NEW YORK UNIVERSITY

CENTER FOR URBAN SCIENCE+PROGRESS

Exploring the relationship between Road roughness and Vehicle Speeds : Syracuse

Data driven Mobility Modeling and Simulation

Project Report

Spring 2016

Akshay Penmatcha

1) Introduction:

The roughness of a pavement or the relative damage to the pavement surface in the form of potholes, rutting or cracks can have a direct/indirect effect on the driving behavior. The direct effect could be slowing down of vehicles when a rough patch of road is encountered and the indirect effect could be a precautionary style of driving due to a perception of danger. This affects the efficiency of the Traffic Flows in a network. Increased pavement roughness can lead to lost time due to reduction of vehicle speeds and possibly cause congestions.

Previous research on this topic has explored various multivariate models which tried to quantify the effects of road roughness and found some statistically significant results [1]. The HDM-III Model developed a generalized model, but (Marković et al., 2015) found that it cannot ensure accuracy in all types of conditions. Given that, there are a multiple number of factors that affect the speed of a vehicle, it is also hard to isolate the just the effects of road roughness on speed to quantify the effect. Also, when a wide variety of data is used in multi-variate analysis, often the multicollinearity and inter dependency of the variables would pose a problem. Marković et al., 2015 concluded based on the review of HDM-III [2] and Swiss Models [3] that the roughness effects of speed can be statistically insignificant is roads with IRI values less than 3.

This project is an attempt to understand and explore the relationship between the road roughness and vehicle speeds in Syracuse, NY. Although there have been certain limitations, some interesting observations were found which are illustrated in the next few sections.

2) Dataset Description and Limitations

A proprietary dataset from Syracuse, NY which was actually collected to build a computer vision based pothole detection model was used. This dataset was collected on a specific test vehicle with an IoT device mounted on to it. The IoT device collected the accelerometer readings, GPS Speed reading and the images of the road section while it was driven across the city. Since this was a test vehicle driven in controlled conditions vehicle speeds and accelerometer reading readings have an inherent bias and may not exhibit the general behavior of the drivers and their experience. This analysis also attempted to understand the shortcomings where they exist and provide a reasonable explanation for the observed irregularities.

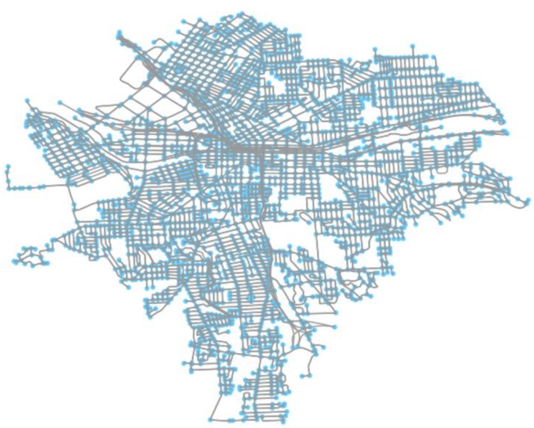
In addition to the accelerometer dataset, the street network was extracted from OpenStreetMap for the aggregation of data wherever it was required.

3) Data Cleaning and Preprocessing

For all future reference I will be using the following notation to refer the various data sources used.

D1 – Street Network Data from OSM containing the edges and nodes of the road network

D2 - Point Data collected by the vehicle while driving around the city



FigX : Road Network of Syracuse

FigX : Data points collected on Residential Roads only

Steps followed in Data Cleaning and Preprocessing:

1) Created buffers along the road segments in D1
2) Created the point geometries for the Lat-Lon values in D2
3) Calculated the Net Vibration from the X,Y,Z components of vibration
4) Spatially merged the D2 with D1 to find the road in which each data point collected lies
5) Filtered the D1+D2 data within the Residential Segments only
6) Cleaned the anomalous data in terms of Speed and Lanes

7) Grouped the D1+D2 data by street to find the mean vibration and speed data across all the data points from which the data was collected.

4) Analysis:

a) <u>Distributions:</u>

Initially, the various distributions of the data set were taken to gain a better understanding. In Fig-3 we can see that the Vibrations data is concentrated between 0.4-0.8 and then flattens out at the end. This shows the base vibration that the accelerometer experiences are in the range of 0.4-0.8. From this it is important to find the threshold value of vibration after which we can consider them to be corresponding to a certain road defect.

