.7 | 1.9 | 1.4 | 4.5 | 3.7 | 3.9 | 4.5 |
| 3 | 10 | 3 | 4.3 | 1.5 | 1.5 | 4.2 | 4.3 | 4.2 | 4.3 |
| 4 | 117 | 1 | | | | | | | |
| 5 | 117 | 2 | 3.8 | 2.1 | 1.1 | 3.9 | | 4.2 | 4.7 |
| 6 | 117 | 3 | 4.3 | 1.2 | 2.5 | 4.5 | | 4.2 | 4.6 |
| 7 | 73 | 1 | 2.6 | 1.1 | 0.7 | 3.1 | 2.3 | 2.8 | 3.5 |
| 8 | 73 | 2 | 4.0 | 2.2 | 1.7 | 4.1 | 4.2 | 4.2 | 4.1 |
| 9 | 73 | 3 | 3.4 | 2.5 | 1.4 | 4.4 | 4.4 | 3.4 | 4.3 |
| 10 | 127 | 1 | 3.7 | 0.9 | 1.4 | 4.1 | 4.0 | 4.1 | 3.8 |
| 11 | 127 | 2 | 3.2 | 2.1 | 1.2 | 4.1 | 4.0 | 4.1 | 4.0 |
| 12 | 127 | 3 | 3.3 | 1.5 | 2.1 | 4.3 | 3.8 | 3.8 | 4.1 |
| 13 | 123 | 1 | 3.6 | 1.5 | 1.0 | 4.2 | 4.3 | 4.0 | 3.5 |
| 14 | 123 | 2 | 3.2 | 1.0 | 1.2 | 4.2 | 3.9 | 3.5 | 4.5 |
| 15 | 123 | 3 | 3.3 | 1.5 | 0.4 | 3.0 | 3.8 | 3.8 | 4.5 |
| 16 | 153 | 1 | 3.9 | 1.4 | 1.0 | 4.7 | 4.7 | 3.2 | 4.9 |
| 17 | 153 | 2 | 2.8 | 0.8 | 0.8 | 3.5 | 4.0 | 3.8 | 3.0 |
| 18 | 153 | 3 | 3.5 | 2.5 | 2.5 | 3.4 | 3.5 | 3.5 | 3.5 |
| 19 | 114 | 1 | 3.2 | 1.2 | 1.1 | 4.1 | 4.1 | 4.1 | 4.1 |
| 20 | 114 | 2 | 3.5 | 1.8 | 0.9 | 3.6 | 3.4 | 3.5 | 3.6 |
| 21 | 114 | 3 | | 1.8 | 0.8 | 3.6 | 3.6 | 3.7 | 4.4 |
| 22 | 16 | 1 | 3.2 | 1.5 | 1.5 | 3.6 | 4.3 | 3.8 | 3.3 |
| 23 | 16 | 2 | 3.4 | 2.0 | 1.4 | 4.0 | 3.6 | 3.5 | 3.5 |
| 24 | 16 | 3 | 3.7 | 1.8 | 0.8 | 2.9 | 3.8 | 3.3 | 3.9 |
| | PAVEMENT TYPE: | | BIT | BIT | BIT | BIT | CON | CON | BIT |

BIT: BITUMINOUS
CON: CONCRETE
SEAT NUMBER 1: FRONT RIGHT
SEAT NUMBER 2: BACK LEFT
SEAT NUMBER 3: BACK RIGHT

## DATA FOR 35 MILE PER HOUR ROUTE

| | | | SECTION # | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| RATER # | CAR # | SEAT # | 22 | 23 | 24 | 25 | 26 | 27 | 28 |
| 1 | 10 | 1 | 3.2 | 3.8 | 3.5 | 3.0 | 3.4 | 3.5 | 2.8 |
| 2 | 10 | 2 | 2.7 | 3.7 | 3.2 | 2.9 | 3.5 | 3.3 | 2.8 |
| 3 | 10 | 3 | 3.6 | 3.6 | 4.3 | 3.9 | 4.2 | 3.8 | 2.0 |
| 4 | 117 | 1 | | | | | | | |
| 5 | 117 | 2 | 3.6 | 3.8 | 3.3 | 4.8 | 4.2 | 2.3 | 2.6 |
| 6 | 117 | 3 | 3.4 | 3.1 | 1.8 | 4.4 | 3.8 | 3.5 | 1.6 |
| 7 | 73 | 1 | 2.0 | 2.8 | 3.1 | 3.3 | 2.8 | 2.5 | 1.2 |
| 8 | 73 | 2 | 3.1 | 3.1 | 3.2 | 4.0 | 4.0 | 3.7 | 2.9 |
| 9 | 73 | 3 | 3.3 | 3.4 | 4.3 | 4.5 | 4.3 | 3.4 | 2.5 |
| 10 | 127 | 1 | 3.8 | 3.7 | 3.3 | 4.1 | 3.8 | 3.5 | 2.4 |
| 11 | 127 | 2 | 3.7 | 3.6 | 3.7 | 4.2 | 4.1 | 3.2 | 3.0 |
| 12 | 127 | 3 | 4.1 | 3.4 | 3.4 | 4.2 | 2.9 | 2.6 | 2.4 |
| 13 | 123 | 1 | 4.0 | 4.0 | 3.6 | 4.0 | 3.6 | 3.0 | 2.5 |
| 14 | 123 | 2 | 3.0 | 3.0 | 3.2 | 4.4 | 3.5 | 3.0 | 2.1 |
| 15 | 123 | 3 | 2.9 | 3.0 | 3.8 | 4.4 | 3.5 | 3.6 | 3.6 |
| 16 | 153 | 1 | 2.9 | 3.3 | 3.3 | 4.9 | 4.2 | 2.6 | 2.9 |
| 17 | 153 | 2 | 2.8 | 3.3 | 2.8 | 3.5 | 3.5 | 1.8 | 1.7 |
| 18 | 153 | 3 | 2.7 | 3.4 | 3.5 | 3.6 | 3.5 | 2.7 | 2.6 |
| 19 | 114 | 1 | 3.1 | 3.2 | 3.1 | 4.1 | 4.1 | 2.2 | 2.2 |
| 20 | 114 | 2 | 3.2 | 3.1 | 3.3 | 3.5 | 3.8 | 3.0 | 2.9 |
| 21 | 114 | 3 | 4.1 | 3.9 | 3.7 | 4.4 | 4.4 | 3.1 | 2.9 |
| 22 | 16 | 1 | 3.0 | 2.5 | 2.4 | 3.1 | 3.9 | 2.6 | 2.0 |
| 23 | 16 | 2 | 3.0 | 3.0 | 3.0 | 3.7 | 3.0 | 2.5 | 2.5 |
| 24 | 16 | 3 | 3.3 | 3.6 | 2.7 | 3.7 | 3.5 | 3.1 | 1.3 |
| PAVEMENT TYPE: | | | CON | CON | BIT | BIT | BIT | BIT | BIT |

