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Correlation of Roughness Ratings with Highway User Opinion

Study SD2001-12
Final Report

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16. Abstract

The South Dakota Department of Transportation's Pavement Management System uses threshold values of pavement roughness to determine the need for highway rehabilitation on South Dakota highways and Interstates. However, these threshold values were set by a panel of experts and therefore may not have been representative of the general public. Panel members representing the general public surveyed test sections to correlate existing threshold values to their perception of highway roughness.

Study objectives were to: establish a mathematical correlation between pavement roughness measured as International Roughness Index and highway users' subjective opinion of roughness; and To identify thresholds of pavement roughness, in terms if International Roughness Index and subjective opinion, acceptable to highway users

During the surveys, 18 survey panel members of varying employment positions, age and gender were selected from DOT offices throughout the State of South Dakota. In the surveys, panel members were driven over thirty-five test sections and asked to rate their roughness on a zero-to-five scale, and to state whether a particular section was in need of immediate repair (Yes or No). The test sections were all one quarter-mile in length, and of varying roughness ranges and pavement families.

After the roughness survey, data from the survey forms were collected, compiled and analyzed. Mathematical models were then deduced, which could be incorporated into the Pavement Management System, allowing executive decisions (theoretically) to better serve public need for road rehabilitation.

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Executive Summary

The South Dakota Department of Transportation currently uses the International Roughness Index (IRI) to rate roughness along its roads, the results of which then play a key role in selecting areas for repair and determining the appropriate rehabilitative treatments for those areas. The IRI serves, since 2000, as the base of for the Roughness Distress Index (RDI). However, since incompatibilities existed between the RDI and the former system, the South Dakota Roughness Index (SDI), a correlation between the two had to be devised. The problem here was that the RDI values were based entirely on the opinions of a panel of experts, comprised exclusively of SDDOT personnel, whose opinions may not have been representative of the general public. One way or the other, preconceptions (by the panel) may have resulted in either over or underrating the importance of pavement roughness.

Research needed to be conducted to correlate the IRI to the opinions of the general public on the roughness of South Dakota highways and Interstates, and to determine margins of acceptable pavement roughness.

The researchers were to complete the following tasks:

1. Meet with the project's technical panel to review project scope and work plan.
2. Review literature on methodology and results from previous correlations of measured roughness to subjective opinion.
3. Present findings to the technical panel to determine whether tasks 4-6 should be performed.
4. Identify and establish test sections that encompass a wide range of roughness conditions on the pavement families prevalent in South Dakota.
5. Obtain measured roughness ratings (International Roughness Index) and subjective ratings from a panel of lay highway users on each of the established test sections.
6. Analyze measured roughness ratings and subjective ratings to determine correlation relationships and thresholds of acceptable roughness levels for each pavement family.
7. Prepare a final report and executive summary of the research methodology, findings, conclusions, and recommendations.
8. Make an executive presentation to the SDDOT Research Review Board at the conclusion of the project.

During the study, 18 survey panel members, of varying employment positions, age and gender, were selected from DOT offices throughout the State of South Dakota, to participate in the road roughness survey. In order to correlate IRI with highway user opinion, the panel members were asked to rate each test section on a zero (infinitely rough) to five (perfectly smooth) scale, and state whether, in their opinion, the road was in need of immediate repair (Yes or No).

During the survey, the panel members were driven over thirty-five test sections, of varying roughness and pavement type. The test sections were selected, with the help of Data Inventory, by reviewing the 2000 IRI readings for SD highways. Three selections were chosen for each of three roughness ranges, on three pavement families, giving a total of 27 test sites. Eight backup sites were also chosen, to ensure that equal numbers of tests were run on each roughness and pavement family. The test sections were all one quarter-mile in length.

Each panel member was given a personalized survey form, assigning him or her to a vehicle and seating position for each test section. The panel members were to ride in one of three vehicle types during the roughness survey. Three survey vehicles were chosen to represent sizes of vehicles used by the general public (large, midsize, and compact). These were one fifteen-passenger Dodge Van, two Chevy Malibu (midsize), and two Ford Tempos (compact). At any given time during the surveys, six panel members were in each vehicle type—three in each of the cars, and six in the van.

After the survey concluded, the survey forms were collected and data compiled for each test section. The averages of panel member ratings were figured, yielding the Mean Panel Rating (MPR) for each section. This was compared to the IRI value calculated from the elevation profile measured by the ARAN Road Profiler. The IRI for each section was given in inches per mile, but was later converted to metric units of meters per kilometer for analytical purposes.

Overall, the panel surveys were very successful, with few complications. After collecting the survey forms, the researchers entered the data in an Excel spreadsheet, inputting each panel member's response to each test section, along with assigned information for that test section. From this, they were able to extract the data necessary to carry out the project objectives.

First, the researchers calculated the MPR for each test section by simply averaging the individual ratings for each test section. The MPR was also figured separately for different vehicle types and pavement families. The MPR values were entered into data tables and analyzed to see which research variables were significant. Results were also plotted, to see what correlations could be recognized visually.

Before scatter plots could be made, however, the IRI values had to be entered for the section. These figures came from the data collected by the ARAN. A single variable regression was done to determine the equation relating MPR to IRI. Then, MPR values for vehicle type and pavement family were plotted and subjected to regression, to determine trend lines which were plotted against the trend line for the overall MPR. This allowed the researchers to visualize the significance of each variable. After plotting the regressed lines against the overall line, and reviewing the regression analysis, it was decided that any differences due to vehicle type and pavement family were probably statistically insignificant, and could be neglected. The variable "Van" showed slight statistical significance, but the uncertainty in the ANOVA was enough to overshadow this. Furthermore, even though data analysis showed slight statistical significance for the Van's variance to the other vehicles, there was no practical significance to deal with this variable. Therefore, the researchers decided to reject all research variables, relating MPR to IRI, except for IRI itself.

These results were confirmed using *SYSTAT 10.0* to run multivariate regressions. Setting MPR as the dependent variable, regressions were run for the independent variables IRI, vehicle type, and pavement family. This was done numerous times, regressing the data for all possible combinations of variables. In the end, the researchers decided that only IRI had any noticeable correlation to MPR. Variance caused by any of the other independent variables was slight enough to disregard. The researchers needed to concern themselves only with the generated coefficient for regression analysis for IRI. From this, the following equation was deduced, completing the first of two research objectives:

$$\underline{MPR = 4.38 - 0.68\ IRI}$$

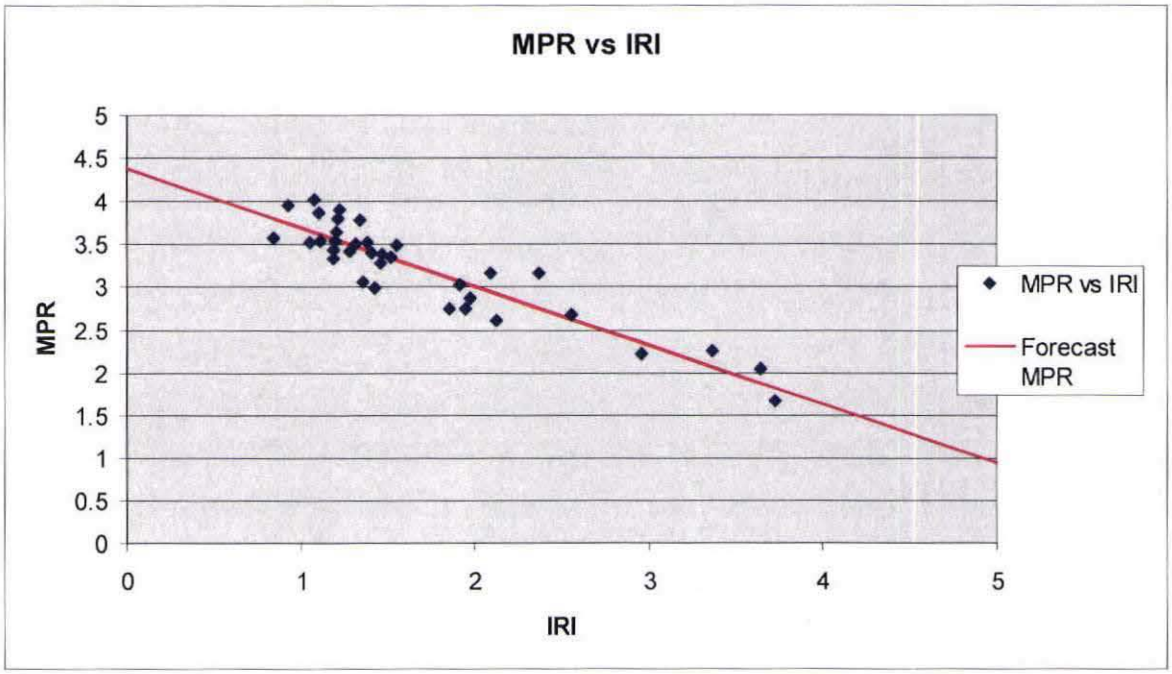


Figure 1: Mean Panel Rating versus International Roughness Index

The next objective instructed the researchers to identify thresholds of pavement roughness, in terms of IRI and subjective user opinion (MPR), requiring pavement rehabilitation. To do this, the researchers first looked to the results of the panel member survey to determine percentages of panel members marking "Yes" (that a particular test section was in need of immediate repair) for each test section. These values were then plotted against the IRI value for the test section, and an ANOVA conducted, to produce a trend line for the data. It was originally planned that the threshold would be set for the IRI value yielding 50%, however a discussion with Steve Gramm, of SDDOT Planning and Programming, said that the office's policy was more "proactive, than reactive," and to use a 40/60 ratio instead. Accordingly, the researchers then tried to determine threshold IRI values, specifically the value yielding a 40% "Yes" response from the panel members. The following tables lists the threshold values, in terms of IRI, for different predicted percentages of Yes's.

Problems arose however when the researchers noticed that threshold values were, in their opinions, unreasonably high. This led the researchers to reexamine their list of test sections, and IRI values. When the recent IRI values were plotted against the IRI values used to pick the test sites, very significant inconsistencies were discovered. For whatever reason, several of the IRI values used to select the test sections were incorrect. Whereas the researchers originally intended to have equal numbers of test sections for each roughness range for each pavement family, the examining the data from the ARAN van revealed that the majority of the test sections were smooth. In fact, in the whole survey, there were actually only three rough sections. Since there was such a high number of smooth sections (with few rough sections), the data set was weighted heavily in that direction. This acted as an anchor to the regression line, for %Yes vs. IRI, restricting its climb. As a result, the IRI threshold values for 40% is unreasonably high.

