Measuring Pavement Smoothness from the Prespective of E-scooters

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*Abstract*— The remarkable growth of e-scooter rental services in many communities in the United States has brought accompanying administrative and public safety challenges; prominent among these challenges is the frequent use of e-scooters on sidewalks, even though many municipalities prohibit this behavior. Restrictive ordinances may have little effect, unless safe and convenient alternative transportation paths are unavailable. In this research, we seek to evaluate the quality of these alternative paths by developing a methodology to measure pavement smoothness experienced by e-scooter users. To do this, we will develop a data collection device based on a personal Nine Bot Segway e-scooter and mobile phone. We will use these devices to develop a catalog of pavement quality measurements for streets in Provo, Utah. Part 2 of this research will correlate this smoothness data with observational data along paths where e-scooters are commonly used in the city. The data will inform a subsequent study of e-scooter route choice, and the proposed methodology holds promise as a civic crowdsourcing data collection endeavor.

Keywords—E-Scooter, Route Choice, Infrastructure, Revealed Preference, Pavement Smoothness

# Introduction (*Heading 1*)

E-Scooter rental services have recently emerged as a popular transportation mode in many large and medium-sized American cities over the last three years, with almost 40 million trips taken in 2018 [1]. This increasing popularity has also resulted in serious administrative challenges, with municipalities struggling to create and implement a framework policy for e-scooters and similar shared mobility transportation modes for where and how they should be safely used. Many cities have passed safety-promoting regulations prohibiting e-scooters from being used on sidewalks or requiring helmets for e-scooter users. However, these regulations are not always understood by the users [2], and the problem can be compounded by many scooter users who are exploring a novel transportation mode and may not have substantial experience as urban cyclists or even as pedestrians [3].

Missing from this discussion is the quality of the paths that e-scooters are required to use. Barring e-scooters from sidewalks with city ordinances will have any practical effect if road shoulders and bike lanes along the route are unavailable or otherwise inadequate. Of particular concern is the pavement smoothness. With novice users, small radius wheels, short wheelbases, and a high center of gravity relative to cyclists, e-scooters are perhaps susceptible to rough pavements in a way that bicycles are not. Users on rough roads may be more likely to crash or to divert from the roadway onto the sidewalk. In theory, testing this hypothesis should be straightforward with a network route choice model [4]; the GPS data available from e-scooter rental services could reveal whether users avoid paths with poor pavement quality. Unfortunately, pavement data for city streets that can inform such a model does not exist at the scale required. Cities do not generally take full pavement quality inventories, and when a city does collect such data, it is almost always limited to the automobile right-of-way.

In this research, we developed equipment and a methodology to measure the pavement smoothness of city streets and paths in Provo, Utah with an e-scooter. We then took a sample of collected streets and performed pavement testing to verify the metric from the e-scooter. This smoothness data informs Provo City of streets that need improvement for e-scooter riders. This paper is organized as follows. In Section II, we give a background of existing research related to e-scooters and discuss the gaps of previous studies. In Section III, we will discuss the methods of collecting and processing, the data of the pavements. The results will be presented in Section IV as long as the verification through visual and standard testing. We then summarized and concluded in Section V. Finally, Section VI will discuss how the data collected in this research will then be used in part 2 to investigate e-scooter route choice and other further research needed.

# Background research

In the latest years Provo city has launched shared mobility programs to release more than 500 e-scooters to serve the community [5]. E-scooters and similar modes of mobility are becoming essential to the sustainability of communities [6] by being a last mile mode of transportation [7]. In Provo, the e-scooters are part of intermodal transportation stations by being available to the users of the light rail system, bus rapid transit system and bus system all at the hub. Additionally, the e-scooters also serve the businesses in downtown Provo and the students and faculty of Brigham Young University.

Due to this recent rise of e-scooters, research and guidelines pertaining to infrastructure and implementation of this shared mobility for cities are still being developed. For this form of shared mobility to be a successful mode of transportation, cities must consider their infrastructure in their master and improvement plans, as well as create policies which provide a safe environment for users [8].

Most local ordinances prohibit e-scooters on sidewalks, which leave the riders using the streets. Provo City Code 9.15.200 prohibits e-scooters on sidewalks [9], however the city understands riders feel unsafe on the road and will design streets that riders will feel safe on [10]. Austin Public Health conducted a study on e-scooter related injuries and they found that 50% of the riders believed surface conditions were the cause of their injuries [11]. Understanding the impact of different riding environments on e-scooter riding experience is helpful for rider’s safety and preference [12].