BIT: BITUMINOUS
CON: CONCRETE
SEAT NUMBER 1: FRONT RIGHT
SEAT NUMBER 2: BACK LEFT
SEAT NUMBER 3: BACK RIGHT

## DATA FOR 35 MILE PER HOUR ROUTE

| RATER # | CAR # | SEAT # | SECTION # 29 | 30 | 31 | 32 | 33 | 34 | 35 |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 10 | 1 | 3.7 | 2.9 | 2.3 | 2.8 | 4.0 | 2.2 | 1.6 |
| 2 | 10 | 2 | 4.2 | 3.2 | 3.0 | 3.3 | 4.3 | 3.2 | 1.7 |
| 3 | 10 | 3 | 4.1 | 4.3 | 2.9 | 3.5 | 4.3 | 3.5 | 1.2 |
| 4 | 117 | 1 | | | | | | | |
| 5 | 117 | 2 | 4.2 | 4.4 | 3.2 | 3.2 | 3.2 | 3.8 | 2.3 |
| 6 | 117 | 3 | 3.8 | 3.7 | 1.5 | 1.2 | 3.6 | 3.6 | 0.8 |
| 7 | 73 | 1 | 3.2 | 3.5 | 1.5 | 2.2 | 3.1 | 2.9 | 0.9 |
| 8 | 73 | 2 | 4.0 | 4.0 | 3.7 | 2.7 | 3.0 | 3.4 | 2.0 |
| 9 | 73 | 3 | 4.3 | 4.4 | 2.5 | 3.4 | 3.3 | 3.4 | 1.5 |
| 10 | 127 | 1 | 4.1 | 3.8 | 3.1 | 2.3 | 4.2 | 3.2 | 1.6 |
| 11 | 127 | 2 | 4.0 | 3.9 | 3.3 | 2.2 | 4.1 | 3.7 | 1.9 |
| 12 | 127 | 3 | 3.7 | 3.6 | 3.1 | 2.4 | 4.2 | 2.8 | 1.5 |
| 13 | 123 | 1 | 3.7 | 3.0 | 1.4 | 2.0 | 4.4 | 3.5 | 0.6 |
| 14 | 123 | 2 | 4.3 | 3.0 | 2.1 | 2.2 | 3.3 | 4.0 | 0.9 |
| 15 | 123 | 3 | 4.0 | 3.5 | 2.6 | 1.7 | 2.8 | 3.9 | 1.1 |
| 16 | 153 | 1 | 4.3 | 4.1 | 2.2 | 2.2 | 4.2 | 3.2 | 1.5 |
| 17 | 153 | 2 | 2.5 | 2.5 | 2.0 | 1.7 | 3.5 | 3.2 | 1.1 |
| 18 | 153 | 3 | 3.5 | 3.7 | 2.6 | 2.6 | 2.6 | 2.8 | 1.8 |
| 19 | 114 | 1 | 3.2 | 2.2 | 2.1 | 2.1 | 3.1 | 3.1 | 1.2 |
| 20 | 114 | 2 | 3.9 | 3.7 | 3.1 | 2.9 | 3.6 | 3.5 | 3.5 |
| 21 | 114 | 3 | 3.9 | 3.4 | 2.8 | 1.9 | 4.1 | 3.5 | 1.5 |
| 22 | 16 | 1 | 3.7 | 4.0 | 3.5 | 2.3 | 4.8 | 3.1 | 1.3 |
| 23 | 16 | 2 | 3.5 | 3.5 | 3.0 | 2.2 | 4.1 | 3.6 | 2.0 |
| 24 | 16 | 3 | 3.6 | 3.5 | 2.4 | 2.5 | 3.7 | 3.4 | 1.0 |
| | PAVEMENT TYPE: | | BIT | BIT | BIT | BIT | BIT | BIT | BIT |

BIT: BITUMINOUS
SEAT NUMBER 1: FRONT RIGHT
SEAT NUMBER 2: BACK LEFT
SEAT NUMBER 3: BACK RIGHT

**DATA FOR 35 MILE PER HOUR ROUTE**

| RATER # | CAR # | SEAT # | SECTION # 36 |
|---|---|---|---|
| 1 | 10 | 1 | 2.1 |
| 2 | 10 | 2 | 3.8 |
| 3 | 10 | 3 | 2.4 |
| 4 | 117 | 1 | |
| 5 | 117 | 2 | 3.8 |
| 6 | 117 | 3 | 3.1 |
| 7 | 73 | 1 | 2.1 |
| 8 | 73 | 2 | 3.8 |
| 9 | 73 | 3 | 3.3 |
| 10 | 127 | 1 | 3.1 |
| 11 | 127 | 2 | 2.8 |
| 12 | 127 | 3 | 2.2 |
| 13 | 123 | 1 | 1.5 |
| 14 | 123 | 2 | 2.0 |
| 15 | 123 | 3 | 3.8 |
| 16 | 153 | 1 | 3.6 |
| 17 | 153 | 2 | 1.8 |
| 18 | 153 | 3 | 2.7 |
| 19 | 114 | 1 | 2.8 |
| 20 | 114 | 2 | 3.1 |
| 21 | 114 | 3 | 3.2 |
| 22 | 16 | 1 | 3.0 |
| 23 | 16 | 2 | 3.0 |
| 24 | 16 | 3 | 2.9 |
| | PAVEMENT TYPE: | | BIT |

BIT: BITUMINOUS
SEAT NUMBER 1: FRONT RIGHT
SEAT NUMBER 2: BACK LEFT
SEAT NUMBER 3: BACK RIGHT

## DATA FOR 55 MILE PER HOUR ROUTE

| RATER # | CAR # | SEAT # | SECTION # 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 10 | 1 | 3.2 | 2.2 | 3.1 | 3.1 | 3.2 | 2.8 | 3.8 |
| 2 | 10 | 2 | 3.5 | 3.3 | 3.3 | 2.1 | 3.7 | 2.6 | 3.8 |
| 3 | 10 | 3 | 3.6 | 3.5 | 3.5 | 2.5 | 3.2 | 2.3 | 3.4 |
| 4 | 117 | 1 | | | | | | | |
| 5 | 117 | 2 | 4.2 | 3.3 | | 4.1 | 2.3 | 2.2 | 2.9 |
| 6 | 117 | 3 | 4.2 | 3.5 | | 2.9 | 2.2 | 1.5 | 3.3 |
| 7 | 73 | 1 | 3.8 | 2.8 | 2.4 | 2.2 | 2.1 | 2.2 | 2.8 |
| 8 | 73 | 2 | 4.1 | 3.1 | 3.0 | 3.9 | 3.2 | 2.8 | 3.8 |
| 9 | 73 | 3 | 4.3 | 3.4 | 3.4 | 3.4 | 3.5 | 3.5 | 3.3 |
| 10 | 127 | 1 | 4.1 | 3.0 | 3.2 | 3.2 | 3.1 | 2.6 | 3.6 |
| 11 | 127 | 2 | 3.2 | 3.0 | 3.3 | 3.1 | 3.2 | 2.9 | 3.7 |
| 12 | 127 | 3 | 3.2 | 2.9 | 2.5 | 3.5 | 3.5 | 2.5 | 4.0 |
| 13 | 123 | 1 | 2.8 | 2.6 | 3.3 | 2.8 | 2.2 | 1.8 | 2.3 |
| 14 | 123 | 2 | 2.5 | 2.0 | | 2.1 | 3.3 | 1.8 | 3.0 |
| 15 | 123 | 3 | | | | | | | |
| 16 | 153 | 1 | 3.3 | 2.9 | | 3.3 | 3.3 | 2.8 | 2.8 |
| 17 | 153 | 2 | 3.7 | 3.5 | | 3.1 | 3.5 | 2.9 | 3.3 |
| 18 | 153 | 3 | 2.7 | 2.8 | | 3.2 | 2.9 | 2.7 | 3.3 |
| 19 | 114 | 1 | 2.9 | 2.1 | 2.2 | 2.9 | 2.9 | 2.2 | 3.2 |
| 20 | 114 | 2 | 2.9 | 2.9 | 2.9 | 2.9 | 3.2 | 2.6 | 3.1 |
| 21 | 114 | 3 | 2.8 | 1.3 | 2.1 | 3.3 | 3.0 | 1.8 | 3.1 |
| 22 | 16 | 1 | 2.2 | 2.3 | 1.8 | 3.3 | 2.1 | 2.0 | 2.3 |
| 23 | 16 | 2 | 3.1 | 3.1 | 3.0 | 3.1 | 3.0 | 2.9 | 3.0 |
| 24 | 16 | 3 | 3.7 | 3.0 | 2.4 | 3.5 | 3.4 | 3.2 | 3.5 |
| | PAVEMENT TYPE: | | CON | CON | CON | CON | CON | CON | CON |

