Characterization of Transit Ride Quality: Executive Summary

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Abstract
Few studies have evaluated the significance of transit ride quality. This study developed a low-cost smartphone-based method and associated data transformations to characterize ride quality for non-uniform speed profiles. The method distinguished between vibrations induced from road unevenness and operator behavior. The authors validated the accuracy of the method by conducting surveys to characterize the perceived roughness intensities from buses traveling routes of distinctly different roughness levels. The surveys found that smooth rides mattered to most passengers and that rough rides could even lead to some loss of ridership.

Introduction

Planners often point to service enhancements of bus transit as an effective strategy to combat the growing traffic congestion problems of urban environments. Therefore, transit service providers wish to identify and understand the significance of factors that could attract more transit riders before investing resources to add capacity. Researchers often identify affordability, accessibility, convenience, and stress as factors that affect the choice of public transit. The latter two factors include parameters such as the uncertainty of schedules, waiting time, travel time, crowding, noises, and smells. However, few studies have evaluated the significance of ride quality.

Practitioners use the term, ride quality, to indicate the degree to which a vehicle protects its occupants from the numerous factors that decrease ride comfort. These factors can be categorized into road, driver, and vehicle impact factors. The road impact factors (RIFs) are road surface unevenness and anomalies such as potholes, cracks, joints, and utility covers. The driver impact factors (DIFs) are operator behaviors such as abrupt braking, rapid acceleration, weaving, and speeding around curves. The RIFs and the DIFs can produce motions and noises that cause rider discomfort. The vehicle impact factors (VIFs) affect how riders perceive those disturbances. VIF depends mainly on vehicle suspension and handling characteristics. However, it is possible to include factors such as furniture design, interior aesthetics, and other features that are not within the scope of this study. Together, the RIF, DIF, and VIF result in the total ride quality (TRQ) experienced

The high cost to collect and analyze roughness data is a likely deterrent to ride quality evaluations. In particular, deployments of existing high-speed instrumentation to measure roughness in urban environments, such as inertial profilers, are impractical because of the stop-and-go conditions.

Methods

To address the affordability and scalability issue, this study developed a low-cost smartphone-based method and associated data transforms to characterize ride quality for any speed profile. The approach is transferrable to connected vehicles by using the same method to transform their inertial, velocity, and geospatial position data. The method distinguished between vibrations induced from road unevenness and operator behavior. The

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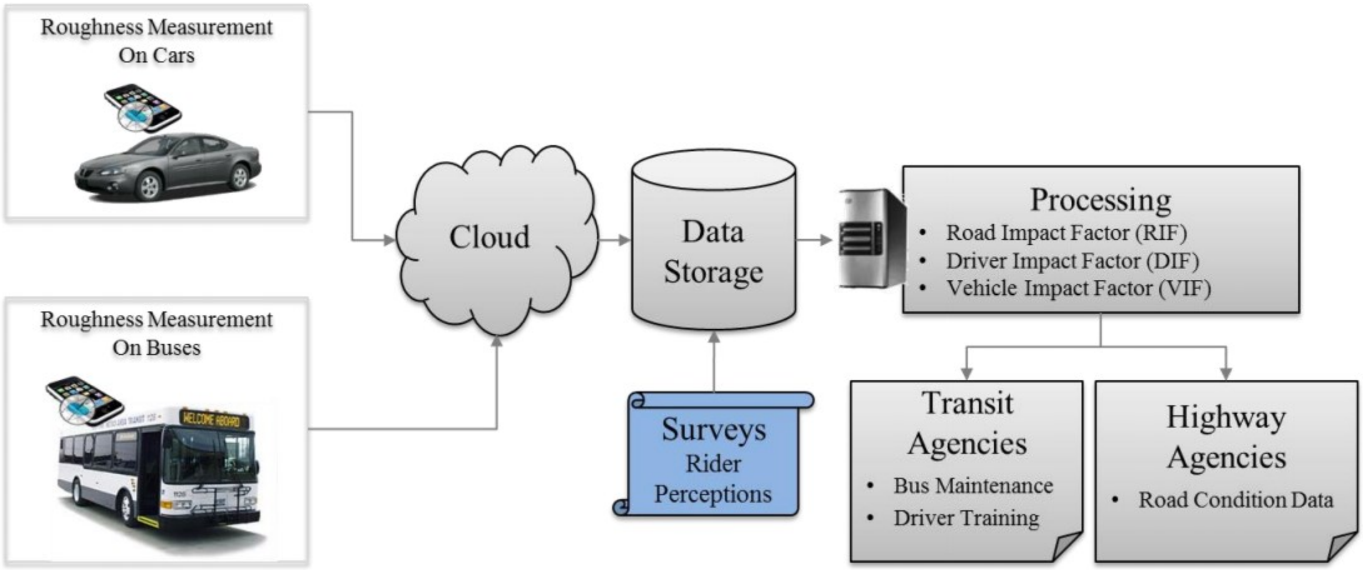

Figure 1. Overview of the Transit Ride Quality Study

theories developed also quantified the vehicle impact factors. The authors validated the accuracy of the method by conducting surveys to characterize the perceived roughness intensities from buses traveling four routes of distinctly different roughness levels.

