Assessing the Impact of Underground Utility Works on Road Traffic and Users: A Study from an Indian City

Ashish Verma, P. Anbazhagan, Sai Kiran Mayakuntla, and Furqan A. Bhat

Abstract Expansion of major cities in India, with its fast-growing economy, has led to a drastic increase in the requirement for basic utility amenities viz. electricity, communication, water etc. There has been a substantial emphasis on developing an underground utility network for providing the essential utilities to people. This leads to excessive construction works both for the installation of new underground tubes as well as for the repair and restoration of the existing ones. Since most of these facilities are placed beneath the roadway surface, the excavation and construction at these sites lead to a reduction in the roadway width, causing congestion. This study analyses the impact of carrying out the underground utility works on road traffic and users at four urban locations in the city of Bengaluru, India. For each site, PTV VISSIM software is used to simulate vehicle trajectories for alternative scenarios with varying obstruction widths using the actual observed traffic volumes and compositions. Vehicle trajectories are fed as inputs to the international vehicle emissions (IVE) model to analyze the impact on transportation systems. The effect is studied in terms of average speed, exhaust emissions and fuel consumption for different classes of vehicles. There is a consistent drop in vehicular speeds for all classes of vehicles with increased obstruction width at all the locations, although the amount of change depends on the characteristics of traffic at that site. While the changes in the vehicle emissions and fuel consumptions are not as consistent in their direction as the vehicle speeds, it is not surprising given the complexity of the vehicle interaction dynamics on Indian roads and the current vehicle technologies.

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In general, there seems to be an increase in the emissions and fuel consumptions with an increased obstruction width.

Keywords Utility services · Average speeds · Exhaust emissions · Fuel consumption · International vehicle emission model

1 Background

Expansion of major cities in India, with its fast-growing economy, has led to a drastic increase in the requirement for basic utility amenities viz. electricity, communication, water etc. (Jaw and Hashim 2013). There has been a paradigm shift in the provision of these facilities with the urban underground of many of the cities being characterized by a dense network of pipelines (Jaw and Hashim 2013). This involves a lot of construction activity which focuses not only on the installation of new facilities but also on the repair and maintenance of the existing underground utility network. Universally, countries are facing a significant challenge of improving underground utility network. There has been a substantial emphasis on developing an underground utility network for providing the essential utilities to people. 70% of the world's population is predicted to be living in urban areas by 2050 (Sterling et al. 2012). In such a scenario, it becomes imperative to develop systems which are robust and sustainable and could provide necessary utility facilities which form a critical facet of an urban living ecosystem.

There is a wide variety of services that are provided through underground utility networks. Many organizations are involved in providing these facilities, and due to lack of coordination and integration between these parties, a number of ducts and tubes are buried under the ground for providing different services without proper planning. This problem termed as "the spaghetti subsurface problem" creates a lot of unnecessary chaos during installation and restoration of utility services primarily due to the scarcity of underground utility maps that could help to determine the exact location and position of utility network (Curiel-Esparza et al. 2004; Curiel-Esparza and Canto-Perello 2013). This dearth of information about the subsurface network also leads to the excavation of broader and longer sections of the roads creating unnecessary bottlenecks and causing the road width to shrink. This eventually leads to a congested highway that has been a significant problem of transportation systems for a very long time (Thomson 1978).

Highway capacity, measured in passenger car units (PCU), has been observed to improve with increasing roadway width for four-wheelers (Arasan and Arkatkar 2010) as well as for 2-wheelers (Cao and Sano 2012). This trend is more prominent in heterogeneous traffic conditions with narrower lanes (Chandra and Kumar 2003; Khanorkar et al. 2014) where traffic volume can be further improved by providing good quality shoulders along the highway section (Gaur and Sachdeva 2020; Khanorkar et al. 2014). Similar effects of the decrease in highway volume are seen due to temporary obstruction caused by illegal roadside parking (Yousif and