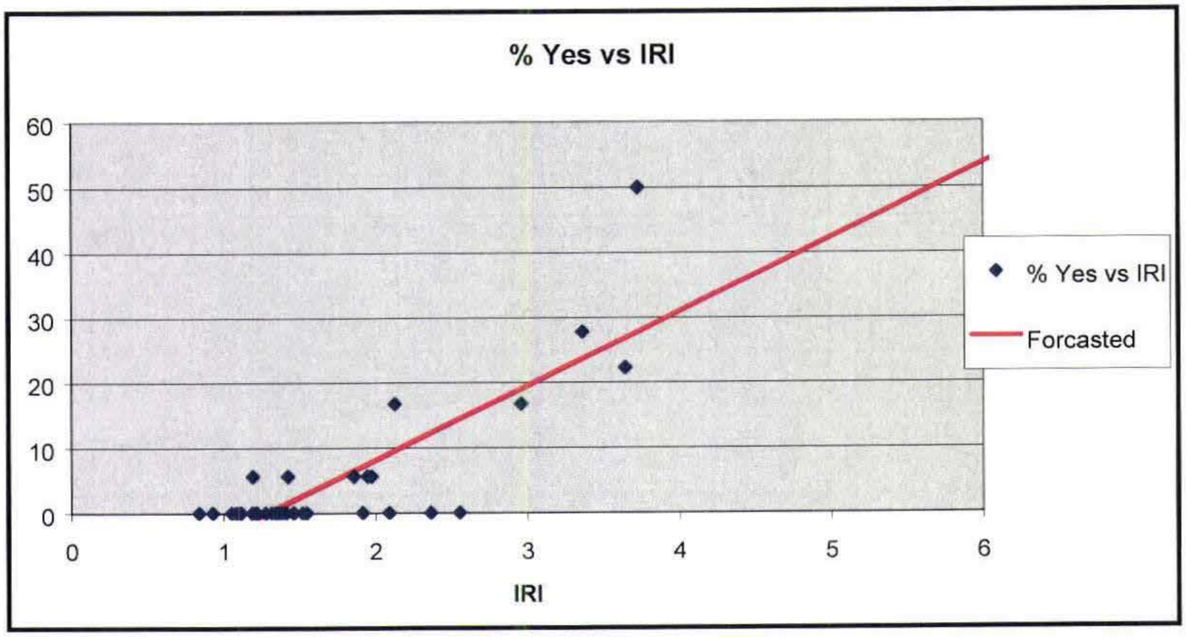


Figure 2: Percent Responding that Test Section Was "In Need of Immediate Repair"

Originally, the researchers intended for the %Yes threshold values to act as trigger values for Planning and Programming in the their Pavement Management System. However, since the data set was biased heavily, Mr. Ormesher and Mr. Powell feel that results of the second study objective are not conclusive, and do not accurately portray thresholds for pavement rehabilitation with respect to general highway user opinion.

The researchers' implementation recommendations come directly from the project objectives, which were laid out in the work plan. These were to: (1) establish a mathematical correlation between pavement roughness, measured as International Roughness Index, and highway users' subjective opinion of roughness (MPR), and (2) identify thresholds of pavement roughness, in terms if IRI and subjective opinion, acceptable to highway users.

Table 1: Threshold Values for %Yes

%Yes	Predicted IRI
5	1.7
10	2.2
15	2.6
20	3.0
25	3.5
30	3.9
35	4.4
40	4.8
45	5.2
50	5.7
55	6.1
60	6.6

The researchers originally intended to recommend that the mathematical models, correlating IRI and MPR, and the roughness thresholds determined by this project be implemented into the SDDOT Pavement Management System. It was the researchers' opinion that doing so would help validate SDDOT pavement management decisions, in regard to the public highway-user opinion. However, since the data set for determining threshold values was heavily biased, the researchers only recommend that only the equation relating MPR to IRI (Objective 1) be implemented. If anything, they feel that the proposed threshold values should be regarded with great discretion by Planning and Programming. Moreover, it may be best to simply disregard the proposed set of trigger values completely.

Finally, the researchers feel that the *Correlation of Roughness Ratings with Highway User Opinion* should be conducted again, in order to produce valid threshold values and to confirm results for the relation of MPR to IRI. Although one of two study objectives was not accomplished successfully, the researchers still feel that if extra steps had been taken to unsure that no roughness range for any pavement family was either under or over-represented in the data set, the project would have been more successful. The error was in the data set, not the methodology. If done correctly, redoing this project would be of great benefit to the Department and to the general public. Since all of the methodology is in place, and research forms and documents have already been created, it would be relatively simple to perform again.

PROBLEM DESCRIPTION

The South Dakota Department of Transportation currently uses the International Roughness Index (IRI) to rate roughness along its roads, the results of which then play a key role in selecting areas for repair and determining the appropriate rehabilitative treatments for those areas. The Office of Planning and Programming analyzes roughness and other distress types in order to predict the performance of roads. The performance curves are then integrated with treatment resets to produce the benefit for the road, which is then balanced with the cost of the treatments to decide which treatment would be most beneficial. This is determined by complex software that considers all roads and all possible treatments and time frames, to maximize the ratio of benefit to cost.

Since 2000, the IRI serves as the basis for the Roughness Distress Index (RDI), a measure representing user perception of highway roughness. Prior to that date, RDI was calculated from another index, the South Dakota Roughness Index (SDI). Because the relationship between IRI and RDI was established somewhat arbitrarily, SDDOT's Office of Planning & Programs felt a better correlation between the two was needed. The problem was that the RDI values were based entirely on the opinions of a panel of experts, comprising SDDOT personnel exclusively, whose opinions may not have been representative of the general public. One way or the other, preconceptions (by the panel) may have resulted in either over or underrating the importance of pavement roughness.

Research needed to be conducted to evaluate the correlation of the IRI to the opinions of the general public on the roughness of South Dakota highways and Interstates, and to determine margins of acceptable pavement roughness.

OBJECTIVES

The technical panel for SD2001-12 defined two research objectives:

Objective 1: To establish a mathematical correlation between pavement roughness measured as International Roughness Index and highway users' subjective opinion of roughness.

For this objective the researchers conducted a survey of selected road sections spanning the range of IRI roughness ratings. A panel of SDDOT staff unfamiliar with the pavement distress and rehabilitative methods was driven over the test sections in a variety of vehicles and asked to rate the sections on roughness. From the survey results, the researchers computed the Mean Panel Rating (MPR), the average of individual panel ratings. A mathematical correlation was established to relate the MPR to the International Roughness Index (IRI). The relationship for MPR to IRI, was found to be linear, producing the following equation:

$$\underline{MPR = 4.38 - 0.69\ IRI}$$

This will serve to validate SDDOT pavement management decisions in the light of the public eye.

Objective 2: To identify thresholds of pavement roughness, in terms if International Roughness Index and subjective opinion, acceptable to highway users.

During the panel survey, the panel members were asked state whether, in their opinion, the road was in immediate need of repair. The results of the panel survey, and IRI values for the test sections, were used to determine thresholds of acceptable pavement roughness. The results were then to be adopted by Planning and Programming to amend existing trigger values and help make Pavement Management decisions more reflective of the public's perception of South Dakota road conditions.

From the survey forms, the researchers totaled the number of survey panel members who responded "Yes" to the question "Is the section in need of immediate repair?" Then percentages of "Yes" responders were figured for each test section (having a particular IRI value). The %Yes figures were then graphed, and regressed against the range of IRI values to determine threshold values for pavement rehabilitation. Results from this are questionable, at best, for large bias was discovered in the sample of survey test sections. The number of smooth test sections greatly outnumbered the medium and rough categories. Therefore, as seen by the researchers, the proposed trigger values are much too high; and, as a result, the second study objective was not met successfully. (See Appendix B-5 for the proposed table of threshold values.)

TASK DESCRIPTION

Task 1—Meet with the project's technical panel to review the project scope and work plan.

The researchers met with the technical panel on the 28th of June, to discuss the work plan and to identify amendments to the project. The meeting was a time for the technical panel to ask questions and provide suggestions on the topic. The researchers incorporated the results and made the appropriate changes made to the final work plan.

During the technical panel meeting, many things were discussed, resulting in several amendments that were made to the overall research design and to the work plan itself. First it was decided that the panel members for the roughness surveys should be selected statewide, whereas originally they were to be selected exclusively from the Pierre area. Although, this would have made the survey easier to coordinate, the technical panel thought that limiting the selections to Pierre would bias the survey sample. Also, in order to allow panel members enough time to travel to Pierre (the start point for the surveys), the dates for the survey was changed from July 16th and 17th to July 17th and 18th, with a short meeting to be held on the 16h in the late afternoon.

Another topic of discussion, was the method that the ARAN van would use to measure the IRI values for the 35 test sections. It was originally intended for the van to follow directly behind the survey vehicles, keeping up as they could. However, Ken Marks informed the researchers, during the meeting, that there was a problem in that the ARAN van could not measure IRI for the exact length of the test sections. That is, it could only take readings for every 500 feet. Since, the test sections were each a quarter mile long (1320 feet), this had to be solved. The need to calculate IRI from point to point was met by using a different module (called View) of the ARAN software. It was decided that it was in the interest of the Department and this project to train the ARAN operators to use the View Software.

Another concern of the researchers and the technical panel members was whether fluctuations in road conditions, caused by changes in weather conditions and temperature, would be substantial enough to be of concern to this project, so that scheduling changes needed to be made for the roughness calibration surveys. The panel learned that scheduling was an issue, but that as long as the ARAN van recorded the IRI data within a few hours of the surveys, fluctuations would be minimal (and of no concern). It was later learned, however, that temperature fluctuations can have a more significant effect on IRI readings than originally thought. So, it was coordinated with the ARAN crew to take roughness ratings within an hour of the test section profiling.

Another concern was how the survey panel members would switch vehicles, so that each person would ride in each vehicle type over each pavement family and roughness range. It was originally thought that the panel members would switch on their own will, and that this would randomize this process. The panel considered the issue to be more complex than this, however, and decided that this was not sufficient. A more structured format was necessary. The researchers and technical panel decided that individualized survey forms should be assigned to each panel member, with specific instructions for seating assignments. The panel member would know when to switch and which car to go to. Assignments were made by test section.

Task 2—Review literature on methodology and results from previous correlation's of measured roughness to subjective opinion.

The literature review for this project was minimal. However, methodology did exist from previous attempts made by other states to perform similar projects. The researchers reviewed the research findings of four states – Ohio[1], Minnesota[2], Iowa[3], and New Hampshire[4] - to familiarize themselves with existing methodology and aid them in designing the project. Results of the literature search were presented to the technical panel.

Task 3—Present findings to the technical panel to determine whether tasks 4-6 should be performed.

After reviewing the literature, it was decided that performing a roughness calibration study would benefit South Dakota. Therefore, the researchers recommended that tasks 4-6 be carried

[1] Spangler, Elson, and Kelly, William. 1990. *Long-term Time Stability of Pavement Ride Quality Data.* Surface Dynamics, Inc.: Bloomfield Hills, MI..

[2] Kuemmel, David; Robinson, Richard; Griffin, Robert; Sonntag, Ronald; and Giese, James. 2001. *Public Perceptions of the Midwest's Pavements – Executive Summary – Minnesota.* Marquette University: Milwaukee, WI.

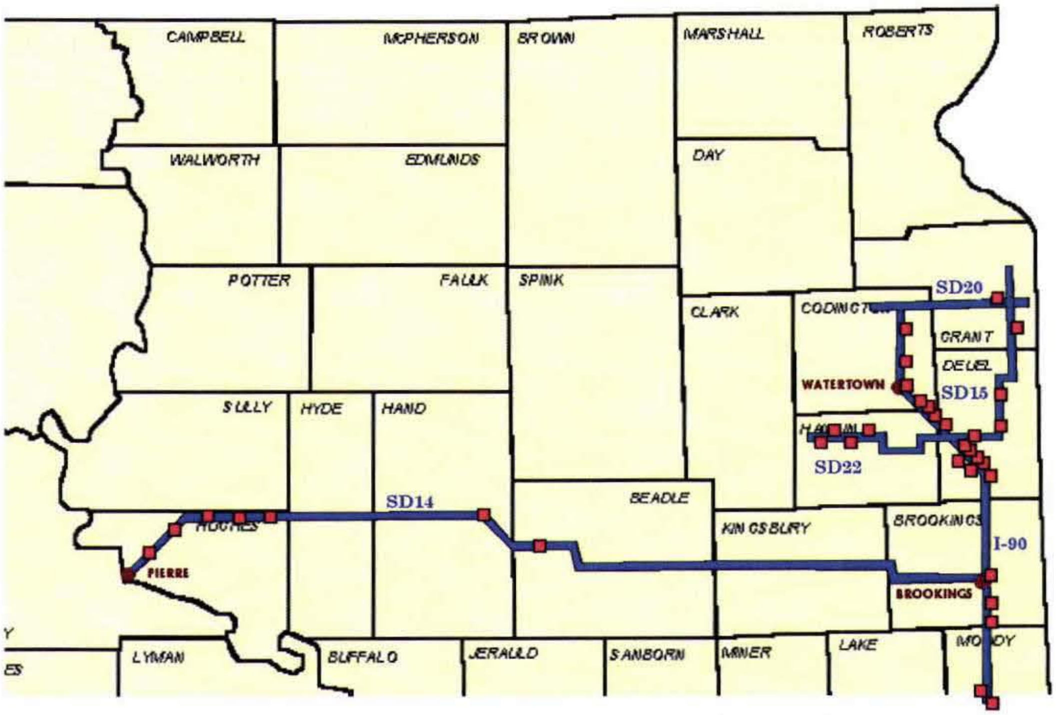
[3] Kuemmel, David; Robinson, Richard; Griffin, Robert; Sonntag, Ronald; and Giese, James. 2001. *Public Perceptions of the Midwest's Pavements – Executive Summary – Iowa.* Marquette University: Milwaukee, WI.

