Vehicular Emission Modelling at Toll Plazas under Mixed Traffic Conditions

Authors

Mr. Chintaman S. Bari
Research Scholar, Dept. of Civil Engineering
SVNIT, Surat, Gujarat 395007 (India)

Dr. Yogeshwar V. Navandar
Assistant Professor, Civil Engineering Department, MIT Academy of Engineering, Pune -412 105 (India)

Dr. Ashish Dhamaniya,
Associate Professor, Dept. of Civil Engineering
SVNIT, Surat, Gujarat 395007 (India)
Introduction

Literature Review

Research Gaps

Objectives

Methodology

Data Collection

Data Analysis

Results and Conclusions

References
2nd Largest Road Network

Vehicular Growth Rate - 9.9% (2018)

1% in Worlds Vehicular Population

Infrastructure (Road Growth Rate-5.87%)

1.7% of NH carries 40% of traffic

(Source: www.morth.nic.in)
Loss of 870 billions per (The Hindu, 2014)
Residents may move court to get Kherki Daula toll shifted
Say Dust & Air Pollution Pose Serious Risks To Health

Gurgaon: After three years of the government dragging its feet on the Kherki Daula toll plaza shift, residents of new sectors along the Dwarka Expressway have decided to move high court.

“We have been holding protests seeking its removal since 2016. Yet, we continue to suffer. Now, we will take the matter to the Punjab and Haryana high court,” said Satish Yadav, a member of Tul Hastoo Samiti, at a press conference.

The toll plaza is a major choke point on the Delhi-Gurgaon Expressway. The traffic congestion adds emissions from vehicles that wait in long lines affect air quality, residents claim. Besides, uneven roads in the vicinity are almost always dusty. All of this, residents of areas along the Dwarka Expressway have been saying.

What would also help, residents said, is completion of the Dwarka Expressway stretch from National Highway-8 to the airport, easing some of the congestion. Last year, the toll operator—Millennium City Expressway Private Limited (MCPEL)—had opposed the proposal to move the toll plaza on the grounds that it would suffer massive revenue losses. “We had filed an RTI, seeking information on the collection of funds at the toll plaza. The response to our RTI revealed that the Delhi-Gurgaon Expressway cost Rs 500 crore, while expenditure on change of scope was Rs 130 crore—which was in addition to the earlier cost... We found out that the toll operator, MCPEL, has already recovered the money,” RTI activist Harinder Dhillon said. In fact, since the project was begun, the area was moving into a persistent health hazard.

“Children and old people are suffering because of the air pollution,” Yadav added.

Emission Estimation under Mixed Traffic Conditions

Need of the Study
Toll Road Classification

Open Toll System

Closed Toll System
Methods of Toll Collection

- Manual Toll Collection (MTC)
- Automatic Coin Machine (ACM)
- Electronic Toll Collection (ETC)
1. Literature review on zone of influence

2. Literature review on emissions
**Reported Zone of Influence by Different Researchers**

<table>
<thead>
<tr>
<th>Researcher</th>
<th>Facility</th>
<th>Country</th>
<th>Zone of Influence (ZOI)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Saka et al. (2001)</td>
<td>Toll Plaza (ETC)</td>
<td>United States of America (USA)</td>
<td>610 m</td>
</tr>
<tr>
<td>Mousa (2002)</td>
<td>Signalized Intersection</td>
<td>Oman</td>
<td>330 m</td>
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<tr>
<td>El-Shawarby et al. (2007)</td>
<td>Signalized intersection (deceleration)</td>
<td>Virginia</td>
<td>93.1 m</td>
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<td>Song et al. (2008)</td>
<td>Toll Plaza (MTC and ETC)</td>
<td>China</td>
<td>400 m</td>
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<td>Song et al. (2010)</td>
<td>Acceleration lane</td>
<td>China</td>
<td>518 m</td>
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<tr>
<td>Song et al. (2010)</td>
<td>Deceleration lane</td>
<td>China</td>
<td>288 m</td>
</tr>
<tr>
<td>Weng et al. (2015)</td>
<td>Toll Plaza (ETC)</td>
<td>China</td>
<td>240 m</td>
</tr>
<tr>
<td>Weng et al. (2015)</td>
<td>Toll Plaza (MTC)</td>
<td>China</td>
<td>300 m</td>
</tr>
<tr>
<td>Yang et al. (2016)</td>
<td>Ramps</td>
<td>California, USA</td>
<td>152 m</td>
</tr>
<tr>
<td>Bokare and Maurya (2017)</td>
<td>Signalized intersection</td>
<td>India</td>
<td>837 m</td>
</tr>
<tr>
<td>Chung et al. (2017)</td>
<td>Toll Plaza (MTC and ETC)</td>
<td>Korea</td>
<td>870 m</td>
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</table>
### Reported Methods of Emission Estimation

