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Urban road congestion toll

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Abstract

Traffic congestion is a phenomenon relating the manner in which vehicles impede each other's progression as demand for limited road space approaches full capacity. Traffic congestions is created due to imbalance between demand and supply in urban transportation and in the structural disarray of different transportation duet to an imbalance in cost and benefit. Congestion pricing is a way of harnessing the power of the market to reduce the waste associated with traffic congestion that works by discouraging travelers on peak hour (FHWA, 2017). Currently used pricing schemes are facility-based, cordon scheme, zonal scheme and distance based scheme. The pricing is differentiated with respect to time as flat toll, time of the day toll and responsive tolling. The ultimate usage of the method is dependent on the available technology and policy. Implementation needs public acceptance with regard to privacy, equity, complexity, and certainty. Congestion pricing can be used for financing, traffic management, the perceptibility of cost, internalization of external cost and calculating the external cost.

1 Introduction

Road traffic congestion is a complicated dynamic process in which radially interrelated with Urbanization, a process whereby population moves from rural to urban area. Urbanization increases result in an increase in transport, the link between the production side and consumption side, and of course economic growth and an increase in energy consumption. Furthermore, unless efficiently managed it is obvious that the number of vehicles on the road would increase from year to year.

Traffic congestion is a phenomenon relating to the manner in which vehicles impede each other's progression as demand for limited road space approaches full capacity. Besides, it is relating to user expectations and road system performance. It is one of the urban ills that highly influence the economic, social, environmental and of course the political outlook of the residents, government, and firms (ECMT, 2007). The fundamental cause of traffic congestions is the imbalance between demand and supply in urban transportation and in the structural disarray of different transportation duet to imbalance in cost and benefit but other specific reasons such as road accidents, incidents, insufficient traffic capacity of the road, traffic surge during peak hour and the disturbance between vehicles in the interweaving zone can be mentioned (Yue-jun Liu, Ming-Zheng Sun, Ling Zhou, Lu Lu, 2016). Traffic congestion increased travel time imposes costs for the road users, not only economic lose but also reduce the quality of life and mobility. The effects of traffic congestion on an urban area can be summarized as follows;

- ✓ **Delays:** people who drive in a congested road network usually thinks about delay. There is additional stress due to delay caused by morning and afternoon peak traffic congestion. This stress has tremendous effect on the peoples work efficiency.
- ✓ **Time:** people who drive on a congested road is unable to estimate the travel time of their journey. Consequently, the city drivers have an experience of "Just in case" the traffic is bad and this takes away time to use leisure time and working time throughout the day.
- ✓ **Fuel consumption and pollution:** fuel consumption increases due to acceleration and deceleration of vehicles on a congested road more than a smooth rate of travel on the uncongested road and of course increases the travel cost. Besides, it contributes to emission of pollutants that cause air pollution and global warming.

- ✓ **Road rage:** If someone is not driving as fast as the person behind him think, he/she show an aggressive behavior which may include rude and offensive gestures, verbal insults or dangerous driving method towards other road users. Road rage can cause accidents on the road that can be rated from light injuries to death.
- ✓ **Emergency vehicle:** because of traffic congestion on the road network emergency vehicles such as ambulance and police car are unable to respond in an appropriate time. The delay of the emergency vehicle can result to loss of life or property.

For a traveling individual, the total direct cost of traveling is the accumulation of costs such as travel time, fuel consumption, parking fee and other fees. As the number of traveler increases the total cost of traveling increase because the travel time increases. Besides, a huge amount of congestion-related costs are not directly paid by individual car users but covered by the whole society. Thus stimulates individual car consumption and waste of resources. As a vital measure congestion pricing is used as a tool for regulating the transport system in a sustainable way by reducing negative externalities.