In a case study of the small urban environment of Fargo, North Dakota, the authors surveyed the bus riders to classify their qualitative perception of the roughness intensity on four bus-route segments. The survey validated the objective measurements of roughness differences among the segments. Hence, this research provides transit agencies with a cost-effective tool and framework to quantify the total ride quality of transit routes.

The ride quality theory developed in this research isolated roughness impacts from road unevenness, operator behavior, and vehicle responses. A smartphone app collected the inertial and speed data. The roughness characterization models transformed the data into the three impact factors and then integrated them to produce the total ride quality. Figure 1 provides an overview of the study approach, and Figure 2 illustrates the mathematical transformation of the signal samples from the accelerometer, gyroscope, velocity sensor, and timer to directional-referenced roughness indices that in turn produce the impact factors that lead to a final quantification of the ride quality experienced.

Ride Quality Measurements and Perceptions

The surveys found that smooth rides mattered to most passengers. In fact, a noteworthy portion (21%) of the passengers who perceived the ride to be rough would consider other modes of transportation. Hence, even though a majority of the riders were captive in this case

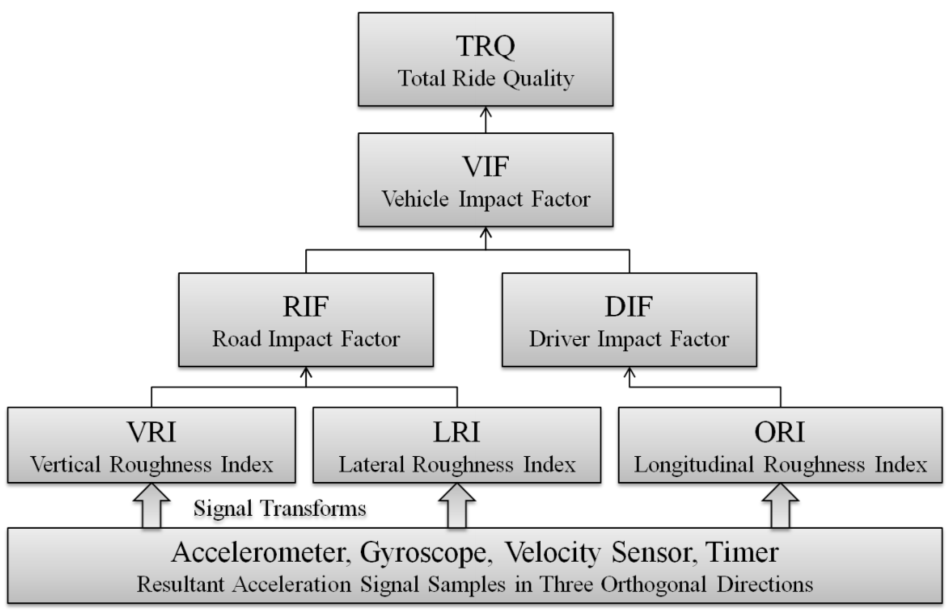

Figure 2. Transformations from Roughness Measurements to Total Ride Quality

study, many felt that rough rides could be a deterrent to choosing bus transit. Comfort was the top reason provided as a reason for the importance of a smooth ride. The results also showed that road impact factors were the most important in determining total ride quality.

A summary of the conclusions that relate to the objective measurements of ride quality, the perception of roughness levels experienced, and other characteristics of ridership are shown below.

1) The measurements of all factors that affect total ride quality were consistent among all the road segments tested.

2) The road impact factors were consistent across all segments tested for both the buses and sedans. The road impact factors dominated the total ride quality in all cases. This result indicated that roughness from roadway anomalies or roadway unevenness dominated the total ride quality.

3) Previous studies have determined that vertical vibrations cause human discomfort. Given the fact that the road impact factors dominated the vibration levels experienced, the road impact factors alone may be used to quantify the discomfort level of a ride.

