Economic Impact of Traffic Congestion- Estimation and Challenges

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Abstract

Traffic congestion has become a critical concern when its detrimental effects are taken into account. Incremental delay, excessive fuel consumption and higher vehicle emission are thoughtful impacts of traffic congestion. These negative impacts cause substantial economic losses to the transport system. Hence, it is essential to enumerate these impacts in their monetary terms to provide a better economic growth and social welfare to the society. Thus, a comprehensive review on the impact of traffic congestion comprises traffic delay, fuel consumption and vehicle emission has carried out. Moreover, the paper reviews the economic quantification of this three impacts of traffic congestion. Systematic understanding and estimation are possible by the support of empirical data. Hence, this paper discusses the data requirements and data collection methods for the estimation of delay cost, fuel cost and emission cost. A new methodology has proposed to estimate delay cost for the link, intersection and corridor as separate facilities. This paper also focuses on the challenges to be confronted while quantifying the congestion impacts in monetary value and further research direction are proposed.

Keywords: Traffic congestion; Delay cost, Fuel cost; Vehicle Emission cost; link delay cost; intersection delay cost; corridor delay cost.

1. Introduction

Traffic congestion is defined as the condition of traffic delay of vehicles and that relates to the difference between the existing roadway system performances and its actual condition. (Lomax et al.,1997). It occurs when the number of vehicles set out to use a roadway at same time and when the vehicular volume on transportation system exceeds the capacity of that system. (Weisbrod et al, 2001),(Rosenbloom, 1978). Congestion may take place either at regular intervals of time which can be predicted or at irregular times which are unexpected and unpredictable. Latter happens in numerous situations like random accidents, extreme weather conditions and unusual large vehicle merging

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movements. Congestion adversely affects the economy and social well-being of the road users by wastage of time, deterioration of the health, travel time delay, inability to forecast travel time, increased fuel consumption which causes air pollution and gas emission, wear and tear on vehicles, noise pollution and reduction in road safety.

When the transportation system collapses to the condition of traffic congestion from the normal condition, the financial planning of the transport system increases because it has to provide mitigation measures such as widening of roads and construction of fly overs for the smooth flow of traffic. Congestion leads to an economic inflation, referred as an inconvenience and incremental cost resulting from the interference among road users (Litman, 2013). Traffic congestion costs constitute both internal and external parameters in which internal or direct cost is induced by vehicle users while the congested surroundings generate an external or social cost. Direct cost is borne by the non-productive activity of road users and extraneous consumption of fuel. Likewise, the social cost is brought about by external elements in transport system such as air and noise pollution, accidents and risk from accidents and imposes society as whole.(Thomson & Bull, 2002).

The review of literatures related to the above subjects reveals that many analyses have been performed to establish the cost of traffic congestion. Many conventional works deal with different types of congestion estimation methods such as total cost, marginal cost and excess burden cost (OECD Transport Research Centre, 2007).Researchers also recognized the agglomeration externalities to estimate the traffic congestion cost. The agglomeration externalities concentrates on the estimation of economic activity in the area and thus by providing different policies to mitigate traffic congestion.(Arnott, 2007).Though, various investigations have been carried out to examine the cost of congestion, only limited number of studies were made to quantify the economic impact of traffic congestion. However, this review proposes a framework for emphasizing the three important impacts of traffic congestion and its economic estimation.

A challenge to transport investors and planners is to mitigate traffic congestion and thus provide a better economic growth and social welfare to the society. For this, congestion impacts have to be estimated on their monetary terms. Hence, a comprehensive review concentrates on three important impacts of traffic congestion namely delay impact, fuel consumption impact and emission impact. Furthermore, a systematic review of data requirements and data collection methodology is addressed in this paper. A new methodology has been proposed to estimate delay cost for the link, intersection and corridor as separate facilities. The heterogeneity in vehicle and location characteristics made the cost evaluation technique unique for various countries. Moreover, the challenges to be addressed while quantifying the congestion impacts and further research direction are presented in this paper.

2. Evaluation Of Congestion Impacts

The general methodology that has been followed in many studies for the congestion cost estimation is depicted in the Fig.1. In view of this framework, the three main impacts are considered. Primarily, the discussion of the congestion impact on traffic delay is considered and delay cost is estimated by means of the value of travel time. A method for the delay cost estimation for different facilities such as link, intersection and corridor are pointed out. Secondly, the review of the impact on fuel consumption and fuel cost estimation is presented. Impact on emission, emission factor estimation by direct method and indirect method and emission cost estimation are presented. The data requirements and data collection techniques for delay cost, fuel cost and emission cost are presented.