[4] No Author Listed. 1995. *New Hampshire Department of Transportation Ride Quality Study.* Bureau of Materials and Research: Concord, NH.

out. For the sake of time, this issue will be addressed at the original meeting with the technical panel (see Task 1). Another meeting need not be scheduled.

Task 4—Identify and establish test sections that encompass a wide range of roughness conditions on the pavement families prevalent in South Dakota.

A list of test sections of asphalt concrete (AC), jointed Portland cement concrete (JPC), and continuously reinforced concrete (CRC), with previously tested IRI values ranging from very smooth to very rough, was provided by Data Inventory. These sections were then inspected by the researchers and properly marked on the road. Ideally, the test sections were to be in relatively close proximity, while embodying the full range of roughness. Originally, the researchers looked toward western South Dakota, but its highways could not accommodate the full range of roughness and pavement families. Instead, test sites were chosen along US 14, SD15, SD20, SD22, and I-29, in northeastern South Dakota near Watertown and Brookings. The technical panel approved the suggested test sites.



Routes for Panel Member Survey of Selected Test Sections

Figure 3: Location of Test Sections

The test sections were marked with brightly colored paint and wooden lath. Previous to the roughness surveys, the researchers marked out the survey test sites, so that they would be visible to the drivers while traveling at highway speeds. To do this, one piece of pink wooden lath was placed at the delineator preceding the test site, at the start of the test site, and at the section end. The researchers also painted brightly colored highway markings at the beginning and end of each test site.

Figure 4: Photograph of Test Site Markings

Task 5—Obtain measured roughness ratings (International Roughness Index) and subjective ratings from a panel of lay highway users on each of the established test sections.

A panel, composed of 18 selected SDDOT staff, was chosen to ride over the selected test areas and rate the roughness of the road in those areas. SDDOT staff was chosen for liability and convenience reasons. It was decided that it would be easier to obtain staff from various offices around the state than to recruit volunteers from the general public. One thing to be considered is whether or not the results were biased by the fact that all survey panel members were SDDOT employees.

The survey panel members and drivers were instructed to attend a meeting the afternoon before the survey, where they were given a brief overview of the project and a tentative agenda for the surveys. The researchers answered any questions that the panel members had at that time. Before departing on the survey the next morning, the panel members were given instructions as well as their personalized survey forms (See Appendix A.) The drivers were given laminated maps that showed the approximate location of the test sites. They were also given an official list of test sites listed by MRM, which the crew of the ARAN van also received.

The survey forms consisted of the list of 35 sections on which the panel members were to rate the roughness of each test section on a line scale ranging from zero to five. There was also a space where they were to circle either yes or no, stating whether or not they believed that each particular test section was in immediate need of repair.

Three survey vehicles were chosen, to represent sizes of vehicles used by the general public (large, midsize, and compact). These were as follows: One fifteen-passenger Dodge Van, two Chevy Malibu's (midsize), and two Ford Tempos (compact). At any given time, during the surveys, six panel members were in each vehicle type – three in each of the cars, and six in the van. The researchers randomized seating by generating random numbers in a Microsoft Excel spreadsheet. Each panel member had a form made specifically for him or her, assigning the vehicle each panel member would ride in for each test section (See Appendix A.) Randomizing the seating assignments was done to avoid forming an unintentional correlation between independent variables.

Along with this, an ARAN van measured the IRI of the specific test sections within an hour from the time the survey panel members rated them. The ARAN van uses accelerometers and lasers to measure an elevation profile of a road. The profile is fed into a numerical algorithm[5]

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[5] Sayers, Michael W.; Gillespie, Thomas D.; Queiroz, Cesar A. V. 1986. *The International Road Roughness Experiment.* (World Bank: Washington, D.C.)

that simulates the response of the suspension of one corner of an automobile (quarter-car) to the profile, generating the International Roughness Index, a measure of the road's smoothness or roughness. The IRI values generated by the ARAN van are reported in units of inches per mile. A newly paved road might have an IRI value of around 50 or 60 inches per mile (0.8 m/km), where an extremely rough road may reach values of 250 to 300 inches per mile (4.3 m/km).

During the surveys, it was hoped that weather conditions would be mild, so that they did not interfere with the panel members' perception of the test sections. Rain and/or wind were not desirable. Problems arose on the second day, when a thunderstorm struck the Watertown area. Since the ARAN van cannot take accurate readings when roads are wet, the survey itinerary had to be rerouted and coordinated with the ARAN personnel. Adjustments were made, and all went smoothly from then on. Having returned to the Watertown area, the survey crew found that the storm had passed and that the precipitation had evaporated from the roads. The surveys then went on as scheduled

At the survey's conclusion, the researchers compiled the survey forms, compiled the results and analyze the results. For analytical purposes, the IRI was converted from units of inches per mile to metric units of meters per kilometer.

Task 6—Analyze measured roughness ratings and subjective ratings to determine correlation relationships and thresholds of acceptable roughness levels for each pavement family.

From the surveys, and collected ARAN IRI values, the researchers analyzed and compared the measured panel ratings for the test sections to determine the relationship between IRI values and panel roughness ratings. The results of this were used to adjust existing thresholds of acceptable roughness levels for the different pavement families.

First, the values from the surveys were plotted against the IRI values for the test sections to determine the relationship. Also, an ANOVA (analysis of variance) was conducted for the MPR to determine which research variables are significant. Linear coefficients were calculated for each variable, to determine the extent of its significance. Statistically significant coefficients were then isolated and used to establish mathematical equations to determine threshold values for road roughness.

Using the survey questionnaires for the panel survey, the researchers' determined threshold values for acceptable versus unacceptable road conditions. On the survey forms, the panel members were asked to rate the selected road sections using a zero-to-five scale (called MPR), and to decide whether the road was in need of immediate repair (Yes or No). The results of the surveys were then compiled and entered into an Excel spreadsheet. By graphing Yes/No against the MPR scale, probabilities of Yes/No for certain MPR were determined and used to decide threshold values for repair needs. If accepted, the threshold values could then be implemented by the Office of Planning and Programming in their pavement management system.

Task 7—Prepare a final report and executive summary of the research methodology, findings, conclusions, and recommendations.

Having concluded the research, the researchers prepared a final report, which will be presented to the technical panel. This report tells, in detail, the findings of the literature review, the methodology used, the conclusions of the research, and provides recommendations for changes to be made by the SDDOT Office of Planning and Programming to the Department's pavement management system. The report was prepared as an electronic document in Microsoft Word.

Task 8—Make an executive presentation to the SDDOT Research Review Board at the conclusion of the project.

At the conclusion of the research, the researchers made an executive presentation to the Research Review Board on the *Correlation of Roughness Ratings with Highway User Opinion.* The Research Review Board convened on the morning of Thursday, August 16, 2001.

FINDINGS AND CONCLUSIONS

Having collected the survey forms, the researchers then entered the results into an Excel spreadsheet, inputting each panel member's response to each test section, along with their assigned information for that test section. From this, they were able to extrapolate the data necessary to carry out the project objectives.

First of all, the researchers calculated the MPR for each test section. This was found by simply tallying the individual ratings for each section, and dividing by the number of raters for that section. It is simply the average rating for the section. The MPR was also figured independently, for different vehicle types and pavement families. For each test section, the MPR was figured for those people only riding in a certain vehicle type (compact, mid-size, and large). For example, the researchers figured the MPR for the test sections, for only those raters riding in a Chevy Malibu. When finding the MPR for different pavement families, most of the work was already done. Since, the test sections were picked so that each section consisted only of one pavement family, and since the MPR had already been figured for the individual test sections, the researchers simply sorted the data by pavement family, and made individual plots of the values.

Before scatter plots could be made, however, the IRI values had to be entered for the section. These figures came from the data collected by the ARAN van crew. Having received the IRI readings for the test sections, the information was entered into the Excel spreadsheets.

Using Excel, single variable regressions were done, to determine the equations relating MPR to IRI, overall and for each vehicle type and pavement family. Regressions were done for the different variables, and plotted against that of the overall MPR, to see the significance of each variable. After plotting the regressed lines against the overall line, it was decided that any differences due to vehicle type and pavement family were statistically insignificant, and could be neglected. This was also proven, by using *Systat 10.0* to run a multivariate regression for MPR. For this, the dependent variable was MPR. The regression was run for the independent variables: IRI, vehicle type, and pavement family. This was done numerous times, regressing the data for all possible combinations of variables. In the end, the researchers decided that the variance caused by any of the independent variables, excluding IRI, was slight enough to overlook them completely. That is to say that the P values from the regression, for any of the other variables, were not low enough to reject the null hypothesis (that the variable causes "no effect" to the MPR value). Therefore, researchers needed to concern themselves with only the generated coefficient (from the regression) for IRI, which they found to be –0.6881397. From this, the following equation was deduced, completing the first of two research objectives:

$$\underline{MPR = 4.38 - 0.68\ IRI}$$

The next objective instructed the researchers to identify thresholds of pavement roughness, in terms of IRI and subjective user opinion (MPR), for possible pavement rehabilitation. To do this, the researchers first looked to the results of the panel member survey, in order to determine percentages of panel members, marking "Yes" (that a particular test section was in need of immediate repair), for each test section. These findings were then plotted against the IRI value for the test section, and an ANOVA conducted, to produce a trend line for the data. It was originally planned that the threshold would be set for the IRI value yielding 50%, however Steve Gramm of SDDOT's Office of Programming and Planning said that the office's policy was more "proactive, than reactive," and suggested using a 40/60 ratio instead. The researchers then decided to set threshold equations for the IRI yielding 40% of the panel members. Problems arose however when, the researchers noticed that threshold values were, in their opinions, unreasonably high.

This led the researchers to reexamine their list of test sections, and IRI values. When the recent IRI values were plotted against the IRI values used to pick the test sites, very significant inconsistencies were discovered. For whatever reason, several of the IRI values used to decide the test sections were incorrect. Whereas the researchers originally intended to have equal numbers of test sections for each roughness range, for each pavement family, the examining the data from the ARAN van revealed that the majority of the test sections were smooth. In fact, in the whole survey, there were actually only three rough sections. Since there was such a high number of smooth sections, the data set was weighed heavily in that direction. This acted as an anchor to the regression line, for %Yes vs. IRI, restricting its climb. As a result, the IRI threshold values for 40% is unreasonably high.