Congestion pricing - sometimes called value pricing - is a way of harnessing the power of the market to reduce the waste associated with traffic congestion that works by shifting purely discretionary rush hour highway travel to other transportation modes or to off-peak periods, taking advantage of the fact that the majority of peak hour drivers on a typical urban road are not commuters (FHWA, 2017) . Traffic congestion is one of the major negative externalities of road transport which affects the environmental, social, political and economic welfare of the society. Consequently quantifying the effect of congestion and provision of a method to alleviate the impact is vital. Supply oriented construction of infrastructures, such as increase the number of lane is a traditional way of reducing traffic congestion and it is not sustainable as there is limited space in condensed urban area. Currently, congestion price is used as a tool to reduce traffic congestion in many cities of the world (e.g. Singapore, London, and Milan). The briefing by (Pillath, 2016) outlines the main benefits from congestion pricing as follows.

a) Financing: The theoretical basis for just financing was developed without considering the expenditure side of the process. In 1920 Pigou by his book "the economics of welfare" the optimal quantity to be supplied based on marginal utility theory and propose a solution that marginal benefit should be equal to marginal cost. Road infrastructures are among the public good which needs special concern. Traffic congestion charging revenue can be used to cover the cost of infrastructure that switches from the taxpayer to the road user.

b) **Traffic management:** implementation of road pricing at a specified place and time reduces traffic congestion. As evidence indicated road pricing can influence traffic flow and spread traffic peaks and also in reducing and smoothing the emissions of pollutants over time and space. It also has brought a reduction in emission due to an increase in vehicle speed (Jessica Coria & Xiao-Bing Zhang, 2017)

c) **Making all costs perceptible:** Encouraging road charge reflects the environmental impact and resource scarcity more clearly so that the user can respond appropriately.

d) **Internationalisation of external cost:** transport policies are aimed to minimize the gap between the private cost and social cost. This can be done with taxation, **user charge,** and emission trading. The sum of private and external costs constitutes the social cost of transport activities and represents the total consumption of the resources caused by using a vehicle. The internalisation of external cost, the price paid for transport activity reflects the external cost, use to minimize the mismatch between private and social cost.

e) **Calculating external cost:** To charge any external costs to the polluter, a quantitative estimation of these costs is necessary. Basic requirements are the methodology and the data to calculate the external costs so that any road charges can be aligned with the actual external costs. When a number of drivers on the road increases, the traveling cost increases because of the fact that travel time is increased. Thus newly entering vehicles are easily creating traffic congestion for the road system (Yue-jun Liu, Ming-Zheng Sun, Ling Zhou, Lu Lu, 2016).

A well-designed congestion pricing scheme can largely facilitate the enforcement and implementation of the system on a particular city. Toll scheme designed for congestion have been slow to develop. The main examples are the London congestion charge, Singapore Electronic Road Pricing (ERP) system, a Stockholm cordon charge, and High Occupancy Toll (HOT) lane in the USA. The scheme can be categorized in different ways but (André de Palma, Robin Lindsey, 2011)classify into four and the detail is as follow.

1) **Facility-based scheme:** toll can be imposed on a specific facility such as a road, tunnel, and bridge. These tolls can be levied either all lane of the facility or on a designated toll lane.
2) **Cordons scheme:** it is a form of road charge by which a vehicle traveling to cross the cordons inbound, outbound or in both direction pay a toll.

3) **Zonal scheme:** It is also called area based road pricing in which the vehicle is charged to enter and to exit, or to travel inside the boundary. The zonal boundary can be defined by natural features like rivers, lakes, mountains, and oceans in addition to built-in environmental elements such as road, tunnel, bridge, residential neighborhood, and provinces. One of the issues an area charge raises is that local residents are charged for all trips within the area during charging hours. This could be mitigated by restricting charging to peak hours or granting residents a discount to enable some essential trips to be undertaken without excessive penalty.
4) **Distance-based scheme:** distance-based scheme is more complex in which the vehicle pay a fee based on the distance traveled, either linearly or non-linearly. This scheme is supported by vehicle position system. This scheme is the main topic of this paper and explained below.

Based on the degree of time differentiation congestion price can be classified as a flat toll, time of the day toll, or responsive toll.