CON: CONCRETE
SEAT NUMBER 1: FRONT RIGHT
SEAT NUMBER 2: BACK LEFT
SEAT NUMBER 3: BACK RIGHT

## DATA FOR 55 MILE PER HOUR ROUTE

| RATER # | CAR # | SEAT # | SECTION # 8 | 9 | 10 | 11 | 12 | 13 | 14 |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 10 | 1 | 4.2 | 3.2 | 3.2 | 4.2 | 4.2 | 4.2 | 1.8 |
| 2 | 10 | 2 | 3.8 | 3.0 | 2.1 | 3.7 | 3.9 | 3.1 | 3.5 |
| 3 | 10 | 3 | 3.8 | 2.9 | 2.6 | 4.3 | 4.2 | 3.7 | 2.7 |
| 4 | 117 | 1 | | | | | | | |
| 5 | 117 | 2 | 2.9 | 1.8 | 2.6 | 1.9 | 3.9 | 2.5 | 3.3 |
| 6 | 117 | 3 | 3.3 | 1.5 | 1.8 | 3.8 | 4.5 | 1.5 | 1.8 |
| 7 | 73 | 1 | 2.8 | 2.1 | 1.6 | 3.0 | 3.4 | 2.2 | 1.5 |
| 8 | 73 | 2 | 3.0 | 3.9 | 3.8 | 4.2 | 4.1 | 3.8 | 3.0 |
| 9 | 73 | 3 | 2.5 | 3.4 | 3.4 | 4.4 | 4.4 | 3.3 | 3.3 |
| 10 | 127 | 1 | 3.4 | 3.0 | 2.9 | 4.1 | 4.0 | 3.3 | 1.8 |
| 11 | 127 | 2 | 3.1 | 4.0 | 3.1 | 4.0 | 4.2 | 3.4 | 2.3 |
| 12 | 127 | 3 | 2.7 | 3.4 | 3.5 | 2.5 | 4.2 | 2.9 | 2.9 |
| 13 | 123 | 1 | 1.7 | 1.5 | 1.8 | 3.3 | 3.4 | 1.9 | 1.8 |
| 14 | 123 | 2 | 2.5 | 3.0 | 3.0 | 3.1 | 3.7 | 3.8 | 2.4 |
| 15 | 123 | 3 | | | | | | | |
| 16 | 153 | 1 | 3.7 | 4.1 | 3.7 | 4.3 | 4.7 | 3.5 | 2.6 |
| 17 | 153 | 2 | 3.5 | 3.1 | 2.4 | 3.7 | 3.0 | 3.0 | 2.0 |
| 18 | 153 | 3 | 2.9 | 2.9 | 3.1 | 3.3 | 4.1 | 3.9 | 2.8 |
| 19 | 114 | 1 | 2.9 | 2.2 | 2.1 | 3.7 | 3.2 | 2.8 | 1.8 |
| 20 | 114 | 2 | 3.3 | 3.0 | 2.8 | 3.2 | 3.5 | 2.5 | 1.9 |
| 21 | 114 | 3 | 2.2 | 2.8 | 2.6 | 4.2 | 3.9 | 3.2 | 2.6 |
| 22 | 16 | 1 | 2.4 | 1.6 | 2.2 | 4.6 | 3.7 | 3.0 | 2.3 |
| 23 | 16 | 2 | 3.0 | 3.0 | 2.6 | 3.4 | 3.5 | 3.0 | 2.6 |
| 24 | 16 | 3 | 2.3 | 3.2 | 3.5 | 3.0 | 3.5 | 2.5 | 2.6 |
| | PAVEMENT TYPE: | | CON | CON | CON | CON | BIT | BIT | BIT |

BIT: BITUMINOUS
CON: CONCRETE
SEAT NUMBER 1: FRONT RIGHT
SEAT NUMBER 2: BACK LEFT
SEAT NUMBER 3: BACK RIGHT

**DATA FOR 55 MILE PER HOUR ROUTE**

| RATER # | CAR # | SEAT # | SECTION # 15 | 16 | 17 | 18 | 19 | 20 | 21 |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 10 | 1 | 3.7 | 3.3 | 3.8 | 2.8 | 3.2 | 2.7 | 2.2 |
| 2 | 10 | 2 | 2.2 | 3.4 | 3.4 | 2.3 | 3.7 | 3.8 | 2.5 |
| 3 | 10 | 3 | 3.3 | 3.8 | 3.9 | 3.9 | 3.8 | 3.8 | 2.6 |
| 4 | 117 | 1 | | | | | | | |
| 5 | 117 | 2 | 2.5 | 3.9 | 3.1 | 2.3 | 4.1 | 3.8 | 2.2 |
| 6 | 117 | 3 | 1.8 | 3.5 | 3.8 | 1.8 | 4.1 | 4.2 | 2.2 |
| 7 | 73 | 1 | 2.1 | 2.9 | 2.6 | 1.6 | 2.4 | 2.9 | 1.7 |
| 8 | 73 | 2 | 3.7 | 3.9 | 4.0 | 3.1 | 4.0 | 3.9 | 3.0 |
| 9 | 73 | 3 | 2.4 | 3.3 | 4.2 | 2.5 | 3.3 | 3.3 | 3.5 |
| 10 | 127 | 1 | 2.2 | 3.5 | 3.5 | 3.4 | 3.8 | 3.8 | 3.6 |
| 11 | 127 | 2 | 3.1 | 3.9 | 4.1 | 3.0 | 4.2 | 3.7 | 3.2 |
| 12 | 127 | 3 | 2.5 | 3.7 | 3.6 | 2.5 | 3.6 | 3.3 | 2.9 |
| 13 | 123 | 1 | 1.4 | 2.5 | 3.4 | 1.8 | 2.1 | 2.0 | 1.7 |
| 14 | 123 | 2 | 2.4 | 4.0 | 3.7 | 3.4 | 4.0 | 2.9 | 3.2 |
| 15 | 123 | 3 | | | | | | | |
| 16 | 153 | 1 | 3.2 | 4.7 | 4.1 | 3.5 | 4.1 | 3.7 | 2.8 |
| 17 | 153 | 2 | 2.4 | 3.1 | 3.3 | 2.6 | 4.1 | 3.2 | 3.2 |
| 18 | 153 | 3 | 2.9 | 3.1 | 3.1 | 2.9 | 3.9 | 3.6 | 3.1 |
| 19 | 114 | 1 | 2.8 | 3.2 | 3.1 | 2.2 | 3.1 | 2.8 | 2.7 |
| 20 | 114 | 2 | 3.0 | 3.2 | 3.5 | 2.6 | 3.2 | 3.1 | 2.2 |
| 21 | 114 | 3 | 2.8 | 3.4 | 3.7 | 2.8 | 3.8 | 3.9 | 2.1 |
| 22 | 16 | 1 | 3.0 | 3.0 | 3.3 | 1.5 | 3.4 | 3.0 | 2.6 |
| 23 | 16 | 2 | 1.9 | 2.4 | 2.6 | 2.4 | 3.1 | 2.8 | 2.0 |
| 24 | 16 | 3 | 3.0 | 2.4 | 2.9 | 2.7 | 3.2 | 3.5 | 2.1 |
| PAVEMENT TYPE: | | | BIT | BIT | BIT | BIT | BIT | BIT | BIT |

BIT: BITUMINOUS
SEAT NUMBER 1: FRONT RIGHT
SEAT NUMBER 2: BACK LEFT
SEAT NUMBER 3: BACK RIGHT

**DATA FOR 55 MILE PER HOUR ROUTE**

| | | | SECTION # | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| RATER # | CAR # | SEAT # | 22 | 23 | 24 | 25 | 26 | 27 | 28 |
| 1 | 10 | 1 | 1.3 | 3.8 | 3.2 | 3.2 | 3.3 | 3.8 | 4.7 |
| 2 | 10 | 2 | 1.5 | 3.1 | 3.3 | 3.4 | 3.2 | 3.5 | 4.3 |
| 3 | 10 | 3 | 1.5 | 3.5 | 3.6 | 3.3 | 3.5 | 4.0 | 4.6 |
| 4 | 117 | 1 | | | | | | | |
| 5 | 117 | 2 | 1.9 | 3.2 | 3.9 | 3.2 | 4.1 | 3.2 | 4.2 |
| 6 | 117 | 3 | 1.8 | 3.4 | 4.1 | 3.3 | 3.8 | 4.6 | 4.1 |
| 7 | 73 | 1 | 1.0 | 2.7 | 2.7 | 2.1 | 3.2 | 3.0 | 3.1 |
| 8 | 73 | 2 | 2.9 | 4.0 | 3.8 | 3.4 | 3.9 | 3.9 | 3.9 |
| 9 | 73 | 3 | 2.4 | 4.3 | 4.3 | 4.4 | 3.4 | 4.4 | 4.3 |
| 10 | 127 | 1 | 3.8 | 3.6 | 3.9 | 3.4 | 3.2 | 3.8 | 3.5 |
| 11 | 127 | 2 | 3.6 | 3.2 | 4.0 | 3.9 | 3.7 | 4.1 | 4.0 |
| 12 | 127 | 3 | 3.3 | 4.0 | 4.0 | 4.0 | 4.0 | 4.0 | 4.4 |
| 13 | 123 | 1 | 1.7 | 2.1 | 2.2 | 2.0 | 2.7 | 3.2 | 3.8 |
| 14 | 123 | 2 | 3.2 | 3.4 | 3.6 | 3.6 | 3.8 | 3.9 | 4.2 |
| 15 | 123 | 3 | | | | | | | |
| 16 | 153 | 1 | 2.0 | 4.0 | 4.0 | 3.8 | 3.6 | 4.2 | 3.7 |
| 17 | 153 | 2 | 2.2 | 3.3 | 3.1 | 3.0 | 3.6 | 3.5 | 3.5 |
| 18 | 153 | 3 | 3.1 | 3.7 | 3.9 | 4.0 | 4.0 | 4.2 | 4.2 |
| 19 | 114 | 1 | 1.8 | 2.7 | 2.8 | 2.7 | 3.2 | 3.7 | 3.2 |
| 20 | 114 | 2 | 2.3 | 3.4 | 3.2 | 3.2 | 3.1 | 3.4 | 3.1 |
| 21 | 114 | 3 | 2.2 | 2.5 | 3.3 | 3.0 | 3.1 | 3.8 | 3.0 |
| 22 | 16 | 1 | 2.7 | 3.6 | 2.7 | 2.8 | 3.2 | 3.2 | 3.6 |
| 23 | 16 | 2 | 2.6 | 3.0 | 3.0 | 2.7 | 3.0 | 3.5 | 3.2 |
| 24 | 16 | 3 | 3.3 | 3.3 | 3.3 | 3.5 | 3.4 | 3.3 | 3.3 |
| PAVEMENT TYPE: | | | BIT | BIT | BIT | BIT | BIT | BIT | BIT |

