Behaviour of Drivers towards Vehicle Idling at Signalized Intersections

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Abstract

The rapid urban population growth and limited public transit services have led to sever congestion in large urban agglomerations. Vehicle idling is very common at controlled traffic intersections, thus resulting in unnecessary fuel consumption and increase in exhaust emissions. On encountering a traffic signal, drivers are in dilemma for turning-off the engine or keeping it on while waiting for the signal to turn green. The present study analyses the heterogeneity in the idling behaviour at signalized intersections for Indian traffic conditions, identify the factors which influence the decision making for turning-off the engine or keeping it on and potential to contribute to stop idling. The results indicates that position of the vehicle in the queue and level of congestion are primary reasons which are impacting the decision of turning-off the engine. Persons who are turning-off the engines (80%) report fuel saving, reducing air and noise pollution as important reasons for their decision. Persons who are not turning-off the engine, report that usually they are in hurry or require the air conditioning in the car. Under the current behaviour and circumstances, the average fuel wastage per person per trip is shown for different values of fuel consumption rate during idling for car and motorized-two-wheelers. A large number of respondents (74%) are willing to use an app/ system which assist in providing a dynamic, vehicle-specific threshold value for turning-off the engine.

Keywords: Vehicle Idling, Fuel Wastage, Emission, Idling Behaviour, Intersections

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1 Introduction

1.1 Background

Energy usages and fuel consumption Over the past few years, climate change has become a matter of grave concern across the world. Rapid population growth has led to a considerable rise in the number of vehicles on the road. The greenhouse gas (GHG) emissions resulting from vehicles plying on the roads have had a significant impact on climate change. The transportation sector represents 30% of world annual energy consumption (Noussan et al., 2020), and road-transport accounts for 13% of the total energy use globally (Frey, 2018). In India, the transport sector is the third most GHG emitter sector with road transport having the biggest share. Fuel consumption by road transport has increased by almost four times since 1991 (Goel et al., 2016). According to Petroleum Planning and Analysis Cell (PPAC), the road transport sector of the country consumes 70% of the diesel and 99.6% of the petroleum (PPAC, 2013). Fuel consumption of a vehicle and emission rate is affected by engine type, age of the vehicle, vehicle condition, accessories installed in the vehicle, driving speed, driving behaviour, traffic conditions, travel characteristics, road condition, weather condition, etc. (Vaezipour et al., 2015; Zhou et al., 2016).

Idling and negative impacts Idling is the continuous working of a vehicle's main propulsion engine while the vehicle is stopped. It is very common during stop&Go traffic conditions and at traffic intersections. In fact, the greenhouse gas (GHG) emissions at a traffic intersection is largely due to higher traffic activities and the idling of the vehicles in the queue. Although the idling time for an individual vehicle at an intersection is short, due to frequent encounters with traffic intersections, it becomes a large portion of journey time, thus resulting in unnecessary significant fuel wastage. Consequently, emissions of pollutants like, hydrocarbons, nitrogen oxides and particulate matter, etc. increases significantly. This not only contributes to the greenhouse gases but also exposes the persons to the local pollutants which has an adverse impact on human health.

Idling reduction approaches Various methods have been studied and adopted to reduce vehicle idling at intersections. Optimization of signal cycle timing is the most basic common approach for reducing the vehicle idling at intersections. In this approach, the average vehicle delay of each signal cycle is minimized which contributes to the reduction of the fuel. For instance, Jung et al. (2016) proposed bi-optimization of fuel and delay at an intersection. Concept of a dynamic traffic signal control system is also being adopted in many countries to reduce the delays at the signalized intersections. It adapts the traffic signals based on the traffic flow on the approaching streams and reduces waiting time and consequently vehicle idling (Asadi and Vahidi, 2009). Another practical method is the introduction of a signal countdown timer that displays the time remaining for current displayed light i.e. red, and green. If the timer shows a longer time for signal to turn green, the users are supposed to turn off the engine (Biswas et al., 2015). In addition to this, the local civic bodies, sometimes, provides general guidelines to reduce the idling which is not the same for all type of vehicles (PCRA, 2017, accessed 2019). In addition to these measures at a signalized intersection, an idling stop function[1] is provided in some of the vehicles (Huang et al., 2019). It not only saves fuel but also reduces the release of harmful pollutants. However, usage of such feature is not very common in India yet, especially when a vehicle stops shortly at a traffic signal, mainly due to lesser knowledge related to technical information on fuel consumption by the vehicle in different processes. The process of idling is complex to understand for a normal driver and therefore, drivers are in dilemma for turning off the engine or keeping it on while waiting for the signal to turn green at an intersection.

