Australasian Transport Research Forum 2018 Proceedings
30 October – 1 November, Darwin, Australia
Publication website: http://www.atrf.info

An advanced method to provide best route information in city logistics with toll roads

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Abstract

There have been rising concerns that freight trucks are diverting off toll roads onto arterial roads, in order to avoid toll charges. This paper presents the development of a freight route model which can advise truck drivers on the optimum route to take between an origin and destination. This model considers various factors when determining optimal travel routes, including truck ownership and type of transportation they provide. Primarily the model compares total costs incurred on a toll route and their non-toll route equivalent, and also considers travel time and travel distance.

The model is illustrated using a case study with 10 pre-determined Key Freight Areas in Melbourne covering two tollways, CityLink and East Link. Travel time and distance data is extracted from the Google API platform, based on all the different Origin-Destination pairs formed from the Key Freight Areas. By considering toll charges on the two links, the cost model is evolved from existing literature to consider the impacts of new variables. Results show that route choice is governed by a combination of factors, which traditionally includes vehicle classification. This model introduces a means of predicting the influence of operator type and freight type on route choice. Consideration of ancillary and hire & reward operators show that operator type is a significant factor in determining whether or not a toll route is preferred. The former is more sensitive towards travel costs due to its smaller capacity, whilst the latter is more sensitive towards travel time savings. This consideration allows for a better representation of different road users and their preferences within the freight network.

1. Introduction

The Australian freight industry is booming and expected to grow considerably as the population in Australia increases. The Bureau of Infrastructure, Transport and Regional Economics (Bureau of Infrastructure, 2011) predicts that the number of freight transactions is set to double by 2030. Road freight is the most dominant part of the industry, and is a main source of truck presence on Melbourne roads (Lu and Cregan, 2003). Internal freight transportation with in Melbourne Metropolitan Region (MMR) is quite high, amounting to 14% of the freight moved with in Australia by weight (Perera et al., 2017). Tollways have fast become an attractive way of financing transportation infrastructure, and this is apparent in the previous construction of CityLink and East Link, and the development of the upcoming West Gate Tunnel and North East Link under Public Private Partnership initiatives. Tollways are designed to allow for more rapid and reliable travel, and they also have a secondary initiative in taking trucks off arterial roads. However, there have growing concerns of trucks avoiding tollways due to toll charges, causing increased social and environmental problems (Perera et al., 2016). This study is centered on these concerns and the means in which they may be addressed. It is clear that costs play a key role in whether a freight vehicle will divert off tollways, and hence there is a need to investigate costs incurred across a truck's journey.

Research into the diversion of freight vehicles from toll roads has been undertaken by multiple parties in the past, and there are generally quite consistent opinions on what influences a vehicle's route of path within the freight network. Since truck drivers do not have the same freedom as car drivers in changing their time and location of travel (King et al., 2014), most considerations are taken from start of travel at the route's origin. A study by Cullinane and Toy (2000), pitches the top most influential factors as (1) cost, (2) time-saving, (3) transit time reliability, (4) characteristics of the goods, and (5) services. This is supported by another study Hensher et al. (2016), which states that route choice is primarily determined by the route that results in the lower cost. It is apparent that a fair amount of literature is derived from this concept, however, it is not clear what governs these costs.

In all cases, modelling is the preferred methodology for pursing further research on route choice. A truck cost model developed by Yang et al. (2016) considers both direct and indirect costs in calculating truck externalities. This was done in accordance with a number of different vehicle classifications. Direct costs are made up of Vehicle Operating Costs (VOC), Value of Time (VOT), and other costs such as tolls. Indirect costs consist of social and environmental costs. It is however said that generally only direct costs have an effect on route choice (Quak and van Duin, 2010). VOC makes up a significant part of truck costs, and is a combination of time related costs and distance based costs (Drewello and Scholl, 2015). The time related costs consist of interest, administration, registration, insurance and time based depreciation to the truck; and the distance related costs consist of fuel, tyre, maintenance, distance based depreciation to the truck (Yang et al., 2016). Time and distance-based depreciations are defined based on the time factor (e.g: year of manufacture) and distance factor (e.g: odometer reading) which determines the present value of a truck. The time related cost (usually fixed per year) has been converted to more practical unit, that is distance-based unit (km) by considering average working distance travelled by a truck per day.

Driver cost is the main determinant of VOT (Belenky, 2011), however it has also been said that this cost component may also be considered as part of VOC (Bennett and Greenwood, 2003). The latter considers time related costs as all costs by time incurred, regardless of whether the vehicle is on the road or not. Hence, it seems appropriate to include driver costs as part of VOC time related costs, as wages are paid out by the hour which typically incorporates unloading and loading time at Key Freight Areas (KFAs). Drivers are not expected to be constantly driving for the entirety of their shift. Out of all the cost components of truck costing, fuel costs have been singled out as a key factor of VOC (Yang et al., 2016). Fuel costs are significantly affected by truck speed and traffic conditions, which shows the correlation of these costs to another indicator of route choice, time-saving. Fuel cost models have been developed to account for stop-go conditions and free-flow conditions, however, it is most commonly based on average speed (Naudé et al., 2015). This makes it difficult to apply to route paths with tollway segments, since speed is expected to vary with traffic exponentially. Whilst it may be simple to say that higher travel speed results in lower fuel costs, in reality the optimum speed for fuel is not always the lowest if traffic condition is considered (Yang et al., 2016). This can result in underestimations when costing fuel.