Purnawan 1999) or by road accidents (Zheng et al. 2020). Reduction in highway capacity when the demand for travel remains the same leads to traffic congestion. Different transportation system variables (viz reduction in road width due to obstructions, congestion, vehicular speed, fuel consumption and exhaust emission) that are affected by construction works are all interrelated. For example, a reduction in lane width reduces road width, which in turn causes congestion and reduces vehicular speed. Reduced vehicle speed further affects fuel consumption and exhaust emission. There seems to be a lack of consensus in the literature regarding the impact of lane width on travel speed. While the travel speed is found to increase with increasing lane width in some of the studies (Beevers and Carslaw 2005; Gattis and Watts 1999; Godley et al. 2004; Heimbach et al. 1983), there are pieces of evidence to suggest lane width has little to no impact on travel speed (Gattis and Watts 1999). However, in cases of a sudden reduction in lane width leading to the creation of a bottleneck, the speeds are found to decrease (Yousif and Purnawan 1999; Zheng et al. 2020). Traffic congestion not only affects the vehicular speeds but also has an impact on fuel consumption and exhaust emissions. Traffic congestion and subsequent reduction in travel speed lead to increase in fuel consumption (De Vlieger et al. 2000; Errampalli et al. 2015; Greenwood et al. 2007; Samaras et al. 2019). However, reduced travel speed has different impacts on different types of pollutants (Abdull et al. 2020; Elmi and Al Rifai 2012; Nasir et al. 2014; Zhang et al. 2011).

As the demand for underground utility network continues to grow, it is essential not to just focus on lowest cost of installation but to also focus on other allied systems that it might have an impact upon. Utility installation and restoration work in any urban area have a direct relation with transport movement and congestion since in most of the cases the utility network is laid beneath the carriageway. Add to this the fact that in most of the Indian cities, the roads are not very wide and utility maps are not available due to which additional space is required to carry out these works. Considering the underground utility network is being provided in most of the metropolitan cities in India, not much research has been done to understand the impacts that these have on the overall transportation system. This study tries to fill this gap in the literature by attempting to answer the following research questions in the context of obstructions along the roadway section due to utility works:

1. How are the average vehicular speeds affected by varying obstruction widths?
2. How does the exhaust emission vary for different classes of vehicles for different road widths?
3. What is the impact of road obstruction on fuel consumption for different vehicle classes?

This paper has five sections in addition to this introductory section. Section two gives a brief overview of the methodology used for this study. Site description and data collection methods are discussed in section three. Section four details the emission model used for this study and various inputs and factors used for the model. Results are discussed in section five, and section six concludes the paper.

2 Methodology

The flowchart in Fig. 1 gives an overview of the overall methodology used for this study. Firstly, specific sites in urban areas of Bengaluru where utility repair works were being carried out during the timeframe of this study were selected, and video data were collected from these sites. The data extracted from these traffic videos were used to simulate vehicle trajectories and obtain vehicular behavior for unobstructed and obstructed roadway scenarios. IVE model was then used to estimate exhaust emissions. All these steps are explained in detail in the following sections.

3 Site Description and Data Collection

Four different locations inside the city bounds of Bengaluru, where utility restoration works were ongoing during the months of December 2019 and January 2020, were selected for the purpose of this study. The relevant details about each location and the data collection process are explained in the following subsections.

