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Truck-Only Lanes on Urban Arterials: A Value of Time Approach

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Abstract

This study evaluates the travel cost benefits of truck-only lanes (TOL) on arterial roads, from a value of time perspective. A simple three-lane TOL corridor is developed and demand and value of time scenarios are systematically analysed using a user equilibrium assignment procedure. It is concluded that implementing a TOL when truck proportions are too low results in significantly higher travel costs than if all lanes are left as general purpose lanes. Implementing a TOL when truck proportions are too high also does not result in travel cost benefits. Based on travel cost considerations, TOL on arterial roadways appear to be marginally justifiable only under quite specific traffic volume, truck percentage and value of time conditions.

Keywords: Truck only lane; value of time; user equilibrium

1. Introduction

Recent rapid growth in employment and population in the Greater Toronto and Hamilton Area (GTHA), Canada, has led to increasing demands on the transportation network from both the goods movement and the passenger travel sectors. The GTHA has also experienced an increase in urban goods movements due to the increased adoption of just-in-time (JIT) delivery practices, which has resulted in a greater number of lighter weight shipments, and the increased use of air and rail intermodal shipments, each of which begin and end with a truck trip (iTRANS, 2004). The majority of urban freight trips in the GTHA occur on local or regional roads. Sixty seven percent of truck trips in 2006 between the City of Toronto and the adjacent regions of York and Peel were

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not on freeways (DMG, 2006). Due to this high proportion of non-freeway truck trips in the GTHA, the local and regional road networks face increased pressures related to congestion, safety, delay, and productivity losses for the trucking industry and other users (i.e. auto, bus, etc.) of the road, thereby negatively impacting the economic vitality of the region.

One potential strategy that has recently emerged to improve the efficiency of goods movement is the segregation of trucks from other users of the road. Studies done internationally have shown that truck-only lanes (TOL), which restrict trucks to certain lanes of the roadway, have the potential to alleviate congestion for both light vehicles and trucks (De Palma, 2008). Truck-only lanes impact three main aspects of the transportation system: safety, mobility, and cost. First, large trucks pose a safety hazard in mixed traffic because of their lack of manoeuvrability, their larger size, and their unique acceleration characteristics (Middleton & Lord, 2005). Second, if trucks experience reduced traffic volumes on truck-only lanes, they will incur less congestion delay. Third, designing infrastructure for trucks requires higher road-design standards than for light vehicles, in terms of pavement thickness, grades, etc. (Holguin-Veras, Sackey, Hussain & Ochieng, 2003). If trucks travel in a dedicated lane, the rest of the road network can be built to a lower standard, thus resulting in cost savings.

Reich, Davis, Catala, Ferraro & Concas (2002) developed a methodology to select potential sites for exclusive truck facilities based on the following criteria: truck-related crashes; truck volume; percentage of trucks; highway level of service; proximity to seaports; and proximity to other intermodal facilities. Abdelgawad, Abdulhai, Amirjamshidi, Whaba, Woudsma & Roorda (2011) and Bachmann, Roorda & Abdulhai (2011) used microscopic traffic simulation to assess travel time and safety impacts on freeways.

Little formal analysis has been done to quantify the economic benefits of truck-only lanes on arterial roadways. The purpose of this study is to evaluate truck-only lanes on arterial roadways from a travel cost perspective. To accomplish this goal, this research pursues two objectives. First, a simple truck-only lane arterial corridor is analysed to compare travel time savings for trucks against travel time increases for non-trucks through the implementation of truck-only lane. Second, demand conditions (total volume and truck percentage) are identified that would be needed to justify the implementation of a TOL from a value of time perspective.

2. Literature Review

General purpose lanes (GPL) dominate road transportation systems for two main reasons. First, for road capacity in a single direction, two GPL permit higher throughput than two separate lanes (Poole, 2009). Second, if the number of vehicles permitted to use a dedicated lane is much higher or lower than the capacity of that lane, the dedicated lane may provide too little or too much capacity for the designated subset of vehicles (Poole, 2009). Poole refers to this as the “lumpiness” of a lane’s capacity, implying that the risk of building the wrong amount of capacity is less if all the lanes can be used by all vehicle classes. Despite these factors, Poole argues that some corridors could benefit from truck-only lanes, given appropriate truck volume conditions.

When assessing the feasibility of TOL or any other managed lane strategies, the concept of value of time (VOT) is important. Value of time is defined as the opportunity cost of the travel time on a trip, and value of travel time saving is the maximum amount of money that travellers would be willing to pay, in order to reduce their travel time (Qing, Wang & Adams, 2011). Route choice, time of day choice and location choice decisions made by motorists and carriers depend on their perceived value of time, particularly when tradeoffs are being made between cost and time, for example, when a tolled route is available.