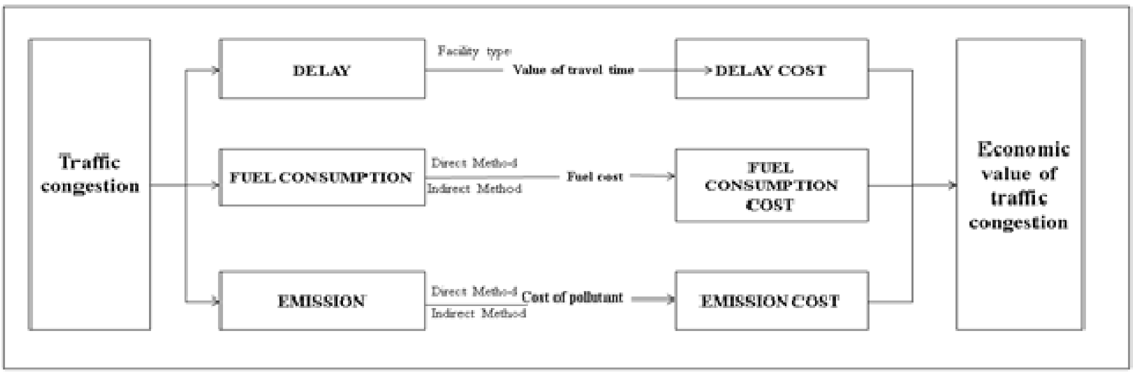

Figure 1. Framework for the estimation of economic impact of traffic congestion

3. Delay Impact

Travel time is one of the important attribute perceived by every traveller in each of their trips. The primary impact of traffic congestion is the delay which results in the waiting of passengers and intensification of peak hours ((European Commission, 2004). Traffic congestion is a state of delay that transitioned between free flow and maximum flow travel conditions. Delay is the travel time difference between peak hour and free flow condition.

The delay causes while wasting time of road users to pass the queue thus by missing important meeting and late arrival for work. Hence, time delay reflected as the economic losses for road users. This is the central cost over the years((Hansen, 2001),(Bilbao-Ubillos,2008),(Goodwin,2004)). Travel time cost is the economic concept that the time spent on travelling has an opportunity cost as it could be used for alternate activity which could harvest some revenue or productive utility.

Value of travel time (VOT) method is extensively used to find the delay cost. Value of travel time is the monetary value that a person will be ready to pay for a unit travel time reduction and it depends on many factors such as the income of the traveller, intention of the trip, the condition and time of travel and mode of travel(Small,2012),. Additionally, variation in the value depends on these factors and is highly location specific (Jiang &Morikawa, 2004). The equation for calculating delay cost is shown in equation 1.

$$d = \sum_{i=1}^{n} \left(t_f - t_o\right) * v * vot \qquad (1).$$

Where is the delay cost per vehicle, is the average travel time at normal conditions, is the average travel time at free flow condition, is the volume of vehicle, is the value of travel time and i is the type of vehicle such as car, two wheeler and bus.

3.1 Data requirement and data collection techniques

The data required for the delay cost estimation comprises travel time data, traffic volume data and value of travel time data. The methodology for the data requirements and data collection for delay cost are depicted in the figure 2.Value of travel time parameter is the cost conversion factor associated with the travel time delay. The effective performance measure of delay is traffic volume and travel time data(NCHRP 618).The detailed description on each component are provided below.

Traffic volume is the fundamental measure of traffic on a road system and it is the number of vehicles that passes through the section of a roadway for a given period of time. Traditional method such as manual method and combination of manual and mechanical methods can be used to find out traffic volume. The automatic devices which consist of detectors and sensors for identifying the presence of vehicles are another tool for counting the vehicles.

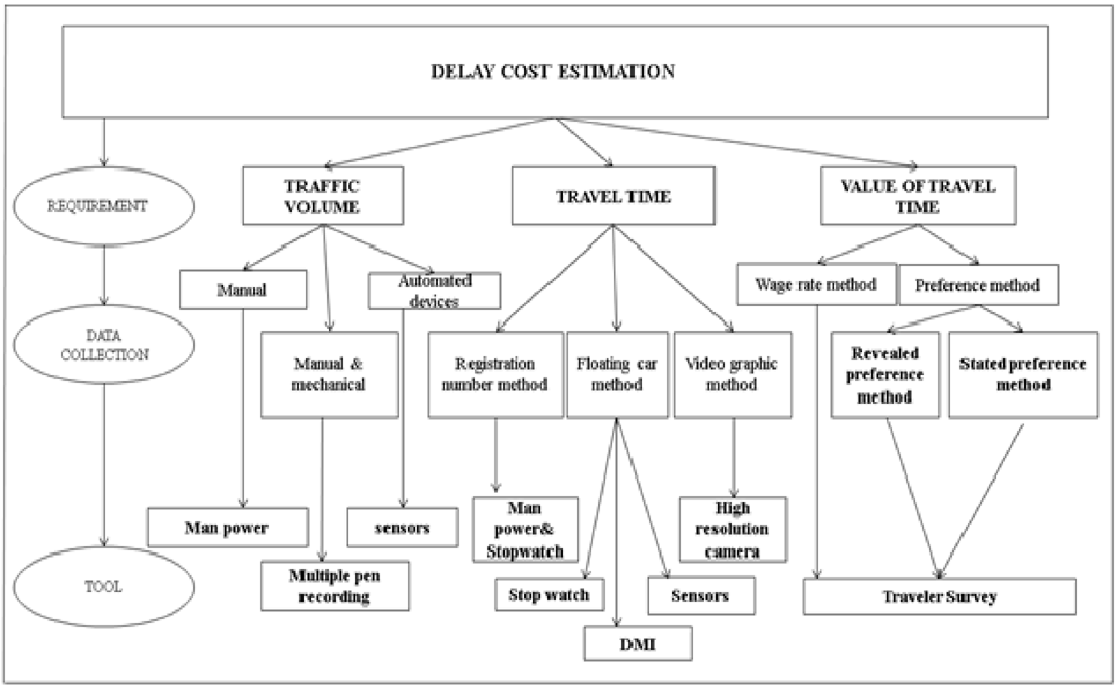

Figure 2. Methodology for the data requirement and data collection for delay cost