BIT: BITUMINOUS
SEAT NUMBER 1: FRONT RIGHT
SEAT NUMBER 2: BACK LEFT
SEAT NUMBER 3: BACK RIGHT

**DATA FOR 55 MILE PER HOUR ROUTE**

| RATER # | CAR # | SEAT # | SECTION # 29 | 30 | 31 | 32 | 33 |
|---|---|---|---|---|---|---|---|
| 1 | 10 | 1 | 1.7 | 3.8 | 2.7 | 2.7 | 3.5 |
| 2 | 10 | 2 | 3.9 | 3.7 | 3.4 | 3.6 | 3.7 |
| 3 | 10 | 3 | 4.3 | 4.0 | 2.5 | 3.4 | 3.6 |
| 4 | 117 | 1 | | | | | |
| 5 | 117 | 2 | 3.8 | 3.5 | 2.7 | 3.5 | 3.2 |
| 6 | 117 | 3 | 4.1 | 3.6 | 2.2 | 3.8 | 4.2 |
| 7 | 73 | 1 | 2.9 | 2.8 | 2.1 | 2.8 | 3.5 |
| 8 | 73 | 2 | 2.8 | 3.0 | 3.0 | 3.8 | 4.0 |
| 9 | 73 | 3 | 4.3 | 4.2 | 3.4 | 3.6 | 4.3 |
| 10 | 127 | 1 | 3.6 | 3.9 | 3.0 | 3.1 | 4.2 |
| 11 | 127 | 2 | 3.9 | 3.5 | 3.0 | 3.7 | 4.1 |
| 12 | 127 | 3 | 4.3 | 3.9 | 3.6 | 3.2 | 3.8 |
| 13 | 123 | 1 | 3.4 | 3.2 | 2.0 | 2.2 | |
| 14 | 123 | 2 | 3.8 | 3.7 | 3.1 | 3.3 | |
| 15 | 123 | 3 | | | | | |
| 16 | 153 | 1 | 3.3 | 4.6 | 2.8 | 3.7 | |
| 17 | 153 | 2 | 2.7 | 2.8 | 2.2 | 3.2 | |
| 18 | 153 | 3 | 2.9 | 3.9 | 3.1 | 3.9 | |
| 19 | 114 | 1 | 2.8 | 2.9 | 2.7 | 3.3 | 3.1 |
| 20 | 114 | 2 | 3.0 | 3.2 | 2.6 | 3.4 | 3.8 |
| 21 | 114 | 3 | 3.6 | 3.0 | 2.8 | 3.8 | 3.2 |
| 22 | 16 | 1 | 1.3 | 3.5 | 3.1 | 3.7 | 3.5 |
| 23 | 16 | 2 | 2.5 | 3.0 | 3.0 | 3.4 | 3.4 |
| 24 | 16 | 3 | 3.6 | 3.5 | 3.3 | 3.0 | 3.6 |
| | PAVEMENT TYPE: | | BIT | BIT | BIT | BIT | BIT |

BIT: BITUMINOUS
SEAT NUMBER 1: FRONT RIGHT
SEAT NUMBER 2: BACK LEFT
SEAT NUMBER 3: BACK RIGHT

## AUTOMOBILE DATA

| CAR # | CAR TYPE | LICENSE PLATE | MILEAGE |
|---|---|---|---|
| 10 | Dodge Aries K | 0010 | 45,802 |
| 16 | Dodge Aries K | 0016 | 17,878 |
| 73 | Dodge Aries K | 0073 | 11,286 |
| 114 | Dodge Aries K | 0114 | 39,788 |
| 117 | Dodge Aries K | 0117 | 31,809 |
| 123 | Dodge Aries K | 0123 | 43,573 |
| 127 | Dodge Aries K | 0127 | 37,756 |
| 153 | Dodge Aries K | 0153 | 11,319 |

# APPENDIX C.

# MAYS INDEX VALUES

**MAYS INDEX VALUES**

35 MPH ROUTE

| SECTION # | MI VALUE |
|---|---|
| 1 | 73.4 |
| 2 | 187.0 |
| 3 | 74.0 |
| 4 | 157.2 |
| 5 | 104.8 |
| 6 | 245.8 |
| 7 | 133.7 |
| 8 | 109.4 |
| 9 | 138.8 |
| 10 | 96.0 |
| 11 | 117.5 |
| 12 | 118.8 |
| 13 | 86.0 |
| 14 | 90.4 |
| 15 | 95.0 |
| 16 | 281.0 |
| 17 | 266.4 |
| 18 | 68.4 |
| 19 | 115.4 |
| 20 | 116.5 |
| 21 | 41.5 |
| 22 | 136.0 |
| 23 | 130.5 |
| 24 | 89.2 |
| 25 | 48.4 |
| 26 | 37.4 |
| 27 | 123.8 |
| 28 | 176.2 |
| 29 | 106.0 |
| 30 | 74.0 |
| 31 | 117.5 |
| 32 | 267.4 |
| 33 | 119.5 |
| 34 | 106.3 |
| 35 | 206.0 |
| 36 | 80.0 |

55 MPH ROUTE

| SECTION # | MI VALUE |
|---|---|
| 1 | 109.6 |
| 2 | 154.0 |
| 3 | 124.6 |
| 4 | 110.6 |
| 5 | 84.2 |
| 6 | 158.6 |
| 7 | 82.2 |
| 8 | 131.6 |
| 9 | 112.4 |
| 10 | 127.8 |
| 11 | 84.4 |
| 12 | 53.6 |
| 13 | 84.4 |
| 14 | 171.5 |
| 15 | 128.3 |
| 16 | 63.6 |
| 17 | 53.2 |
| 18 | 124.3 |
| 19 | 44.2 |
| 20 | 71.8 |
| 21 | 106.4 |
| 22 | 145.8 |
| 23 | 83.2 |
| 24 | 55.6 |
| 25 | 76.2 |
| 26 | 50.2 |
| 27 | 37.8 |
| 28 | 70.5 |
| 29 | 53.6 |
| 30 | 109.3 |
| 31 | 116.0 |
| 32 | 62.4 |
| 33 | 84.8 |

# APPENDIX D.

# STATISTICAL ANALYSES

**BACK SEAT LEFT VS. BACK SEAT RIGHT COMPARISON**

35 MPH

| CAR | # 10 | | | # 117 | | |
|---|---|---|---|---|---|---|
| RATER | 2 | 3 | 2 - 3 | 5 | 6 | 5 - 6 |
| AVERAGE | 3.164 | 3.381 | 0.217 | 3.409 | 3.103 | 0.297 |
| STD DEV. | 0.808 | 0.888 | 0.571 | 0.849 | 1.116 | 0.909 |
| t VALUE | 2.275 | | | 1.961 | | |

| CAR | # 73 | | | # 127 | | |
|---|---|---|---|---|---|---|
| RATER | 8 | 9 | 8 - 9 | 11 | 12 | 11 - 12 |
| AVERAGE | 3.531 | 3.136 | 0.394 | 3.331 | 3.067 | 0.264 |
| STD DEV. | 0.648 | 0.982 | 0.820 | 0.679 | 0.878 | 0.581 |
| t VALUE | 2.887 | | | 2.726 | | |

| CAR | # 123 | | | # 153 | | |
|---|---|---|---|---|---|---|
| RATER | 14 | 15 | 14 - 15 | 17 | 18 | 17 - 18 |
| AVERAGE | 2.900 | 3.158 | 0.258 | 2.728 | 3.100 | 0.372 |
| STD DEV. | 0.962 | 0.989 | 0.765 | 0.853 | 0.472 | 0.633 |
| t VALUE | 2.027 | | | 3.530 | | |

| CAR | # 114 | | | # 16 | | |
|---|---|---|---|---|---|---|
| RATER | 20 | 21 | 20 - 21 | 23 | 24 | 23 - 24 |
| AVERAGE | 3.008 | 3.277 | 0.183 | 3.050 | 3.067 | 0.017 |
| STD DEV. | 0.808 | 0.847 | 0.608 | 0.676 | 0.833 | 0.545 |
| t VALUE | 1.778 | | | 0.183 | | |