The following tables lists the threshold values, in terms of IRI, for different predicted percentages of Yes's:

Table 2: Threshold Values for %Yes

%Yes	Predicted IRI
5	1.7
10	2.2
15	2.6
20	3.0
25	3.5
30	3.9
35	4.4
40	4.8
45	5.2
50	5.7
55	6.1
60	6.6

Threshold IRI = (Desired %Yes + 14.7) / 11.4

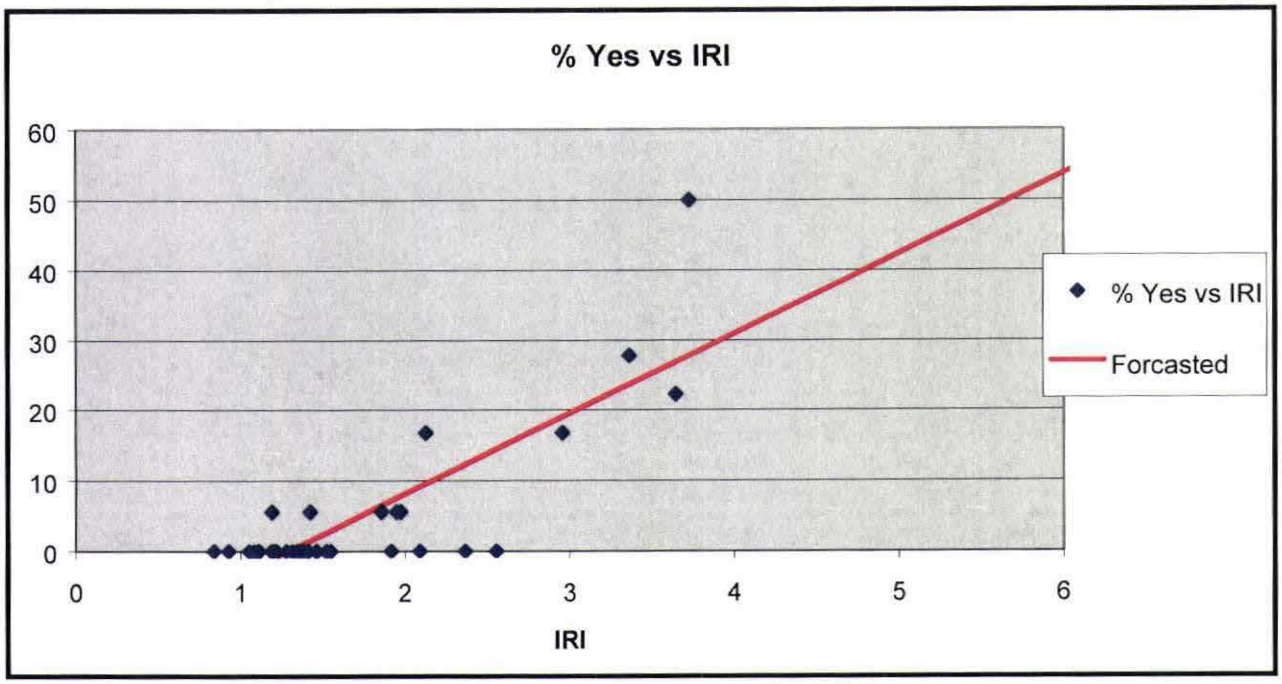


Figure 5: Percent Responding that Test Section Was "In Need of Immediate Repair"

Originally, the researchers intended for the %Yes Threshold values to act as trigger values for Planning and Programming in the their Pavement Management System. However, since the data set was biased heavily, the researchers feel that results of the second study objective are not conclusive, and do not accurately portray thresholds for pavement rehabilitation with respect to general highway user opinion. They recommend that Planning and Programming implement the proposed trigger values with much discretion, or reject them as they see fit.

Although the study done by New Hampshire did not propose threshold values, their findings seem to support the seemingly unreasonably high projection of threshold trigger values. This was also the case with other states, doing similar research, in that in the panel members were more forgiving of rough road conditions than existing pavement-rehabilitation trigger values. In New Hampshire's report, a line of best fit shows their relation of MPR to IRI. From this graph, MPR is greater for IRI values less than 2. However, MPR becomes increasingly less than IRI for values past 2. In fact, at an IRI of 4.5, the MPR is approximately 4 (nearly a half point behind).

IMPLEMENTATION RECOMMENDATIONS

The researchers' implementation recommendations come directly from the project objectives, which were laid out in the work plan. These were to:

1. Establish a mathematical correlation between pavement roughness, measured as International Roughness Index, and highway users' subjective opinion of roughness (MPR), and
2. Identify thresholds of pavement roughness, in terms if IRI and subjective opinion, acceptable to highway users.

The researchers had originally intended to recommend that the mathematical models, correlating IRI and MPR, and the roughness thresholds determined by this project be implemented into the SDDOT Pavement Management System. It was the researchers' opinion that doing so would help validate SDDOT pavement management decisions, in the regard to the public highway-user opinion. However, since the data set for determining threshold values was heavily biased, the researchers only recommend that the equation relating MPR to IRI (Objective 1) be implemented. If anything, they feel that the Office of Planning and Programming should regard the proposed threshold values with great discretion. Moreover, it may be best to simply disregard the proposed set of trigger values completely.

Although one of two study objectives was not accomplished successfully, the researchers still feel that, if extra steps had been taken to ensure that no roughness range for any pavement family was either under or over-represented in the data set, the project would have been successful. The error was in the data set, not the methodology. If redone correctly, this project would be of great benefit to the Department and to the general public. Since all of the methodology is in place, and research forms and documents have already been created, it would be relatively simple to perform again. This was the first attempt for this project by the State of South Dakota, but future attempts would be of value. If the SDDOT does, in fact, decide to do a follow up study, the researchers would stress the following points:

1. Redo the panel member roughness survey.
2. Recalculate the equations and threshold values as required of the project study objectives.

3. Take care to ensure that the proposed test sections comprise the entire array of roughness ranges for all pavement families, so that the data set is not biased for any roughness range, pavement family, or combination thereof. To do this, the researchers should profile the test sections just prior to performing the roughness survey and verify IRI values.
4. When performing the surveys, it may help to have more survey panel members. This will serve to smooth out any undesired data trends, due to sample biases. The more data points collected, the better the results will reflect the perspective of the general highway user.
5. If not enough test sections for the entire range of roughness and pavement families cannot be located, in general proximity, in one part of the State of South Dakota, the survey should be conducted on more than one occasion, in other areas. If needed, the request for survey panel members should be sent well in advance of the proposed test dates, so that adequate numbers of raters can be acquired.
6. The ARAN survey crew should be given a list of expected IRI values for the proposed test sections, and should contact the survey crew supervisors during the surveys if discrepancies arise.

Appendix A: Survey Documentation

Official Panel Member Survey Form
Correlation of Roughness Ratings with
Highway User Opinion
SD2001-12

Directions:

- Please rate each test section on a scale from 0 to 5, five being perfectly smooth and zero being infinitely rough.
- Remember to rate the roads to the nearest 1/10 (I.E. 3.5, 3.8, 4.0, etc.)
- In the blank provided, please indicate whether, in your opinion, you believe that the individual test section is in need of immediate repair (YES or NO).

Name: **Example**

Section Number	Vehicle	Rate Test Section (Mark line with an "X")	Needs Immediate Repair
1	Van	0----+----1----+----2----+----3----+----4----+----5	Yes No
2	Van	0----+----1----+----2----+----3----+----4----+----5	Yes No
3	Van	0----+----1----+----2----+----3----+----4----+----5	Yes No
4	Van	0----+----1----+----2----+----3----+----4----+----5	Yes No
5	Van	0----+----1----+----2----+----3----+----4----+----5	Yes No
6	Malibu 1	0----+----1----+----2----+----3----+----4----+----5	Yes No
7	Malibu 1	0----+----1----+----2----+----3----+----4----+----5	Yes No
8	Van	0----+----1----+----2----+----3----+----4----+----5	Yes No
9	Van	0----+----1----+----2----+----3----+----4----+----5	Yes No
10	Van	0----+----1----+----2----+----3----+----4----+----5	Yes No
11	Van	0----+----1----+----2----+----3----+----4----+----5	Yes No
12	Van	0----+----1----+----2----+----3----+----4----+----5	Yes No
13	Malibu 1	0----+----1----+----2----+----3----+----4----+----5	Yes No
14	Malibu 1	0----+----1----+----2----+----3----+----4----+----5	Yes No

Section Number	Vehicle	Rate Test Section (Mark line with an "X")	Needs Immediate Repair
15	Malibu 1	0----+----1----+----2----+----3----+----4----+----5	Yes No
16	Malibu 1	0----+----1----+----2----+----3----+----4----+----5	Yes No
17	Malibu 1	0----+----1----+----2----+----3----+----4----+----5	Yes No
18	Malibu 1	0----+----1----+----2----+----3----+----4----+----5	Yes No
19	Tempo 1	0----+----1----+----2----+----3----+----4----+----5	Yes No
20	Tempo 1	0----+----1----+----2----+----3----+----4----+----5	Yes No
21	Tempo 2	0----+----1----+----2----+----3----+----4----+----5	Yes No
22	Tempo 2	0----+----1----+----2----+----3----+----4----+----5	Yes No
23	Tempo 2	0----+----1----+----2----+----3----+----4----+----5	Yes No
24	Tempo 2	0----+----1----+----2----+----3----+----4----+----5	Yes No
25	Malibu 2	0----+----1----+----2----+----3----+----4----+----5	Yes No
26	Malibu 2	0----+----1----+----2----+----3----+----4----+----5	Yes No
27	Malibu 2	0----+----1----+----2----+----3----+----4----+----5	Yes No
28	Malibu 1	0----+----1----+----2----+----3----+----4----+----5	Yes No
29	Malibu 1	0----+----1----+----2----+----3----+----4----+----5	Yes No
30	Malibu 1	0----+----1----+----2----+----3----+----4----+----5	Yes No
31	Malibu 1	0----+----1----+----2----+----3----+----4----+----5	Yes No
32	Malibu 1	0----+----1----+----2----+----3----+----4----+----5	Yes No
33	Malibu 1	0----+----1----+----2----+----3----+----4----+----5	Yes No
34	Malibu 2	0----+----1----+----2----+----3----+----4----+----5	Yes No
35	Malibu 2	0----+----1----+----2----+----3----+----4----+----5	Yes No

Official List of Numbered Survey Sites

Correlation of Roughness Ratings with Highway User Opinion SD2001-12

Section Number	Start MRM+Disp	End MRM+Disp	Highway	Pavement Family	Roughness Range	IRI Value
1	237 + 0.943	238 + 0.242	14 East Bound	PCC	Medium	115
2	244 + 0.199	244 + 0.498	14 East Bound	PCC	Smooth	65
3	256 + 0.209	256 + 0.507	14 East Bound	ACC	Medium	145
4	258 + 0.432	258 + 0.733	14 East Bound	ACC	Smooth	80
5	264 + 0.317	264 + 0.615	14 East Bound	ACC	Rough	250
6	308 + 0.610	308 + 0.910	14 East Bound	JCC	Smooth	71
7	321 + 0.979	322 + 0.282	14 East Bound	JCC	Medium	160
8	109 - 0.828	108 - 0.140	I-29 South Bound	CRC	Smooth	88
9	99 + 0.804	99 + 1.106	I-29 North Bound	CRC	Smooth	60
10	124 + 0.291	124 + 0.591	I-29 North Bound	CRC	Smooth	61
11	127 + 0.391	127 + 0.691	I-29 North Bound	CRC	Medium	135
12	133 + 0.375	133 + 0.663	I-29 North Bound	CRC	Medium	150
13	152 + 0.892	153 + 0.149	I-29 North Bound	CRC	Rough	240
14	154 + 0.145	154 + 0.443	I-29 North Bound	CRC	Rough	240
15	157 + 0.145	157 + 0.446	I-29 North Bound	CRC	Rough	240
16	160 + 0.25	160 + 0.549	I-29 North Bound	JCC	Rough	205
17	162 + 0.35	162 + 0.649	I-29 North Bound	JCC	Medium	150
18	364 + 0.948	365 + 0.251	22 East Bound	ACC	Rough	220
19	142 + 0.714	143 + 0.01	15 North Bound	ACC	Smooth	65
20	149 + 0.059	149 + 0.357	15 North Bound	ACC	Medium	150
21	337 + 0.017	337 + 0.260	22 East Bound	ACC	Smooth	75
22	339 + 0.90	340 + 0.290	22 East Bound	ACC	Medium	145
23	342 + 0.90	342 + 1.201	22 East Bound	ACC	Smooth	86
24	346 + 0.441	346 + 0.742	22 East Bound	ACC	Medium	140
25	165 + 0.936	166 + 0.240	I-29 North Bound	JCC	Rough	205
26	169 + 0.348	169 + 0.746	I-29 North Bound	JCC	Medium	150
27	174 + 0.372	174 + 0.673	I-29 North Bound	JCC	Rough	230
28	178 + 0.327	178 + 0.624	I-29 North Bound	JCC	Medium	170
29	180 + 0.01	180 + 0.309	I-29 North Bound	JCC	Smooth	65
30	184 + 0.21	184 + 0.511	I-29 North Bound	JCC	Smooth	86
31	188 + 0.916	189 + 0.220	I-29 North Bound	JCC	Smooth	70
32	439 + 0.445	439 + 0.753	20 East Bound	ACC	Rough	230
33	443 + 0.222	443 + 0.524	20 East Bound	ACC	Rough	205
34	157 - 0.099	157 - 0.396	I-29 South Bound	CRC	Smooth	89
35	155 - 0.791	154 - 0.100	I-29 South Bound	CRC	Medium	130