Secondly, the travel time for the vehicle, different methods available for travel time data collection are registration number method, floating car method and video graphic method. In registration number method, observers are stationed at both ends of the section and the time and registration number of the vehicle entering and leaving section are to be noted by using synchronized watches. By matching the registration number of vehicles entering and leaving the study section, the travel time for different vehicle can be ascertained. This method is best suitable for the highway section having minor or no intersections. A major disadvantage of this method is the prolonged duration which causes undue strain on the observers. In order to overcome that, video graphic method can be used.

In video graphic method, high resolution video cameras are placed at two ends of the section by synchronizing the time and record video to obtain the travel time. By replaying the recorded video and noting down the time taken to the entry and exit time of the vehicle in the section. This method has an advantage over the registration number method because it can capture different vehicle type data accurately with less manpower. In congested state vehicle occupies on the road fully, video graphic method provides more accurate data than registration number method.

In floating car method, global positioning system (GPS) and distance measuring instruments (DMI) can be fitted in the vehicle to obtain travel time and it will give microscopic features of a travel time component. The manual method using stopwatches in the floating car survey is also a tool for travel time data collection. For congestion prevailing under homogeneous conditions floating car method gives the best results and where as in heterogeneous conditions, several runs have to be taken for different vehicle types to get accurate data.

Time is an economic commodity, and it helps to accomplish products and services as valuable items. Generally, travellers prefer to choose the route of less travel time, even at long distance and high running cost of the vehicle. Since travel time has a value, but the value of travel time depends on many factors, each of varying importance depending upon the traveller, the purpose of travel, the amount of time available, the reliability of having the time to use etc. Hence, data collection should include the factors affecting their travel journey of different rod users.

Wage rate approach and preference approach are the two distinct approaches in the economic evaluation of travel time. The common and simple approach to ascertain the passengers travel time cost is to evaluate the average wage rate of the road user and to treat it as the time value of his travel. As the trip characteristics changes from work time journey and leisure time journey, the value of travel time for trips also may vary. A major disadvantage of the wage rate approach is that, it does not account the trip characteristics of the passengers and is difficult to find the travel time value for unemployed road users. Hence, preference survey helps to find the distinct behaviour and value of travel time for different trips.

In preference survey approach, the travellers are asked to value the price they would pay for reduced travel durations. The actual rating of travellers would depend upon their wage rate, personal choice, trip characteristics and purpose of the trip. This include revealed preference (RP) and stated preference approach (SP) and it is the most scientific way to estimate the value of travel time .Value of travel time is defined as the ratio of the marginal utility of travel time over the travel cost. It is done by studying the choice of people and their preference to reduce travel time and travel cost (Beshears et al 2008). The RP approach evaluate value of time which is best to explain actual observed choices (Boter et al, 2005),. Since RP approach uses data collected on real life choices, the choices as made by individual decision makers are bound by the real constraints confronted by those same decision makers. Researchers have contributed value of travel time through RP survey method(Román et al., 2014),(Fezzi et al, 2014).Revealed preference survey is not adequate in case where a new transport invention is under considerations, which necessitates the use of hypothetical scenarios.

In Stated Preference approach, information about decision maker's preferences is elicited by using specifically designed hypothetical situation. In SP approach, all passengers were capable to make choices about preferred travel options and also able to provide justifications for their choices(Jiang &Morikawa, 2004). Moreover, it is possible to control the choices offered to respondents and thereby ensure data of sufficient quality. This method permits generation of multiple observations per respondents and are also asked to consider a number of situations in a set of option to maximize their utility in this choice of transport system. SP method is considered as a better method for value of travel time estimation because the travellers themselves evaluate different trade off possibilities between travel time and travel cost. Research has contributed to value of travel time through SP survey(Tseng &Verhoef, 2008),(Calfee& Winston, 1998). The underlying principle behind the preference is that the results will reflect the revealed and stated behaviour of the preference of the people, which is therefore nearer to the reality.

3.2 Challenges and mitigation for delay cost data collection

Measuring traffic volume count for roadway sections under varying traffic, traditional data collection techniques such as manual and mechanical method or advanced data collection techniques using sensors can be used.