4) The driver impact factors were consistent with relatively narrow spreads across all segments tested. They were comparable among buses and sedans, and there were no outliers in the data set. This result indicated that the operators handled their vehicles in a similar and consistent manner, including their velocity profile patterns. However, it is not possible to tell whether or not the drivers changed their normal behavior because they were aware of the ride roughness testing.

5) The vehicle impact factor measurements were consistent across all segments tested.

6) A majority of the riders were captive. However, a noteworthy proportion (18%) had access to alternative ride modes. That is, the proportion of passengers with access to ride alternatives ranged from approximately 12% to 24%, with an average of 18% across all routes. This suggests that there is an opportunity to encourage more bus users to select bus transit as their primary mode of transportation by addressing factors that would increase the attractiveness of public bus transit. By extension, therefore, programs that encourage mode shift to bus transit would also likely retain non-captive riders.

7) Ride smoothness mattered to a majority (63%) of the passengers across all routes. Their responses indicated that a smooth ride is either "very important" or "somewhat important." Ride smoothness did not matter for only about 9% of the passengers. The response was neutral for the remainder (28%) of the passengers.

8) The proportion of respondents for which ride smoothness mattered increased from 50% to 69% as the objectively measured segment roughness decreased. This phenomenon suggests that as passengers adapted or acclimated to the smoother rides, their perception of ride roughness will become more negative.

9) Comfort was the top reason (75%) that smoothness mattered. Other reasons provided were the ability to read or text (22%), and health reasons (3%).

10) A majority of the passengers (79%) who perceived the ride to be "rough" would not consider other modes of transportation because of the roughness. However, a significant proportion (21%) would consider other modes when the ride is too rough. Of that group, there were no responses that a smooth ride was "Not Important," thus validating that roughness would be their primary reason for considering other modes.

11) The proportion of riders who would consider other modes diminished rapidly as the measured segment roughness decreased.

12) The previous two findings provide strong evidence that excessive roughness is a factor in mode choice for a significant portion of the riders, at least in this case study.

Roughness Acclimation Theory

In addition to the above conclusions, this study presented and validated a roughness acclimation theory. Passengers assigned a mid-range roughness rating to the average roughness measured objectively for any segment. Therefore, the value of the mid-range ratings increased with segment roughness and visa-versa. However, within a segment, perceptions of roughness levels that were below and above the mid-range values corresponded to the objective measurements of lower and higher values, respectively. In essence, passengers as a group tended to translate the mid-range of the perceived roughness scale to values that matched the average roughness measured for a given segment.

These findings indicate that humans adapt to roughness levels because the thresholds for their subjective perception of a given roughness intensity increases with the roughness that they typically experience. This phenomenon is likened to temperature acclimation. For example, the temperature that residents of cold climates would perceive as "hot" is typically lower than the corresponding value for residents of warmer regions. The implication of the roughness acclimation theory, therefore, is that subjective measures of ride quality could result in non-uniform ratings and significant biases. However, the authors recommend additional case studies in other settings and demographics to evaluate further the roughness acclimation theory. For instance, a study that surveyed the same riders across routes of different roughness levels should remove some of the acclimation effects. The ride duration may also affect the rate of roughness acclimation.

Recommendations

The results of this research provide agencies with a low-cost framework and tools to assess the ride quality of transit services. Such assessments can inform decisions about operator training, equipment maintenance, and ridership enhancement programs. Smart city initiatives that urge urban planning practices to integrate diverse data sources and ideas from different agencies to realize synergies across the entire multimodal system will particularly benefit. For example, transit agencies can provide a connection from the ride quality database to highway asset management platforms. Such initiatives would allow highway agencies to leverage transit ride quality data for optimized urban roadway maintenance planning, and the prioritization of remediation needs. Subsequently, smoother roads will reduce vehicle operating costs, decrease roadway maintenance costs, and enhance the ride quality for all travelers.

To use this framework in a practical setting, agencies should consider investing in technology transfer that would standardize the data collection app and the data transform methods. Practical solutions that utilize the framework will require development of data warehousing schemes, data visualization tools, and decision-support platforms that are tailored to the specific applications and business processes. For example, when only the driver impact factor is needed to help optimize operator training programs, the design of the decision-support platform could be simplified for broader appeal to all personnel. Similarly, the design should support a standardized application programmer's interface (API) to provide easy and secure access to the ride quality data so that other agencies could benefit. The system should be capable of accessing ride quality data by the dates and times collected to isolate or eliminate data that corresponds to the timing of specific events, for example, rain or snow.

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