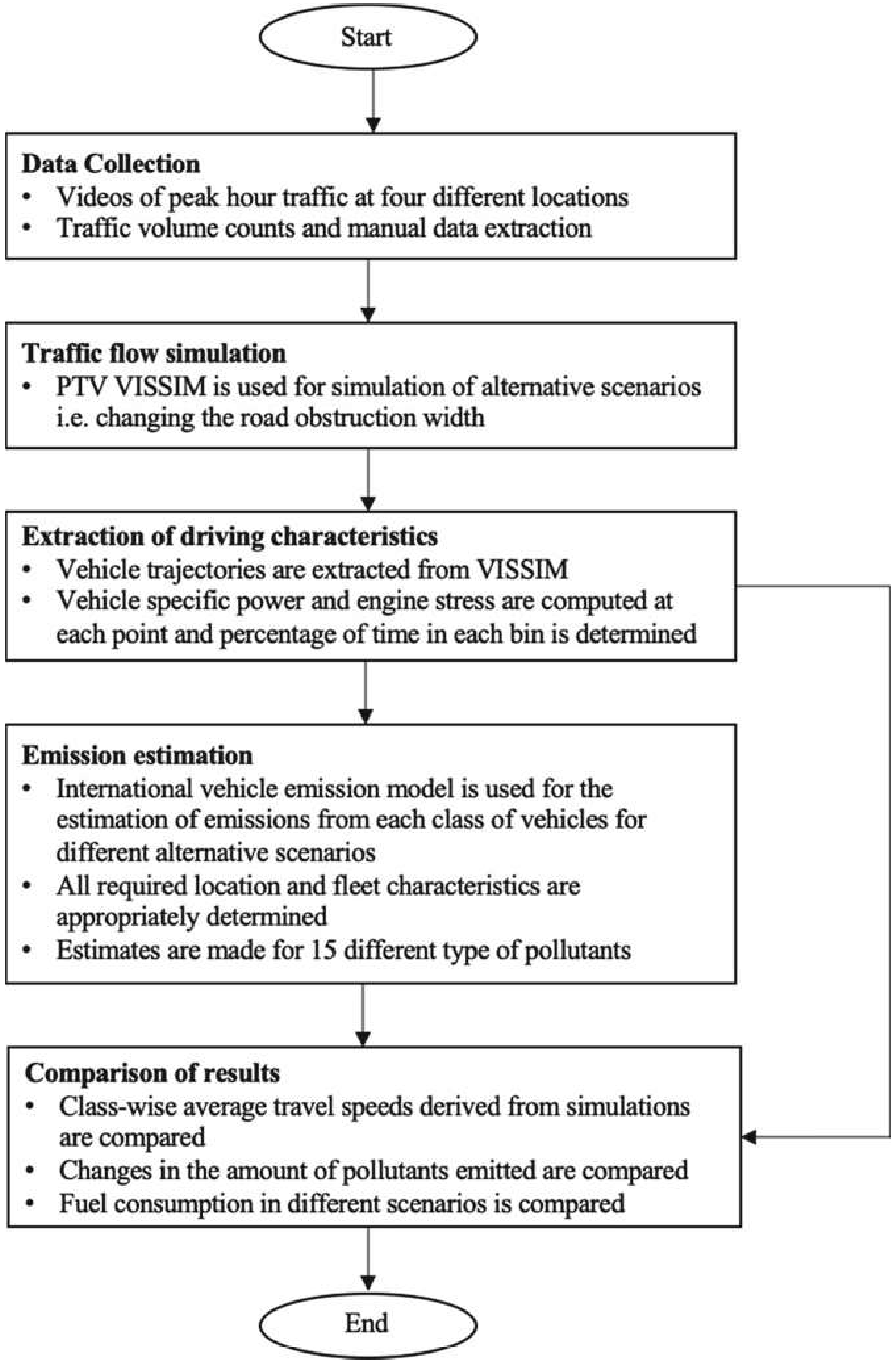
3.1 Site Description

Site 1 – MS Ramaiah Road (MSSR)

Figure 2 shows the layout along with the direction of the traffic of the first location chosen for the study, which is located on the MS Ramaiah road. The portion of the road marked dotted rectangles represent vehicles parked along the road reducing the effective road width. In addition, the rectangle with wavy lines in the figure represents the roadway obstructed by the restoration work. It occupies a length of 10 m along the highway and 5 m across it. It was also observed that about 3 m on the left edge of this 10 m wide road is occupied by parked vehicles, indicating obstruction on that part of the road even before the beginning of the utility work.

Site 2 – Thanisandra Main Road (TSMR)

Figure 3 shows the schematic diagram of the second location, which is on Thanisandra main road in RK Hegde Nagar. As indicated in the diagram, the obstruction covers an entire lane (7 m) of a two-lane road for a length of 30 m. The road is undivided on the R-side of the diagram until the end of the obstruction. Therefore, the vehicles travelling from R to L weave into the other lane at the beginning of the obstruction and weave back at the end of the obstacle. And similar manoeuvres are made by the vehicles travelling from L to R. A small percentage of two-wheelers and cars coming from L is observed to take a U-turn on the L-side of the obstruction, as indicated in the diagram.



Data Collection
- Videos of peak hour traffic at four different locations
- Traffic volume counts and manual data extraction

Traffic flow simulation
- PTV VISSIM is used for simulation of alternative scenarios i.e. changing the road obstruction width

Extraction of driving characteristics
- Vehicle trajectories are extracted from VISSIM
- Vehicle specific power and engine stress are computed at each point and percentage of time in each bin is determined

Emission estimation
- International vehicle emission model is used for the estimation of emissions from each class of vehicles for different alternative scenarios
- All required location and fleet characteristics are appropriately determined
- Estimates are made for 15 different type of pollutants

Comparison of results
- Class-wise average travel speeds derived from simulations are compared
- Changes in the amount of pollutants emitted are compared
- Fuel consumption in different scenarios is compared