There has been few e-scooter infrastructure preference studies conducted, but from those studies it was claimed that e-scooter riders feel safer on bike lanes that are protected or separated from traffic, smoother pavement, and surrounded by natural landscaped [13]. Missing from these studies is a route choice model using e-scooter GPS data to determine rider behavior. Similar to the infrastructure preference, the research existing for e-scooter route choice are still transpiring. In this part of our research, we have measured the pavement smoothness of roads and pathways in Provo city. We plan to present the data to show case the roughness of the pavement from the perspective of an e-scooter. Using this data we plan on analyzing how the pavement quality contributes to a rider’s route choice in further research.

# Methodology

The overall purpose of this research project is to determine if e-scooter rider behavior is related to the quality of the pavement of the available paths. An overview of the research is illustrated in Fig. 1. Our objective was to append pavement data to a topological network of roads, bicycle lanes, and paths in Provo. To accomplish this task, we designed and fabricated an e-scooter to measure pavement smoothness while it traversed a road segment. After collecting the data, we began to process the data to determine a metric of pavement smoothness and attach it the Utah street network from the Utah GIS library.

Graphical user interface

Description automatically generated

Fig 1. Overview of Research to be performed.

As previously mentioned, using an electrically powered motorized scooter can be dangerous. Before being able to ride the e-scooter, researchers were required to undergo safety training to understand how to use the equipment properly. Additionally, riders were to perform a pre-ride check process and wear personal protective gear in Fig. 2 to ensure the e-scooter was working properly and the riders were protected. Furthermore, researchers were not allowed to collect during peak traffic hours and when weather conditions prevented safe riding. If riders were to collect on roads with speed limits higher than 25 miles per hour, they were to be followed by a truck with an attenuator trailer to protect them from other vehicles. Under these conditions the researchers were authorized to safely collect the pavement smoothness data.



Fig. 2 E-Scooter Safety Gear

## Collecting the Data

In order to capture the data needed to determine the quality of the pavement, we mounted a smart phone to Nine Bot Segway e-scooter. Using the phone application, *Nav Sensor Recorder*, riders were able to collect geospatial data using global navigation satellite system (GNSS), acceleration data on all three axes, and a timestamp. All other data recorded by the app is not relevant.

In order to analyze a route choice model, we collected data on the roads that matched the GPS data given to us by the LINK e-scooter system in Provo. Researchers started the app, mounted the phone to the e-scooter and began riding the route. Routes were traversed where e-scooters are most likely to be ridden, shoulder of the roadway, bike lane, and pathways. In addition to popular roadways, the Provo River Bike Trail was collected due to its popularity for cycling and e-scooters. Each route was traversed in both directions so that when the pavement data could be joined to the Utah street network it can be linked to each individual segment.

The Utah street network was downloaded from the Utah GIS library []. The network system consisted of links and nodes that consisted of the following information for each link: Node A, Node B, Annual Average Daily Traffic (AADT), Speed Limit, Bike Lane Type, Path Classification, and Geospatial Information. The links clipped to the Provo City parcel for relevance of this project.

The network ended up having 10,391 links with about 4273 nodes. The data collected from the e-scooter is multiple point data along a path. A total of 59,925 points were collected during this project.

## Processing the Data

Having all the necessary data gathered, we then began processing the data to come up with pavement smoothness metric. We used two outputs from the Nav Sensor Recorder app, one that consisted of the GNSS data and the other which contained the acceleration data. Using the acceleration output, we integrated an algorithm to determine a metric of pavement smoothness.

\*Insert Dr. Mazzeo’s section on coming up with the acceleration metric.\*

Having a metric score of the quality of the pavement, we then needed to be able to assign this metric to a link on the street network. We combined all the GNSS outputs into one dataset and did the same with the acceleration outputs. The first step required us to join the GNSS and processed acceleration data. Due to the GNSS and acceleration data being collected at different frequencies the timestamps for each output were a little different, making it difficult to do a perfect match.

Instead, we interpolated between the closest timestamp match from the GNSS and acceleration data. Looping through each of the GNSS points, we filtered the acceleration data to be during the same time period of collection of the current GNSS point. We found the closest acceleration timestamp to our current GNSS timestamp and then depending on its location found the average acceleration metric between the surrounding points. We then assigned the average metric to the current GNSS point and iterated through the GNSS dataset until each point had an acceleration metric.

# Results and Verification

Having the GNSS and acceleration data together we are able to visualize the conditions of streets in Provo from the point of view of e-scooters. Fig. 3 shows a gradient map of the pavement smoothness. The lower the metric (lighter the color), the smoother the pavement for the e-scooter.

We can see segments that have similar smoothness and others where the metric varies along the segment. As mentioned before there are some limitations in our measuring and processing method, which can be adjusted to be more accurate. In order to justify the current method, field tests were performed on a sample of roadways that shared similar roadway characteristics but contrasting pavement metrics.

## Authentication of Pavement Smoothness

Map

Description automatically generated

Fig. 3 Acceleration Metric Map

# Conclusion

# Further Research

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