<table>
<thead>
<tr>
<th>Researcher</th>
<th>Country</th>
<th>Method</th>
<th>Facility</th>
</tr>
</thead>
<tbody>
<tr>
<td>Saka et al. (2001)</td>
<td>Baltimore Metropolitan area</td>
<td>MOBILE 5b and Simulation</td>
<td>ETC, MTC lane</td>
</tr>
<tr>
<td>Feng and Cheng (2002)</td>
<td>Chongqing</td>
<td>Mobile5</td>
<td>Urban Freeway</td>
</tr>
<tr>
<td>Ahn et al. (2002)</td>
<td>Oak Ridge National Laboratory (ORNL)</td>
<td>Regression Method</td>
<td>Freeway</td>
</tr>
<tr>
<td>Rakha and Ding (2003)</td>
<td>Phoenix</td>
<td>Floating car Method and PEMS</td>
<td>Freeway</td>
</tr>
<tr>
<td>Coelho et al. (2005)</td>
<td>Portugal</td>
<td>Microwave Doppler sensor</td>
<td>ETC, MTC lane</td>
</tr>
<tr>
<td>Song et al. (2012)</td>
<td>China</td>
<td>Floating car Method and PEMS</td>
<td>Freeway</td>
</tr>
</tbody>
</table>
To carry out the emission modelling at the manually operated toll plazas under mixed traffic conditions

To compare the estimated emissions with the emissions from empirical formulae

Objectives of the Study
Methodology of the present study

1. Selection of Objectives
2. Data Collection
   - Videographic Data Collection
   - Performance Box Data Collection
3. Statistical Approach for finding Influence Zone at Toll Plaza
4. Emission modelling
5. Overall Emission Modelling using Vehicle Specific Power (VSP) Approach
6. Using Formulae
7. Results and Conclusions
Data Collection
## Vehicle Class for Study

<table>
<thead>
<tr>
<th>Sr. No.</th>
<th>Vehicle Class</th>
<th>Vehicle Included</th>
<th>Average Length (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Small Car (SC)</td>
<td>Car</td>
<td>3.72</td>
</tr>
<tr>
<td>2</td>
<td>Big Car (BC)</td>
<td>Big Utility Vehicle</td>
<td>4.58</td>
</tr>
<tr>
<td>3</td>
<td>Large Commercial Vehicle (LCV)</td>
<td>Light Motor Vehicle</td>
<td>5.00</td>
</tr>
<tr>
<td>4</td>
<td>Bus</td>
<td>Standard Bus</td>
<td>10.30</td>
</tr>
<tr>
<td>5</td>
<td>Heavy Commercial Vehicle (HCV)</td>
<td>2 to 3 Axel Truck</td>
<td>7.20</td>
</tr>
<tr>
<td>6</td>
<td>Multi Axle Vehicle (MAV)</td>
<td>4 to 6 Axel Truck</td>
<td>11.70</td>
</tr>
<tr>
<td>7</td>
<td>Trailer</td>
<td>More than 7 Axel Truck</td>
<td>15.60</td>
</tr>
</tbody>
</table>
Performance Box Analysis

Field Data Collection

Extracted P-Box Data for Speed-Distance
## Descriptive Statistics for Zone of Influence (ZOI)