List of Survey Panel Members

Name	Position	From	Gender
Lisa Melius	Seasonal	Aberdeen	F
Naomi Fossen	Engineering Intern	Pierre	F
Deanna Lehrkamp	Secretary	Data Inventory	F
Nancy Pitlick	Secretary	Pierre	F
Brenda Flottmeyer	Project Engineer	Rapid City	F
Jenessa Steiner	Administrative Assistant	Pierre	F
Jo Ann Sherman	Accounting Assistant	Mitchell	F
Mona Kapfenstein	Senior Secretary	Aberdeen	F
Earl Brown	Highway Maintenance Worker	DeSmet	M
Clarence Ingle	Equipment Mechanic	Huron	M
Bill Engelhart	Building Maintenance Supervisor	Pierre	M
Larry Wimmer	Area Maintenance Mechanic	Mobridge	M
Jerald Wildberger	Highway Maintenance Worker	Sturgis	M
Brian Thompson	Journey Technician	Rapid City	M
Curtis Theisen	Parts Room Assistant	Sioux Falls	M
Paul Peterson	Highway Maintenance Worker	Beresford	M
Steve Schelske	Project Engineer	Rapid City	M
Ryan Fosness	Engineering Intern	Sioux Falls	M

Drivers
Mike Powell
Adam Ormesher
Katie Heyd
Don Slag
Scott Brady

Randomizing Panel Member Vehicle Assignments

Panel Member	Number	Random	Vehicle	Ran. 1		Ran. 2		Ran. 3		Ran. 4		Ran. 5		Ran. 6		Ran. 7		Ran. 8		Ran. 9	
Lisa Melius	18	0.968	Van	0.035	2	0.500	11	0.127	3	0.924	16	0.995	18	0.795	13	0.901	15	0.012	1	0.429	10
Naomi Fossen	8	0.328	Van	0.088	4	0.867	17	0.969	18	0.049	2	0.733	13	0.321	5	0.286	6	0.263	5	0.277	7
Noel Pothast	10	0.364	Van	0.604	15	0.654	13	0.242	6	0.637	10	0.053	1	0.543	8	0.876	14	0.588	10	0.026	3
Nancy Pitlick	3	0.145	Van	0.762	17	0.980	18	0.173	4	0.890	15	0.634	11	0.732	12	0.530	9	0.481	8	0.618	14
Brenda Flottmeyer	2	0.062	Van	0.186	6	0.218	3	0.018	1	0.473	6	0.450	8	0.225	3	0.546	10	0.897	14	0.490	13
Jenessa Steiner	11	0.556	Van	0.277	8	0.631	12	0.908	17	0.051	3	0.065	2	0.481	6	0.371	8	0.799	12	0.634	16
Jo Ann Sherman	13	0.585	Tempo 1	0.366	9	0.457	8	0.908	11	0.810	14	0.116	4	0.948	17	0.917	16	0.635	11	0.384	9
Mona Kapfenstein	9	0.340	Tempo 1	0.771	18	0.438	7	0.908	10	0.032	1	0.819	15	0.704	11	0.289	5	0.906	16	0.434	11
Earl Brown	4	0.158	Tempo 1	0.488	12	0.483	9	0.908	12	0.380	5	0.369	6	0.131	2	0.041	1	0.498	9	0.114	6
Clarence Ingle	1	0.049	Tempo 2	0.544	13	0.499	10	0.908	2	0.752	12	0.810	14	0.255	4	0.047	2	0.396	6	0.021	2
Bill Engelhart	16	0.927	Tempo 2	0.041	3	0.346	5	0.908	8	0.609	8	0.094	3	0.875	15	0.963	18	0.479	7	0.097	5
Larry Wimmer	12	0.570	Tempo 2	0.564	14	0.013	1	0.908	15	0.736	11	0.958	16	0.012	1	0.309	7	0.818	13	0.010	1
Jerald Wildberger	6	0.254	Malibu 1	0.177	5	0.395	6	0.908	16	0.951	17	0.697	12	1.000	18	0.132	3	0.912	18	0.716	17
Brian Thompson	15	0.742	Malibu 1	0.262	7	0.279	4	0.908	13	0.297	4	0.476	9	0.796	14	0.759	13	0.249	4	0.304	8
Curtis Theisen	14	0.590	Malibu 1	0.690	16	0.130	2	0.908	7	0.625	9	0.993	17	0.613	10	0.667	11	0.908	17	0.751	18
Paul Peterson	7	0.301	Malibu 2	0.478	10	0.746	14	0.908	14	0.523	7	0.352	5	0.920	16	0.160	4	0.158	3	0.439	12
Steve Schelske	5	0.221	Malibu 2	0.485	11	0.811	15	0.908	5	0.986	18	0.389	7	0.596	9	0.928	17	0.904	15	0.627	15
Ryan Fosness	17	0.949	Malibu 2	0.032	1	0.813	16	0.908	9	0.789	13	0.493	10	0.528	7	0.688	12	0.121	2	0.042	4

Researchers' Comments:

- *The researchers made vehicle assignments by generating random numbers for each of the 9 vehicle changes (Random 1-9) and for the Panel Members, themselves.*
- *The numbers in the columns to the right, directly proceeding each "Random #" generation correspond to the "Number" column for the Panel Members. This is how the vehicle assignments were made.*

Raters' Instructions

1. You will be asked to rate the roughness of designated test sections.
2. Assign each test section a rating from zero to five (very smooth to very rough) on your survey forms based upon your personal overall impression of that sections ride quality (roughness).
3. Remember to rate the roads to the nearest 1/10 (I.E. 3.5, 3.8, 4.0, etc.)
4. It may help to close your eyes and simply feel the ride.
5. You will also be asked whether or not the test section is in need of immediate repair. Please check either yes or no.
6. Drivers will notify you at the beginning and end of each test section.
7. Please rate only the designated test sections, not the road before or after.
8. Please make your decisions quickly, in order to prepare for upcoming test sections.
9. Do not go back and change your answers to previous sections once they have been completed.
10. Please make individual decisions in rating a test section. Do not look to others for input or share your own opinions with the other surveyors. Trust your instincts – there is no wrong answer.
11. Have fun!

Drivers Instructions

1. You will be given a list of selected test sections. Please inform the raters, when approaching a new test section.

2. Inform the raters well enough in advance of the upcoming test sections, so that they may adequately prepare themselves.

3. When the test section has been reached, inform the raters at the beginning and the end of each test section. Watch for the highway markings (bright pink paint and painted lath).

4. Periodically, the raters are to change vehicles. Pay attention to the lead vehicle for this. The lead vehicle will periodically stop, to allow the raters to switch.

5. Drive only at the designated test section speeds. (65 mph for highways and 72 mph for interstates).

6. Please, drive carefully.

Drivers Test Section List

- *Test sections were put in the order they would be surveyed, and placed in the following list.*
- *Fonts were made large, for easy visibility while driving.*

Section Number	Highway	Look for MRM:
1	14 East Bound	237 + 0.943
2	14 East Bound	244 + 0.199
3	14 East Bound	256 + 0.209
4	14 East Bound	258 + 0.432
5	14 East Bound	264 + 0.317
6	14 East Bound	308 + 0.610
7	14 East Bound	321 + 0.979
8	I-29 South Bound	109 - 0.828
9	I-29 North Bound	99 + 0.804
10	I-29 North Bound	124 + 0.291

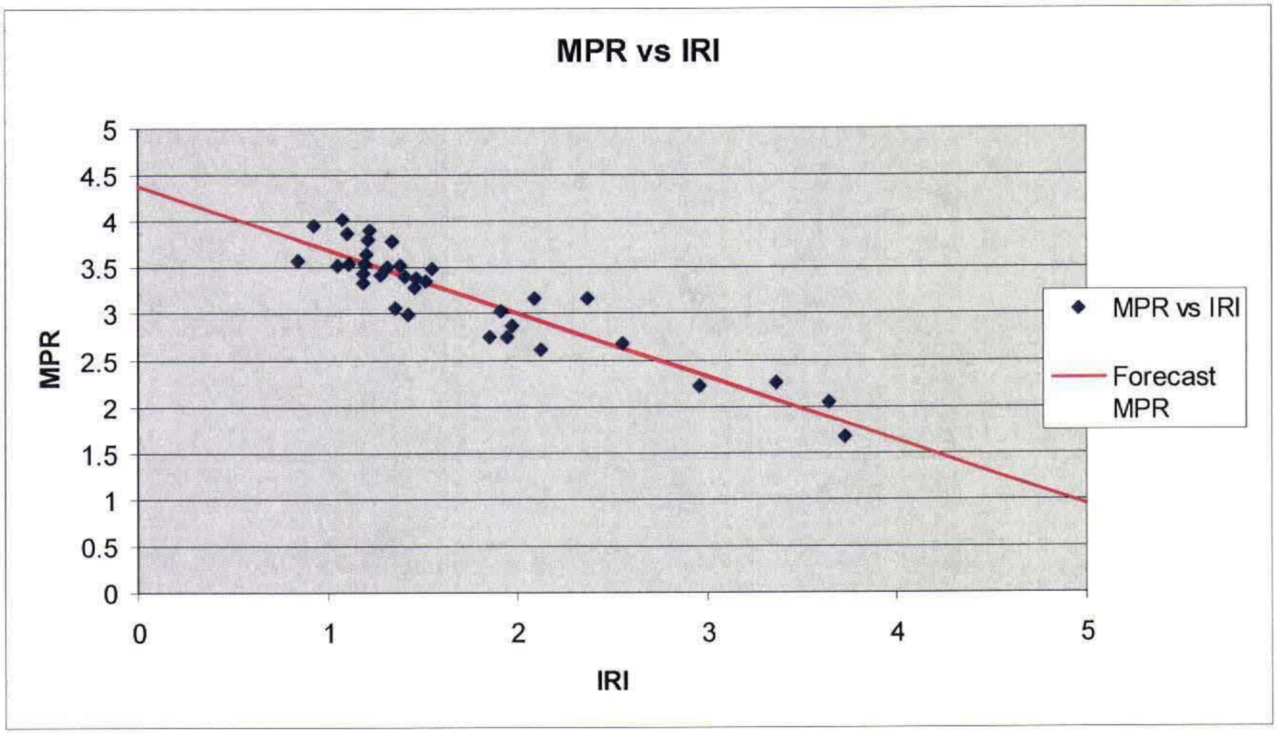
Section Number	Highway	Look for MRM:
11	I-29 North Bound	127 + 0.391
12	I-29 North Bound	133 + 0.375
13	I-29 North Bound	152 + 0.892
14	I-29 North Bound	154 + 0.145
15	I-29 North Bound	157 + 0.145
16	I-29 North Bound	160 + 0.25
17	I-29 North Bound	162 + 0.35
18	22 East Bound	364 + 0.948
19	15 North Bound	142 + 0.714
20	15 North Bound	149 + 0.059
21	22 East Bound	337 + 0.017
22	22 East Bound	339 + 0.90
23	22 East Bound	342 + 0.90