- ✓ **Flat tolls**: This type of toll does not vary over time. As historical evidence shows most tolls were flat due to administrative and technological difficulties.
- ✓ **Time of the day toll**: It is also called schedule tolling varies by time of days, weeks and seasons in accordance with a predetermined schedule. The practice has been more pragmatic. In Singapore, toll schedules are adjusted quarterly, and during June and December school holidays, to maintain target speeds of 45 km/hr to 65 km/hr on expressway and 20 km/hr to 30 km/hr on arterials at least 85% of the time (André de Palma, Robin Lindsey, 2011).
- ✓ **Responsive tolling**: This scheme is a reactive type of pricing by which the variation is in a real-time or approximately a real-time depending on the current traffic condition. When the road is more congested the drivers should pay more and if the road is in uncongested or less congested the toll should be less. The responsive tolling scheme needs advanced technologies that the other (flat tolls and time of the day toll) that can collect real-time information and manage the payment.

2 Congestion price technologies

A number of studies evaluate the relative merit of technology options for using distance-based road charge. The study by (André de Palma, Robin Lindsey, 2011) points out the main function of congestion tolling system as:

- Measurement of road usage by a vehicle and recording location and their characteristics.
- Communication of data for billing purpose
- Enforcement

Electronic toll collection system that is integrated with different technologies can be used to overcome the shortcomings of conventional systems that use toll booth vehicle detection and manual payment. These are roadside only system, dedicated short-range communications, and in-vehicle only system. Each electronic toll collection system compromises one or more component technologies such as automated number plate recognition (ANPR), dedicated short range communication (DSRC) and GPS on board unit (OBU) to perform one or more of the three main functions.

3 Public support of congestion price.

Among the main factors for implementation of congestion price is the acceptance of it by the user. Accordingly, the designed scheme and technology should be accepted by the society who use the road. The study by (Drazenko Glavic, Milos Mladenovic, Tapio Luttinen, Svetlana Cicevic, Aleksandar Trifunovic, 2017)summarizes the multidimensionality of the road pricing questions in two. These are the economic dimensions and the political dimensions. The economic dimensions should investigate the Willingness to Accept (WTA) and the Willingness to Pay (WTP). In general WTP, the monetary borderline where an individual would be willing to pay to secure the use of goods and services, depends on road type, trip purpose, the amount of travel time savings, total trip travel time, day in a week, time in a day, frequency of motorway use, distance travel on the motorway, total journey length and estimated risk of traffic accident. The acceptability in the political dimensions which are identified as a factor with intrapersonal, interpersonal, and chronologically variability include: frequency of motorway use, problem perception and awareness, attribution of responsibility, subjective knowledge, mobility-related social norms and attitude towards car use, perceived effectiveness, environmental consciousness, and conviction about the introduction of road pricing. In addition, the following

are the main influencing factors of public acceptance (Ziyuan Gu, Zhiyuan Liua, Qixiu Cheng, Meead Saberi, 2018):

3.1 Privacy

Privacy is the main cause of opposition to congestion pricing because the transaction uses many of travelers' personal information. The issue of privacy was addressed when congestion price systems in London and Singapore. For instance, the smart card used in Singapore's Electronic road pricing system doesn't carry personal information of the drivers or vehicles. Public acceptance can be promoted when the transport authorities take the responsibility to keep the privacy of the smart card users.

3.2 Equity

The tolling mechanism may result in the issue of equity. Traditionally for road maintenance and externality of the road user, the government would increase tax on other wealth creating activities in terms of income tax or value added tax which are not related to road use. Thus, the social cost of driving remains to be external and general tax affect individuals who do not use the road.

3.3 Complexity

Complexity is one of the major obstacles to congestion pricing. Acceptability in the public increases if the scheme is less complex. From the experience of Stockholm, ease of understanding should be the initial focus rather than an efficient but complex theoretical tolling structure.

3.4 Uncertainty

The other reason to decrease the acceptability of congestion price is uncertainty. The uncertainty of the scheme and/or technology used in terms of its effectiveness which is closely related to the modal substitution costs, willingness to pay, or revenue collection.

4 Case studies

The distance-based toll-charge method more preferable for the next generation of congestion pricing schemes that can maximize total social benefits. The distance-based toll-charge method can be efficiently implemented with the aid of global positioning system (GPS) and an on board

unit (OBU) integrating a GPS receiver, a digital map, and a general packet radio service (GPRS) communication device. It is note that toll charges for the distance-based toll-charge method should be a function of the travel distance between the pricing cordons, which is termed distance- based toll-charge function.