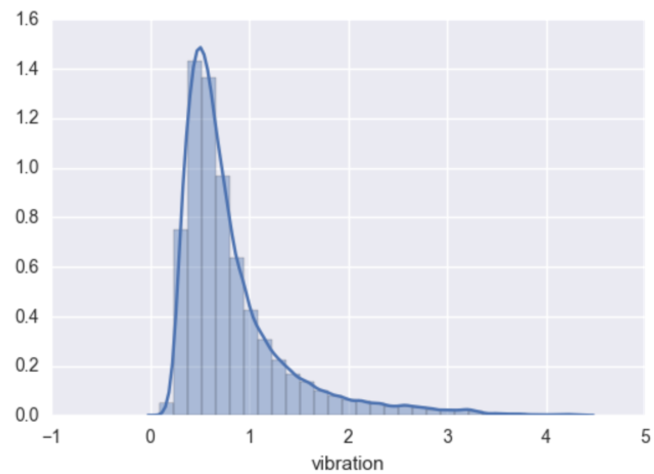


Fig-3: Distribution of Point Vibrations Data

In Fig-4 we can see the average speed of the driver within the road links. The speed limits in all the roads considered were 30mph. But as we can observe in Fig-4 most of the times the driver maintained a speed between 12-18mph indicating a cautious style of driving. In a realistic scenario, the peak of this distribution would shift towards 30mph and slightly above if we consider the aggregate behavior across a larger pool of drivers. Another point to note about choosing the aggregate speeds instead of point speeds is because the actual reading come from a GPS sensor which has certain innate inaccuracies. In order to make more sense out of the data, I have cleaned up the abnormal values and averaged them over the segment considered.

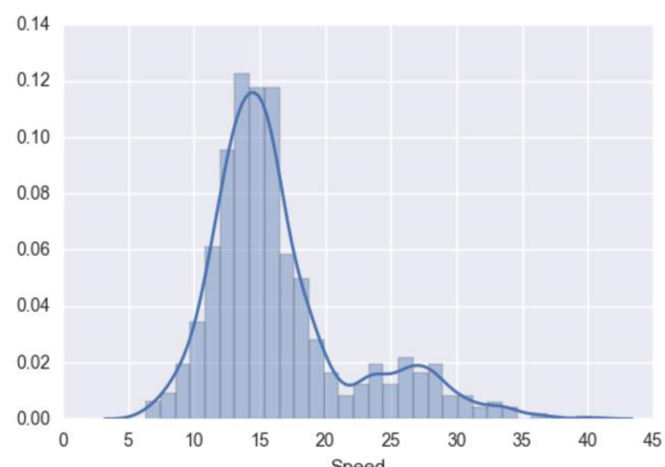


Fig-4: Distribution of Mean Speeds along Road Links

b) Analyzing the Correlation Relationships between Mean Vibration and Mean Speed:

Here we computed the correlation between the 3 factors: Length of the Road, Mean Vibration within the road link and Mean Speed within the road link respectively.

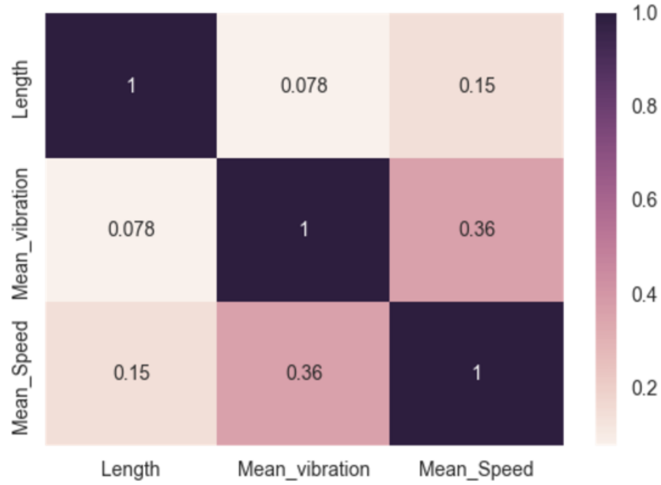


Fig-5: Correlation relationship between Length, Mean Vibration and Mean Speed

The values in Fig-5 indicate that, Length of the road and the Mean Speed have a positive correlation i.e the mean vehicle speeds increases with the Length of the road link. The interesting case appears in terms of the relation between the Mean Vibration and Mean Speed. Based on intuition we would expect that as the vibrations experienced by the vehicle increases the vehicle speeds should decrease. But in this case, we observed a positive correlation (0.36) indicating that the vehicles speeds would increase with the increase in vibration. After a close observation of the data and real-world scenarios it was found that this is true only when the vehicle crosses a certain threshold speed.