Section Number	Highway	Look for MRM:
24	22 East Bound	346 + 0.441
25	I-29 North Bound	165 + 0.936
26	I-29 North Bound	169 + 0.348
27	I-29 North Bound	174 + 0.372
28	I-29 North Bound	178 + 0.327
29	I-29 North Bound	180 + 0.01
30	I-29 North Bound	184 + 0.21
31	I-29 North Bound	188 + 0.916
32	20 East Bound	439 + 0.445
33	20 East Bound	443 + 0.222
34	I-29 South Bound	157 - 0.099
35	I-29 South Bound	155 - 0.791

Appendix B: Data Analysis

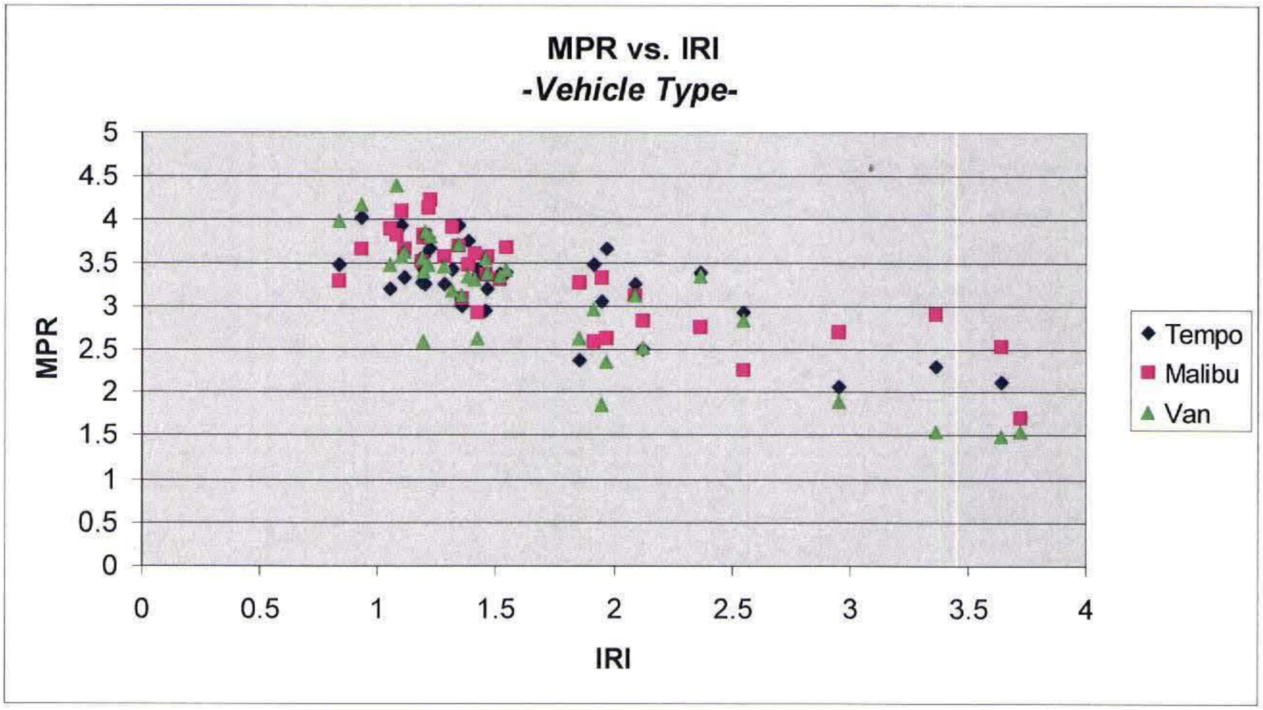
MPR vs. IRI

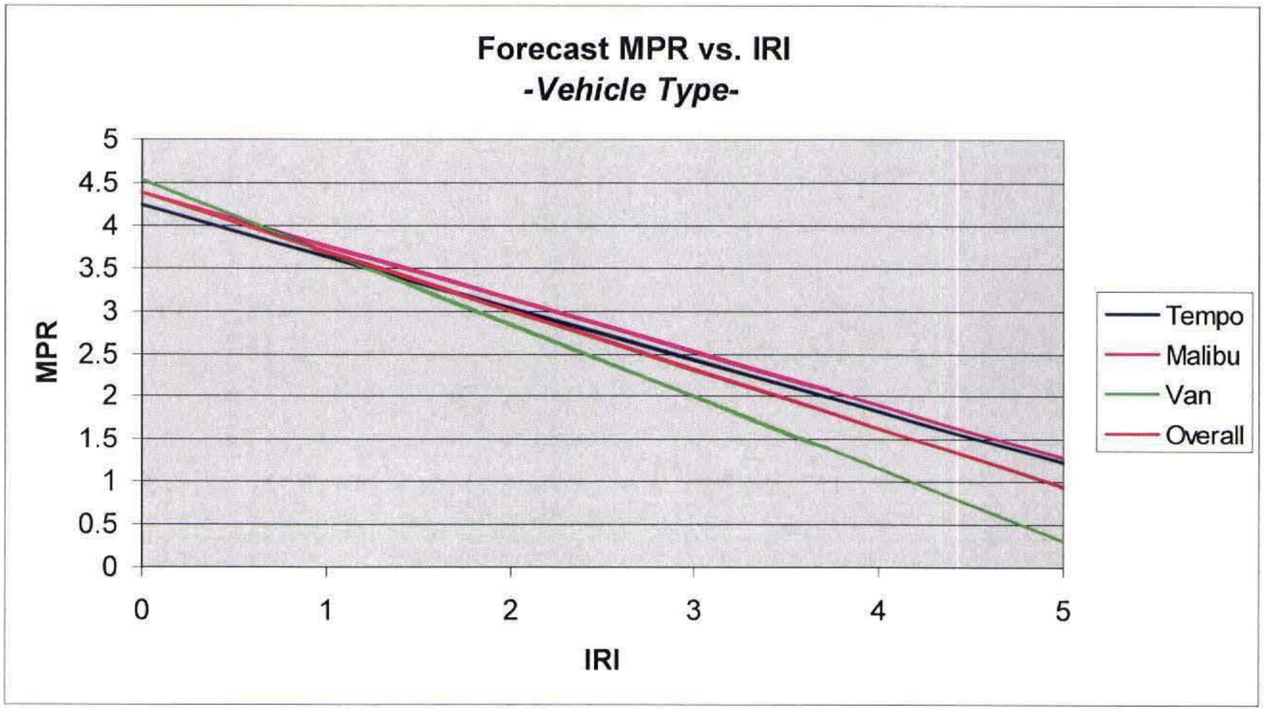
Mean Panel Rating versus IRI: Overall



$$MPR = -0.6881397(IRI) + 4.38125998$$

Mean Panel Rating versus IRI by Vehicle Type





Tempo: MPR = -0.60302(IRI) + 4.238445
Malibu: MPR = -0.6189(IRI) + 4.379078
Van: MPR = -0.84159(IRI) + 4.526257

Appendix C:

Statistical Analysis using Systat 10.0

Appendix C-1: Trial 1
ANOVA with independent variables TEMPO, VAN and AC, CRC

3 case(s) deleted due to missing data.

Eigenvalues of unit scaled X'X

1	2	3	4	5	6
3.380	1.016	1.000	0.362	0.178	0.063

Condition indices

1	2	3	4	5	6
1.000	1.824	1.838	3.054	4.356	7.311

Variance proportions

	1	2	3	4	5	6
CONSTANT	0.009	0.000	0.000	0.002	0.139	0.851
IRI	0.009	0.001	0.000	0.008	0.144	0.838
TEMPO	0.017	0.001	0.250	0.383	0.278	0.071
VAN	0.017	0.001	0.250	0.383	0.278	0.071
AC	0.016	0.144	0.000	0.208	0.504	0.128
CRC	0.015	0.321	0.000	0.325	0.338	0.002

Dep Var: MPR N: 105 Multiple R: 0.839 Squared multiple R: 0.703

Adjusted squared multiple R: 0.688 Standard error of estimate: 0.354

Effect	Coefficient	Std Error	Std Coef	Tolerance	t	P(2 Tail)	Coefficient	Lower 95%	Upper 95%
CONSTANT	4.414	0.104	0.000	.	42.246	0.000	4.414	4.206	4.621
IRI	-0.619	0.055	-0.728	0.705	-11.157	0.000	-0.619	-0.729	-0.509
TEMPO	-0.115	0.085	-0.086	0.750	-1.362	0.176	-0.115	-0.283	0.053
VAN	-0.230	0.085	-0.172	0.750	-2.725	0.008	-0.230	-0.398	-0.063
AC	-0.182	0.097	-0.137	0.568	-1.887	0.062	-0.182	-0.374	0.009
CRC	0.096	0.087	0.068	0.776	1.101	0.274	0.096	-0.077	0.268

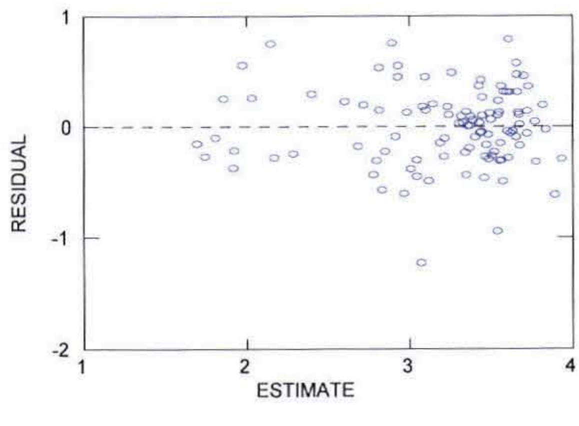
Analysis of Variance

Source	Sum-of-Squares	df	Mean-Square	F-ratio	P
Regression	29.364	5	5.873	46.902	0.000
Residual	12.396	99	0.125		

*** WARNING *** Case 105 is an outlier (Studentized Residual = -3.796)

Durbin-Watson D Statistic 1.914
First Order Autocorrelation -0.017

Plot of Residuals against Predicted Values



Appendix C-1: Trial 2
ANOVA with independent variables TEMPO, VAN and CRC, JPC

3 case(s) deleted due to missing data.

Eigenvalues of unit scaled X'X

1	2	3	4	5	6
3.295	1.002	1.000	0.399	0.268	0.037

Condition indices

1	2	3	4	5	6
1.000	1.813	1.815	2.873	3.509	9.473

Variance proportions

	1	2	3	4	5	6
CONSTANT	0.005	0.000	0.000	0.000	0.013	0.981
IRI	0.009	0.000	0.000	0.071	0.098	0.822
TEMPO	0.018	0.000	0.250	0.034	0.653	0.045
VAN	0.018	0.000	0.250	0.034	0.653	0.045
CRC	0.014	0.243	0.000	0.382	0.001	0.360
JPC	0.012	0.159	0.000	0.311	0.007	0.511

Dep Var: MPR N: 105 Multiple R: 0.839 Squared multiple R: 0.703

Adjusted squared multiple R: 0.688 Standard error of estimate: 0.354

Effect	Coefficient	Std Error	Std Coef	Tolerance	t	P(2 Tail)	Coefficient	Lower 95%	Upper 95%
CONSTANT	4.231	0.146	0.000	.	29.002	0.000	4.231	3.942	4.521
IRI	-0.619	0.055	-0.728	0.705	-11.157	0.000	-0.619	-0.729	-0.509
TEMPO	-0.115	0.085	-0.086	0.750	-1.362	0.176	-0.115	-0.283	0.053
VAN	-0.230	0.085	-0.172	0.750	-2.725	0.008	-0.230	-0.398	-0.063
CRC	0.278	0.096	0.199	0.637	2.899	0.005	0.278	0.088	0.468
JPC	0.182	0.097	0.140	0.548	1.887	0.062	0.182	-0.009	0.374

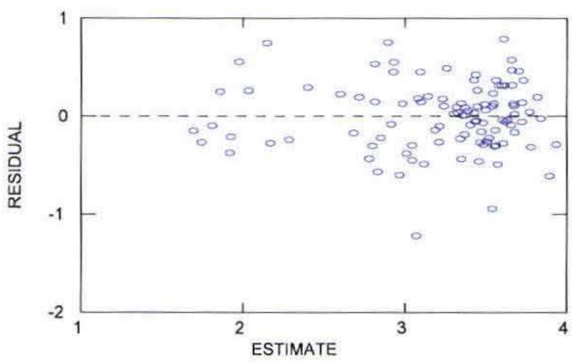
Analysis of Variance

Source	Sum-of-Squares	df	Mean-Square	F-ratio	P
Regression	29.364	5	5.873	46.902	0.000
Residual	12.396	99	0.125		

*** WARNING *** Case 105 is an outlier (Studentized Residual = -3.796)

Durbin-Watson D Statistic 1.914
First Order Autocorrelation -0.017

Plot of Residuals against Predicted Values



Appendix C-1: Trial 3
ANOVA with independent variables TEMPO, VAN and JPC, AC

3 case(s) deleted due to missing data.