[1]Idling stop is a functionality in the newer vehicle which automatically shuts down and restarts the vehicle engine to reduce the idling duration.

1.2 Review of past studies

The consumption of fuel at signalized intersection is generally more than on the other sections of the road due to deceleration, stopping and acceleration of vehicles (Liao and Machemehl, 1998). The drivers often let the engine running while waiting for their turn to cross the intersections and as a consequence of idling, fuel is wasted (Li et al., 2009). Keeping the vehicle engine idle for a long period contributes to unnecessary air pollution, fuel consumption and noise pollution. Over the past few years, various studies have been conducted to quantify the excess fuel consumption and to develop various policies and technologies to reduce the fuel consumption and CO_2 emission during idling of vehicles Sharma et al. (2019). Consumption of fuel during idling is found to be dependent on vehicle type, idle engine speed, maintenance quality of vehicle and surrounding atmospheric conditions like temperature and humidity (Jou et al., 2011; Pekula et al., 2003).

Traffic intersections are the locations where many vehicles idle, couple of times a day, which results in increased fuel consumption and release of harmful gases into the atmosphere (Sekhar et al., 2013; Bhandari et al., 2013). Typically, for diesel vehicles if the idling period is more than 10 seconds, it consumes more fuel and produces more CO_2 than restarting the engine (Rahman et al., 2013). Fuel consumption increases with an increase in idling engine speed (RPM), which leads to increase in the overall average emissions (e.g., NO_x, VOCs, etc.) (Pekula et al., 2003). Typically, emission of NO_x increases with increasing ambient temperature, depending on the type of vehicle and the idling speed. Fuel consumption and production of CO_2 is proportional to engine load, which is directly linked to vehicle accessories power requirements. Accessory loading is determined by the actual accessories and their corresponding power requirements which is different for different loads. For instance, if the gear is shifted to driving, more fuel is consumed. Further, if air-conditioning (or heating) is switched on, an even greater amount of fuel is consumed. Consequently, this increases the consumption of fuel, leading to increased emissions. Emissions of pollutants like NO_x during idling can be reduced by using the minimum engine speed (RPM) with a marginal accessory load such as heating and air conditioning system, safety lights, aerial lifts in trucks, etc. (Brodrick et al., 2002). Across the world, many studies have examined the effectiveness of idling policies on the reduction of fuel consumption and CO_2 emissions. It has been observed that $6 - 13\%$ of fuel savings can be achieved by enforcement of idling policies (Jou et al., 2014). Typically, In USA and Canada, allowable limits for idling of trucks are five and three minutes per hour respectively (Morshed, 2010). European countries have recommended guidelines for the duration of vehicle idling, which varies from 10 seconds to 3 minutes. Presence of stricter greener policies in various states have lower threshold for idling duration e.g., Hawaii, California. Jou et al. (2014) use a stated preference survey to proposes an idling stop fine system if idling increases beyond the limit of m three minutes in Taiwan. Vehicle idling is completely banned at red-traffic lights in Switzerland and in few cities of Taiwan.

These idling policies seem to have been effective mostly in developed countries because of the strict traffic rules enforcement and increased awareness of the environmental effects caused by vehicular emissions. In developing countries like India, turning off engine at traffic intersections is not common at least in private vehicles which have major share among all the vehicles plying on roads (Sharma et al., 2019). It is quite evident that when vehicles stop for a short time especially at traffic signals, people don't turn off their engines. However, this perception of a short time varies from person to person. In India, Petroleum Conservation Research Association has recommended to turn off the engine if the vehicle is stopping for more than 15 seconds (PCRA, 2017). Matsuura et al. (2004)

state that if the percentage of the invalid idling stopping frequency increases[2], the fuel consumption also increases.

Thus in order to assess the quality of service provided at the traffic intersections and study the driver behaviour and its impact on idling emissions, A couple of works attempt to study the impact of behavioural changes on the idling reduction strategies (de Vyver et al., 2018; Sekhar et al., 2013; Meleady et al., 2017; Shancita et al., 2014). For instance, Meleady et al. (2017) examine the potential to reduce idling at rail crossings by spreading awareness among the drivers. The authors find that self-surveillance (self-regulation) approach is more effective. Similar results are supposed by de Vyver et al. (2018). The study has applied financial losses, self-interest kins related to heath and pollution due to unnecessary fuel consumption, which has proven to be very effective in encouraging drivers to switch off their engines. Many studies have suggested traffic control strategies like pre-signalling, optimization of signal timings, geometric improvements like flyover, grade-separated intersections for reducing the idling delays at intersections, thus putting a curb on vehicular emissions (Sekhar et al., 2013; Ghanbarikarekani et al., 2018). Idling reduction technologies are also being used to prevent unnecessary engine idling by providing alternative sources of power for accessory loading and increasing the vehicle fuel efficiency. Few of these technologies are automatic stop-start system, battery-based cabin heating and air conditioning system, auxiliary power system, fuel cells, etc. (Shancita et al., 2014; Huang et al., 2019; Ziring and Sriraj, 2010). However, market penetration of these technologies in the vehicles and the effectiveness of these technologies can vary with place and time.