<table>
<thead>
<tr>
<th>Vehicle class</th>
<th>SC</th>
<th>BC</th>
<th>LCV</th>
<th>Bus</th>
<th>HCV</th>
<th>MAV</th>
<th>Trailer</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of observation</td>
<td>35</td>
<td>31</td>
<td>35</td>
<td>30</td>
<td>32</td>
<td>32</td>
<td>30</td>
</tr>
<tr>
<td>Minimum</td>
<td>60.00</td>
<td>50.00</td>
<td>100.00</td>
<td>40.00</td>
<td>100.00</td>
<td>40.00</td>
<td>143.80</td>
</tr>
<tr>
<td>Maximum</td>
<td>160.00</td>
<td>240.00</td>
<td>206.50</td>
<td>220.00</td>
<td>208.00</td>
<td>180.00</td>
<td>200.00</td>
</tr>
<tr>
<td>Average</td>
<td>90.00</td>
<td>130.00</td>
<td>167.00</td>
<td>175.00</td>
<td>161.80</td>
<td>143.20</td>
<td>175.40</td>
</tr>
<tr>
<td>Standard Deviation</td>
<td>28.90</td>
<td>26.70</td>
<td>31.68</td>
<td>57.66</td>
<td>31.58</td>
<td>37.06</td>
<td>19.75</td>
</tr>
<tr>
<td>Minimum</td>
<td>60.00</td>
<td>60.00</td>
<td>40.00</td>
<td>120.00</td>
<td>120.00</td>
<td>60.00</td>
<td>100.00</td>
</tr>
<tr>
<td>Maximum</td>
<td>140</td>
<td>180</td>
<td>240</td>
<td>230</td>
<td>240</td>
<td>240</td>
<td>240</td>
</tr>
<tr>
<td>Average</td>
<td>85</td>
<td>126</td>
<td>185</td>
<td>206</td>
<td>212</td>
<td>192</td>
<td>195</td>
</tr>
<tr>
<td>Standard Deviation</td>
<td>33.60</td>
<td>55.00</td>
<td>52.00</td>
<td>35.00</td>
<td>32.60</td>
<td>51.50</td>
<td>47.70</td>
</tr>
</tbody>
</table>

Distance before toll plaza: Minimum 60.00, Maximum 240.00, Average 130.00, Standard Deviation 26.70.
Distance after toll plaza: Minimum 60.00, Maximum 240.00, Average 126.00, Standard Deviation 55.00.
Emission Estimation

IVE Model

Inter Relation

IVE Architecture

Inter Relation

IVE Model

Speed-Acceleration-Frequency Density (SAFD) Plots
**Vehicle Specific Power (VSP)**

\[
V_{SP} = \frac{d}{dt} (KE + PE) + F_{rolling} \cdot v + F_{aerodynamic} \cdot v
\]

\[
V_{SP} = \frac{v \cdot [\alpha + (1 + \varepsilon) + (g \cdot \text{grade}) + (g \cdot f)] + 0.5 \cdot \rho \cdot C_D \cdot A \cdot v^3}{m}
\]