Eigenvalues of unit scaled X'X

1	2	3	4	5	6
3.419	1.033	1.000	0.317	0.177	0.055

Condition indices

1	2	3	4	5	6
1.000	1.819	1.849	3.285	4.399	7.915

Variance proportions

	1	2	3	4	5	6
CONSTANT	0.007	0.000	0.000	0.001	0.064	0.928
IRI	0.009	0.003	0.000	0.007	0.206	0.775
TEMPO	0.016	0.002	0.250	0.507	0.156	0.069
VAN	0.016	0.002	0.250	0.507	0.156	0.069
JPC	0.013	0.224	0.000	0.269	0.321	0.174
AC	0.015	0.155	0.000	0.162	0.654	0.014

Dep Var: MPR N: 105 Multiple R: 0.839 Squared multiple R: 0.703

Adjusted squared multiple R: 0.688 Standard error of estimate: 0.354

Effect	Coefficient	Std Error	Std Coef	Tolerance	t	P(2 Tail)	Coefficient	Lower 95%	Upper 95%
CONSTANT	4.509	0.118	0.000	.	38.360	0.000	4.509	4.276	4.742
IRI	-0.619	0.055	-0.728	0.705	-11.157	0.000	-0.619	-0.729	-0.509
TEMPO	-0.115	0.085	-0.086	0.750	-1.362	0.176	-0.115	-0.283	0.053
VAN	-0.230	0.085	-0.172	0.750	-2.725	0.008	-0.230	-0.398	-0.063
JPC	-0.096	0.087	-0.073	0.678	-1.101	0.274	-0.096	-0.268	0.077
AC	-0.278	0.096	-0.209	0.577	-2.899	0.005	-0.278	-0.468	-0.088

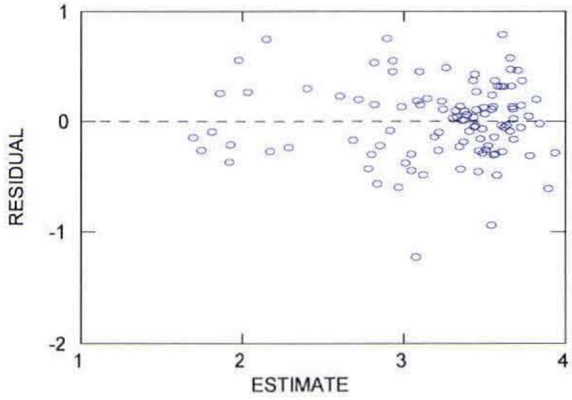
Analysis of Variance

Source	Sum-of-Squares	df	Mean-Square	F-ratio	P
Regression	29.364	5	5.873	46.902	0.000
Residual	12.396	99	0.125		

*** WARNING *** Case 105 is an outlier (Studentized Residual = -3.796)

Durbin-Watson D Statistic 1.914
First Order Autocorrelation -0.017

Plot of Residuals against Predicted Values



Appendix C-1: Trial 4
ANOVA with independent variables MALIBU, VAN and AC, CRC

3 case(s) deleted due to missing data.

Eigenvalues of unit scaled X'X

	1	2	3	4	5	6
	3.380	1.016	1.000	0.362	0.178	0.063

Condition indices

	1	2	3	4	5	6
	1.000	1.824	1.838	3.054	4.356	7.311

Variance proportions

	1	2	3	4	5	6
CONSTANT	0.009	0.000	0.000	0.002	0.139	0.851
IRI	0.009	0.001	0.000	0.008	0.144	0.838
MALIBU	0.017	0.001	0.250	0.383	0.278	0.071
VAN	0.017	0.001	0.250	0.383	0.278	0.071
AC	0.016	0.144	0.000	0.208	0.504	0.128
CRC	0.015	0.321	0.000	0.325	0.338	0.002

Dep Var: MPR N: 105 Multiple R: 0.839 Squared multiple R: 0.703

Adjusted squared multiple R: 0.688 Standard error of estimate: 0.354

Effect	Coefficient	Std Error	Std Coef	Tolerance	t	P(2 Tail)	Coefficient	Lower 95%	Upper 95%
CONSTANT	4.298	0.104	0.000		41.143	0.000	4.298	4.091	4.506
IRI	-0.619	0.055	-0.728	0.705	-11.157	0.000	-0.619	-0.729	-0.509
MALIBU	0.115	0.085	0.086	0.750	1.362	0.176	0.115	-0.053	0.283
VAN	-0.115	0.085	-0.086	0.750	-1.362	0.176	-0.115	-0.283	0.053
AC	-0.182	0.097	-0.137	0.568	-1.887	0.062	-0.182	-0.374	0.009
CRC	0.096	0.087	0.068	0.776	1.101	0.274	0.096	-0.077	0.268

Analysis of Variance

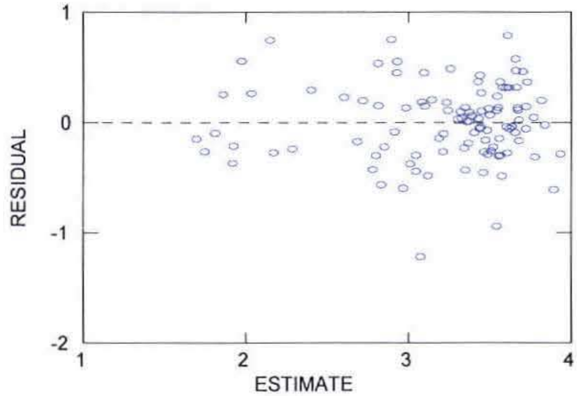
Source	Sum-of-Squares	df	Mean-Square	F-ratio	P
Regression	29.364	5	5.873	46.902	0.000
Residual	12.396	99	0.125		

*** WARNING *** Case 105 is an outlier (Studentized Residual = -3.796)

Durbin-Watson D Statistic 1.914

First Order Autocorrelation -0.017

Plot of Residuals against Predicted Values



Appendix C-1: Trial 5
ANOVA with independent variables MALIBU, VAN and AC, JPC

3 case(s) deleted due to missing data.

Eigenvalues of unit scaled X'X

1	2	3	4	5	6
3.419	1.033	1.000	0.317	0.177	0.055

Condition indices

1	2	3	4	5	6
1.000	1.819	1.849	3.285	4.399	7.915

Variance proportions

	1	2	3	4	5	6
CONSTANT	0.007	0.000	0.000	0.001	0.064	0.928
IRI	0.009	0.003	0.000	0.007	0.206	0.775
MALIBU	0.016	0.002	0.250	0.507	0.156	0.069
VAN	0.016	0.002	0.250	0.507	0.156	0.069
AC	0.015	0.155	0.000	0.162	0.654	0.014
JPC	0.013	0.224	0.000	0.269	0.321	0.174

Dep Var: MPR N: 105 Multiple R: 0.839 Squared multiple R: 0.703

Adjusted squared multiple R: 0.688 Standard error of estimate: 0.354

Effect	Coefficient	Std Error	Std Coef	Tolerance	t	P(2 Tail)	Coefficient	Lower 95%	Upper 95%
CONSTANT	4.394	0.118	0.000	.	37.380	0.000	4.394	4.161	4.627
IRI	-0.619	0.055	-0.728	0.705	-11.157	0.000	-0.619	-0.729	-0.509
MALIBU	0.115	0.085	0.086	0.750	1.362	0.176	0.115	-0.053	0.283
VAN	-0.115	0.085	-0.086	0.750	-1.362	0.176	-0.115	-0.283	0.053
AC	-0.278	0.096	-0.209	0.577	-2.899	0.005	-0.278	-0.468	-0.088
JPC	-0.096	0.087	-0.073	0.678	-1.101	0.274	-0.096	-0.268	0.077

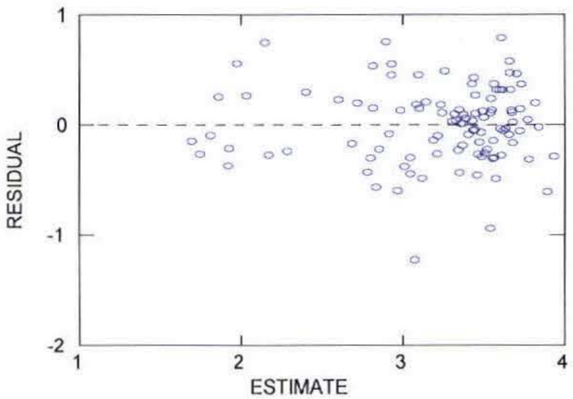
Analysis of Variance

Source	Sum-of-Squares	df	Mean-Square	F-ratio	P
Regression	29.364	5	5.873	46.902	0.000
Residual	12.396	99	0.125		

*** WARNING *** Case 105 is an outlier (Studentized Residual = -3.796)

Durbin-Watson D Statistic 1.914
First Order Autocorrelation -0.017

Plot of Residuals against Predicted Values



Appendix C-1: Trial 6
ANOVA with independent variables MALIBU, VAN and JPC, CRC

3 case(s) deleted due to missing data.

Eigenvalues of unit scaled X'X

1	2	3	4	5	6
3.295	1.002	1.000	0.399	0.268	0.037

Condition indices

1	2	3	4	5	6
1.000	1.813	1.815	2.873	3.509	9.473

Variance proportions

	1	2	3	4	5	6
CONSTANT	0.005	0.000	0.000	0.000	0.013	0.981
IRI	0.009	0.000	0.000	0.071	0.098	0.822
MALIBU	0.018	0.000	0.250	0.034	0.653	0.045
VAN	0.018	0.000	0.250	0.034	0.653	0.045
JPC	0.012	0.159	0.000	0.311	0.007	0.511
CRC	0.014	0.243	0.000	0.382	0.001	0.360

Dep Var: MPR N: 105 Multiple R: 0.839 Squared multiple R: 0.703

Adjusted squared multiple R: 0.688 Standard error of estimate: 0.354

Effect	Coefficient	Std Error	Std Coef	Tolerance	t	P(2 Tail)	Coefficient	Lower 95%	Upper 95%
CONSTANT	4.116	0.146	0.000	.	28.212	0.000	4.116	3.827	4.406
IRI	-0.619	0.055	-0.728	0.705	-11.157	0.000	-0.619	-0.729	-0.509
MALIBU	0.115	0.085	0.086	0.750	1.362	0.176	0.115	-0.053	0.283
VAN	-0.115	0.085	-0.086	0.750	-1.362	0.176	-0.115	-0.283	0.053
JPC	0.182	0.097	0.140	0.548	1.887	0.062	0.182	-0.009	0.374
CRC	0.278	0.096	0.199	0.637	2.899	0.005	0.278	0.088	0.468

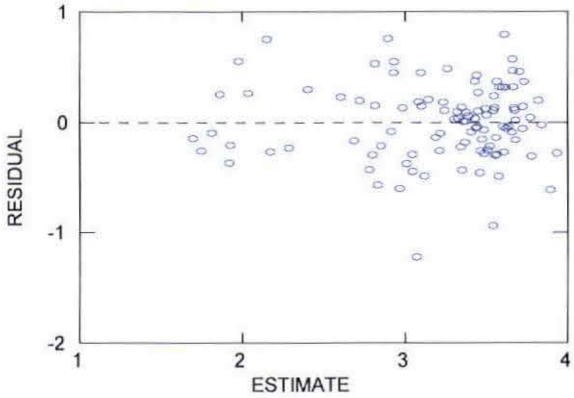
Analysis of Variance

Source	Sum-of-Squares	df	Mean-Square	F-ratio	P
Regression	29.364	5	5.873	46.902	0.000
Residual	12.396	99	0.125		

*** WARNING *** Case 105 is an outlier (Studentized Residual = -3.796)

Durbin-Watson D Statistic 1.914
First Order Autocorrelation -0.017

Plot of Residuals against Predicted Values



Appendix C-1: Trial 7
ANOVA with independent variables TEMPO, MALIBU and AC, CRC

3 case(s) deleted due to missing data.