1.3 Research gap and aim of the study

Idling of vehicles at the controlled traffic intersections (or elsewhere) is one of the major issues in most of the cities in India which results in high operating cost, wastage of precious fuel and increase in emissions (Tiwari et al., 2013; Sharma et al., 2019). The approaches discussed in Sections 1.1 and 1.2 have limited success due to ignorance of the driver/ rider, lack of determination toward saving the fuel and lack of awareness, etc. Sharma et al. (2019) indicate that 9036 litres of petrol, diesel, LPG and 5461 kg of CNG is wasted everyday due to idling of the motor vehicles at controlled intersections in Delhi.

The review of past studies in Section 1.2 confirms that (a) use of adaptive signal systems, countdown times, etc. have limited success in mitigating idling, (b) engaging the driver in taking the decisions is likely be most effective than employing external surveillance and (c) the technological advances such as the idling stop system could be helpful to reduce idling at signalized intersections. The literature lacks in studying the heterogeneous behaviour of drivers for idling stop in mixed traffic conditions. More specifically, the present study focuses on identification of the factors for drivers' ignorance, lack of determination to stop idling.

This study attempts to analyse the heterogeneity in the idling behaviour at signalized intersections for Indian traffic conditions, identify the factors which influence the decision making for turning off the engine or keeping it on and potential to contribute to reduce in idling. The scope of the present study is limited to signalized intersections for heterogeneous traffic conditions.

[2]Invalid idling stop frequency is the number of instances at which engine is turned off however, it would have been better to idle the vehicle at the stop.

2 Methodology

2.1 Threshold for idling

The idea behind this work is to develop an algorithm which assists the drivers by provision of a engine-off threshold value which depends on various factors such as, remaining red signal time, vehicular characteristics (e.g., engine type, fuel type, age of engine, etc.), position of the vehicle in the queue, etc. The whole process can be split into three steps, which are discussed next.

1. **Fuel consumption during idling:** The fuel consumed during idling (f_1) is given by Equation (1).

$$f_i = I \cdot t_{mv} \tag{1}$$

   where I is fuel consumption rate (in m^3/sec) during idling and t_{mv} is the duration (in sec) of the idling and given by Equation (2).

2. **Fuel consumption during reignition:** During re-ignition, energy from battery and the fuel is consumed to bring the engine in stable condition (see Matsuura et al., 2004, for an example). Thus, f_b represents the fuel consumption and energy usages (from battery) in terms of the fuel consumption equivalents.

3. **Vehicle position in the queue:** If a vehicle (A) is at a distance d_r from the red signal, the vehicle will be able to make a move only after all vehicles in front are moving. It will take some time to dissipate the queue; in simple terms, if queue dissipation rate is given by v_{dis} (in m/sec), and the time available for signal to turn green is t_{gr} (in sec), the time after which the vehicle A will be able to move is given by t_{mv} and represented by Equation (2).

$$t_{mv} = t_{gr} + \frac{d_r}{v_{dis}} \tag{2}$$

Let us say, the threshold value below which the engine can be turned off or above which the engine can be kept at idling is given by T (in sec). Now, equating the fuel consumption during reignition and fuel consumption during idling, results in:

$$f_b = f_i = I \cdot (T + \frac{d_r}{v_{dis}}) \tag{3}$$

$$T = \frac{f_b}{I} - \frac{d_r}{v_{dis}} \tag{4}$$

For longer queues, the second part of the Equation (4) becomes greater i.e, it is recommended to turn off the engine when the queue is really long. Therefore, the Equation (4) can be rewritten as:

$$T = max\left(0, \frac{f_b}{I} - \frac{d_r}{v_{dis}}\right) \tag{5}$$

Thus, if the timer on the countdown shows a value greater than threshold value (T), they can turn off the engine whereas can keep the ignition on if timer is showing a value equal or less than threshold value.

In Equation (4), f_b, I can be an average vehicle-specific fuel consumption during reignition and during idling respectively (Pekula et al., 2003; Jou et al., 2011). Similarly, an average value of queue dissipation can also be assumed based on an average reaction time (see, speed of backward traveling hoels Agarwal et al., 2017). However, to estimate the length of the queue ahead (i.e., d_r), combination of GPS, image processing can be used (Koukoumidis et al., 2011). Thus, if it can be integrated in the vehicle dashboard, the fuel wastage due to vehicle idling can be reduced significantly.