Commuter value of time has been widely studied since the concept was introduced by Becker (1965). Time was hence converted to a monetary value, with less cost being assigned to recreation time and more to working time. Mackie, Jara-Diaz & Fowkes (2001) suggested several factors that influence an individual’s value of travel time savings: the time at which the journey is made, the characteristics of the journey, the journey’s purpose, the journey’s length, and the mode of travel.

Value of time for commercial vehicles has been largely neglected in part because it is more challenging to assess. There are two main reasons for this. First, several actors may decide the travel arrangements of commercial vehicles, in contrast to passenger transport where travel choices are generally made by the drivers alone. Second, private firms resist releasing confidential information that may be of significance for their own competitive
advantage. Many studies of goods movement use a single value of time, not explicitly taking into account the value of reliability.

In general, VOT for commercial vehicles is the marginal benefit that a driver derives from a unit reduction in the amount of time necessary to move a particular quantity of goods from an origin to destination (Zamparini and Regianni, 2007). Three possible units of analysis are used: delivery time, transportation time, and travel time (Zamparini & Regianni, 2007). Delivery time is the amount of time from the moment in which there is an arrangement between a shipper and a carrier regarding the consignment of specific goods and the moment at which the goods arrive to the customer. Transportation time includes all logistics operations, such as loading, unloading, travelling, warehousing, and others, performed between the origin and destination. Travel time only takes into account the duration of the travel to move goods from an origin to a destination. Most commercial VOT studies have concentrated on travel time, because delivery time and transportation time may include aspects that are not directly linked to the VOT (Zamparini & Regianni, 2007).

Zamparini and Reggiani provide 46 estimates of VOT from 22 countries. There is a significant range of values provided, which can be partly explained by the different methods used by the researchers to collect observations and partly by external factors, such as the geographical region of the study, per-capita GDP, and others, that vary from study to study. Overall, Zamparini and Reggiani show that VOT estimates range from $0.80 US (2002) to $47.21 US (2002).

Kawamura measured VOT for commercial vehicles using a stated preference survey and a random coefficient logit model (Kawamura, 2003). The variation of VOT estimates was found to depend on fleet characteristics, cargo type, business attributes, for-hire trucks vs. private fleet trucks, and the salary arrangement of the driver. The study identified three elements of commercial vehicles VOT. One, there is a cost element, which refers to the savings or expenditure that occur with a change in travel time. In the short term, these could include operating costs, labour costs, and vehicle depreciation. In the long term, these could include capital costs, licensing and insurance. Two, there is a revenue element, which refers to the use of the additional revenue generated using the travel time savings to increase business volume. Three, there is a stochastic element, which refers to factors such as market demand, business strategy and contract limitations.

3. Study Design

This study uses a test corridor to determine the combinations of total traffic volumes and truck proportions that lead to conditions under which a TOL on three-lane arterial roadways would be favourable in terms of total economic throughput, based on value of time. The test corridor TOL configuration is a three-lane, 5 km long arterial roadway. One lane is converted to a TOL with the other two lanes remaining as general-purpose lanes (GPL) for mixed traffic. The TOL is assumed to be dedicated to medium and heavy vehicles use only (light vehicles are restricted to the GPL), however, the TOL would be optional (medium and heavy trucks are not restricted from using the GPL). The definition of light, medium, and heavy vehicles is derived from the FHWA’s Highway Economics Requirements Systems (HERS) model (Qing et al., 2011). Light vehicles refer to autos and 4-tire trucks. Trucks include medium vehicles (6-tire trucks and 3 to 4-axle trucks) and heavy vehicles (4-axle combinations and 5-axle combinations).

For modelling purposes, light vehicles are assigned a passenger car unit (PCU) of 1, trucks are assigned a PCU of 2. Multiclass generalized cost user equilibrium (UE) is adopted for this research because paths are based on the roadway operating costs (a function of travel time), and because the congested travel times are sensitive to the capacity and volume of the roadway. The term generalized cost reflects a conversion between travel time and travel cost using an assumed value of time. The behavioural assumption of generalized cost UE is that each vehicle travels on the path that minimizes that vehicle’s generalized cost of travel. This implies that at equilibrium, for each origin-destination pair, all used routes have equal travel time, and no unused route has a lower travel time. If the TOL and the two GPL are considered as two routes having the same origin and destination, then the distribution of flows which makes the travel cost of the two routes equal is the user equilibrium solution, subject to the lane access rules. The volume delay function for each lane group in the simple TOL corridor is the BPR formula:
where \( t_f \) is the free flow travel time, \( V \) is the volume on the link in PCUs/hr, and \( C \) is the capacity of the link (PCUs/hr). For the test corridor, \( t_f \) is calculated assuming a freeflow travel speed of 60 km/hr over a 1km corridor, and per lane capacity is assumed to be 1000 PCU/hr/lane.