To understand where this threshold lies, I have tried to approach this problem by binning the data into various speed categories and observing the distribution of vibrations within those bins.

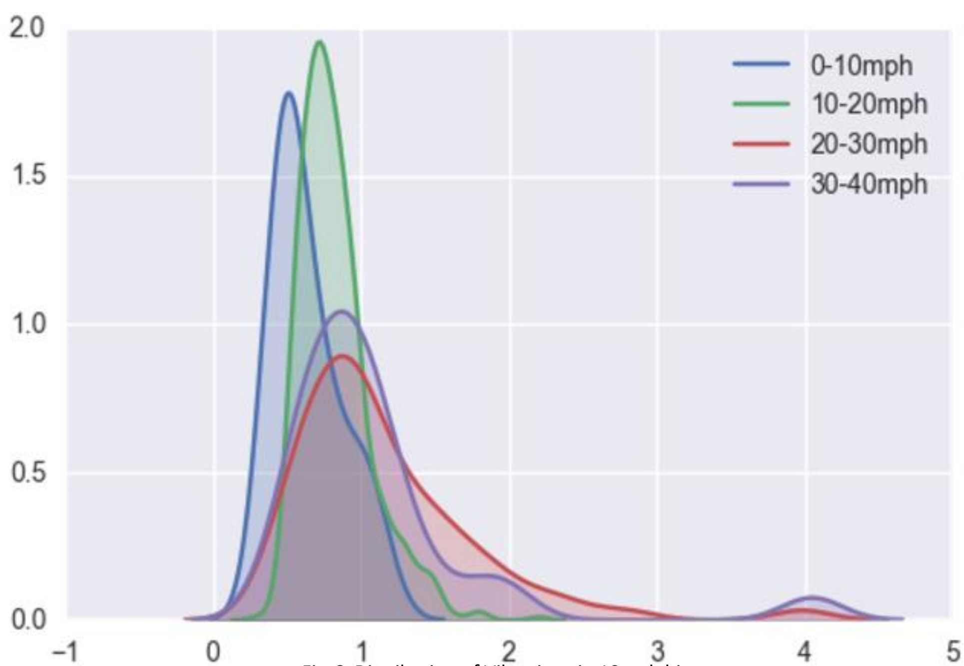


Fig-6: Distribution of Vibrations in 10mph bins

As we can observe from the above plot in Fig-6, the distribution of vibrations is shifting towards the right as we shift to the higher speed categories until 20-30mph and thereafter it has shifted backwards. To illustrate the same with the mean and median values, I have tabulated them in Fig-7.

Based on this, it can be understood that the relationship between Speed and Vibration will follow a negative correlation as expected only above the threshold speed, which in this case seems to lie between 25-30mph.

The correlation matrix in Fig-8 illustrates the same, where 30-40mph bin shows a faintly negative correlation.

Speed Bin	Mean Vibration	Median Vibration
0-10 mph	0.64	0.55
10-20 mph	0.83	0.78
20-30 mph	1.16	1.02
30-40 mph	1.09	0.90