Fig. 1 Methodology

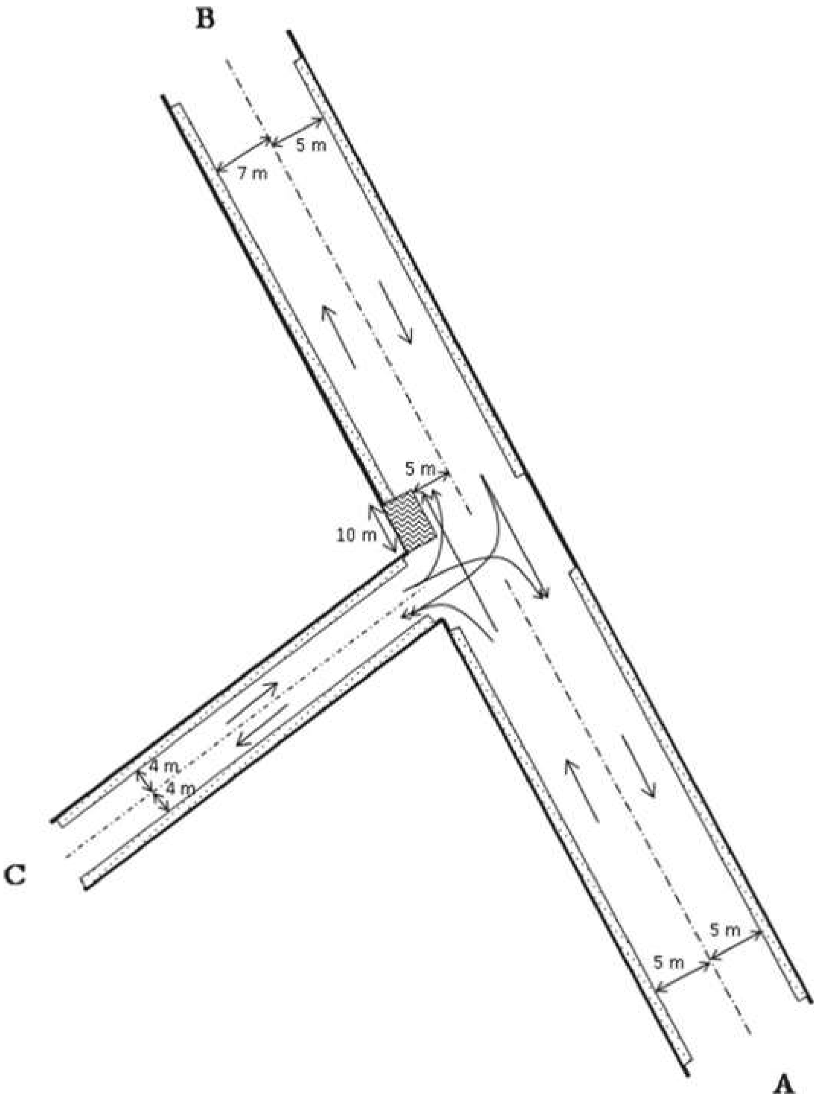


Fig. 2 Schematic diagram of MS Ramaiah Road

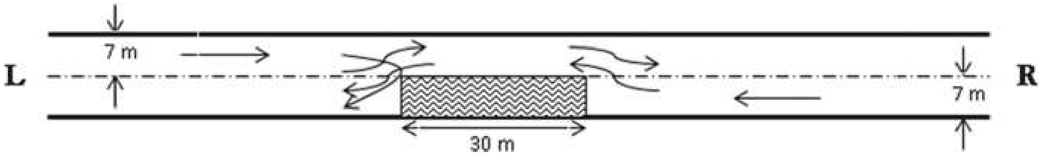


Fig. 3 Schematic diagram of Thanisandra Road

Site 3 – Bannerghatta Main Road

Figure 4 shows the geometric layout of the third location with the obstructed part of the road section highlighted. The repair work at the third location spans approximately 250 m on Bannerghatta main road, which is much longer than the other two. Also, unlike the other two, there are no conflict points significantly affecting

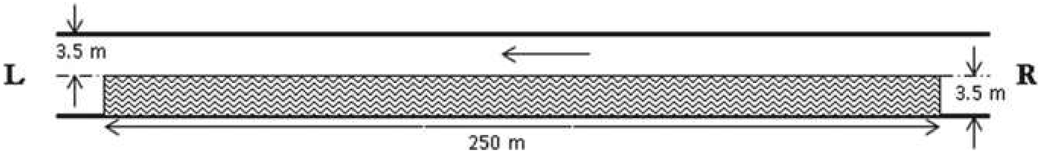


Fig. 4 Schematic diagram of Bannerghatta Road

the traffic resulting in relatively free-flowing traffic. About half of the road width is rendered obstructed by the work throughout the observation length.

Site 4 – 50 Feet Main Road (FFMR).

Figure 5 shows the schematic diagram of the fourth location, which is a work of a length of more than 500 m on 50 feet main road near Avalahalli, Banashankari. Since the traffic entering from the direction P is observed to be relatively small, it has been ignored. As shown in the schematic, while the obstruction width of 0.95 m is small, it extends for a longer length than those in the previous locations.