4.1 London

The congestion was estimated by the reference to the excess travel rate comparing to travel rate in the early hours of the morning with those during charging hours. Immediately after implementation, the rate is decreased from 2.3min/km to 1.6min/km, though it returns to 2.3min/km by 2007. Moreover, traffic has been decreased continuously, being 25% lower in 2016 than in 2007. Generally, the London congestion charge scheme has been successful in any respect: the implementation was with skillful political leadership; there was good public acceptability; technology, which use the number of plate recognition cameras to enforce compliance, has proved reliability.

4.2 Singapore

Singapore has always sought to make the case against congestion through economic terms as the government recognizes that driving creates social costs. As such, the government has always levied a high premium for the right to own and drive private vehicles. Thus, as long as motorists are prepared to pay the full social cost of their driving, they can drive as much as they want. Various measures have been implemented to manage the increase in the number and usage of a vehicle on the road. These include Additional Registration Fee (ARF), Area Licensing Scheme (ALS), Mass Rapid Transit (MRT), Vehicle Quota System (VQS), Off-peak car (OPC) scheme, Road pricing scheme (RPS), Electronic Road Pricing (ERP) and Light Rail Transit (LRT) on 1972, 1975, 1987, 1990, 1994, 1995, 1998 and 1999 respectively. However, the government has not been uniformly successful with its anti-congestion policies.

Electronic Road Pricing (ERP), demand sensitive congestion toll on every vehicle without requiring them to slow down or stop when congestion level in the restricted zone exceeds a preferred threshold level, used to electronically monitor and track vehicles to ensure a smooth traffic flow. The ERP technology employed a complicated combination of radio frequencies, imaging and smart card technologies, optical detection, and cameras and computers working in unison. The system is based on a relatively simple dashboard-mounted device. Motorists insert a cash card into the in-vehicle DSRC unit when they are on the road. As their

cars pass overhead gantries set up along the strategic roads, the card-reader is activated by a microwave signal. There is a beep and the toll is deducted from a cash card – a pre-paid smart card, which can be credited at all local post offices, banks, petrol kiosks or automated teller machines.

On the first day of its implementation (April 1, 1998), the usual morning rush hour traffic from 7:30 a.m. to 9:30 a.m. along one of the heavily congested highways decreased by 17% from 16,203 vehicles to 13,451 vehicles.

The ERP system has several advantages over the other congestion pricing schemes. Firstly, it rations vehicle flow efficiently since it charges directly and can easily be adjusted to charge more during peak hours and high traffic volume periods. Unlike the traditional toll booths, electronically tagged vehicles can be accurately tolled even at a traveling speed of up to 100 km/h. Cars need not slow down, and drivers need not carry the correct change.

4.3 Hong Kong

The city of Hong Kong started investigating congestion price in 1983 and undertaken four steps. These are pricing study, electronic road pricing feasibility study, electronic road pricing modeling and technology update and electronic road pricing pilot scheme development. The study of electronic road pricing modeling and technology update show that there are no strong arguments for introducing congestion charging in Hong Kong at present because of adverse economic conditions that indicate traffic growth would be lower than forecast and a free bypass road should be available so that to the scheme is effective. A survey that was part of the study indicated the road pricing was supported by more than 60%, though the number dropped to 52% among vehicle drivers. Regardless of knowing that buses would exempt from charging the most supportive was from buses drivers from all drivers (Taxi and truck drivers).

A detailed public participation exercise was commenced from 2015 to 2016 that consulted on privacy, effectiveness and complementary measures. The consultation is over basic elements of charging such as charging area, charging mechanism, charging period, charging level, discount and exemptions, and technology.

4.4 Oregon

This project was motivated by a perceived need to replace the fuel tax for road funding, a desire to manage traffic congestion in Portland metropolitan area, and a preference for transparency in road funding. The broader test involved the participation of volunteers with 300 vehicles paying $0.01 per km for driving in Oregon from June 2006 through March 2007. ODOT sought and received approximately US$400,000 in federal grant funding to investigating distance based road pricing as a potential funding mechanism for Oregon's road system. Accordingly, the Road User Fee Task Force (RUFTF) which chose a distance based, a road usage fee as the best replacement option for the fuel tax. Besides the following recommendation was pointed out.

