Bike Pavement Condition Assessment

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("NCST" logo)
Abstract

Though the city of Davis has a reputation as the “Bicycle Capital of the U.S.” due to its large number of cyclists and city-wide support of cyclist infrastructure and bike initiative, it is not unique in its lack of adequate upkeep of its bike paths. Much of the city’s biking infrastructure is visibly showing wear of potholes and cracks, clear signs of pavement surface damage. While most cities use route preferences or visual inspection to determine pavement conditions for bike-paths, there lacks a more efficient and streamlined way to determine bike ride quality. There is also a need for understanding the relationship between measurable pavement condition metrics with ride comfort. This project aims to do just that: to determine how the measured variables previously determined to be significant factors of ride quality can be used to predict ride quality. A team previously working on this project was able to equip a road bike and a mountain bike with a set of sensors which recorded various variables as they rode them along many sections of bike pavement in Davis. The applications of this project pertaining to the current team involved taking these measured variables and applying them to an ordered logit regression model to determine their significance in predicting ride quality. Though we were unable to prove any of the variables besides Mean Texture Depth to be significant factors in predicting ride quality, we were able to prove distance data and acceleration in the vertical direction as predictors of Mean Texture Depth which allows for the conclusions to be drawn that those two measured variables are predictors of bike pavement ride quality.

Introduction

While methods for assessing vehicle roadways are well established, there is still little research on determining what the critical variables to determining ride quality are and how these variables relate to perceptions of ride quality. There also is little known on how the relationship between these variables to traditional pavement rating tests are. It is important to gather these three findings to better determine how bike-path pavement conditions are and to equip cities with the adequate assessment tools needed in maintaining and repairing their bike-paths.

The previous objectives of the project were to define the measurements that are critical variables to pavement ride-quality and to engineer a bike sensor system capable of taking these measurements. The current objectives this research addressed were to determine how these previously determined variables are associated with biker perceptions of ride quality and safety and to be able to detail the relationship between critical variables and traditional pavement rating tests.

This paper describes results of the applications of the bike measurement variables data to an ordered logit regression model aimed to determine the significance of these variables in predicting ride quality. We generated more survey responses for ride quality by re-formatting a Qualtrics survey with more specific instructions and response metrics to apply to the statistical model. The data collected by previous researchers who rode the sensor equipped bikes on
different bike paths in Davis were compiled and also applied in the statistical model to determine its relationship to ride quality responses. The first section of the paper provides background information on standard pavement condition assessment methods and the advances previous research teams have made on this particular project as well as an explanation on ordered logit regression models. The methods section details the strategy of research used for collecting data and analyzing the statistical model. The next section lists and explains the results of the statistical analysis and the future recommendations for the project.

Background

Pavement Surface Macro Texture Measurement

Pavement surface profile characteristics are thought to influence bicycle ride quality in the same way it directly affects vehicle ride quality (1). The four components affecting pavement surface texture are roughness, megatexture, macrotexture, and microtexture. Macrotexture, categorized by surface irregularities of wavelength measurements between 0.5 mm and 50 mm, is the largest contributor to pavement surface profile and highly influenced by the type of material used on the surface. Macrotexture can be measured in terms of mean texture depth and mean profile depth, each measured in different ways and each with their own set of limitations making it clear there needs to be an alternative way of determining bike-pavement conditions.

Mean Texture Depth (MTD)

Mean texture depth, or the “mean average vertical height differences of texture” (2) is calculated by performing a Sand Patch Test (SPT) per ASTM Standard E – 965; International standard ISO 10844 (3). This test is time-intensive as it requires one to go out on each pavement section and take measurements by hand. It is often inconsistent as the measurements, if not taken in the same ambient temperature and weather conditions, may have skewed results. Additionally, this method is not feasible for cities to use as their main way of analyzing bike pavements because it would require many hours of man-power and, depending on how many miles of bike paths the city has, it would be difficult to generate all the desired data.

Mean Profile Depth (MPD)

Mean profile depth can be collected using an inertial road profiler with laser macrotexture subsystem, which estimates the macrotexture of a roadway by scanning the pavement and measuring the two-dimensional surface texture (4). An inertial profiler is incredibly accurate and efficient to use as it takes measurements easily but is extremely expensive and requires a high level of training to operate and maintain. Measuring MPD is not a very feasible way for cities to quantify surface macrotexture either as it is expensive and requires highly skilled technicians.
Previous Project Accomplishments

The previous team of researchers have determined the necessary variables in measuring bike pavement quality and collected sensor data on these variables by riding sensor-equipped bikes along test sections of bike paths in Davis.

Sensor Equipped Bikes

The team equipped both a mountain bike and a road bike with a series of sensors designed to measure steering angle, speed using a GPS, vibration using an accelerometer, and collect distance data. The sensors were chosen to measure the variables listed above as they were assumed to be large contributors to ride quality assessment.
**Test Sections**

The sensor equipped bikes were tested on 57 different sections of bike paths in Davis. The bike paths were all exclusive bike paths, or bike paths exclusively for pedestrian and bicycle use. Non-exclusive bike paths, ones running on the same pavement as vehicle roads, are usually maintained as cities update and fix their roads. The focus on exclusive bike paths is necessary because these paths are less frequently maintained by cities.

![Map of bike pavement test sections in Davis, CA](image)

**Figure 3: Bike pavement test sections in Davis, CA (7)**

For the focus of this project, as opposed to the work done in the past by researchers on the project, 30 different test sections were chosen at random to further analyze. 15 of these sections were rough and 15 of these sections were smooth. The reason for this secondary analysis was to generate more rough section data and create a more balanced model for predicting ride quality.