Example: Let us say queue dissipation rate is 15KPH, I is 0.17 cc/sec, f_b is 1.20 cc. Thus, the threshold value for $d_r = 0$ m will be = 7.05 sec i.e., if timer shows more than 7 sec, the drivers of the vehicles in the front of the queue can turn-off the engine. For the same example, if a vehicles is about 30 m behind the queue, the threshold will become = max(7.05 - 3.6, 0) = 0 sec. That means, all vehicles which are in a queue longer than 30 m, can turn-off the engine and save fuel. As discussed above, this value will differ for different vehicles.

2.2 Data collection

This study investigate the dilemma of the drivers for idling the vehicles at traffic controlled intersections and attempts to list down the factors to mitigate it. The reduction in idling will not only save money but also put a curb on the release of environmental pollutants like CO_2, NO_x, CO and other harmful substances, thereby reducing adverse effect on health. For this, an online web-based survey is conducted for the two cities of India; Varanasi and Bihar. The purposes of the survey are to identify:

- the response of people on encountering a red light at a traffic signal,
- finding the correlation between the driver behaviour and socio-demographic,
- factors affecting the decision of drivers to turn off their vehicle engines,
- signal countdown timer range at which the driver is ready to stop idling and
- decision of the driver if a vehicle-specific, threshold value is provided to stop idling (see Section 2.1 for details).

2.2.1 Pilot survey

A pilot study was conducted in order to determine the feasibility and productivity of our research project. To analyse the response of drivers on encountering a red light at a traffic signal, a one-day, pen-paper based questionnaire survey was conducted in the city of Dehradun (capital of Uttaranchal in northern India) on 23rd Feb. 2020. A total of 90 drivers were interviewed at three different locations, namely, ISBT Dehradun, Silver Plaza (Rajpur Road, Dehradun) and Pacific mall area (Rajpur Road, Dehradun). Respondents of different age groups, gender and economic background were targeted in order to get a better perspective. A total of 75 valid responses were taken into consideration after removing incomplete samples. The overall responses from the Pilot survey were positive and it was found that people are interested in reducing the fuel wastage. Therefore, the questionnaire from Pilot study was improved and a survey is conducted in two cities of India as explained in the next section.

2.2.2 Web-survey

Since the situation was not favourable for an in-situ personal-interview due to outbreak of Pandemic Covid-19, in contrast-to pilot survey, the survey is conducted online in Patna (capital of Bihar) and Varanasi (Uttar Pradesh). The link for the survey was shared with friends, their family and subsequently, they were requested to share among their acquaintances and groups. The data was collected by circulating the URLs of google form (consisting of relevant questions along with a cover letter). Branching is used in the google form to simplify the questions and reduce the response time. Regular reminders were sent to fill up the google form. The respondents participated in the survey voluntary with the assurance of confidentiality and anonymity. The questionnaire was divided into multiple sections based on the purposes, mentioned at the beginning of the Section 2.2. The results of the survey are discussed in the next section.

3 Results

3.1 Demographics and summary of vehicular data

In total 570 responses are recorded, of which 258 belongs to Patna and 184 belongs to Varanasi. Rest of the responses are discarded since they are beyond the study region. After discarding the invalid entries, a total of 442 responses are used to present the analysis. About 16% of the respondents are don't drive whereas approximately 50% of the respondents drives almost every day. Among the persons who are living in the study areas (Patna, Varanasi) and can drive MTW/ car, 46% are between $18 - 25$ years old, about 38% are between $25 - 35$, approximately 13% are older than 35 years.

Out of total respondents who can drive, 38% can drive both motorized two-wheeler (MTW) and car or SUVs. Interestingly, about 10% of the drivers (primarily MTW drivers) don't have a valid driving license which shows lack of enforcement as well as ignorance of the rules by the drivers. Further, about 26% of MTW drivers own a car license even though they cannot drive a car which highlights the lack of testing before issuing the licenses. More than 68% of respondents have three or longer years of driving experience. For 47% of persons, the typical frequency of vehicle maintenance and servicing is less than 3 months which also indicates a variation in the servicing which eventually results in different rate of fuel consumptions. Both car and MTW are used primarily for work trips and for educational trips, mostly MTW is used. This supports the finding that approximately 50% person drives almost everyday.

3.2 Behaviour at traffic signals

About 58% of the respondents encounter less than five traffic signals and approximately 34% of the face $5 - 10$ traffic signals per trip. More than 81% of persons always stop if the traffic signal is red and about 6% of persons stop at a red signal only if there is a policeman around.

