Analysis of Rush Hour Driving Conditions and Vehicle Specific Power Distribution in a Large Urban Area: Case study of a Major Highway

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ABSTRACT

Passenger cars have been observed to increase on the roads of Karachi, the largest metropolitan city of Pakistan. This has resulted in a significant increase in on-road vehicle density and traffic congestion. To assess the actual driving conditions for passenger cars at a main highway in Karachi, that is, Shahrah-e-Faisal, vehicle driving patterns were recorded using Global Positioning System (GPS) data loggers and main factors related to urban driving conditions were calculated including road elevation, vehicle speed and Vehicle Specific Power (VSP) distribution during the evening rush hour. Our results showed that average road elevation was 19.7 m (ASL) with as low as 2 m (ASL) and as high as 38 m (ASL). Average speed was around 37.0 km/h (standard deviation ±15.2) with highest instantaneous speed recorded at 73.1 km/h. VSP bin 11 had the highest share of 35.4% whereas vehicle driving predominantly (99%) belonged to lower engine stress mode.

Key words: Road traffic, driving pattern, global positioning system, vehicle specific power, Karachi.

INTRODUCTION

Karachi is the country's largest city with highest population as compared to other cities of Pakistan (KMC, 2012). In this large metropolitan city located almost at the sea level (UNDP, 2015), road traffic and pollution have been termed as major challenges for city administration with air pollution levels higher than recommended WHO guidelines (KMC, 2015). Traffic congestion is reported to have increased significantly causing severe traffic related problems in the city (Kabir et al., 2014). Named after the Saudi King Shah Faisal, Shahrah-e-Faisal is well-known and one of the busiest highways of Karachi. Sometimes called as 'Faisal Highway', its length has been found to be around 16 km starting near the Bhittai Rangers Headquarters towards the airport and ending near the Avari tower (Club road), as shown in Figure 1.

Most offices of the multinational organizations working in Karachi and Pakistan are situated along or near the Shahrah-e-Faisal road (Wikipedia, 2015). This main road also connects to several of the other important roads of the Karachi city such as Main National Highway, Rashid Minhas Road, Karsaz Road, and Korangi Road. People facing difficulties in reaching their destinations on time and lower number of traffic police officials related to the large volume of on-road vehicles have been previously reported to cause traffic jams (Tribune, 2014). This road has been found to be heavily congested with motor vehicles throughout the day (NESPAK, 2011) with vehicles highly heterogeneous by type and technology (Adnan, 2014). The city's administrative body, Karachi Metropolitan Corporation (KMC) has established traffic flow monitoring system yet its performance has been found to be unsatisfactory (Ali et al., 2013). A view of evening traffic congestion at Shahrah-e-Faisal is shown in Figure 2.

With increasing traffic jams and extremely lower average speeds encountered my many drivers, this
research work was designed and undertaken to quantitatively study the driving conditions at one of the busiest road in Karachi. To evaluate the driving conditions on this road, a Global Positioning System (GPS) data logger device that records vehicle location and movement for every second was used. The main objective of this work was to identify the average vehicle speed, peak velocities, road altitude and the Vehicle Specific Power (VSP) distribution during the evening rush hours. VSP is based on power output of a vehicle engine per unit mass of that vehicle and was developed by Jimenez (1999) at Massachusetts Institute of Technology.
MATERIALS AND METHODS

The GPS device used in this study records vehicle speed and location in terms of latitude, longitude and altitude. These recordings are stored in the device and can be retrieved with the help of a computer program. To collect random driving data, volunteer drivers were requested to use this device while operating their vehicles in usual pattern. This was done to ensure that behavioral factors of driving do not affect the data collection process. Vehicle driving activity was recorded during working days of the week. Since the focus of our work was to analyze the evening rush hour vehicle activity, therefore driving patterns recorded for the corresponding period were used and studied. Tough morning rush hours are expected to have similar driving pattern, it is however recommended to study other hours of the day as well in the future.

The GPS data logger device is a simple and handy device that can be placed in a vehicle while it is operated normally. This device does not require any prior driver training or skill. As the drivers run the vehicle, on-road vehicle activity is recorded and subsequently analyzed. In order to collect data that can be considered representative of the actual driving conditions at Shahrah-e-Faisal, 30 passenger vehicles were contacted and selected to record driving patterns. The volunteer drivers included individuals from different backgrounds to ensure randomness in data collection. In total, 8 students, 6 private employees, 6 government employees, 6 businessmen, and 4 women drivers were given the GPS devices for their vehicles. The study period started from July 6, 2015 and ended on August 28, 2015. From this study period, a data for 30 days was collected. The GPS data was also used to calculate VSP distribution of local driving. VSP bins are distributed over 60 bins with each bin representing a different point of driving. VSP is a very good indicator of local driving conditions and is widely used in emission models for the estimation of vehicular exhaust emissions. In our study, method developed by Jimenez (1999) was used as shown in Equation 1:

\[
VSP = v \times [1.1 a + (9.81 \times \tan (\text{grade})) + 0.132] + 0.000302 \times v^3
\]

Where,
VSP: vehicle specific power (kW/t);
v: vehicle speed (m/s);
a: vehicle acceleration (m/s²);
grade: vertical rise/slope length;
g: acceleration due to gravity (9.8 m/s²).

The data analysis part included the calculation of average altitude along the route at Shahrah-e-Faisal, average and peak vehicle velocity and the VSP distribution. Altitude was studied since it also has an impact on vehicle speed and engine stress. Altitude was measured in meters Above Sea Level (ASL) while speed was reported kilometers per hour (km/h). VSP was presented in terms of kilowatt per ton (kW/t) as shown in Equation 1. Since the road was travelled multiple times (during different days), all data pertaining to our hours of interest was incorporated in this study.