**MTD Data**

As shown in figure 4 below, more of the 57 test sections were smooth (shown in blue) than they were rough (shown in red). Though indicative of pavement smoothness, these sections needed additional rough pavement data to adequately run the regression models to generate a statistical conclusion regarding predictors of ride-quality.
Figure 4: Previously gathered MTD data per SPT (7)

**Ordered Logit Regression Model**

The ordered logit model, or ordered logistic regression or proportional odds model, is an ordinal regression model. An ordinal regression model is one for ordinal dependent variables. Logit models estimate the probability of the dependent variable to be 1 (Y=1) (8). This model is chosen to apply the data set to because the variables are ordinal dependent variables with a range of responses.

The listed survey responses for ride quality are “very comfortable” – 1, 2, 3, 4, 5, 6, and “very uncomfortable” – 7 the logarithms of the odds of answering in certain ways are as follows:

- **Very comfortable [1]**, \( \log \frac{p_1}{p_2+p_3+p_4+p_5+p_6+p_7} \), 0
- **[1] or [2]**, \( \log \frac{p_1+p_2}{p_3+p_4+p_5+p_6+p_7} \), 1
- **[1] or [2] or [3]**, \( \log \frac{p_1+p_2+p_3}{p_4+p_5+p_6+p_7} \), 2
- **[1] or [2] or [3]**, \( \log \frac{p_1+p_2+p_3+p_4}{p_5+p_6+p_7} \), 3
Methods

Qualtrics Ride Quality Survey

The initial portion of the project was to restructure the survey sent out to participants riding the test sections. The instructions sent out with the survey also needed to be reformatted to be more detailed. We achieved this by changing the response metrics to “very comfortable” – rating 1 sections and “very uncomfortable” – rating 2 sections and explaining the study in further detail on the survey collection instructions sheet.

Figure 5: Qualtrics ride survey questions

Regression Analysis

After collecting the necessary survey response data, we were able to apply all the collected variable data to a statistical model designed to determine the significance of the variables in predicting ride quality. Initially, we had to determine the correlation coefficients of the various measured variables (speed, distance data, steering angle, bump density, etc.) to each other in the hopes of eliminating some of the variables from the ultimate ordered logit regression model. The idea was to group the variables together based on correlation coefficients so instead of having to test all the variables in combination in the regression model, we only had to test the variables that were uncorrelated to each other. The “cor” correlation function in R Studio generated the correlation matrix for each bike type as desired. By looking at the excel file generated the correlations between variables was able to be analyzed.
**Predicting Ride Quality**

The variables were then applied to the ordered logit regression model to determine if they were significant in predicting ride quality. The POLR function in the RStudio package MASS applied the listed variables to the ordered logit regression model. The CLM or cumulative link models function in the ORDINAL package of RStudio was also used to test for significance in the proportional odds model.

**Predicting MTD**

As the results section will indicate, the initial model was inconclusive in determining any of the measured bike variables significant in predicting ride quality, so they were further tested in their ability to predict MTD directly.

**Results and Discussion**

**Ride Quality Survey Data**

**Participant Bike Skill**

Most participants in the survey indicated themselves as experienced bikers with survey results between 1-4. Most female participants reported themselves as being a level 2 experienced biker whereas most males reported themselves to be a level 3 experienced rider.

![Bike Skill Survey Data](image)

**Figure 6. Example figure caption**
These ride experience survey results are not particularly telling or out of the ordinary. We expected riders who chose to participate in the survey were of adequate bike skill.

**Participant Age**

Most participants were between the ages of 20-30 which is as expected because most participants were students at the University of California, Davis. There were a few outliers in the sample however, with ages of 15 and 54.

**Ordered Logit Regression Model Analysis**

**Significant Variables for Predicting Ride Quality**

The only variable deemed significant for predicting ride quality directly was Mean Texture Depth (MTD) which was surprising considering variables like steer angle, distance data, acceleration in the z-direction (vertical acceleration), and bump density were expected to contribute significantly to ride quality as intuition and study suggests. MTD has already been known to affect pavement surface profile macrotexture which is the largest factor in determining pavement condition so the relationship between MTD and its role in predicting ride quality is expected.

![Table of Coefficients]

*Figure 7: MTD is the only significant variable in predicting ride quality*

**Significant Variables for Predicting MTD**

As the purpose of this study is to be able to use the measured sensor data to predict ride quality, a secondary statistical analysis was conducted in an attempt to predict MTD with the bike sensor data variables. After running the code, it was shown that distance data was significant for predicting MTD by the mountain bike model and acceleration in the z direction was significant in predicting MTD for the road bike model.
The difference in these two bike type results is likely due to the difference in suspension systems each bike is equipped with. Mountain bikes are equipped with different shock suspension systems than road bikes are which make mountain bikes a smoother ride than road bikes (9). Road bikes are affected by acceleration in the z direction, or vertical acceleration, because of the lack of this type of suspension system.

Future Recommendations

Future researchers could consider applying the gathered data to a different type of regression model. Though we found the ordered logit regression model to be the one most suitable for this type of study, there may be other models more appropriate in the applications desired for the project. Additionally, the survey response data collection effort could be furthered to generate more data. This added data would possibly show a stronger correlation between variables and ride quality as anticipated.

Conclusions

Mean texture depth (MTD) is the only statistically proven significant variable in determining ride-quality as determined through this study. Distance data and acceleration in the z-direction are significant variables in determining MTD meaning the sensor-equipped bikes may be used to gather this data to be used in anticipating ride-quality along the sections analyzed. Though this research can be added to in some ways, the preliminary findings prove cities can use the design this project engineered to take valuable measurements indicative of the conditions of
their bike-pavements. A future model considering road and mountain bikes would link distance data and acceleration in the z-direction as adequate predictors of ride quality.
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