3.1 Scenarios

Total vehicle volume and the truck proportions on the test corridor were varied systematically for each assignment scenario. Conditions were assessed where congestion related delays occur, since travel cost differences only manifest themselves when congestion occurs. The total demand on the test corridor was varied from 1000 PCU/hr to 3400 PCU/hr. The total truck percentage was varied from 22 to 38 percent of total vehicles, since this is the range in which interesting tradeoffs occur.

3.2 Determination of Truck Percentage Thresholds

After performing the multiclass generalized cost user equilibrium assignment for each scenario, the travel cost for vehicles using the corridor was calculated using the equation:

\[
\text{Travel Cost} = \sum_k \sum_l t_l VOT_k V_{kl} \tag{2}
\]

Where \( t_l \) is the travel time on link \( l \), \( VOT_k \) is the value of time of vehicle class \( k \), and \( V_{kl} \) = the volume of vehicles of class \( k \) on link \( l \). The travel cost was calculated for the corridor with and without the introduction of a TOL. The difference in the travel cost between the two corridors was calculated, making it possible to determine the truck percentage thresholds where the travel cost of an arterial road with a TOL was less than the travel cost without the TOL. If the travel costs on the two corridors are the same, then we are indifferent to whether a TOL is implemented or not. However, if the travel cost on the TOL corridor was less than the cost on the corridor without the TOL, then there is a potential travel cost savings with the implementation of a TOL.

The magnitude of potential savings is affected by the VOT assumptions. We assume a light vehicle value of time of $15/hr. Given the variability in estimates of truck value of time, we have assessed three cases for truck value of time. In Case 1, truck VOT are two times that of light vehicles ($30/hr). In the Case 2, truck VOT is three times that of light vehicles ($45/hr). In Case 3, truck VOT is four times that of light vehicles ($60/hr). Clearly, if there is no difference between truck and light vehicle VOT, then there is no rationale for a TOL from the perspective of total travel cost.

4. Results and Discussion

4.1 Assignment results

Traffic assignment results are shown in Tables 1 to 3. Table 1 shows the distribution of cars and trucks on the TOL corridor for all scenarios. The shaded cells indicate the scenarios for which some trucks choose to use the GPL due to congestion related delays. If the total volume is held constant and the total truck percentage is systematically increased, then for a truck proportions greater than or equal to 33% some trucks spill onto the GPL.

Tables 2 and 3 display the travel times on the corridor with and without a TOL, respectively. Travel times on the corridor without a TOL are as expected. As the number of PCUs (i.e. the demand) on the corridor increases, the travel time increases according to the volume delay function. As the truck percentage increases, the travel time remains the same because the overall number of PCUs on the corridor is unchanged.

Examining Table 3 leads to three observations. First, as the total demand on the corridor increases, the travel times on both the GPL and TOL increase. However, travel times on the GPL increase more significantly for scenarios with low truck percentages. Second, as the proportion of trucks increases, there is a greater demand for
the TOL, and thus, the travel time on the TOL increases. Third, the shaded region of the table shows that for scenarios above a truck percentage of 33%, travel times on the corridor with the TOL are equal to travel times on the corridor without the TOL (as shown in Table 3). For these scenarios, trucks start to spill over to the GPL as there is no longer a travel time incentive to use the TOL because of congestion. This follows the principle of user equilibrium, whereby after a certain truck percentage is reached there is no time savings incurred by switching lanes as the travel times on the GPL and the TOL are equal.

Table 1. Distribution of vehicles on the GPL and TOL

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Table 2. Travel times (minutes) without a TOL

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Table 3. Travel times (minutes) with a TOL

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4.1 Travel Cost Analysis

The differences in travel costs with and without the TOL are given in Tables 4 to 6 for different ratios of VOT between trucks and light vehicles. Table 4 shows the increased travel cost of implementing a TOL where light vehicle VOT is $15/hr and truck VOT is $30/hr. Tables 5 and 6 show the travel cost increases where truck VOT is then increased to $45/hr and $60/hr, respectively.