- **Jimenez-Palacios (1999)**
- **Song et al. (2012)**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>SC</th>
<th>BC</th>
<th>LCV</th>
<th>Bus</th>
<th>HCV</th>
<th>MAV</th>
<th>Trailer</th>
</tr>
</thead>
<tbody>
<tr>
<td>(\varepsilon)</td>
<td>0.10</td>
<td>0.10</td>
<td>0.10</td>
<td>0.10</td>
<td>0.10</td>
<td>0.10</td>
<td>0.10</td>
</tr>
<tr>
<td>(g \text{ (m/s}^2))</td>
<td>9.81</td>
<td>9.81</td>
<td>9.81</td>
<td>9.81</td>
<td>9.81</td>
<td>9.81</td>
<td>9.81</td>
</tr>
<tr>
<td>(f)</td>
<td>0.02</td>
<td>0.02</td>
<td>0.01</td>
<td>0.01</td>
<td>0.01</td>
<td>0.01</td>
<td>0.01</td>
</tr>
<tr>
<td>(C_D)</td>
<td>0.26</td>
<td>0.40</td>
<td>0.60</td>
<td>0.70</td>
<td>0.80</td>
<td>0.80</td>
<td>0.96</td>
</tr>
<tr>
<td>(\rho \text{ (kg/m}^3))</td>
<td>1.21</td>
<td>1.21</td>
<td>1.21</td>
<td>1.21</td>
<td>1.21</td>
<td>1.21</td>
<td>1.21</td>
</tr>
<tr>
<td>(A)</td>
<td>2.38</td>
<td>3.38</td>
<td>3.91</td>
<td>10.45</td>
<td>10.49</td>
<td>10.49</td>
<td>11.50</td>
</tr>
<tr>
<td>(m\text{(kg)})</td>
<td>1570</td>
<td>1850</td>
<td>12000</td>
<td>16200</td>
<td>25000</td>
<td>31000</td>
<td>36600</td>
</tr>
</tbody>
</table>
Overall Emission Estimation

**CO**
- SC: 3%
- BC: 2%
- LCV: 29%
- Bus: 19%
- HCV: 4%
- MAV: 41%
- Trailer: 4%

**VOC**
- SC: 3%
- BC: 6%
- LCV: 24%
- Bus: 24%
- HCV: 3%
- MAV: 38%
- Trailer: 2%

**NOx**
- SC: 6%
- BC: 7%
- LCV: 56%
- Bus: 7%
- HCV: 13%
- MAV: 9%
- Trailer: 6%

**PM**
- SC: 9%
- BC: 3%
- LCV: 4%
- Bus: 2%
- HCV: 1%
- MAV: 9%
- Trailer: 72%
Emission by Formulae

\[ E_i = \sum E_{ik} \]

\[ E_{ik} = \frac{\sum EF_{ij} \cdot V_i \cdot L}{10^6} \]

(He and Zhong, 2014)

<table>
<thead>
<tr>
<th>Vehicle Category</th>
<th>( V_i ) (km)</th>
<th>( L ) (km)</th>
<th>( EF_{ij} )</th>
<th>( E_{ij} ) kg/day</th>
</tr>
</thead>
<tbody>
<tr>
<td>SC/BC</td>
<td>1000</td>
<td>0.5</td>
<td>0.055 4.564 1.183</td>
<td>0.028 2.282 0.592</td>
</tr>
<tr>
<td>LCV</td>
<td>120</td>
<td>0.5</td>
<td>0.168 0.870 0.357</td>
<td>0.010 0.052 0.021</td>
</tr>
<tr>
<td>Bus</td>
<td>44</td>
<td>0.5</td>
<td>0.694 5.139 1.965</td>
<td>0.015 0.113 0.043</td>
</tr>
<tr>
<td>HCV/MAV/Trailer</td>
<td>310</td>
<td>0.5</td>
<td>1.268 12.028 1.589</td>
<td>0.197 1.864 0.246</td>
</tr>
</tbody>
</table>

Calculated 0.249 4.312 0.903
IVE 1.826 11.964 2.163
Ratio 7.318 2.775 2.396
Conclusions

1. Zone of Influence (ZOI) was found to be total 500m (250m upstream and downstream)
2. Small car and Big cars are the highest emitter for CO
3. The percentage of NOx, VOC and PM were found to be highest from LCV and Bus
4. Empirical methods underestimate the emissions
5. Speed fluctuations should be decreased for better air quality
The major contributor of NOx, VOC and PM was Bus and LCV, thus making strict measures of dedicated lanes for LCV and Bus will decrease idling cycle and thus helps to decrease the emission level.

Use of high speed transaction methods such as FasTag will help to decrease emissions.
• Annual Report, 2018. Ministry of Road Transport and Highways (MoRTH).
• IANS, 2014. Electronic toll collection to enable fuel savings worth Rs 86,000 crore: Gadkari. The Hindu.
3 December 2019
References

Roads are made for journeys not for Destinations.

Confucius