Eigenvalues of unit scaled X'X

	1	2	3	4	5	6
	3.380	1.016	1.000	0.362	0.178	0.063

Condition indices

	1	2	3	4	5	6
	1.000	1.824	1.838	3.054	4.356	7.311

Variance proportions

	1	2	3	4	5	6
CONSTANT	0.009	0.000	0.000	0.002	0.139	0.851
IRI	0.009	0.001	0.000	0.008	0.144	0.838
TEMPO	0.017	0.001	0.250	0.383	0.278	0.071
MALIBU	0.017	0.001	0.250	0.383	0.278	0.071
AC	0.016	0.144	0.000	0.208	0.504	0.128
CRC	0.015	0.321	0.000	0.325	0.338	0.002

Dep Var: MPR N: 105 Multiple R: 0.839 Squared multiple R: 0.703

Adjusted squared multiple R: 0.688 Standard error of estimate: 0.354

Effect	Coefficient	Std Error	Std Coef	Tolerance	t	P(2 Tail)	Coefficient	Lower 95%	Upper 95%
CONSTANT	4.183	0.104	0.000	.	40.040	0.000	4.183	3.976	4.390
IRI	-0.619	0.055	-0.728	0.705	-11.157	0.000	-0.619	-0.729	-0.509
TEMPO	0.115	0.085	0.086	0.750	1.362	0.176	0.115	-0.053	0.283
MALIBU	0.230	0.085	0.172	0.750	2.725	0.008	0.230	0.063	0.398
AC	-0.182	0.097	-0.137	0.568	-1.887	0.062	-0.182	-0.374	0.009
CRC	0.096	0.087	0.068	0.776	1.101	0.274	0.096	-0.077	0.268

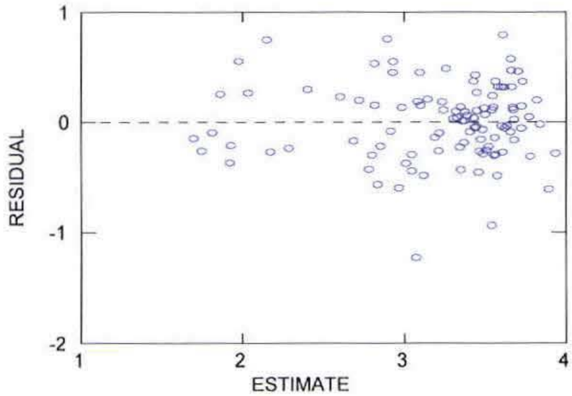
Analysis of Variance

Source	Sum-of-Squares	df	Mean-Square	F-ratio	P
Regression	29.364	5	5.873	46.902	0.000
Residual	12.396	99	0.125		

*** WARNING *** Case 105 is an outlier (Studentized Residual = -3.796)

Durbin-Watson D Statistic 1.914
First Order Autocorrelation -0.017

Plot of Residuals against Predicted Values



Appendix C-1: Trial 8
ANOVA with independent variables TEMPO, MALIBU and AC, JPC

3 case(s) deleted due to missing data.

Eigenvalues of unit scaled X'X

	1	2	3	4	5	6
	3.419	1.033	1.000	0.317	0.177	0.055

Condition indices

	1	2	3	4	5	6
	1.000	1.819	1.849	3.285	4.399	7.915

Variance proportions

	1	2	3	4	5	6
CONSTANT	0.007	0.000	0.000	0.001	0.064	0.928
IRI	0.009	0.003	0.000	0.007	0.206	0.775
TEMPO	0.016	0.002	0.250	0.507	0.156	0.069
MALIBU	0.016	0.002	0.250	0.507	0.156	0.069
AC	0.015	0.155	0.000	0.162	0.654	0.014
JPC	0.013	0.224	0.000	0.269	0.321	0.174

Dep Var: MPR N: 105 Multiple R: 0.839 Squared multiple R: 0.703

Adjusted squared multiple R: 0.688 Standard error of estimate: 0.354

Effect	Coefficient	Std Error	Std Coef	Tolerance	t	P(2 Tail)	Coefficient	Lower 95%	Upper 95%
CONSTANT	4.279	0.118	0.000		36.399	0.000	4.279	4.045	4.512
IRI	-0.619	0.055	-0.728	0.705	-11.157	0.000	-0.619	-0.729	-0.509
TEMPO	0.115	0.085	0.086	0.750	1.362	0.176	0.115	-0.053	0.283
MALIBU	0.230	0.085	0.172	0.750	2.725	0.008	0.230	0.063	0.398
AC	-0.278	0.096	-0.209	0.577	-2.899	0.005	-0.278	-0.468	-0.088
JPC	-0.096	0.087	-0.073	0.678	-1.101	0.274	-0.096	-0.268	0.077

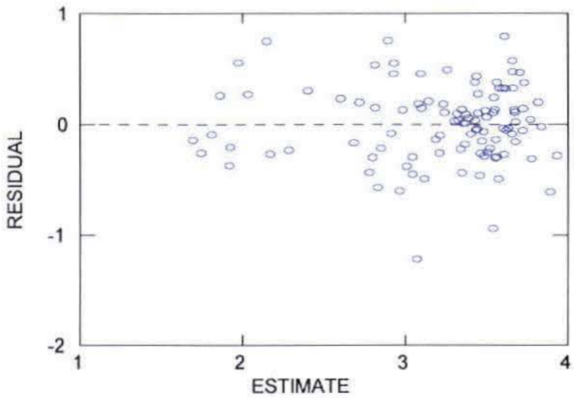
Analysis of Variance

Source	Sum-of-Squares	df	Mean-Square	F-ratio	P
Regression	29.364	5	5.873	46.902	0.000
Residual	12.396	99	0.125		

*** WARNING *** Case 105 is an outlier (Studentized Residual = -3.796)

Durbin-Watson D Statistic 1.914
First Order Autocorrelation -0.017

Plot of Residuals against Predicted Values



Appendix C-1: Trial 9
ANOVA with independent variables TEMPO, MALIBU and JPC, CRC

3 case(s) deleted due to missing data.

Eigenvalues of unit scaled X'X

	1	2	3	4	5	6
	3.295	1.002	1.000	0.399	0.268	0.037

Condition indices

	1	2	3	4	5	6
	1.000	1.813	1.815	2.873	3.509	9.473

Variance proportions

	1	2	3	4	5	6
CONSTANT	0.005	0.000	0.000	0.000	0.013	0.981
IRI	0.009	0.000	0.000	0.071	0.098	0.822
TEMPO	0.018	0.000	0.250	0.034	0.653	0.045
MALIBU	0.018	0.000	0.250	0.034	0.653	0.045
JPC	0.012	0.159	0.000	0.311	0.007	0.511
CRC	0.014	0.243	0.000	0.382	0.001	0.360

Dep Var: MPR N: 105 Multiple R: 0.839 Squared multiple R: 0.703

Adjusted squared multiple R: 0.688 Standard error of estimate: 0.354

Effect	Coefficient	Std Error	Std Coef	Tolerance	t	P(2 Tail)	Coefficient	Lower 95%	Upper 95%
CONSTANT	4.001	0.146	0.000	.	27.422	0.000	4.001	3.711	4.290
IRI	-0.619	0.055	-0.728	0.705	-11.157	0.000	-0.619	-0.729	-0.509
TEMPO	0.115	0.085	0.086	0.750	1.362	0.176	0.115	-0.053	0.283
MALIBU	0.230	0.085	0.172	0.750	2.725	0.008	0.230	0.063	0.398
JPC	0.182	0.097	0.140	0.548	1.887	0.062	0.182	-0.009	0.374
CRC	0.278	0.096	0.199	0.637	2.899	0.005	0.278	0.088	0.468

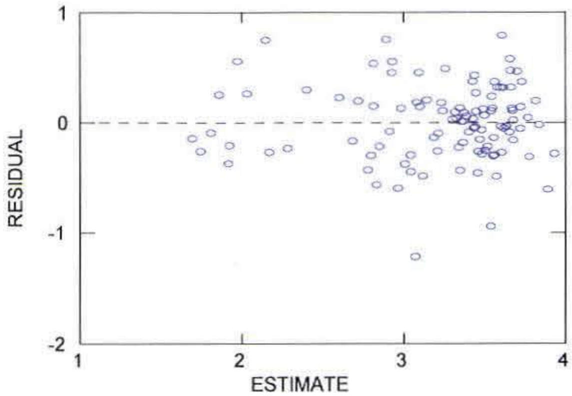
Analysis of Variance

Source	Sum-of-Squares	df	Mean-Square	F-ratio	P
Regression	29.364	5	5.873	46.902	0.000
Residual	12.396	99	0.125		

*** WARNING *** Case 105 is an outlier (Studentized Residual = -3.796)

Durbin-Watson D Statistic 1.914
First Order Autocorrelation -0.017

Plot of Residuals against Predicted Values



Appendix C-2:

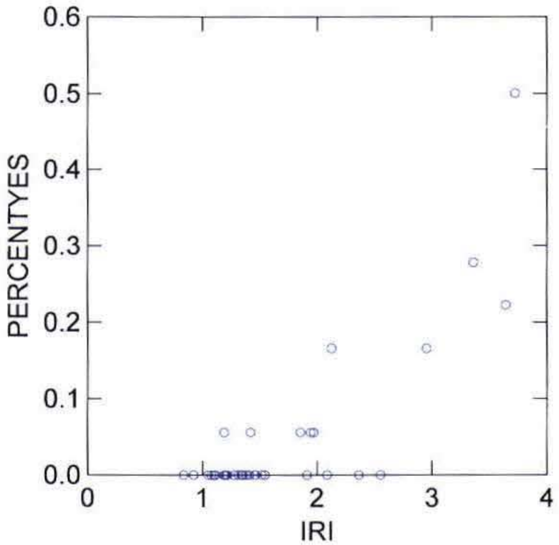
%Yes vs. IRI Analysis

SYSTAT Rectangular file K:\Prob2001\Sd0112\Systat\roughness cal.SYD,
created Tue Jul 31, 2001 at 15:45:40, contains variables:

SECTION	IRI	MPR	TEMPO	MALIBU	VAN
AC	CRC	JPC			

SYSTAT Rectangular file K:\Prob2001\Sd0112\Systat\MPR vs IRI.SYD,
created Thu Aug 02, 2001 at 14:23:30, contains variables:

SECTION	IRI	IRIEQUIV	MPR	TEMPO	MALIBU
VAN	PAVETYPE$	YES	NO	PERCENTYE S	



Dep Var: PERCENTYES N: 35 Multiple R: 0.816 Squared multiple R: 0.666

Adjusted squared multiple R: 0.656 Standard error of estimate: 0.061

Effect	Coefficient	Std Error	Std Coef	Tolerance	t	P(2 Tail)
CONSTANT	-0.147	0.026	0.000	.	-5.655	0.000
IRI	0.114	0.014	0.816	1.000	8.111	0.000

Analysis of Variance

Source	Sum-of-Squares	df	Mean-Square	F-ratio	P
Regression	0.249	1	0.249	65.788	0.000
Residual	0.125	33	0.004		

*** WARNING ***
Case 18 is an outlier (Studentized Residual = 5.982)

Durbin-Watson D Statistic 1.689
First Order Autocorrelation 0.152

Plot of Residuals against Predicted Values