55 MPH

| CAR | # 10 | | | # 117 | | |
|---|---|---|---|---|---|---|
| RATER | 2 | 3 | 2 - 3 | 5 | 6 | 5 - 6 |
| AVERAGE | 3.180 | 3.403 | 0.171 | 3.153 | 3.212 | 0.000 |
| STD DEV | 0.677 | 0.647 | 0.469 | 0.807 | 1.100 | 0.683 |
| t VALUE | 2.122 | | | 0.000 | | |

| CAR | # 73 | | | # 127 | | |
|---|---|---|---|---|---|---|
| RATER | 8 | 9 | 8 - 9 | 11 | 12 | 11 - 12 |
| AVERAGE | 3.649 | 3.751 | 0.047 | 3.697 | 3.651 | 0.106 |
| STD DEV | 0.907 | 1.083 | 0.599 | 1.357 | 1.538 | 0.480 |
| t VALUE | 0.458 | | | 1.286 | | |

| CAR | # 123 | | | # 153 | | |
|---|---|---|---|---|---|---|
| RATER | 14 | 15 | 14 - 15 | 17 | 18 | 17 - 18 |
| AVERAGE | | | | 3.476 | 3.791 | 0.247 |
| STD DEV. | DISREGARD THESE | | | 2.444 | 2.558 | 0.554 |
| t VALUE | SECTIONS | | | 2.602 | | |

| CAR | # 114 | | | # 16 | | |
|---|---|---|---|---|---|---|
| RATER | 20 | 21 | 20 - 21 | 23 | 24 | 23 - 24 |
| AVERAGE | 3.463 | 3.506 | 0.147 | 3.451 | 3.729 | 0.226 |
| STD DEV. | 2.867 | 3.067 | 0.559 | 3.376 | 3.501 | 0.439 |
| t VALUE | 0.153 | | | 3.005 | | |

## FRONT SEAT VS. BACK SEAT COMPARISON

### 35 MPH

| CAR | # 10 | | | # 117 | | |
|---|---|---|---|---|---|---|
| RATER | 2 & 3 | 1 | 1,2&3 | 5 & 6 | 4 | 4,5&6 |
| AVERAGE | 3.272 | 3.097 | 0.175 | | | |
| STD DEV. | 0.800 | 0.795 | 0.447 | DISREGARD THESE SECTIONS | | |
| t VALUE | 2.350 | | | | | |

| CAR | # 73 | | | # 127 | | |
|---|---|---|---|---|---|---|
| RATER | 8 & 9 | 7 | 7,8&9 | 11&12 | 10 | 10,11&12 |
| AVERAGE | 3.333 | 2.544 | 0.789 | 3.200 | 3.194 | 0.004 |
| STD DEV. | 0.724 | 0.819 | 0.510 | 0.729 | 0.890 | 0.435 |
| t VALUE | 9.280 | | | 0.057 | | |

| CAR | # 123 | | | # 153 | | |
|---|---|---|---|---|---|---|
| RATER | 14&15 | 13 | 13,14&15 | 17&18 | 16 | 16,17&18 |
| AVERAGE | 3.029 | 3.106 | 0.076 | 2.914 | 3.253 | 0.339 |
| STD DEV. | 0.897 | 1.072 | 0.654 | 0.613 | 0.966 | 0.660 |
| t VALUE | 0.701 | | | 3.081 | | |

| CAR | # 114 | | | # 16 | | |
|---|---|---|---|---|---|---|
| RATER | 20&21 | 19 | 19,20&21 | 23&24 | 22 | 22,23&24 |
| AVERAGE | 3.186 | 2.889 | 0.297 | 3.058 | 2.947 | 0.111 |
| STD DEV. | 0.685 | 0.872 | 0.496 | 0.708 | 0.880 | 0.560 |
| t VALUE | 3.542 | | | 1.190 | | |

### 55 MPH

| CAR | # 10 | | | # 117 | | |
|---|---|---|---|---|---|---|
| RATER | 2 & 3 | 1 | 1,2&3 | 5 & 6 | 4 | 4,5&6 |
| AVERAGE | 3.339 | 3.206 | 0.133 | 3.131 | 2.515 | 0.615 |
| STD DEV. | 0.599 | 0.765 | 0.673 | 0.818 | 0.615 | 0.498 |
| t VALUE | 1.138 | | | 6.958 | | |

| CAR | # 73 | | | # 127 | | |
|---|---|---|---|---|---|---|
| RATER | 8 & 9 | 7 | 7,8&9 | 11&12 | 10 | 10,11&12 |
| AVERAGE | 3.591 | 3.397 | 0.194 | 3.473 | 2.394 | 1.064 |
| STD DEV. | 0.447 | 0.522 | 0.475 | 0.465 | 0.663 | 0.586 |
| t VALUE | 2.347 | | | 10.271 | | |

| CAR | # 123 | | | # 153 | | |
|---|---|---|---|---|---|---|
| RATER | 14&15 | 13 | 13,14&15 | 17&18 | 16 | 16,17&18 |
| AVERAGE | | | | 3.223 | 2.785 | 0.319 |
| STD DEV. | DISREGARD THESE | | | 0.398 | 0.475 | 0.695 |
| t VALUE | SECTIONS | | | 2.595 | | |

| CAR | # 114 | | | # 16 | | |
|---|---|---|---|---|---|---|
| RATER | 20&21 | 19 | 19,20&21 | 23&24 | 22 | 22,23&24 |
| AVERAGE | 2.998 | 2.803 | 0.195 | 3.020 | 2.803 | 0.217 |
| STD DEV. | 0.463 | 0.733 | 0.609 | 0.333 | 0.733 | 0.701 |
| t VALUE | 1.845 | | | 1.775 | | |

# APPENDIX E.

# INSTRUCTIONS TO RATERS

## INSTRUCTIONS TO RATERS

PURPOSE

The purpose of this study is to survey typical Colorado drivers in order to determine what they think of the quality of the ride provided by the roads in the state. The Colorado DOH will use this information to help decide which roads they should improve first with the limited funds available to make highway improvements.

OBJECT

We are going to drive you over a number of road pavement sections which we believe are representative of the roads as they exist throughout the state. We will then ask you to make two judgments concerning each pavement section. First, we want you to rate the roughness or smoothness of the ride provided by each section, and second, we want you to indicate whether or not you think an effort should be made to improve the ride quality of each road.

MARKING YOUR RATINGS OF RIDE QUALITY

The first thing we want you to consider as you drive down a road is the roughness or smoothness of the ride provided by the road and then to rate it on the scale provided. You will indicate your rating by placing a small mark across the vertical line of the scale at the place which you think best describes the ride provided by each road.

DEFINITIONS OF ENDPOINTS

All of the roads you drive over in this survey will be between two extremes. That is, somewhere between impassable and perfect.

Impassable: A road which is so bad that you doubt that you or the car will make it to the end at the speed you are traveling -- like driving down railroad tracks along the ties.

Perfect: A road which is so smooth that at the speed you are traveling you would hardly know the road was there. You doubt that if someone made the surface smoother that the ride would be detectably nicer.

Since these roads probably do not exist, you will probably not consider any road to be worse than impassable or better than perfect.

In order to help make your rating, we have included a number of words along the scale which could be used to describe how the ride sensation seems to you. For example, if you should encounter a road for which you could describe the road as FAIR but not quite GOOD, place your mark just below the line between these two words. On the other hand, if you think the next road is still fair, but somewhat worse than the previous road, place your mark at a point which you think is the appropriate distance down in the FAIR category. To indicate small differences between the ride quality provided by the roads, you may place your mark anywhere you like along the scale.

> NOTE: We are not asking you to place roads into one of the five categories! You should use small differences in the position of your marks to indicate small differences between the ride quality provided by the roads. You may place your mark anywhere you like along the scale.

INDICATING THE NEED FOR IMPROVEMENT

After you have made your rating of the degree of ride quality provided by any particular road, we want you to check the appropriate box alongside the rating scale to indicate whether or not you think the state should spend part of the money it receives from gasoline taxes, vehicle registration fees, etc. to improve the ride quality of the road.