Even though, several methods are available for travel time data collection, suitable method need to be selected for travel time data collection under congested conditions. For homogeneous and lane based traffic conditions, travel time data has to be collected for the same type of vehicle, for that any of the methods such as a registration number method, video graphic method and floating car method can be used. But in heterogeneous and non-lane based traffic conditions, vehicle has to perform stop and go conditions with available space of road stretches, and travel time differs for different types of vehicle. Hence, travel time estimation by video graphic method gives more accurate data than floating car method and registration number method in terms of manpower and several runs for floating car.

In computing the value of travel time from the field, the challenges to be confronted as that questionnaire has to be designed in such a way that it includes the trip characteristics, trip maker's characteristics, and vehicle related characteristics and transport service characteristics. Hence, a suitable measurement to be taken for the information regarding the characteristics of the field while experiencing congestion. To address that, a pilot traffic survey needs to be conducted to identify the period of congestion and those temporal variations to be included while making questionnaire. Even though, underlying uncertainties makes estimation of travel time value more vulnerable to the transport planners, the temporal variation identification holds good estimates for economic estimation of traffic congestion delay impact.

4. Delay cost estimation for various Facilities

The road transport network system consists of different facilities and their performance is different from one another. The economic cost may vary from one facility to another facility and as a whole. The congestion mitigation measures including widening of the road and provision of an overpass and under pass to be provide at dis aggregate level for links and nodes in the road. Hence, it must be essential to study the congestion cost for different facility. A method is proposed to estimate the delay cost for link, intersection and corridor as separate facilities.

4.1 Delay Cost Estimation at link

Delay estimation at link is assessed based on the link travel time data during peak and off peak periods. Even though, several methods are used to find out the link travel time, registration number method gives the better result (Cambridge Systematics et al., 2008).But in the congested condition due to several vehicles, video graphic method provides more accurate data. Volume count for link can be done by either manual, video graphic survey or any advanced data collection techniques. The link delay cost estimation formula is shown in the equation 2.

$$d_{link} = \sum_{i=1}^{n} t_{ab} * v * vot_{ab,i} \quad (2)$$

Where, d_{link} is the delay cost at link, t_{ab} is the travel time delay between points a and b in the link, v is the traffic volume on the link, $vot_{ab,i}$is the value of travel time for the link and i is the vehicle type.

4.1.1 Challenges and mitigation for delay cost at link

A number of connected link form a route. As the link is very short in length, the number of passengers choosing to travel within it is a part of their trip.. Hence, the sample of the travelers who uses the link is very difficult to identify. Hence there is an uncertainty in the estimation of value of travel time for the link travelers. In order to mitigate this stated preference survey has to be adopted in the locality including the link characteristics such as link length, specified link travel time and frequency of travel through link.

4.2 Delay Cost Estimation at Intersection

Delay is the effective measure used for the performance evaluation of the intersection and is estimated as the extra time consumed by the vehicles in traversing the intersection. The intersection delay cost formula as shown in the equation 3. Video graphic survey, manual method and registration number methods are commonly adopted data collection technique of traffic volume and delay at an intersection.

$$d_{intersection} = \sum_{i=1}^{n} \sum_{m=1}^{k} delay_{i,m} * v_{i,m} * vot_{i,m} \quad (3)$$

Where *delay* is the delay of the vehicle, v is the traffic volume, *vot* is the value of travel time, *i*is the vehicle type and m is the different approaches for an intersection.

4.2.1 Challenges and mitigation for delay cost at Intersection

The value of travel time of travelers varies on each approach and the surveying is to be conducted for each approach travelers separately .When vehicles move in a mixed traffic regime, the travel time value of travelers using different vehicle types is also to be estimated. Due to different approaches in an intersection, an estimation of value of travel time is a complex task. Hence, Value of travel time for intersection associated with stop and go the process of the vehicle can be assessed using the survey at network level because the field survey is difficult to acquire as the people is an urge to pass the intersection.

4.3 Delay cost estimation at corridor

Delay estimation at corridor is conformed through traditional travel time measurements. Floating car method gives the best measure of the delay and volume along the corridor. Several studies has been conducted to find the delay cost at corridor level(Harford, 2006),(Errampalli et al, 2015), (Well et al, 2011),(Goodwin, 2004),(T. Khan & Mcips, 2013). The equation to find out the delay cost at corridor is shown in equation 4.

$$d_{corridor} = \sum_{i=1}^{n} t_{corridor} * v * vot_i \quad (4)$$

Where, $t_{corridor}$ is the corridor travel time delay, v is the average volume on the corridor,*vot*is the value of travel time and i is the vehicle type.

4.4 Discussion

To summarize, the primary impact of traffic congestion, delay and its economic evaluation are examined in the present study. Systematic methodology proposed for estimation of delay cost at link, intersection and corridor. Even though, several techniques are available for data collection, challenges and mitigations in data collection process and under congested conditions are explained.

5. Fuel Impact

The rapid growth of vehicles in the roadway tends to use the same road section at the same time subsequently leads to wastage of fuel in the vehicle. The fuel consumption of vehicles increases in the operation stages of vehicles. Fuel is wasted due to acceleration, deceleration and idling of the vehicles and it leads to air pollution. This operation arises in the congested conditions and subsequently leads to wastage of fuel and indicated as an impact of traffic congestion. It is dignified based on the journey time and fuel consumption rate during the journey time of the vehicle. Excessive use of fuel in congested condition increases the road user cost.