For the demand scenarios with no shading, there is no incentive to implement a TOL, from a travel cost perspective, because the TOL would be underutilized. If a TOL is implemented under these conditions, there is an increase in total travel cost. For the scenarios shaded in light grey there is also no rationale for implementing a TOL because there is no time or cost advantage for trucks using the TOL (both TOL and GPL are experiencing the same travel speed). The darker shaded cells highlight conditions where the travel cost with a TOL is less than without a TOL. Clearly, it is only under very specific demand conditions that a TOL would be warranted from a travel cost perspective.
For the case where truck VOT is double that of light vehicles (Table 4), there is no rationale for a TOL at all. This is because, although a truck’s value of time is twice that of cars, it also has a passenger car equivalent of 2, so that each truck will supplant 2 passenger cars, cancelling out the higher VOT of trucks. For the case where truck VOT is three times that of light vehicles (Table 5) TOL are only justified if trucks represent between 30% and 33% of the total traffic flow. If truck VOT is four times that of light vehicles (Table 6), then the TOL is justified if the truck percent ranges from 28 to 33%. Within this percentage range, the cost savings increase as the total demand increases. In the unshaded range the cost penalty also increases as demand increases, and the cost penalties of a TOL when truck percentages are too low, are much higher than the cost advantages when the in the truck percentages are in the desirable range.

These conclusions can be extended to any absolute VOT, provided that the ratios between light vehicle VOT and truck VOT are consistent with these two cases. For example if light vehicle VOT were $30/hr and truck VOT were $90/min, then all values shown in Table 6 would be multiplied by two and the demand scenarios that justify TOL would remain the same.

Table 4. (Travel Cost With TOL) - (Travel Cost Without TOL) ($)
Light Vehicle VOT = $15/hr, Truck VOT = $30/hr

<table>
<thead>
<tr>
<th>Total Truck %</th>
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<th>1900</th>
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Table 5. (Travel Cost With TOL) - (Travel Cost Without TOL) ($)
Light Vehicle VOT = $15/hr, Truck VOT = $45/hr

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Table 6. (Travel Cost With TOL) - (Travel Cost Without TOL) ($)
Light Vehicle VOT = $15/hr, Truck VOT = $60/hr

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5. Conclusion

This study has identified thresholds of truck percentages for different total demand and VOT scenarios which would justify the implementation of a TOL on a 3-lane urban arterial on the basis of travel cost. In particular, the following conclusions can be drawn:

- A significant factor in determining whether there is a travel cost saving is the VOT of the vehicle classes using the roadway. As the VOT of trucks increases relative to that of light vehicles, the magnitude of potential cost savings increases. Furthermore, the greater the VOT for trucks, relative to light vehicles, the lower the proportion of trucks needed to justify implementing a TOL, from a travel cost perspective.
- Appropriate demand conditions are needed to warrant a TOL. If not enough trucks use the TOL, the corridor is not operating at its maximum efficiency. However, if too many trucks wish to use the lanes, leading to TOL delays, the benefit of these lanes is lost.
- Implementing a TOL on an arterial that does not meet the thresholds established in this research results in higher travel costs than if all the lanes are left as general purpose lanes. This observation highlights the importance of establishing appropriate criteria for the selection of corridors that can support TOL.
- While truck travel times can improve slightly through the implementation of a TOL, light vehicle travel times potentially increase much more.

This study has limitations that could be addressed with further analysis, as follows:

- This study is for a single corridor and does not take into account system-wide effects caused by the implementation of a TOL. For example, implementation of a TOL may draw trucks from other parallel corridors, which could result in better utilization of the facility. System-wide effects could be assessed using a more extensive network model incorporating parallel routes.
- The study does not explicitly consider the impact of time-of-day restrictions on TOL usage. For example, enforcing TOL only at times when the truck percentage is in the preferred range, could be an effective strategy.
- This research only looks at an urban arterial case study, however, could the same method could also applied to examine TOLs on freeways, which carry a significant portion of truck trips. We would expect similar conclusions.
- The analysis for this study was performed using a macro-level trip assignment model (user equilibrium). Micro-effects, such as lane-changing, car-following, and queuing behaviour are ignored. If the right lane is designated as a TOL, it would be useful to examine how cars and trucks interact, particularly in congested conditions, when a truck or car needs to change multiple lanes in order to make a turn or to access the appropriate lane. A microscopic traffic simulation model could be used to analyze this behaviour.
• The analysis only considers the cost of travel time as justification of TOL. Total economic impacts of TOL should also include the value of reliability, potential for accidents, etc. The cost of implementation (i.e. lane construction, pavement rehabilitation, signage, lane striping, etc.) would also be part of the economic equation.

References