When making this decision, you should take into account the fact that since the state has only a certain, fixed amount of money each year to make improvements, it must determine which roads should be improved first. Therefore, before deciding on the need for improvement, you should not only consider how rough a ride is provided by each road but whether you feel the road is important enough to be placed high on the state's priority list of roads needing improvement. For example, you may ride across two roads which give identically rough rides but, if you had your choice, you would rather see your tax dollars used to improve only one of them because the type or character of that road seems to you to make it more worthy of improvement.

PROCEDURE FOR SURVEY

1. For this survey, we are going to ask you to evaluate 24 road sections.

Note: You will not be rating an entire road for its ride quality. We have carefully selected small test sections to represent each road. It is these sections that we want you to rate for ride quality.

2. As you approach each section, the driver will call out the number of the section. Be sure you have the proper numbered form.

3. When the driver says START, begin concentrating on what the rating of ride quality should be based on how the ride feels to you.

4. It will only take about 30 seconds to drive over each section so maintain your concentration until the driver says STOP. At that point, place your rating mark on the scale.

5. Next, while taking into account both the roughness of the ride through the representative test section, as well as the nature and type of the entire ride, indicate whether or not you think the ride quality needs to be improved by checking the appropriate box next to the rating scale.

6. Since some sections are only 3-4 minutes apart, make your decisions as quickly as possible and pass your form to the person sitting in the right front seat.

7. This procedure will be repeated for each site.

8. We will be driving over a predetermined course in an ordinary passenger car. The trip will take 2-3 hours.

SPECIAL INSTRUCTIONS

1. When making your rating of ride quality, do not consider any of the road before or after a test section. We are only interested in a rating for a small section of road.

2. When making your decision concerning the need for improvements, assume that the ride provided by the entire road is the same as that for the test section.

3. Concentrate only on the ride quality provided by the roads. Do not let the appearance of the road surface influence your ratings. Judge only how the road feels!

4. Do not be distracted by conversations in the car or pretty scenery.

5. Do not reveal your ratings to the other raters. There is no right or wrong answer, so do not "cheat". We are interested only in your opinion which is as valid as

anyone else's.

6. Be critical about the ride quality provided by the roads. If they are not absolutely perfect as far as you are concerned, be sure to give them a rating on the scale which you think best reflects the diminished quality of the ride.

7. Be aware that there many ways that the ride could be considered less than PERFECT. The road could:

a) be so bumpy that it rattles your bones and makes your teeth chatter, or

b) have bumps or undulations which make the car heave up and down as if it was a roller coaster, or

c) have other imperfections in the surface which you think detract from the ride quality.

# APPENDIX F.

# SECTION LOCATION

## 35 MPH CIRCUIT - TEST SECTION LOCATIONS

| SECTION NUMBER | MILE | LANE | LOCATION |
|---|---|---|---|
| **HAMPDEN** | | | Set 0.00 at flagged phone pole in front of mall |
| 1 | 0.93-1.46 (1.43) | C | Start: Omnibank intersection (Willow Street)<br>End: 0.1 miles before Tamarac (in tree just before school sign<br>Landmarks: Akron int. @ 0.6 miles, next int. is a Food Mart, next int. is Omnibank |
| 2 | 2.89-3.37 (1.94) | R | Start: At Ivanhoe Way, 0.2 miles after crossing I-25 structure (road narrows to 2 lanes)<br>End: At Dahlia Street (must go through 1 light)<br>Landmarks: I-25 structure @ 2.7 miles |
| 3 | 5.31-5.52 (1.87) | C | Start: At Gilpin intersection just before large condo complex on right<br>End: At Lafayette/Jefferson intersection 0.3 miles after start<br>Landmarks: University Boulevard (SH 177) @ 4.85 miles |
| 4 | 7.39-7.90 (1.21) | C | Start: At start of right hand merge lane onto Hampden (NO FLAG)<br>End: At next set of lights (West Hampden Avenue) (**YELLOW** FLAG)<br>Landmarks: Santa Fe underpass @ 7.25 miles, turn right onto Federal |
| **FEDERAL** | | | |
| 5 | 9.11-9.55 (2.15) | R | Start: At 40 mph speed limit/Hwy 88 sign just past lights at 9.05 miles<br>End: At Yale Avenue<br>Landmarks: |
| **6 | 11.7-12.1 (1.68) | R | Start: 0.1 mile after Mississippi Avenue<br>End: At Exposition, 0.4 miles after start (clock this section on odometer)<br>Landmarks: **NO FLAGS THIS SECTION** turn left onto Alameda |

| SECTION NUMBER | MILE | LANE | LOCATION |
|---|---|---|---|
| **ALAMEDA** | | | |
| 7 | 13.78-14.08<br>(2.38) | R | Start: At 35mph sign past light at Winona<br>End: At Sheridan (FLAG IS PAST SHERIDAN--DISREGARD FLAG !)<br>Landmarks: Turn right onto Wadsworth |
| **WADSWORTH** | | | |
| 8 | 16.46-17.02<br>(2.18) | R | Start: At 5th Avenue lights<br>End: At "Right Lane Must Turn Right" sign just past Kentucky Fried Chicken<br>Landmarks: |
| 9 | 19.20-19.56<br>(1.65) | R | Start: At 40 mph speed limit sign past 32nd Avenue intersection<br>End: At light pole 0.1 miles before lights<br>Landmarks: 32nd Avenue at 19.13 miles, turn right onto I-70 West |
| **I -70** | | | |
| 10 | 21.21-21.57<br>(1.39) | R | Start: At start of Jersey Barriers after 1st underpass<br>End: Where overlay starts on 1st bridge **NO FLAG AT END OF SECTION**<br>Landmarks: Underpass is 0.15 miles after entering I-70 |
| 11 | 22.96-23.44<br>(1.36) | R | Start: At W70 sign just past Ward/44th Avenue exit sign<br>End: At "Exit 266 - Camping" sign<br>Landmarks: Kipling bridge at 22.6 miles, turn right onto SH 72 (Ward) |
| **SH 72 (Ward)** | | | |
| 12 | 24.80-25.28<br>(2.12) | R | Start: At first set of lights after entering SH 72 (Ward)<br>End: 0.2 miles past 54th St.<br>Landmarks: RR-Xing @ 24.45, 54th @ 25.00 miles, turn left @ Ralston/ 64th Street (this will become Indiana) |
| **SH 72 (INDIANA)** | | | |
| 13 | 27.40-27.91 | R | Start: At 50 mph sign just past chicken |

| SECTION NUMBER | MILE | LANE | LOCATION |
|---|---|---|---|
| 13 (continued) | (1.67) | | farm on right<br>End: At phone pole 0.1 miles after sharp curve to right (white sign set back from road a little)<br>Landmarks: Stop light (DeFrame) at 27.1 miles |
| 14 | 29.58-30.13<br>(2.49) | R | Start: At start of white 4-slat wooden fence on right<br>End: At RR bridge underpass<br>Landmarks: Small bridge @ 29.45 miles, when SH 72 turns west, continue straight -- this is McCaslin |
| 15 | 32.62-33.13<br>(1.68) | R | Start: At "No Parking" sign 0.7 miles past farm buildings on right<br>End: At stop lights to Rocky Flats<br>Landmarks: turn left at stop sign, then right onto McCaslin |
| **McCASLIN** | | | |
| 16 | 34.81-35.54<br>(2.13) | R | Start: At 45mph sign 0.1 miles after making right turn<br>**NO FLAG AT START OF SECTION**<br>End: 0.6 miles after start (near end of sweeping left turn)<br>Landmarks: |
| 17 | 37.67-37.95<br>(2.10) | R | Start: At mailboxes just past dirt pile 0.2 miles over crest of hill<br>End: At bridge near bottom of hill<br>Landmarks: Crest of hill @ 37.1 miles |
| 18 | 40.05-40.38<br>(0.86) | R | Start: At 35 mph sign just past Alder Avenue<br>End: At South Boulder Road (make left turn here)<br>Landmarks: Washington Avenue at 39.75 miles, turn left onto South Boulder Road |
| **SOUTH BOULDER ROAD** | | | |
| 19 | 41.24-41.78<br>(1.19) | R | Start: At end of guiderail 0.1 miles past 2nd small bridge past stop lights at 76th Avenue<br>**NO FLAG AT START OF SECTION**<br>End: At phone pole 0.1 miles past chicken house on right (just past |

| SECTION NUMBER | MILE | LANE | LOCATION |
|---|---|---|---|
| 19 (continued) | | | high wires)<br>Landmarks: Light at 41.0 miles |
| 20 | 42.97-43.39<br>(1.68) | R | Start: Cherryvale Road<br>End: At start of bridge overlay<br>Landmarks: turn right onto Foothills Parkway (SH 157) |