Figure 1 shows the action of respondents who stop at a signalized intersections and using either car or motorized two-wheelers (MTWs) for their trips. Most of the MTW drivers attempt to do lane filtering/ seepage (Agarwal and Lämmel, 2016) and come in front of the queue. Interestingly, almost 30% of the MTW users also stop at the end of the queue and few persons also attempt to use footpath/ cycleway if available.

Figure 2 shows the actions of the car and MTW drivers at red signal, differentiated by the driving experience. Only marginal number of persons never turn-off the engine which

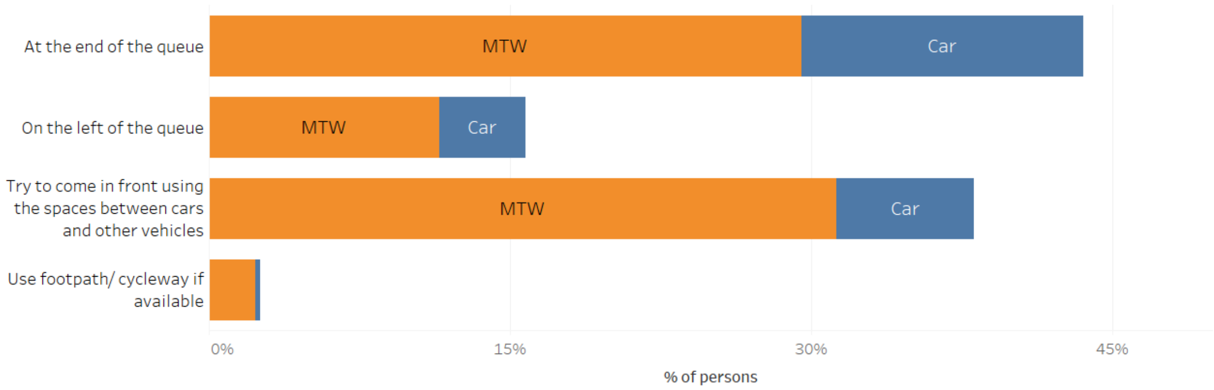


Figure 1: Position of vehicles at a signalized intersection

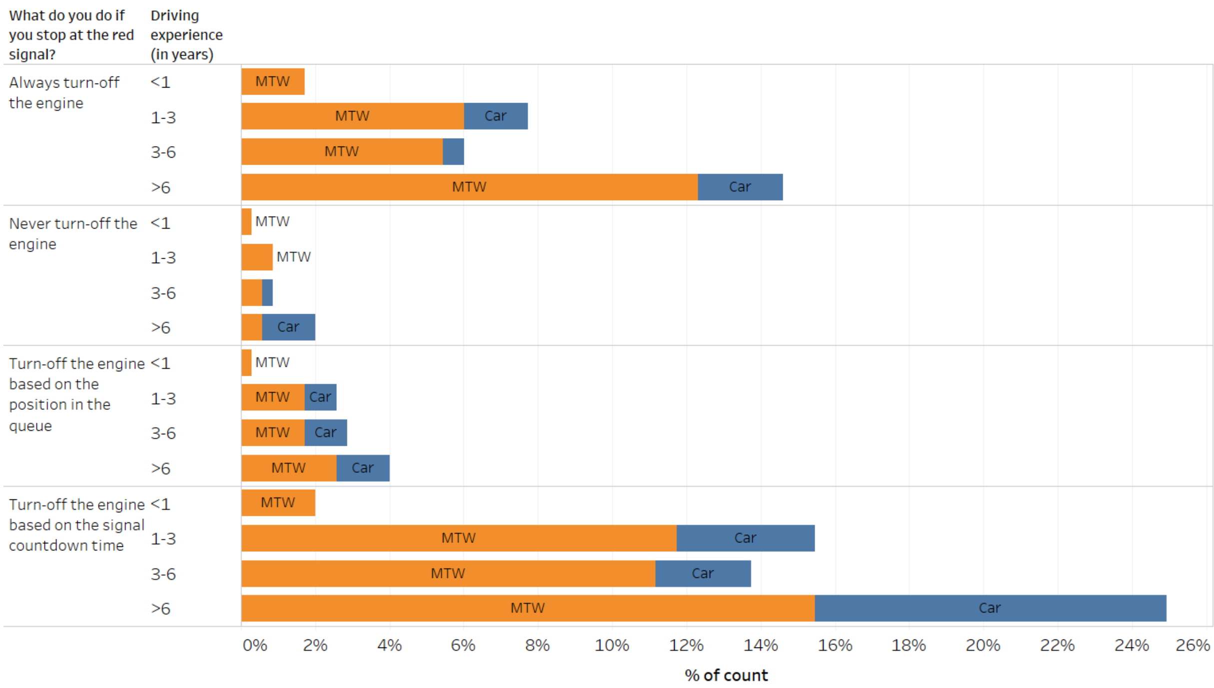


Figure 2: Action of car and MTW drivers at a red signal

could be a result of awareness towards saving the fuel. More than 55% of persons reported that they turn-off the engine based on the signal countdown timer which highlights the need and positive effect of installing signal countdown timers at a signal. Surprisingly, about 30% of the persons always turn-off the engine. Clearly, always turning off the engine also does not result in fuel savings because of higher consumption of the fuel during reignition compared to savings by turning off the engine (Matsuura et al., 2004). More than 80% of the users reported fuel saving as one of the most important reason for turning off the engine. Other important reasons are reducing air pollution, noise pollution.

3.3 Potential to reduce idling

With the analysis in Section 3.2, it can be emphasized that there is a great potential and willingness to save fuel which can be achieved by providing a facility which gives a threshold value to turn-off the engine (see Section 2.1). This is also supported by the fact that position of the vehicle in the queue and level of congestion are primary reasons which are impacting the decision of turning-off the engine. Long queues at signalized intersections across the cities can save significant fuel as well as reduce the exhaust emissions (Sharma et al., 2019).