3.2 *Data Collection*

Data at all the four sites were collected by traffic video for a period of 45 min during the evening peak-hour on weekdays. The class-wise traffic movement counts were extracted through manual counting by watching the videos. The details of the class-wise vehicle count for all the study locations are given in Table 1.

3.3 *VISSIM Simulations*

PTV VISSIM was used to recreate the kind of traffic stream that was observed from the field survey. Using the data collected manually from the streets i.e. the road geometry and class-wise vehicular counts, we created scenarios in VISSIM setting traffic routes and counts. The simulations were run, and the trajectory data was collected. This was followed by introducing the roadway obstructions and re-running the simulations to obtain the vehicular trajectories. Thereafter, vehicle trajectories are extracted from the VISSIM simulations. These trajectories are used to extract the parameters to give an idea about the driving behaviour, the details of which are fed into the emissions modelling software (International Vehicle Emissions model).

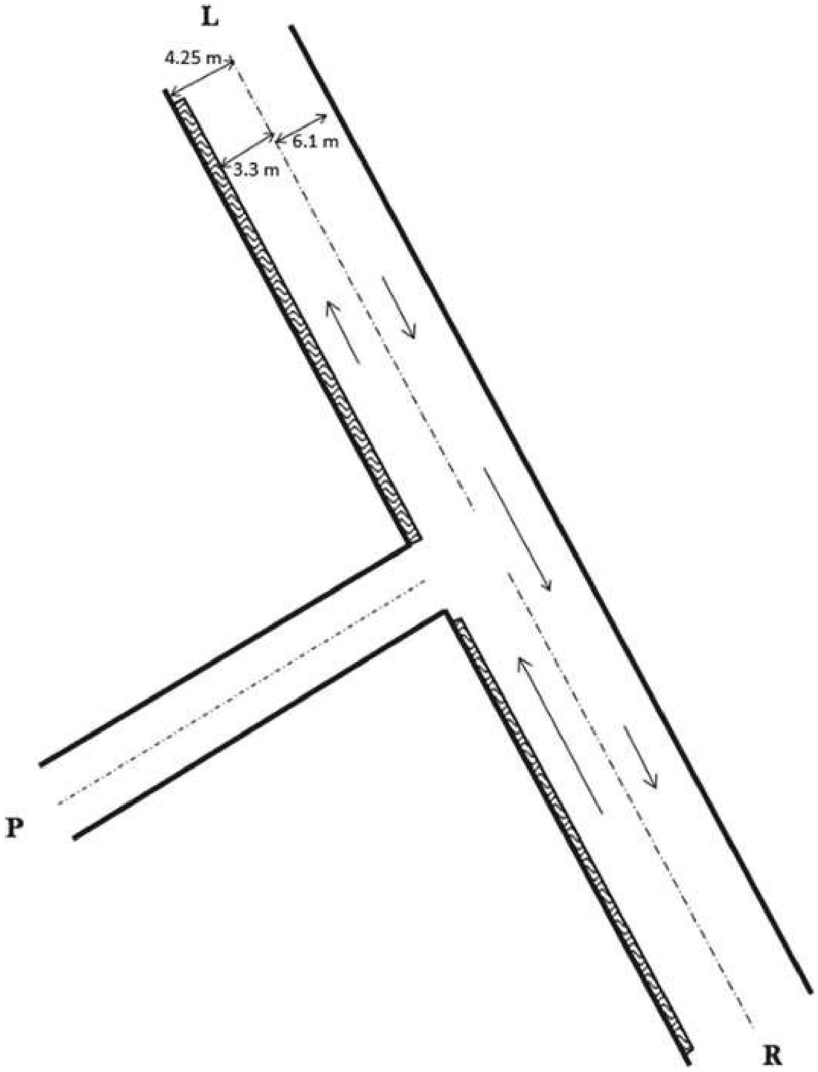


Fig. 5 Schematic diagram of 50 feet road

4 Description of the Model Used

Realizing the importance of estimating the emissions from the mobile sources, the United States developed an advanced model that could predict the emissions based on the local conditions viz. fuel type, vehicle classes, maintenance schedules and emission standards. Many of the developing nations modified these models as per their needs while many others adopted the same models and employed it to their fleets. Clearly, this leads to highly unreliable results. As a consequence, an international standard model was developed for estimating emissions from mobile sources under wide-ranging environmental, traffic and regulatory conditions. The international vehicle emissions (IVE) model was funded by the US environmental protection agency and developed by the University of California and the International Sustainable Systems Research Centre (Davis et al. 2005), with the aim of designing