**SH 157 (FOOTHILLS PARKWAY)**

| SECTION NUMBER | MILE | LANE | LOCATION |
|---|---|---|---|
| 21 | 45.07-45.40<br>(1.48) | R | Start: At 45 mph sign past Baseline<br>End: At "CU Stadium" sign just before going under footbridge before Colorado Avenue<br>Landmarks: Baseline Road @ 44.90 miles, turn right onto Pearl Street |

**PEARL STREET**

| SECTION NUMBER | MILE | LANE | LOCATION |
|---|---|---|---|
| 22 | 46.88-47.42<br>(0.59) | R | Start: At "Road Narrows" sign (where Pearl goes to one lane)<br>End: At 2nd 40 mph sign<br>Landmarks: Turn right onto 55th Street |

**55th STREET**

| SECTION NUMBER | MILE | LANE | LOCATION |
|---|---|---|---|
| 23 | 48.01-48.38<br>(1.69) | R | Start: 0.2 miles after turn onto 55th Street, at curbed driveway on right<br>End: At RR-Xing (go through 1 light)<br>Landmarks: turn left onto Arapahoe Road |

**SH 7 (ARAPAHOE ROAD)**

| SECTION NUMBER | MILE | LANE | LOCATION |
|---|---|---|---|
| 24 | 50.07-50.61<br>(3.29) | R | Start: 0.1 miles past 3rd light after entering Arapahoe (on phone pole)<br>End: 0.1 miles past 50 mph sign (flag set back in pine tree on right)<br>Landmarks: Light at 50.0 miles, 50 mph sign at 50.5 miles, turn right onto SH 42 |

**SH 42**

| SECTION NUMBER | MILE | LANE | LOCATION |
|---|---|---|---|
| 25 | 53.90-54.39<br>(3.00) | R | Start: At mailbox at start of tall trees on right side of road<br>End: 0.1 miles before 45 mph sign<br>Landmarks: Turn onto SH 42 @ 53.7 miles |
| 26 | 57.39-57.93 | R | Start: At "Intersection" sign just before 104th Street (near crest |

| SECTION NUMBER | MILE | LANE | LOCATION |
|---|---|---|---|
| 26 (continued) | (2.36) | | of hill)<br>End: Just past 3rd mailbox on right past 104th Street intersection<br>Landmarks: turn right onto SH 287 |
| **SH 287** | | | |
| 27 | 60.29-60.72<br>(3.24) | R | Start: At 50 mph sign past RR-Xing<br>End: Where reflectors start just past crest of hill<br>Landmarks: Bridge @ 60.00 miles, RR-Xing @ 60.20 miles |
| 28 | 63.96-64.45<br>(2.64) | R | Start: At mailbox/driveway just past telephone pole (0.3 miles past Lamar Street)<br>End: At Sheridan Boulevard<br>Landmarks: Lamar Street @ 63.70 miles, stay on SH 287 south (angles to right) |
| 29 | 67.09-67.54<br>(2.40) | R | Start: At yellow gas vent pipe, 0.2 miles past 112th Avenue<br>End: At mile post #293 just past 107th Avenue<br>Landmarks: 112th Ave. @ 66.80 miles, 108th Ave. @ 67.33 miles |
| 30 | 69.94-70.33<br>(2.65) | R | Start: At 40 mph sign just past 88th Avenue<br>End: At 84th Avenue<br>Landmarks: 88th Avenue light with Texaco station @ 69.80 miles |
| 31 | 72.98-73.35<br>(3.77) | R | Start: At flagpole past 45 mph sign, before Yamaha dealer<br>End: At bridge before underpass<br>Landmarks: 64th Avenue @ 72.84 miles |
| 32 | 77.12-77.63<br>(3.47) | R | Start: At 23rd Avenue<br>End: 1 light past 20th Avenue (must go through 1 light during rating)<br>Landmarks: turn right onto Alameda Ave. |
| **ALAMEDA** | | | |
| 33 | 81.10-81.40<br>(2.22) | R | Start: At 35 mph sign past light at Winona<br>End: At Sheridan **FLAG IS PAST SHERIDAN---DISREGARD FLAG !**<br>Landmarks: turn left onto Wadsworth |

| SECTION NUMBER | MILE | LANE | LOCATION |
|---|---|---|---|
| **WADSWORTH AVENUE** | | | |
| 34 | 83.62-83.93 (2.24) | R | Start: At start of guiderail on right after Ohio Avenue<br>End: At Mississippi Avenue<br>Landmarks: Ohio Avenue @ 83.40 miles |
| 35 | 86.17-86.59 (1.44) | R | Start: At phone pole just past bridge past Yale Avenue (past 45mph sign)<br>End: At next light (Eastman)<br>Landmarks: Yale Avenue @ 85.90 miles, turn left onto Hampden |
| **HAMPDEN** | | | |
| 36 | 88.03-88.43 | R | Start: 0.1 mile past "Sheridan Blvd" (SH 95) sign (at start of 2 large trees to right of hwy)<br>End: At "Exit" sign for Sheridan Blvd off-ramp<br>Landmarks: END 35MPH TEST CIRCUIT |

## 55 MPH CIRCUIT - TEST SECTION LOCATIONS

| SECTION NUMBER | MILE | LANE | LOCATION |
|---|---|---|---|
| **I -225 NB** | | | Set 0.00 at center of Parker Road (SH 83) bridge |
| 1 | 0.21-0.74<br>(1.52) | R | Start: Where median ends for SH 83 (Parker Road) on-ramp<br>End: At Iliff Avenue sign 0.5 miles later<br>Landmarks: SH 83 bridge @ 0.00 miles |
| 2 | 2.26-2.75<br>(2.47) | R | Start: At 55mph sign past I-225 sign<br>End: At yellow "Exit - 35mph" sign 0.5 miles later<br>Landmarks: Iliff Avenue bridge @ 1.49 miles, I-225 sign @ 2.10 miles |
| 3 | 5.22-5.68<br>(2.82) | R | Start: At yellow merge sign just over 6th Avenue bridge<br>End: At 2nd "Exit 10 - Colfax Avenue" sign<br>Landmarks: 6th Avenue bridge @ 5.02 miles, Colfax Avenue bridge @ 6.05 miles, turn onto I-70 westbound |
| **I - 70 WB** | | | |
| 4 | 8.50-8.98<br>(3.32) | C | Start: At 1st "I-70" sign after merge from I-225<br>End: At 2nd large "Exit 281 - Peoria Street" sign<br>Landmarks: Peoria Street bridge @ 9.30 miles |
| **I - 270 NW** | | | |
| 5 | 12.30-12.85<br>(2.52) | R | Start: 0.05 miles before 1st bridge over I-270<br>End: At "I-270" sign<br>Landmarks: 1st bridge @ 12.35 miles |
| 6 | 15.37-15.75<br>(3.08) | R | Start: 0.2 miles after 55mph sign past Vasquez bridge (just before "York Street" sign<br>End: At start of bridge just past "Junction I-76" sign<br>Landmarks: Vasquez bridge @ 14.58 miles, 55mph sign @ 15.10 miles, Junction I-76 sign @ 15.71 miles, take I-76 |

| SECTION NUMBER | MILE | LANE | LOCATION |
|---|---|---|---|
| **I -76** | | | |
| 7 | 18.83-19.34<br>(2.37) | R | Start: At 1st underpass past SH 224 bridge<br>End: At 1st reflector, 0.10 miles before next underpass<br>Landmarks: SH 224 (Exit 8) bridge @ 18.05 miles |
| 8 | 21.71-22.19<br>(2.91) | C | Start: At end of guiderail after 96th Avenue bridge<br>End: At 55mph sign 0.5 miles later<br>Landmarks: 84th Avenue underpass @ 20.50, 96th Avenue bridge @ 21.60 miles |
| 9 | 25.10-25.57<br>(3.20) | R | Start: At underpass 50 ft before 65 mph sign<br>End: 0.2 miles after "Commerce City" sign (at 2nd reflector)<br>Landmarks: Single tree on right @ 24.70 miles, Commerce City sign @ 25.40 |
| 10 | 28.77-29.32<br>(2.68) | R | Start: At small blue/white trailer camping sign on right<br>End: At 65mph sign after road comes in from right (not an exit/ entrance road)<br>Landmarks: SH 51 (Exit 17) underpass @ 27.00 |
| 11 | 32.00-32.48<br>(3.24) | R | Start: 2nd reflector before "Exit 22 - Bromley Lane" sign<br>End: At Exit 22 underpass<br>Landmarks: Road to right @ 31.5, end overlay @ 31.8, take "Exit 25 -- Lochbuie", turn left, then another left at the Frontage Road |
| **FRONTAGE ROAD** | | | |
| 12 | 35.72-36.24<br>(1.66) | R | Start: 0.20 miles after left turn onto Frontage Road at triple reflectors<br>End: 0.5 miles later @ delineator<br>Landmarks: Lochbuie "T" intersection left turn @ 35.30, Frontage Road left turn @ 35.50, west onto SH 7 |