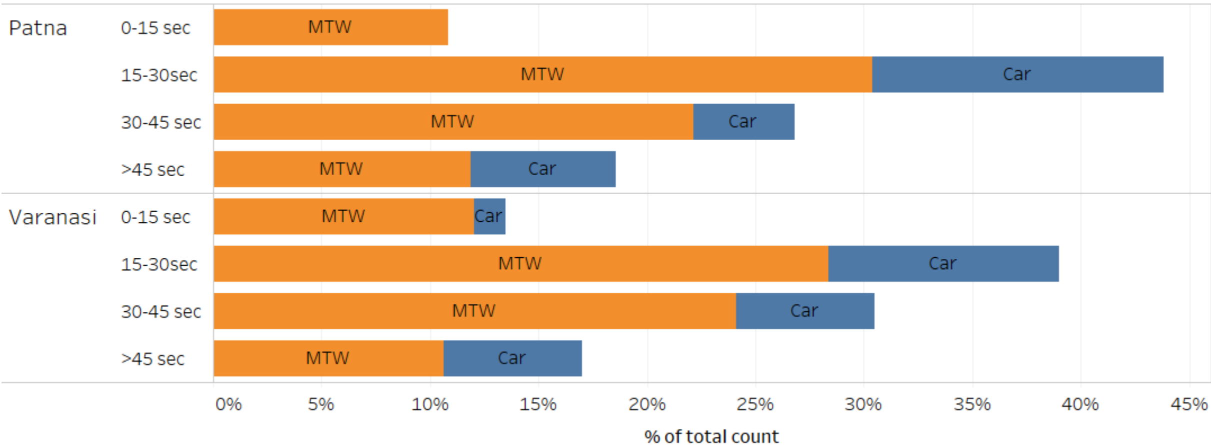


Figure 3: Distribution of countdown timer at which the persons turn-off the engine.

Figure 3 shows the share of respondents in Patna and Varanasi for different ranges of countdown timer at which they turn-off the engine. Clearly, significant number of persons are turning off the engines at a higher value than recommended value of 15 sec by PCRA (2017) which is leading to significant waste of the fuel at signalized intersections. The pattern is almost similar for both cities. Persons who are not turning off the engine, reported that usually they are in hurry or require the air conditioning in the car.

In order to save the fuel, more than 74% respondents are willing to use an app/ system which assist in providing a dynamic, vehicle-specific threshold value for turning-off the engine. Further, only 10% of the users are unsure of using such service. Approximately, 44% of persons would like to have this feature on dashboard of their car/ MTW, whereas more than 40% of the users would like to get a notification on their mobile phone.

For further details, a cross-analysis is summarized in Table 1. It shows that those who are not interested or unsure about having an app/ system, have more driving experience. This suggests that these users have gained better perception of the driving condition at signalized intersection. This is also corroborated by the fact that persons who are not in favour or unsure of using the app/ system, drives almost everyday. Furthermore, individuals with no app/ system or unsure preferences are MTW drivers (73%, 86.8% respectively) confirming the continuous possibilities of lane filtering and seepage behaviour of MTW users. Moreover, high share of the drivers interested in having a system stop at the end of the queue suggesting these drivers are not able to decide whether they have to turn-off the engine or keep it idle on the basis of signal countdown timer.