Fuel economy of an automobile is the ratio of distance travelled and the amount of fuel consumed by the vehicles. Stop and go process of vehicle during the congested period extends wastage of fuel, which results in the increase of fuel usage. Hence, the increase in congestion increases fuel consumption cost. Therefore, fuel cost in congested condition is assessed based on the difference between fuel consumed under congested condition and normal condition.

The types and number of vehicles experiencing congestion, fuel used in the vehicles and its fuel consumption rate are the important parameters for the fuel cost estimation. Cost of fuel is a monetary parameter used in the fuel cost estimation. The general equation for fuel cost is shown in equation 5. Fuel consumed during the journey time of vehicles depends on vehicle characteristics, driving conditions and pavement conditions. Therefore, the fuel cost study evolved based on these factors and Table 1 represents the fuel cost estimation performed in different countries.

$$f_{cost} = \sum_{i=1}^{n} \left(f_c - f_0 \right) * n * c_f \quad (5)$$

Where, f_{cost} is the cost of fuel, f_c is the fuel consumed at congested conditions in liters, f_o is the fuel consumed at actual conditions, n is the number of vehicles experiencing congestion, *i* is the vehicle type and c_f is the fuel cost.

5.1 Data Requirement and data collection methodology

Fuel consumption rate, types and number of vehicles, type of fuel used and cost of fuel are the five important parameters used for fuel cost estimation. Any of the traffic volume measure that mentioned above can be used for the observation of the number of vehicles. Types of vehicle and fuel types are two measures to be taken along the traffic volume count survey. In order to convert fuel in economic terms, different cost of fuel has to be assessed and that would be taken from the locality under the survey.

Fuel consumption measurements are important parameters in the estimation of fuel cost. The predominant methods which are used for fuel consumption are direct method and indirect method and their components are depicted in figure 3.In direct method, fuel consumption is measured using flow meters which are directly connected to the fuel tank, by making several runs in the normal and congested condition which gives the extra fuel consumed. Flow meter gives the fuel consumption measure based on the types of vehicles.