RESULTS AND DISCUSSION

Road elevation

The 30 days GPS data showed that altitude along the selected highway was variable but was lower than 38 m on all times. For instance, a 34 min driving activity recorded on GPS on Tuesday (from FTC flyover towards airport till Jinnah terminal road) showed a mean road elevation of 18.4 m (ASL) with a standard deviation of ±5.7 m. Figure 3 shows second by second variation in road elevation for this individual journey. As can be seen in the figure, highest elevation was at around 38 m (ASL) at Natha Khan Bridge (Latitude: 24.887168 and Longitude: 67.136928). Bridges are considered to be a better alternative to traffic signals in Karachi keeping in view the huge number of on-road vehicles, and this 38 m elevation was also found at Natha Khan Bridge. This also indicated that the sections of Shahrah-e-Faisal other than the elevated bridges should normally be lower than 38 m. Overall, average road elevation was found to be 19.7 m (ASL) with as low as 2 m and as high as 38 m. As mentioned before, Karachi is a coastal city with a large sea port, thus, its road elevation is likely to be closer to the sea level.

Average and instantaneous speed

Since average speed is an important factor in determining overall driving conditions at any given area and time, we also calculated average speed by using the GPS data. Our results revealed that average speed was around 37.0 km/h with a standard deviation of ±15.2. Highest instantaneous speed was recorded at 73.09 km/h. Figure 4 shows second by second variations in vehicle speed for a 120 s driving recorded on different vehicles. As shown, the vehicle speed varies significantly over the driving period of 120 s. However, the figure is indicative of instantaneous vehicle speeds recorded on 4 different vehicles separately and must not be considered the average driving speed at Shahrah-e-Faisal. The average vehicle speed was lower at Shahrah-e-Faisal resulting mainly from the extreme congestion during the evening rush hours.

VSP Distribution

The VSP results based on the GPS data and calculated following the method developed by Jimenez (1999) is presented in Table 1. As can be seen, VSP bin 11 had the highest share (in percentage) of 35.4%, this was followed
Figure 3. Chart of variation in road elevation over a 34 min driving on Shahrah-e-Faisal at an average speed of 24.6 km/h.

Figure 4. Chart showing variation in instantaneous vehicle speed over a 120 second driving at Shahrah-e-Faisal during evening rush hours.

Table 1. Overall distribution (%) of 60 power bins (Average Speed: 37.0 km/h).

<table>
<thead>
<tr>
<th>Stress modes</th>
<th>VSP power bins</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0   1   2   3   4   5   6   7   8   9   10  11  12  13  14  15  16  17  18  19</td>
</tr>
<tr>
<td>Low</td>
<td>0    0   0   0   0   0   0.2  0.3  1.3  3.6  11.7  35.4  25.3  13.4  5.9  1.9  0.4  0   0   0</td>
</tr>
<tr>
<td>Medium</td>
<td>0    0   0   0   0   0   0   0   0   0   0   0   0   0   0   0.3  0.3  0   0   0</td>
</tr>
<tr>
<td>High</td>
<td>0    0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0</td>
</tr>
</tbody>
</table>
Figure 5. Share of individual VSP bins in overall driving pattern.

by the share of VSP bin 12 at 25.3%. VSP bins equal to or less than 11 represent negative power conditions and are classified under the low engine stress mode. They occur when a vehicle is slow in speed for some reason, idling for shorter period and going down a hill or any combined effect of these situations. Low engine stress mode ranges from bin number 0 to 19 (first 20 bins) whereas medium engine stress mode corresponds to the next 20 VSP bins (bin number 20 to 39), and high engine stress mode contains last 20 VSP bins and corresponds to vehicle operation at higher speeds. Our results showed that nearly half of the driving at Shahrah-e-Faisal was took place in VSP bins less than 12, and almost 99% of the driving took place in lower engine stress mode as earlier classified. The high values corresponding to lower engine stress mode signifies the fact that driving conditions become highly deteriorated during the evening rush hours at Shahrah-e-Faisal. The share of VSP bin 12 was second highest at 25.3% coming under the lower engine stress mode. This VSP bin shows conditions of zero or extremely low engine power, these conditions occur frequently when we wait at a traffic signal. However, it was noted that there were only a few traffic intersections or signals at Shahrah-e-Faisal, and these stops mainly correspond to recurrent traffic jams on this road. These stops result in reduced average speed, more fuel combustion and higher exhaust emissions.

Bin 13 and above had the share of only 22.2% which shows that higher vehicle speed was not achieved for longer periods of time. VSP bin 13 and above correspond to power engine power when a vehicle operates at constant speeds, accelerates and goes up a hill or any combined situation. Further details on VSP can be found in Lents et al. (2004) and Shrestha et al. (2013). Figure 5 shows the share of individual VSP bins in overall driving pattern at Shahrah-e-Faisal, Karachi for our study period.

**Conclusion**

With an ever increasing number of passenger cars in most urban areas of Pakistan including Karachi, road congestion, traffic jams and slower average speeds have become common on the roads of Karachi, the largest cosmopolitan city of Pakistan. This has resulted in a significant increase in on-road vehicle density and congestion. This study aimed at analyzing key parameters related to urban driving patterns was designed to study local driving at one of the busiest highway that is, Shahrah-e-Faisal. GPS system based results revealed an average road elevation of 19.7 m (ASL), average vehicle speed of 37.0 km/h, highest instantaneous speed of 73.1 km/h and predominant vehicle driving (99%) in lower engine stress mode.

The results of our study can be very helpful to urban traffic planners in designing improved traffic management systems. This work can be extended to assess the impact of reduced vehicle speed and lower engine stress mode
driving on local air quality, human health, economy and environment while other hours of the day can also be included in future studies.

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