3.4 Chi-square

A chi-square test of independence is conducted on important categorical parameters to test the significant relationship between them. The relationship between vehicle type with; position of vehicle at a signalized intersection, signal countdown timer at which the drivers turn-off the engine and actions of driver at a red signal, differentiated by the driving experience is tested. The null hypothesis refer to the fact that there is no relationship or dependency between the categorical variables, on the other hand alternate hypothesis refers that there exist a relationship or dependency between the variables. Table 2 shows that the null hypothesis is rejected (at 5% significance level) in all the

Table 1: Results of cross-analysis

Parameters	Options	In favour of an app/system in % (responses)	Not in favour of an app/system % (responses)	Unsure % (responses)
Driving experience (in years)	< 1	4.25 (11)	2.7 (1)	5.66 (3)
	1-3	28.57 (74)	21.62 (8)	20.75 (11)
	3-6	24.32 (63)	18.92 (7)	22.64 (12)
	> 6	42.86 (111)	56.76 (21)	50.94 (27)
Driving frequency	Almost everyday	57.53 (149)	64.86 (24)	66.04 (35)
	Few days in a week	28.57 (74)	13.51 (5)	13.21 (7)
	Few days in a month	8.11 (21)	16.22 (6)	16.98 (9)
	Few days in a year	5.79 (15)	5.41 (2)	3.77 (2)
Vehicle used	Car	27.80 (72)	27.03 (10)	13.21 (7)
	MTW	72.20 (187)	72.97 (27)	86.79 (46)
Position of vehicle at signalized intersection	At the end of the queue	44.79 (116)	43.24 (16)	37.74 (20)
	On the left of the queue	15.44 (40)	10.81 (4)	20.75 (11)
	Try to come in front	37.07 (96)	45.95 (17)	33.96 (18)
	Use footpath/ cycleway if available	1.93 (5)	0.00 (0)	7.55 (4)

three cases inferring that there is a high correlation between these variables. Furthermore, the P values are less than the significance levels indicating there is sufficient evidence to conclude that relationship exists between the selected variables. These results confirmed the conclusions mentioned in Sections 3.2 and 3.3.

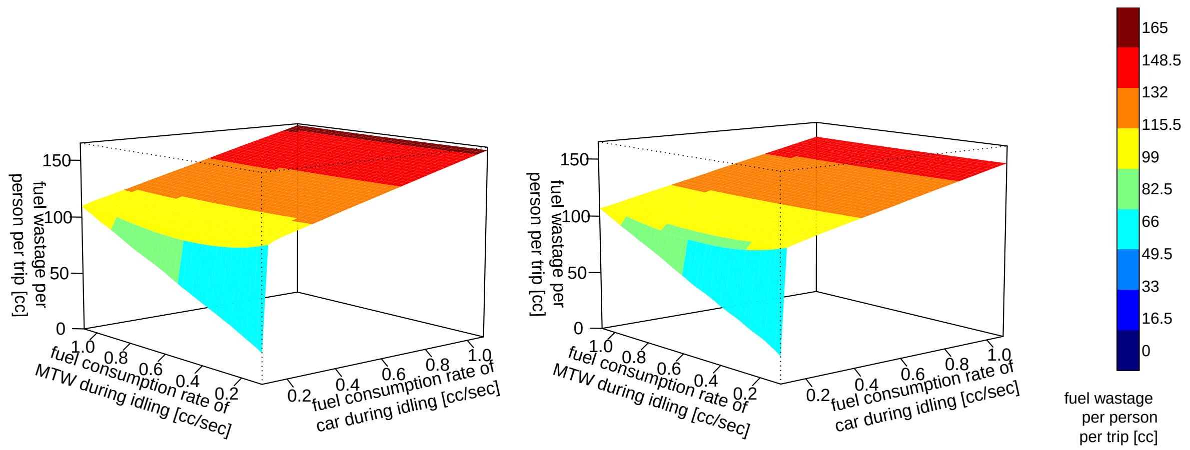
3.5 Fuel wastage

Though, to keep the survey short, simple, fewer, range-based questions are asked. From the survey responses, an estimate of fuel wasted per person per trip is provided to demonstrate the extent of the problem. For this, Equation (5) is used and a short program is written to produce fuel wasted per person per trip using the survey data and different values of fuel consumption rate during idling (I) and during reignition (f_b) for car and MTWs. For all the responses in a range, a random number is drawn (i.e., as per uniform distribution) between the range. Ideally, the position of the vehicle in the queue can be obtained from the field conditions. However, in the present study, the vehicles are assumed to be placed randomly between $0 - 100$ m if driver is staying behind the queue, between $0 - 70$ m if a driver is taking the left lane to move forward and between $0 - 20$ m if a driver is using footpath or attempting seepage/ lane-filtering. Further, to determine