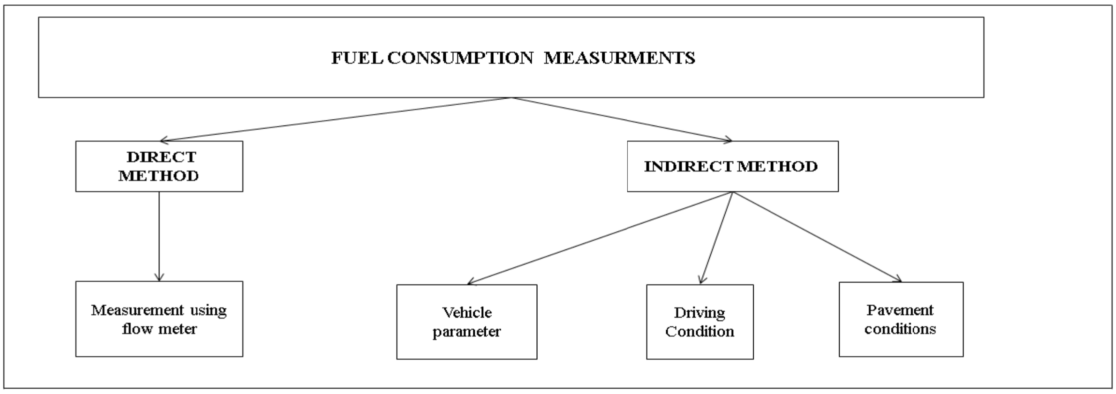

Figure 3. fuel consumption measurement methods

TABLE 1. Fuel cost study performed in different countries

Author & year	Country	Formulae and Notations	Remarks
Shabbar et al 2014	Pakistan	$\boldsymbol{FCCm} = \sum_{FT=1}^{FT=3} \boldsymbol{FCm} * \boldsymbol{Fp} * \boldsymbol{\mu}$ FCC→ fuel consumption cost, FC→fuel consumption quantity Fp→ fuel price μ →proportion of vehicle FT→ fuel type, m→ vehicle type	Representation of mixed traffic condition.
T Khan et al 2013	Bangladesh	$\boldsymbol{C} = \sum_{v\,f} \boldsymbol{n} * \boldsymbol{A} * \boldsymbol{FC} * \boldsymbol{EC}$ C →cost of fuel per day,n→no of vehicle A →average run per day FE→fuel efficiency,EC→fuel cost	Applicable in mixed traffic conditions. Average run per day considered.
Sarkar 2012	India	$\boldsymbol{FLC} = \boldsymbol{IFL} * \boldsymbol{D} * \boldsymbol{FL} * \boldsymbol{n}$ FLC→fuel consumption cost IFL→ $\imath$dling fuel consumption (ml/m),D→delay (min) FL→fuel rate (Rs/ml),n→No of vehicles	Best suited for idling condition.
Znatak et al 2011	Egypt	$\boldsymbol{AFC} = \boldsymbol{8.8} + \boldsymbol{0.25}\ \boldsymbol{APS}$ AFC →average fuel economy in congestion APS→average peak period congested system speed	Based on the speed of the vehicle
Darry j et al 2010	Florida	$\boldsymbol{AFC} = \left(\frac{\boldsymbol{ASP}}{\boldsymbol{FE}}\right) \boldsymbol{DVHD} * \boldsymbol{FC} * \boldsymbol{WD}$AFC →annual fuel cost,FC→ fuel economy FE→ fuel economy DVHD→ daily vehicle hours of delay APS→average peak period congested system speed , WD →working days	Based on the speed of vehicle and daily delay of vehicle
Ubillos B 2008	Canada	$\boldsymbol{C} = \boldsymbol{P}(\boldsymbol{D1G1} - \boldsymbol{D2G2})$ C →financial cost due to additional fuel consumption, P→ average price of fuel consumed D1→ length of urban roadway,D2 →length of proposed alternative route G1 →average in town fuel consumption of vehicle G2 →average out of town fuel consumption of vehicle	Empirical equation Theoretical derivation
LUO et al 2007	China	$\boldsymbol{Cfuel} = \boldsymbol{Ctf}\ \frac{\boldsymbol{Vo}}{\boldsymbol{Vo+Vc}}$C→ fuel consumption by congestion Ctf→fuel consumption by transport Vc→average speed at congested conditions Vo→ average speed at normal condition	Compare with normal conditions

Fuel consumption from vehicle influences on the road characteristics, vehicular characteristics and driver characteristics(Ma, Xie et al, 2015),(Boriboonsomsin & Barth, 2010).Therefore, assessment of fuel consumption impact on these factors is indispensable for better fuel economy and congestion mitigation policies. Hence, fuel consumption estimation is executed based on these factors by indirect method.

Several empirical models have been developed for the fuel consumption measurements that linked to operating conditions and road geometric conditions. Initially, research contributes to fuel consumption model by means of data correlating traffic operation characteristics (speed) and road geometric characteristics (gradient, rise, fall and pavement conditions)(A. S. Khan & Clark, 2010).

Pavement quality also affects the fuel consumption rate. The rise and fall of the vehicles in the roadway increase the fuel consumption. Table 2 depicts the fuel consumption measurements by various factors and its influence on the fuel consumption rate of the vehicle.

Afterwards, researchers developed the mechanistic model, which predicts fuel consumption based on the efficiency of the engine in converting fuel to energy and the force acting on the vehicles. Mechanistic models are considered as superior to empirical models because it directly accounts for the individual vehicle characteristics and the forces acting on the vehicle. But due to prolonged break, this will make an exception.Mechanistic model mainly considers the vehicle characteristics does not capture the performance evaluation of transportation system properly.

5.1.1Challenges and mitigation for estimation of data for fuel consumption

Fuel cost is estimated based on the types and number of vehicle experiencing congestion. Fuel consumed in each vehicle varies depends upon the condition of vehicle and types of fuel also have a variation such as petrol, diesel and compressed natural gas. These parameters make an uncertainty in the valuation of fuel cost. Therefore, types of vehicle and its fuel type has to be collected separately from the field while experiencing congestion with the aid of manual method and video graphic method.

Fuel consumption depends on the aggressiveness of the driver. Aggressiveness of the driver may vary from normal conditions to congested conditions; a separate study has to be conducted to incorporate these conditions.

The fuel cost is highly sensitive to the cost of the fuel. As the fuel cost rise, fuel consumption cost is also high. Hence, the fuel consumption cost may vary from time to time depending upon the cost of fuel. Even though, the cost of fuel is fixed one for a specific time period, types of vehicle and fuel used in the vehicle which embedded in the congested condition has to be measured to predict the impact of congestion accurately.

TABLE 2. Fuel consumption empirical models

Author & year	Formulas and Notations	Remarks
Sierra 2016	$FC = \sum_{ij} VPij * VKTij * FEij$ FC →Total fuel consumption of road fleet VP→total vehicle population VKT→average vehicle kilometer travelled FE→ average fuel economy,i→vehicle type,J→fuel type	Based on fuel economy. Vehicle type and fuel type are considered
Rakha et al 2011	$FA = a\,s + bsAcc + csAcc^2$ FA → fuel consumption or emission rates for every speed Acc→ acceleration S →speed of the vehicle	Empirical model considering the speed of vehicles
H Wang et al 2008	$FC = \sum_{I=1}^{I} FRi * Ti$ FC→ Trip fuel consumption, I→ no of bins i→ speed-VSP bin index, Ti → vehicle trip time speed FR→ fuel consumption rate for speed-VSP bin	Mechanistic model based on vehicle specific power
Hall 1992	$F = 0.0723 - 0.00312V + 5.403.10^{-5}V^2$ F→ is fuel consumption at cruising speed (gallons/mile) V→ is average speed (miles/hour).	Cursing speed considered
Chensher and Harrison 1987	$FC = a_0 + Sa_1 + a_2S_2 + a_3RISE + a_4FALL + a_5IRI$ FC→is the fuel consumption **S**→ vehicle speed in km/h IRI→ international roughness index RISE→ rise of the road FALL → fall of the road in m/km,a_0 to a5 are constants	Empirical model considering vehicle speed and pavement characteristics

5.2 Discussion

The fuel impact and its economic evaluation are reviewed. Fuel consumption is measured by direct and indirect method under prevailing conditions. Direct method gives the fuel consumption rate of a vehicle directly for normal and congested conditions. Moreover, while taking the measurements, the representation of the aggressiveness of the driver and types of vehicles are to be incorporated. In the indirect method, several empirical relations can be represented as an indicator of congestion such as average speed of vehicles.