Table 1 Vehicular counts at the study sites

Site 1- MS Ramaiah Road						
From	To	Car	2-wheeler	3-rickshaw	Bus/HCV	LCV
A	C	4	49	17	0	0
A	B	227	725	77	71	27
C	A	10	143	9	0	3
C	B	66	610	113	3	29
B	A	221	535	141	12	15
B	C	146	571	130	19	38
Site 2-Thanisandra Main Road						
From	To	Car	Two-wheeler	3-rickshaw	Bus/HCV	LCV
L	R	193	581	162	60	37
R	L	228	653	144	48	39
L	L	10	31	0	0	0
Site 3 – Bannerghatta Main Road						
From	To	Car	Two-wheeler	3-rickshaw	Bus/HCV	LCV
R	L	743	1941	374	57	77
Site 4 – 50 Feet Road						
From	To	Car	2-wheeler	3-rickshaw	Bus/HCV	LCV
R	L	422	1381	297	65	59

an emission estimation tool specifically to help transportation planners from developing economies in devising effective emission control strategies and measure their performance over time. Since its development in 2008, the model has been used in emission studies of several cities from developing economies. This model can be employed to evaluate emissions from practically any kind of fleet distribution while being sensitive to future changes in fuel and vehicle technology. To create accurate mobile source emission inventories for a given location, the following inputs are needed by the model:

Vehicle technology and emission rates;
Driving behaviour and vehicle activity; and.
Vehicle fleet distributions.

4.1 Vehicle Technology and Emissions Rates

The emission rates are estimated separately for each vehicle type under running (in grams/km) and start conditions (in grams). First, a series of multiplicative factors are applied to the base emission rates to determine the adjusted emission rates. These are then weighted by the corresponding fractions of vehicle technology and driving types.

The total emissions are then calculated by multiplying the total distance travelled and the total number of starts with the running and start emission rates, respectively. The following equations are used in the calculation just described. Note that the adjusted emission rates are calculated separately for running and start conditions using different base emission rates.

$$\begin{aligned} Q_{[t]} = B_{[t]} * K_{(Base)[t]} * K_{(Tmp)[t]} * K_{(Hmd)[t]} \\ * K_{(IM)[t]} * K_{(Fuel)[t]} * K_{(Alt)[t]} * K_{(Cntry)[t]} \end{aligned} \tag{1}$$

$$Q_{[t]} = Q_{running} = \sum_{t} \left\{ f_{[t]} * \sum_{d} \left[Q_{[t]} * \overline{U}_{FTP} * f_{[dt]} * K_{[dt]} \right] \right\} / \overline{U}_{C} \tag{2}$$

$$Q_{start} = \sum_{t} \left\{ f_{[t]} * Q_{[t]} * \sum_{d} \left[f_{[dt]} * K_{[dt]} \right] \right\} \tag{3}$$

where,

$B_{[t]}$	Base emission rate for each technology in grams for start and grams/km for running
$Q_{[t]}$	Adjusted emission rate for each technology in grams for start and grams/km for running
Q	Average emission rate for the entire fleet in grams for start and grams/km for running
$f_{[t]}$	Fraction of travel by a specific technology
$f_{[dt]}$	Fraction of each type of driving or soak by a specific technology
$\overline{U}_{FTP}$	Average velocity of the LA4 driving cycle in km/hr
D	Total distance travelled in km
$\overline{U}_{C}$	Average velocity from the input driving cycle in km/hr
$K_{(Base)[t]}$	Adjustment to the base emission rate
$K_{(Tmp)[t]}$	Temperature correction factor
$K_{(Hmd)[t]}$	Humidity correction factor
$K_{(IM)[t]}$	Inspection/Maintenance correction factor
$K_{(Fuel)[t]}$	Fuel quality correction factor
$K_{(Alt)[t]}$	Altitude correction factor
$K_{(Cntry)[t]}$	Country correction factor
$K_{[dt]}$	Driving or soak style correction factor (includes the effects from air conditioning usage and road grade)

4.2 Driving Behaviour and Vehicle Activity

Driving behaviour

The IVE model considers two parameters to be the most correlated to the emissions: vehicle specific power (VSP) and engine stress. VSP can be computed using instantaneous acceleration and velocity, and it depends on the altitude and grade of the road section. Subsequently, the engine stress at any time (second) is computed using the VSP values from the previous 25 s and the engine RPM. Each travel second is assigned to one of 60 bins based on its corresponding VSP and engine stress values. The overall percentage of time spent in each bin is computed and is used in the calculation of emissions.