- ✓ A congestion pricing trial should be integrated with distance based road usage fee as a base rate adjustment to the base fee by adding a peak hour rate.
- ✓ A GPS based system should be trailed for congestion pricing through peak hour pricing by area, pricing primary routes and side roads and streets equally so as to minimize traffic diversion
- ✓ Area charging should involve charging variable rates within a defined geography without discrimination for a particular roadway with all routes priced the same per mile drove within the area during the same periods.

Two methods of recording distance, using click client devices installed within participating vehicles for uploading data wirelessly at service stations traveled was employed. These are;

- ✓ A method used GPS only devices to identify location and distance traveled
- ✓ A method used GPS for location only and accessed the vehicles speed sensor through onboard diagnostic port for calculating distance traveled.

There was an encouragement for participants by providing incentives to change behavior by the creation of accounts for their vehicles that would reward them at the end of the trial for reducing their driving behavior. Service stations remitted the accumulated distance traveled fees and the congestion charge to ODOT once a month.

Privacy is one of the most attributes for public acceptance of the scheme. Regarding this, the individual privacy was protected by use of thick client in-vehicle GPS device that erased detailed travel coordinates concurrently with measuring distance traveled and only summary

distance traveled data was uploading for the use in determining the congestion charge. Moreover, the devices proved accurate in differentiating zones for congestion pricing, though this was by no means a sophisticated from network pricing.

Evaluation of the entire effort combined the congestion charging demonstration with the distance based road usage fee pilot test. The volunteers' opinion were surveyed at before the pilot, mid of pilot and after the pilot to evaluate results. Overall, the pilot was successful in terms of acceptability to participants, achieving 91% satisfaction among participants though few hundred participants were evaluated.

4.5 Seattle

Citizens in the great Seattle metropolitan area face a significant traffic congestion problem; they spend 40% more time traveling by automobile during peak periods that they would spend if congestion were not present. Annual Cost of congestion at the start of the pilot project, for residents and businesses in the central Puget Sound region, ranges between $1.5 billion to $2 billion. To eliminate these problem constructions of new transportation capacity such as highway, transit lines, and vehicles, bike lanes, or sidewalks is expensive due to the regions topography and development pattern. Accordingly, the public policy paid more attention to improve the effectiveness of the existing system and managing the demand of travel. Congestion tolling is one of the effective management toll to make more efficient use of the roads by charging people who use them. The major problem in transportation occurs when too many people want to use the same route at the same time. Therefore, road pricing is based on charging a variable toll: one that is higher on congested routes at the congested time, offering a lower cost option when demand is less. A few existing variable tolling projects have demonstrated that pricing can increase the efficiency of a transportation system.

In 2002, the Puget Sound Council (PSRC) received a grant from the Federal Highway Administration to conduct a pilot project. The main aim of the project was to see travelers' reaction to road pricing in response to variable charges for the road use. The Traffic Choices Study recruited a statistically significant sample of volunteers and, after establishing their baseline "before-tolling" driving routine, began charging them for access to selected roadway facilities at particular time periods in the day. The experiment integrated functions that are already commonly found in automobiles into a single onboard device, or meter. Global

Positioning System (GPS) technology is used to provide a highly detailed record of travel behavior for each vehicle.

On July 1, 2005, the tolling system became operational. As study participants drove their vehicles on tolled roads the appropriate charges were deducted from their venture account balance. The on-board tolling meters which had previously been displaying only the name of roads driven were now displaying the name of the road and the toll rate per mile.

Costs would be determined based on the measured and recorded data about road usage with vehicle classification information. The Occasional Program offers only a flat rate for the usage of the road network for a period of time. The flat rate would be based on the vehicle category and the registration period. Invoices for road usage under the Main Program would be generated monthly and distributed via e-mail, Internet, or postal service depending on the choice of the user. Payment would be possible by several methods such as direct debit, credit cards, debit cards, and checks. The Occasional Program requires prepayment via any of the same payment methods used for the Main Program.