6. **Emission Impact**

Emission impacts are offseted by the increase of vehicle in the road and also vehciles tend to use the same road at same time regularly,which leads to severe air pollution.Vehicular emissions from the traffic are the primary source of air pollution in the urban area. It consist of pollutants such as carbon monoxide, carbon dioxide, nitrous oxides and particulate matter (Zhang et al, 2011) and cause health problem to the road users. Prolonged carbon dioxide emission from the vehicle contributes to global warming and also significantly affects the ambient air quality.The magnitude and intensity of emission depend upon the tarffic activity, traffic performances in the roadway,fuel consumption rate and emission control srtategy of vehicles.

Traffic Congestion has been indicated as the main contributor to air pollution by vehicular emission. The negative effect of pollution depends not only on the quantity of pollution produced, but also on the types of pollutants emitted as well as the conditions into which they are released. The vehicle emits pollutants such as carbon monoxide, carbon dioxide, nitrogen oxide and other particulate matters to the environments. Due to the stop and go conditions during congested periods, vehicle emits more pollutant than normal steady state conditions.

The emission impact of congestion was calculated based on the fuel consumed and number of pollutants burned. Emission cost of an automobile is related to the distance travelled by the vehicle, number of vehicle and emission factors of pollutant that emits from the vehicle. Table 3 represents the work done in different countries to assess the emission cost. Emission cost of a particular component derived from traffic is calculated from the following equations 6.

$$e_{\cos t} = \sum_{i=1}^{n} v_i * l * e_f * c_f \qquad (6)$$

Where e $_{cost}$ is the emission cost of pollutant, *v* traffic volume, *l* is the length of the road section,$e_f$is the emission factors per unit weight of pollutant, $c_f$is the value of the cost of pollutant and *i* is the vehicle type.

Data requirements and data collection methodology for emission cost

The emission cost components comprise traffic volume, length of the road section, cost of pollutant and emission factors. Traffic volume under various traffic flow are measured any of the methods that explained above. Information about the cost of pollutant is given by the locality under the survey.

The idea to measure emission factors can be done by two methods namely direct method and indirect method. In direct method, pollutants emitted from the vehicle are assessed based on the portable emission instruments which are fitted to the vehicles.On board emission measurement can be done using instruments. The instrument carrying vehicle run along the stretch of the road gives emitted particle directly.

PEMS (Portable Emission Measuring System) represents an advanced emission data collection technology. GPS is enabled in vehicles and this system is made to run along the study stretches which will bring out the emission data. PEMS provide emission data from the field and used in many studies,(Wyatt et al, 2014),(Liu et al, 2010),(Tong et al, 2000).

The different factors that influences the vehicular emission are vehicular characteristics, fuel characteristics, emission control strategy and operating condition of vehicle (Franco et al., 2013). In indirect method, emission factors are derived using the factors which affect congestion such as vehicle parameters, driving conditions and fuel consumption rate.

TABLE 3. Emission cost study performed in different countries

Author & year	Country	Formulae and Notations	Remarks
Alexander et al 2013	USA	$Emission\ cost = \sum_p c_{e,p}\ e_p(q)$ $c_{e,p}$→Unit cost of emission pollutant $e_p(q)$→Emission rate of pollutant(Kg per vehicle mile) P→ pollutant	Cost is based on the vehicle mile travel on the vehicle and its pollutant.
Sarkar 2012	India	$pc = conc * D * cost$ Pc →Pollution cost Conc →concentration of pollutant (total vehicle population * emission factor) D →delay of vehicle cost →* cost per kg of pollutant	Best for both homogeneous and heterogeneous traffic conditions.
Znatak et al 2011	Egypt	$c_{co2} = W_{CO2}U_{CO2}$ C_{CO2}→cost of carbon dioxide W_{CO2}→Weight of carbon dioxide U_{CO2} →Unit cost of carbon dioxide	Only carbon dioxide cost is considered

The speed of a vehicle is the governing factors that control emissions of a pollutant from vehicles. Several researches have been done to find instantaneous emission by considering speed variation (Ahn et al, 2002), (M. Wang et al, 2011).Dynamometer test is one of the traditional methods to find out the fuel consumption and emission factors under laboratory conditions. It tests the operational condition of vehicles, namely speed of the vehicle. It consists of driving cycle that contains stops, starts, and idling of vehicles which provide the overall weighted average of speed. The limitation of this test is that it does not account for actual driver and field conditions. The study has been done to find the emission factors using dynamometer test,(Samuel et al., 2006).