Table-7: Distribution of Vibrations in 10mph bins

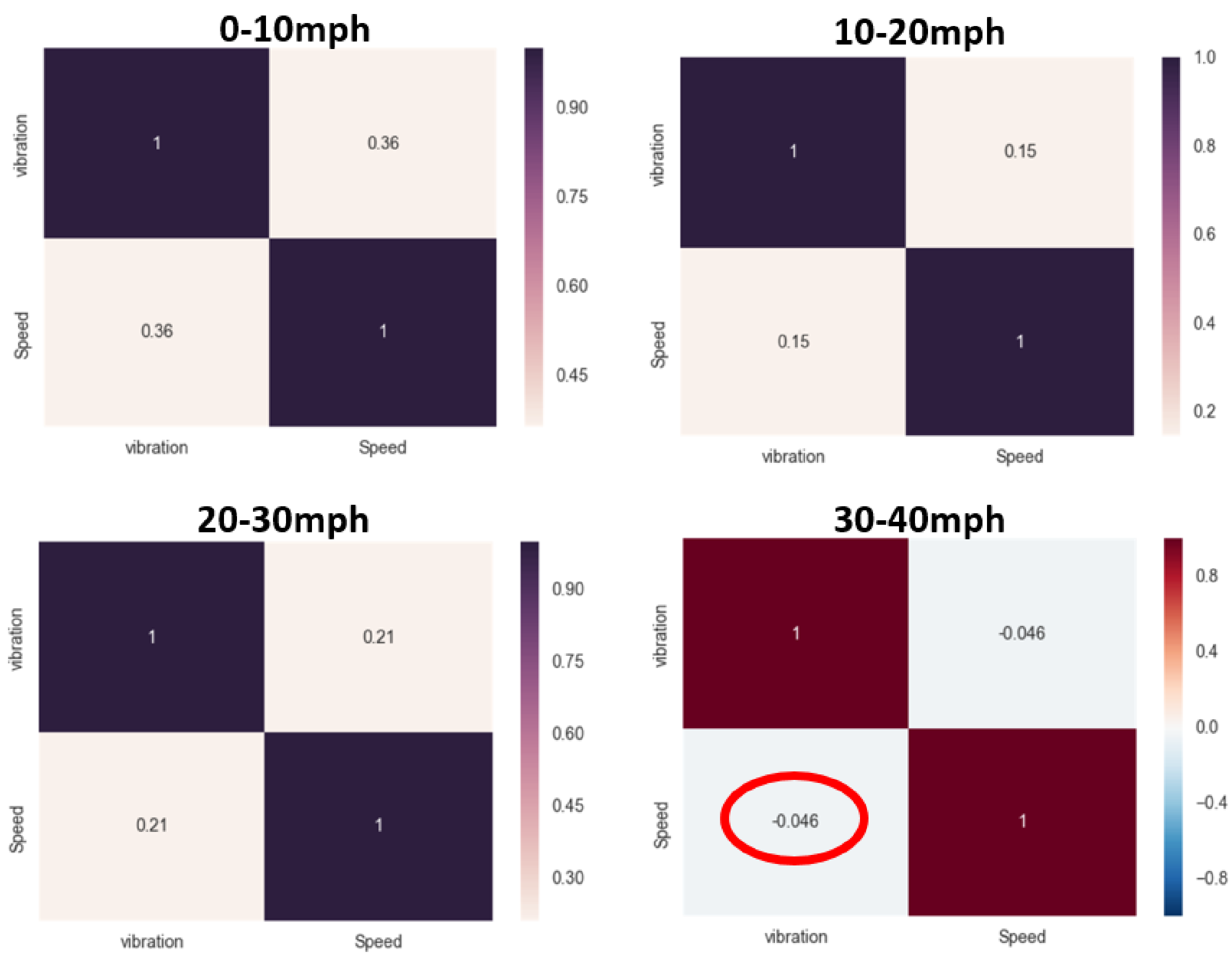


Fig-8: Correlation Matrices of Vibrations and Mean-Speed for each of the 10mph bins

c) Analyzing the Correlation Relationships between Max Vibration and Mean Speed:

Another hypothesis that I wanted to test through this analysis is to check if the maximum vibration (which indicates the presence of major road defect or pothole) has a negative impact on the vehicle speeds. For this I computed the correlation relationship between the maximum vibration and the mean speed. The results can be seen in the Fig-9 below.

A negative correlation (-0.23) here implies that, as the size of the major defect on the road increases the vehicle speeds decrease to a significant level. This can be related to a real world scenario as the driver trying to reduce his overall speed well in advance to avoid a high impact while passing the road defect.