Start patterns

The time for which the engine is shut off when it is started, known as engine soak, can have a significant impact on the emissions. Longer soak periods typically result in higher emissions. However, since specific road sections are considered in the present study, it is unlikely that any vehicle under consideration would stop on any of them for more than 15 min and therefore should fall in the first soak period.

Environmental variables:

Ambient temperature, humidity, altitude and road grade are also observed to have a significant impact on the vehicular emissions. The road grade is clearly constant for a given road section, but the rest might vary with time. For the purposes of this study, the average temperature, humidity and altitude of Bengaluru city are used, which are 27 °C, 60% and 920 m, respectively.

Fuel characteristics:

The impact of fuel characteristics of diesel and gasoline fuels can be significant on the vehicle emissions. The overall fuel quality and sulphur content are considered for diesel, and the levels of lead, benzene and oxygenate are considered in addition for gasoline. Except the overall quality, all the characteristics are determined from Bharat Stage (BS) IV fuel norms, which are currently enforced in India. While there may be some variation in the overall qualities of gasoline and diesel, they have been approximated as moderate/pre-mixed and diesel, respectively.

4.3 Vehicle Fleet Distribution

The IVE model defines 1372 technologies based on six parameters, namely vehicle class, vehicle size, fuel type, vehicle usage, fuel delivery system, evaporative control system and exhaust control system. A distribution of these technologies must be provided to the model for each location in the form of a fleet file. The earlier studies using this model have typically been limited to a single vehicle class, often with specific models. Table 2 presents the fleet distribution used in the study for model analysis. Two likely factors that could explain the observed usage percentages are the vehicle category and the vehicle price. Commercial vehicles like Buses and 3-wheelers have much larger high usage percentages than typically personal vehicles like 2-wheelers. In the present context, there may be a slight increase in the commercial usage of cars and 2-wheelers due to thriving e-commerce and food deliveries, but it is reasonable to expect the usage percentages to be qualitatively similar. The usage percentages are chosen based on these insights and the rest of the parameters are selected based on the specifications of the most popular models in each vehicle type.

5 Results

The repairing of roads or the utility services affects the road width, which in turn affects the average vehicular speeds, exhaust emissions and fuel consumption. These effects are discussed in the following subsections.

5.1 Average Vehicular Speed

At each location, the average vehicle speeds have consistently increased with a reduction in the obstruction width. This confirms our intuition that even a slight increase in the available road width can have a significant impact on vehicle speeds. The actual amounts of change vary across the locations, but this should not be surprising given the complex interaction dynamics between the vehicles. It may be observed that in location 1, which is the most congested of the three, the amount of change increases with the vehicle size. This indicates that the manoeuvrability of the vehicles plays a larger role under congested conditions than under free-flow conditions. Table 3 compares the class-wise average vehicle speeds for all four study sites.

5.2 Exhaust Emissions

In this study, the IVE model is used to estimate the pollutant emissions using the vehicle trajectories extracted from VISSIM simulations. Tables 4 and 5 present the percentage changes and changes in actual amounts of pollutant emissions for reduced roadway width. The results calculated at the four locations are less straightforward to interpret than the average vehicle speeds. While the pollution levels significantly increase in the first location (MSRR) which is highly congested with many conflicted points, the same is only broadly true for the rest of the locations. Moreover, the changes in the level of CO2 is unambiguously positive in each case, and it takes

Table 2 Vehicle distribution based on class and distance

Vehicle type	Class	Weight	Fuel type	Fuel delivery system	Exhaust control system	Evaporative control system	Vehicle usage	
							Distance	Proportion
Car	Auto/Sml Truck	Light	Petrol	Multi-Pt FI	3-Way/EGR	PCV	< 79 K km	0.52
							80-161 K km	0.0975
							> 161 K km	0.0325
	Auto/Sml Truck	Light	Diesel	FI	Euro IV	PCV	< 79 K km	0.28
							80-161 K km	0.0525
							> 161 K km	0.0175
2-wheeler	Sml Engine	Light	Petrol	4-cycle, Carb	Catalyst	None	< 25 K km	0.65
							26-50 K km	0.25
							> 50 K km	0.10
3-rickshaw	Sml Engine	Medium	CNG/LPG	4-cycle, Carb	Improved	None	< 25 K km	0.19
							26-50 K km	0.03
							> 50 K km	0.78
LCV	Auto/Sml Truck	Heavy	Diesel	FI	Euro IV	None	< 79 K km	0.00
							80-161 K km	0.10
							> 161 K km	0.90
Bus/HCV	Truck/Bus	Heavy	Diesel	FI	Euro IV	None	< 79 K km	0.00
							80-161 K km	0.10
							> 161 K km	0.90