An empirical model for emission was developed by Cappiello et al(2002) considerding vehicle characteristics.They developed a model for engine out emission and tapline emision model.The emission level during idling, acceleration and deceleration conditions of the vehicle in the congested traffic were studied widely. Idling reduction option for heavy duty vehicles trucks and diesel vehicle were studied by Gaines et al(2009)(Gaines, Hartman, & Solomon, 2009).

Challenges and mitigation for emission cost data collection

The emission rate of pollutant from the vehicle is an important parameter in the estimation of emission cost. In direct method, portable emission monitor is fixed in the vehicles to get the emission rate of pollutant during normal and congested conditions.Driver behavioral characteristics have a direct impact on the emission of pollutant. Hence, during the operation of vehicle in the direct data collection technique various driver behaviors have to be incorporated.

Even though, several methods are used in the indirect method for emission rate calculation, congestion indicators such as speed and fuel consumption rate are to be accurately measured in the locality to provide an accurate database for emission estimation.

Excessive emission occurs when the vehicle undergoes in the congested conditions. The emission rate of pollutant from vehicle depends upon the vehicular characteristics such as type of vehicle and emission control strategy of the vehicle .Depending upon the type and condition of the vehicle the emission varies from vehicle and thus makes remarks in the cost calculations. Hence, it is essential to provide advance emission control strategies to every vehicle.

Discussion

The emission impact and its economic evaluation are reviewed. The emission factor of each pollutant which is emitted from the vehicle is estimated by direct and indirect method. In direct method, on board emission instrument which can fit on different vehicle provides the pollutant and its emission rate directly from the field for both normal and congested conditions. In indirect method, the factors which are influence on the vehicular emission which is also a parameter of traffic congestion has taken into account.

Challenges ahead and Research direction

The objective of studying the economic impact of traffic congestion is to propose a realistic estimate of the economic value of traffic congestion, which is being used for the evaluation of many highway improvement proposals such as congestion mitigation, cost benefit analysis and carbon credit for the project. Detailed study and gap to be addressed are summarized below.

Delay impact causes to travelers to wait in the queue for a period of time and thus by losing their important time. Therefore, delay is an unwanted travel time for the road users. Delay cost is estimated by the difference between the average travel time of both normal and free flow conditions, traffic flow in the roadway and value of travel time for travelers.

To combine engineering and economic perspective of delay, the value of travel time for travelers plays a major role. A review has carried out to estimate value of travel time. As traffic congestion has both spatial and temporal variation, delay cost estimation differs with respect to these factors. The review stated that preference survey provides most scientific method of estimating value of travel time at congested conditions. Different stated conditions are to be added in the surveying process of the value of travel time for different facilities because of the variation of the travelers' trip length, travel time for their trip and frequency of their trip along that route.

Even though, each facility contributes data to the estimation of value of travel time.Data requirement and data collection of delay cost varies from facility to facility. This review proposes different data collection techniques, and its advantages and dis advantages and best data collection process.

More vehicles tend to use the road at the same time, fuel consumption rate of vehicle increases and thus by increasing the operating cost of vehicles. Fuel cost in the

congested condition is estimated by the extra fuel consumed during congested period, number of vehicle and cost of fuel. The traffic regime consists of different vehicles and having different vehicle characteristics. Hence, the complexity arises to calculate the fuel cost of each vehicle in the road way. Therefore, the vehicle characteristics such as type and make of vehicle are to be noted down while taking the data collection for the fuel cost. The cost of fuel may vary for a period of time. Hence, cost of fuel variation taken into account while forecasting fuel consumption cost.
Indirect method describes a different fuel consumption model based on the empirical data set. This estimation considered the factors affecting fuel consumption such as vehicle parameters, driving condition and pavement conditions. A challenges in the quantification of the fuel consumption using empirical method is that whether it represents the congestion adequately. A drawback for considering the average speed to predict congestion is that, the same average speed result in both peaks and off peak periods.

The different Pollutant emits form the vehicle causes air pollution in the area. Traffic congestion causes the vehicle emission. The emission cost is estimated by the emission factor of pollutant per unit weight, length of road section travelled and cost of pollutant. Direct and indirect method gives the emission rate of pollutant from vehicle. While taking the measurements from the direct method, the aggressiveness of the driver has to be tackled since the roadway accommodates different drivers behaving in a different manner.
In indirect method, by use of the indicators of congestion such as average speed, idling of vehicles can take to find the emission factors of each pollutant. This may cause bias estimates because it represents a vehicle emission and a driver behavior. In order to overcome that research has also to be focused on the driver behavioral and vehicular characteristics of emission while measuring through direct method to get accurate data for congestion.

Conclusion

This study presents a review of the different traffic congestion component, their economic evaluation, and the challenges associated with quantifying each component. This review highlights the various methods proposed by different researchers. Therefore, in order to assess the overall economic impact of traffic congestion, it is essential to take into account of all the relevant components and their economic value. Even though, there is a considerable uncertainty in quantifying the impact of congestion in economic terms, this paper provides an insight to do that.

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