| SECTION NUMBER | MILE | LANE | LOCATION |
|---|---|---|---|
| **SH 7** | | | |
| 13 | 37.90-38.40<br>(2.11) | R | Start: At white gas pipe vent posts 0.1 miles after intersection (no lights)<br>End: At natural gas pipeline sign before driveway to farmhouse<br>Landmarks: "T" intersection with SH 7 @ 36.95 miles, next intersection (no lights) @ 37.70 |
| 14 | 40.51-40.88<br>(2.41) | R | Start: At "Bail Bondsman" sign on right (past Burger King)<br>End: At 9th Avenue<br>Landmarks: 18th Avenue @ 40.30 miles 12th Avenue @ 40.65 miles |
| 15 | 43.29-43.71<br>(1.08) | R | Start: At dirt road to right past crest of hill<br>End: At phone pole 0.2 miles past driveway to farmhouse<br>Landmarks: 55mph sign @ 42.70, drive to farmhouse @ 43.50 |
| 16 | 44.79-45.29<br>(2.94) | R | Start: At Yosemite (2nd road to right with turn lane)<br>End: At next road to right (Amato)<br>Landmarks: 1st road to right with turn lane (Lomand) @ 44.43 |
| 17 | 48.23-48.68<br>(0.93) | R | Start: 0.1 miles past small bridge past Colorado Boulevard and railroad underpass<br>End: At "Intersection" sign on right before York Street<br>Landmarks: Colorado Boulevard underpass @ 47.80 |
| 18 | 49.61-49.96<br>(2.33) | R | Start: At yellow\white "Colorado Investor Realty" sign set back in field just past farmhouse/mobile homes<br>End: At 45 mph sign<br>Landmarks: Farm road to right @ 49.77 miles, turn left onto I-25 Southbound |

| SECTION NUMBER | MILE | LANE | LOCATION |
|---|---|---|---|
| **I - 25 SB** | | | |
| 19 | 52.29-52.82<br>(2.14) | C | Start: 0.1 miles past McDonald's billboard<br>End: 0.15 miles before long billboard on small hill on right (flag on 4th delineator past mile marker)<br>Landmarks: Left turn to I-25 @ 50.44 miles, underpass @ 51.45 miles |
| 20 | 54.96-55.41<br>(2.45) | R | Start: At "Bronco Inn" billboard<br>End: 0.1 miles before underpass<br>Landmarks: Underpass @ 53.47 miles, underpass past billboard @ 55.50 miles, take 120th Street Exit , turn right onto SH 128 at lights |
| **SH 128 WB** | | | |
| 21 | 57.86-58.37<br>(2.74)<br>**FLAG IS ON BRIDGE PAST FEDERAL LIGHTS - DISREGARD FLAG** | R | Start: At 2nd street (Zuni) to right past Pecos lights<br>End: At Federal lights<br>Landmarks: SH 128 WB "T" from I-25 @ 56.53 miles, Pecos Street lights @ 57.35 miles, Federal lights @ 58.38 miles, continue straight on SH 128, it turns into SH 287 |
| **SH 287 NB** | | | |
| 22 | 61.11-61.50<br>(1.50) | R | Start: At start of chain link fence 0.06 miles before Emerald Street (flag on delineator)<br>End: At 3rd phone pole past Hemlock Way<br>Landmarks: Lamar Street @ 60.62 miles, lights @ 60.87 miles, Hemlock Way @ 61.46, turn left onto SH 36 |
| **SH 36 EB** | | | |
| 23 | 63.00-63.47<br>(2.02) | R | Start: At 3rd delineator past the 5th street light on on-ramp to SH 36 |

| SECTION NUMBER | MILE | LANE | LOCATION |
|---|---|---|---|
| 23 (continued) | | | End: Just past 55mph sign 0.5 miles after start<br>Landmarks: SH 128 underpass @ 62.00 miles, lights at left turn to SH 36 @ 62.60 |
| 24 | 65.49-65.97<br>(2.34) | R | Start: At 2nd delineator past end of guiderail (past high wires)<br>End: At large "Sheridan Boulevard" exit sign<br>Landmarks: bridge @ 64.60 miles, high power lines @ 65.00 miles, end of guiderail @ 65.36 miles |
| 25 | 68.31-68.77<br>(2.19) | R | Start: At overhead sign structure (no signs on it)<br>End: 0.2 miles past underpass<br>Landmarks: Sheridan Boulevard underpass @ 67.14 miles, 55mph speed limit sign @ 67.86 miles |
| 26 | 70.96-71.36<br>(1.13) | R | Start: At large overhead "I-25 North" sign 0.3 miles past Pecos bridge<br>End: At 45mph sign before Broadway bridge **END NOT FLAGGED**<br>Landmarks: Federal Boulevard underpass @ 69.50, footbridge underpass @ 70.07 miles, Pecos bridge @ 70.61 miles, turn right onto I-25 Southbound **END OF SECTION NOT FLAGGED** |
| **I - 25 SB** | | | |
| 27 | 72.49-73.00<br>(2.08) | RC | Start: At 3rd underpass (NO FLAG AT START)<br>End: At orange diamond-shaped signs on both sides of highway<br>Landmarks: underpasses @ 72.06 and 72.42 miles, footbridge @ 72.84 miles |
| 28 | 75.08-75.57<br>(1.69) | LC | Start: At end of bridge just past 2nd "Limon/Grand Junction" overhead sign |

| SECTION NUMBER | MILE | LANE | LOCATION |
|---|---|---|---|
| 28 (continued) | | | End: 0.13 miles past 2nd underpass at "Right Lane Must Exit" sign **END OF SECTION NOT FLAGGED**<br>Landmarks: Limon/Grand Junction overhead sign @ 74.90 miles, I-70 underpass @ 75.20 miles, 2nd underpass @ 75.37 miles **END OF SECTION NOT FLAGGED** |
| 29 | 77.26-77.81<br>(1.60) | LC | Start: At "Exit 212B" sign 0.10 miles before Speer Boulevard underpass<br>End: At "Sports Complex Parking" sign on right just past underpass 0.5 miles after start<br>Landmarks: underpasses @ 76.73 (exit 212C), 76.91, 77.10, 77.20, 77.40 (Speer Boulevard) and 77.74 miles |
| 30 | 79.41-79.79<br>(1.65) | LC | Start: At 6th Avenue overhead sign just before exit 209B (has "35mph Exit Speed" sign on post) **NO FLAG AT START**<br>End: 0.12 miles past 6th Avenue underpass<br>Landmarks: underpasses @ 78.46 and 78.56 miles, 6th Avenue underpass @ 79.68 miles |
| 31 | 81.44-81.77<br>(2.17) | C | Start: At 55mph sign on bridge over Santa Fe Drive<br>End: At "Washington/Emerson" overhead sign **END OF SECTION NOT FLAGGED**<br>Landmarks: Santa Fe overhead sign @ 80.65 miles, Alameda underpass @ 80.90 |
| 32 | 83.94-84.50<br>(2.27) | C | Start: At "Exit 205A" sign 0.10 miles past University Boulevard bridge<br>End: At the 5th street light on right 0.15 miles past next underpass<br>Landmarks: Logan underpass @ 82.30 miles, Emerson underpass @ 82.77 miles, Franklin |

| SECTION NUMBER | MILE | LANE | LOCATION |
|---|---|---|---|
| 32 (continued) | | | underpass @ 83.32 miles, next underpass @ 84.35 miles |
| 33 | 86.77-87.18 | C | Start: At 1st big "Hampden Avenue" sign after Exit 202<br>End: At small "Exit 201" sign at exit ramp just before Hampden underpass<br>Landmarks: Evans underpass @ 85.37 miles, bridge @ 86.30 miles |