Table 3 Percentage decrease in class-wise velocities at peak-hour volume traffic with the increased obstruction widths

Location	Car	Two-wheeler	Auto rickshaw	Bus/HCV	LCV
MSRR	16.32	1	1.4	27.85	6.5
TSMR	0.631	0.9	0.52	0.58	0.9
BGMR	14.4	13	11.6	9.5	13
FFMR	7.2	6.9	5.3	4.3	4.8 s

Table 4 Percentage increase in the pollutant emissions at peak-hour volume traffic with the increased obstruction widths

Location	CO2	HC	PM	NOx	CO
MSRR	6.5	36.03	32	7.73	35
TSMR	10	−6.02	−2.01	19.5	5.3
BGMR	2.9	−11.9	−14.3	−7.4	−34.6
FFMR	1.7	−4.4	−8.2	−4.2	−18.2

Note Negative sign indicates a decrease in the pollutant emission

Table 5 Amounts of increase in the pollutant emissions (in kilograms) in one hour at peak-hour volumes with the increased obstruction widths

Location	CO2	HC	PM	NOx	CO
MSRR	32	1.6	4.04e−04	0.194	12.6
TSMR	14.2	−0.07	−9.93e−04	0.156	0.47
BGMR	1.48	−0.074	−2.62e−03	−2.43e−02	−2.3
FFMR	0.66	−0.021	−1.05e−03	−0.011	−0.822

larger values compared to the rest of the pollutants. Nevertheless, it is not a surprise to find this complexity in the pollutant values and may be attributed to the complexity of the vehicle interactions in a mixed traffic environment and on the wide-ranging factors that they depend on.

5.3 Fuel Consumption

Table 6 shows the increase in fuel consumption due to an increase in the obstruction width. The total fuel consumption estimated for petrol, diesel and LPG using the emission estimates from the previous section also seem to follow the observation made earlier. There is a noticeable increase in fuel consumption under the congested condition. But there is no discernible pattern when the road is heavily congested even before the obstruction is introduced.

Table 6 Increase in fuel consumption (in litres) in one hour at peak-hour volumes with the increased obstruction width

Location	Petrol	Diesel	LPG
MSRR	16.8	7.47	−2.12
TSMR	3.97	1.96	0.05
BGMR	−1.34	0.23	0.14
FFMR	−1.03	0.18	0.19

6 Discussions and Conclusions

The overall cost imposed on the road users by higher obstruction widths can be assessed in various dimensions including the increased travel time, fuel consumption and the impact of the increased emissions on the physical and psychological health of the road users. Most of these works are carried out in urban areas that typically form a part of people's daily commute; it can be expected that the same individuals would be exposed to the emissions for prolonged durations. This is a worrisome situation given the fact that several Indian cities are frequently listed among the most congested cities of the world. The impact of air pollution on the urban population has been well-studied and has been recognized as one of the major causes of death across the world. (Dominici et al. 2007; Zanobetti et al. 2009)revealed that with every 10 μg/m3 daily increase of PM2.5 concentration in the US, the rate of respiratory diseases increased by 2.7%, and the rate of hospitalization increased by 8%. Prolonged exposure to carbon monoxide has been observed to cause heart damages that may outlast its presence in the bloodstream (Suner and Jay 2008). Exposure to NOx is known to cause eye irritation, reduced lung function and headaches, which are common symptoms observed by many road users in congested Indian cities. In addition to all these, these emissions cause long term harm by damaging natural environments and contributing to global climate change.

This study quantifies the impact of non-restoration/poor quality restoration of the underground utilities on Bangalore traffic in terms of the change in average vehicle speeds, pollutant emissions and fuel consumption. Four actual locations where the works were carried out are considered for the study. For each location, simulations are carried in PTV VISSIM software for alternative scenarios with varying obstruction width using the actual observed traffic volumes and compositions. Vehicle trajectories are extracted from the simulations and are given as an input to the international vehicular emissions (IVE) model, and the emissions of different types of pollutants are determined. These estimates are then used to determine the total fuel consumption based on the carbon balance method. The following observations can be made from a comparison of the results:

There is a consistent drop in vehicular speeds for all classes of vehicles with increased obstruction width at all the locations, although the amount of change depends on the characteristics of traffic at that site.

While the changes in the vehicle emissions and fuel consumptions are not as consistent in their direction as the vehicle speeds, it is not surprising given the complexity of the vehicle interaction dynamics on Indian roads and the current vehicle technologies. Nonetheless, there does, in general, seem to be an increase in the emissions and fuel consumptions with an increased obstruction width.

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