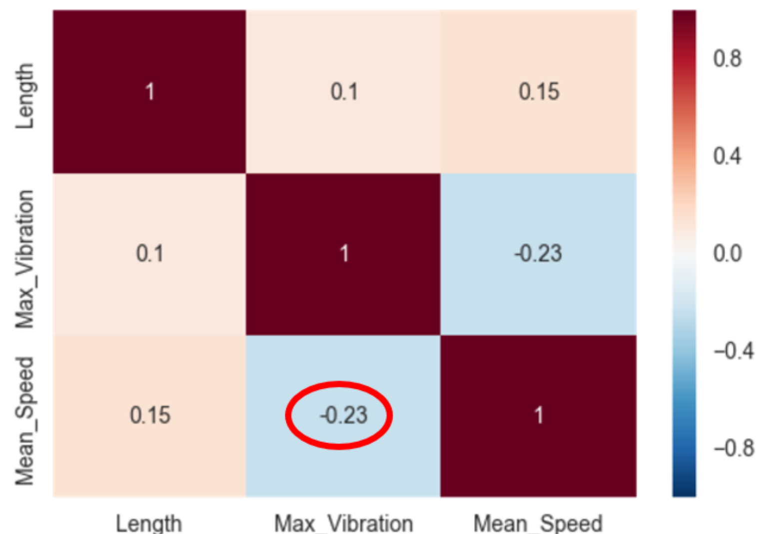


Fig-9: Correlation relationship between Length, Max Vibration and Mean Speed

d) Univariate Regression between Vibration and Speed

Regression model to predict the vehicle speeds based on the mean vibration within the road link is presented below. The R-squared value of 0.732 indicates a decent fit. Although it needs to be

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                            OLS Regression Results
==============================================================================
Dep. Variable:                  Speed   R-squared:                       0.732
Model:                            OLS   Adj. R-squared:                  0.731
Method:                 Least Squares   F-statistic:                     2316.
Date:                Thu, 04 May 2017   Prob (F-statistic):          8.14e-245
Time:                        03:20:34   Log-Likelihood:                -3075.9
No. Observations:                 850   AIC:                             6154.
Df Residuals:                     849   BIC:                             6159.
Df Model:                           1
Covariance Type:            nonrobust
==============================================================================
                 coef    std err          t      P>|t|      [0.025      0.975]
------------------------------------------------------------------------------
vibration      5.8564      0.122     48.126      0.000       5.618       6.095
==============================================================================
Omnibus:                       98.804   Durbin-Watson:                   1.784
Prob(Omnibus):                  0.000   Jarque-Bera (JB):              132.152
Skew:                           0.910   Prob(JB):                     2.01e-29
Kurtosis:                       3.649   Cond. No.                         1.00
==============================================================================
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Fig-10: Univariate Regression results between Mean Vibration and Mean Speed noted that the vibration effects are not taken in isolation so the other major factors affecting the vehicle speeds should be incorporated in to the model.

5) Conclusions and Way Forward:

This research had some innate limitations due to the nature of the data used for analysis i.e. a dataset collected under controlled conditions. Nevertheless, the above analysis made an attempt to validate the conclusions drawn in Marković et al., 2015. The essence of those conclusions was that road roughness had a statistically significant effect on vehicle speeds only after a certain threshold level of road roughness. The same has been verified in section 4(c) by considering the Max vibration experienced with in the road link. Here the underlying assumption remains that Maximum Vibration is linearly proportional to IRI values. The other conclusion that Marković et al., 2015 drew was that, due to the multiplicity of factors that affect the Vehicle Speeds in realistic scenarios the relationship drawn from one study cannot be extended to other scenarios. So, in this case, the regression results cannot be generalized but can be used to better understand the significance of the roughness effects.

To improve the significance or correctness of the results obtained above we may use the INRIX Vehicle Speeds data which is more representative of the aggregate driving behavior and speeds. We can also add other variables like No: of Lanes, Annual Daily Vehicle Traffic data to extend the regression model for better predictive capability. Also, if we can perform this analysis on similar type of roads rather than a mix of many different residential roads the significance of the results would increase. This can be done by clustering the similar roads prior to the analysis.

6) References:

[1] Marković, M., Bajić, J., Ninkov, T., Vasić, D., Sušić, Z., & Bulatović, V. (2015). Savremene Metode Monitoringa Deformacija Građevinskih Objekata. *Savremena Dostignuća U Građevinarstvu*, 807–814. https://doi.org/10.14415/konferencijaGFS

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[3] VSS, 2003b: SN 640 925b: Pavement maintenance management – Condition assessment and index valuing. Swiss Association of Road and Traffic Experts (VSS), Technical Committee 7: Maintenance Management, 2003, Switzerland.

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[5] Paterson, W.D.O., and Watanatada, T.: Relationships Between Vehicle Speed, Ride Quality, and Road Roughness. Measuring Road Roughness and its Effects on User Cost and Comfort. ASTM STP 884, American Society for Testing and Materials, 1985, Philadelphia, USA, pp. 89-110.

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[8] McLean, J.R.: Adapting the HDM-III Vehicle Speed Prediction Models for Australian Rural Highways. Working Document TE 91/014, Australian Road Research Board, 1991, Nunawading, Victoria, Australia