Table 2: Result of Chi Square Statistics

Parameters	Values	Inferences
Position at signalized intersection	Chi-square value = 10.43	Null hypothesis was rejected at 5 % significance value
Vehicle type	P value = 0.015	
Countdown timer at which the persons turn-off the engine	Chi-square value = 16.20	Null hypothesis was rejected at 5 % significance value
Vehicle type	P value = 0.001	
Action of drivers at a red signal	Chi-square value = 30.04	Null hypothesis was rejected
Driving experience (in years)		at 5 % significance value
Vehicle type	P value = 0.012	

the fuel waste for the persons who never turns-off the engine, a maximum phase time (i.e., maximum wait time at one approach) of a traffic signal is taken as 90 sec.



(a) Patna (b) Varanasi

Figure 4: Average fuel consumption per person per trip [in cc].

Figure 4 shows the fuel wasted per person per trip for Patna and Varanasi. The fuel waste also includes the cases where the fuel consumption is higher than savings in fuel idling by turning off the engine. Firstly, it can be observed that the average fuel waste depends on the fuel consumption rate during idling which in turn, is affected by vehicular characteristics (i.e., type of engine, age of vehicle, maintenance frequency, etc.).

Further, the fuel wasted per person per trip is higher in Patna at same values of fuel consumption rate during idling for car and MTW. This happens due to the varying behaviour of persons (e.g., staying behind the queue, taking left lane, seeping to come in front, countdown timer at which vehicle is turned off, etc.) and other attributes such as number of signals per trips, length of phasing, etc. These attributes affect the threshold value (see Equation (5)) which in turn affects the fuel wastage.

Clearly, this necessitates, the need of setting a dynamic threshold values which depends on the vehicular characteristics, driver behaviour as well as the local network attributes.

4 Conclusions and Discussion

Vehicle idling is the most common problem in urban agglomerations, especially at traffic intersections. At a traffic signal, a driver is in dilemma for turning off the engine or keep it on until the signal turns green. The present study analysed the heterogeneity in driver's idling behaviour at signalised intersection and identified the factors for drivers' ignorance, lack of motivation to reduce/ stop idling. An possible approach was presented which can provide the threshold value to turn-off the engine based on vehicular characteristics as well as vehicle position in the queue. This was the motivation for the present study.

For the present study, the data was collected using an online web-based survey, in Patna and Varanasi cities of India. The questionnaire consisted questions related to demographics, vehicular data and the normal response of people on encountering a red light at traffic signal. Respondents were also asked few questions about the willingness to adopt a tool (an app or a system) which assists the driver by provision of an engine-off threshold value.

The fuel wasted at the traffic intersections is high which consequently results in higher exhaust emissions. This occurs due to the drivers' dilemma and lack of knowledge towards the technical information on fuel consumption by the vehicle in different processes. It was observed that of the total persons who can drive, marginal number never turn-off the engine on encountering a traffic signal. 30% always turn off the engine which is unlikely to result in saving of the fuel every time because of the higher losses in the fuel during reignition compared to fuel losses during idling. More than 55% of the person reported that they turn-off the engine based on the signal countdown timer. It was found out that significant number of people are turning off the engines at a higher level than the recommended value of 15 seconds PCRA (2017) which is leading to extra fuel waste.

The drivers' decision to turn-off the engine is also affected by the position of the vehicle in the queue and the level of congestion at the intersection. High number of the persons were observed to stay at the end of the queue, that means, the effect of the tool to reduce the idling will be very high in the metro/mega cities.

The average fuel waste per person per trip is shown under the current vehicle idling behaviour in Patna and Varanasi. It was found that average fuel wastage per person is higher in Patna compared to Varanasi which underscores the need of dynamic, person-specific threshold values to reduce the idling at controlled intersections. In order to save the fuel, many people are in favour of having an app or a system which assists the driver in providing a dynamic, vehicle-specific threshold value for turning-off the engine. Interestingly, even those who don't turn off their vehicle usually, were also interested in using the app/ system. This showed that there is a great potential and willingness to save the fuel which can be achieved by providing such facility.

Though, the present study attempts to show the potential and willingness to save the fuel, the number of users who are turning off the engine at an signalized intersection appears to be high which points to the possible biasedness in the data collection. The data was collected by sharing the links in various groups, sending emails, etc., during the lockdown period owing to Covid-19. This ignores the user group (e.g., lower income people, taxi drivers, etc.) who doesn't have access to smartphone/ internet. In future, this work can be extended by doing a random sampling and developing an app to provide a threshold value depending on the vehicular characteristics and position in the queue.

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