Implementation of this scheme, variable road tolling, causes travelers using congested facilities during the peak period will pay more than they currently pay through the gasoline tax alone. Off-peak and night charges, on the other hand, could be less than they currently are if tolling were implemented broadly enough to permit average gasoline taxes to be reduced. This change in costs would cause some diversion of trips to different routes, at different times, by different modes, and may induce some travelers not to travel at all. Because these adjustments in travel behavior relieve traffic levels on the priced roadway, the roadway offers faster and more reliable travel times to all vehicle types, which may benefit even those who are induced to change their travel behavior.

5 Conclusion and recommendation

Traffic congestion arises in the area of high population density with a high level of car ownership though it is related to user expectation and road system performance. Congestion tends to be self-regulating: if traffic increases on the road and congestion is expected, the travelers change the route they used, the time of travel, the mode they use, or maybe not travel at all. Traffic congestion in an urban area has effects like delay, difficulty to estimate time, road

rage, and limitation of space for emergency vehicles, fuel consumption and pollution thus affects the living condition and the safety of mobility.

Congestion pricing is a way of harnessing the power of the market to reduce the waste associated with traffic congestion that works by shifting purely discretionary rush hour highway travel to other transportation modes or to off-peak periods. Congestion pricing is used as financing, traffic management toll, making all costs perceptible, internalization of external cost, and calculation of external cost. The society hesitates to accept the policy due to the reasons related to privacy, equity, complexity, and uncertainty. Currently used congestion pricing methods are classified into the facility based scheme, zonal based scheme, cordon based scheme and distance based scheme.

The London road congestion charge is started in 2003 in central London that covers 21km^2 which accounts for 3.1% of the city surface. The congestion charge is applicable for driving a vehicle within the charging zone between 07:00 and 18:00 on weekdays. Unlimited entrance, exit, and travel is allowed during the time of application. The London congestion charge scheme has been accepted in many respect: the implementation was with skillful political leadership; there is good public acceptability; technology, which uses a number of plate recognition cameras to enforce compliance, has proved reliability.

In Singapore Electronic Road Pricing (ERP) which is a demand sensitive congestion tolling on every vehicle without requiring them to slow down or stop when congestion level in the restricted zone exceeds a preferred threshold level to ensure a smooth traffic flow is applied. The ERP uses complicated technologies that are a combination of radio frequencies, imaging and smart card technologies, optical detection, and cameras and computers working in unison. Motorists insert a cash card into the in-vehicle unit when they are on the road. As their cars pass overhead gantries set up along the strategic roads, the card-reader is activated by a microwave signal and the toll is deducted from a pre-paid smart card.

The other example is from Hong Kong. The city planned congestion pricing at present because of adverse economic conditions that indicate traffic growth would be lower than forecast and a free bypass road should be available so that the scheme is effective. A detailed public participation exercise was commenced from 2015 to 2016 that consulted on privacy, effectiveness and complementary measures that focused on basic elements of charging such as

charging area, charging mechanism, charging period, charging level, discount, and exemptions and technology.

The Oregon congestion pricing project was motivated by a perceived need to replace the fuel tax for road funding, a desire to manage traffic congestion and a preference for transparency in road funding. Evaluation of the entire effort combined the congestion charging demonstration with the distance based road usage fee pilot test. The volunteers' opinion were surveyed at before the pilot, mid of pilot and after the pilot to evaluate results. Overall, the pilot was successful in terms of acceptability to participants, achieving 91% satisfaction among participants though few hundred participants were evaluated.

For Seattle, on July 1, 2005, the pilot project became operational. As study participants drove their vehicles on tolled roads the appropriate charges were deducted from their account balance. The on-board tolling meters which had previously been displaying only the name of roads driven were now displaying the name of the road and the toll rate per mile

It can be concluded that congestion pricing is one way of eradicating the negative impact of transportation in the urban area and provide a sustainable transport system. Several method of a congestion pricing scheme are currently implemented in some cities all over the world but the applicability is dependent on the city structure and public acceptance.

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