Tolls are another component of direct costs which is considered to be significant when determining route choice. In Melbourne, this is due to the variance in tolls that can be seen with CityLink and EastLink. There are changes in travel costs between different origins to destinations (O-Ds) when tolls are charged, and this is due to the fact that toll charges are set to manage congestion (Yang and Zhang, 2002) or to recover intense capital expenditure (e.g. on structures)(Perera et al., 2016). They do not correlate with distance travelled, but rather to tollway demand or traffic volumes. To assist with travel costing on tollways, the concept of Value of Travel Time Savings (VTTS) has been introduced as a cost function of time (Hensher et al., 2016). VTTS is a different concept compared to VOT. VOT is measured in terms of operational view point, but VTTS represent an opportunity cost of truck being available with respect to time. This may be influenced by various factors such as vehicle classification (size, type, etc.), commodity type being transported, load condition, etc. VTTS is calculated from the time saved whilst using toll routes, and its comparison with the toll charge has been a determinant for deciding if the toll route is more optimal. This brings in the opportunity cost of time for truck users which is vague in general due to variability in influential factors explained above.

The general approach of determining route choice from costs is by comparing the direct costs of different route paths; and the route with the lower cost is typically considered more optimal. It has been argued that this type of modelling has led to over-predictions in traffic demand on tollways (Li and Hensher, 2012). The paper by Li and Hensher (2012) highlights a toll budget constraint that should be considered, which means that different freights operators may have different toll thresholds that cannot be exceeded.

The Australian road freight industry is mainly composed of two types of operators, ancillary operators and hire & reward operators (Lu and Cregan, 2003). Where the operator is a larger company, such as in the hire & reward case, toll charges are less likely to deter them from using tollways. From statistics (Australian Trucking Association, 2004), it is shown that 70% of operators have one truck and 24% have two to four trucks. The variety of operators in the Australian road freight industry shows breadth in cost tolerances that could be considered in truck cost models. It seems there is value in investigating route costing for different operators, and hence this is the area that will be pursued for this study. A freight route model is to be developed to advise truck drivers on optimal route choices, whilst considering a given set of specifications such as vehicle classification (e.g. size) and operator type. This will assist drivers with selecting the best possible route, and maximizing the use of toll roads to provide more efficient travel.

2. Methodology

2.1 Data

To help analyze travel trends across 24 hours of a certain day, travel time data using the Google API was extracted for everyone hour in the day for one typical week (26th October 2017 to 1st November 2017). The Google API is a set of programming applications which is integrated with Google services. It allows access to user data, which in this case is forecasted travel time data for a given O-D in future dates. Travel time and travel distance for each O-D pair is extracted for each hour of the day, across all seven days of the week. Data is also extracted separately for routes taking toll roads, and routes taking only non-toll roads. Note that the data sets are not generated from freight specific traffic, but rather from a generalized vehicle pool of cars, which creates some limitations. Nevertheless, useful insights can still be made from the data. Whilst it is expected that there will be variance between data sets from Monday to Sunday, data from only Thursday is selected for the purpose of detailed analysis. In other words, trips made during Thursday only has been analyzed in this study to reduce the complexity of data analysis, having the assumption that same approach can be applied to trips made on the other days of the week as well. This data is analyzed for (1) travel time, (2) travel distance, (3) time saving, and (4) maximum and minimum speed. The Google API distance and time data for travel along the toll route and non-toll route are compared for all ninety O-D pairs. Where both travel distance and travel time is found to always be greater, the O-D is designated as “non-toll route only”. The rest of the O-Ds is determined to have differing optimal routes according to time of day and will require the use of this study’s freight route model to determine optimal route.

In addition to Google API data, toll charges for two main toll roads considered in the case study was extracted from the toll operators official web site. Since the toll roads in Melbourne has a vague charging structure, vary from section to section, toll charges were extracted for the relevant sections based on the route choice given by the Google API. A separate analysis was also carried out to express the toll charging mechanism in Melbourne toll roads and presented in section 4.2.

2.2 Model Development

For this study’s model, the direct costs for an O-D trip be comprises of the VOC, and tolls that have already been accounted for. Similar to the literature model, VOC is divided into two parts: time-based costs and distance-based costs (Yang et al., 2016). Using both Freight Metrics’ Road Vehicle Operating Costs model (Freight Metrics, 2016) and the model from Perera et al. (2016), cost parameters are selected and developed. Freight Metrics is an existing online guide to truck costing in Melbourne. The influence of vehicle classification on VOC has been well proven in literature models, however, new inputs are also introduced in this model. These inputs are operator type and freight type, both of which are key considerations in the freight market. A summary of the relevance of these inputs in determining the value of costs is shown in Table 1, where assumptions on operator preferences and impacts of freight type on costs are made. Utilizing these assumptions and their corresponding factors, distance-based costs ($/km) and time-based costs ($/hr) are developed as functions. They are linked to the model’s primary and secondary inputs, whereby the primary inputs are to be selected by the truck driver for their journey, and secondary inputs are determined based on the primary input selections. It is assumed that administration costs, driver costs and depot rates will not be relevant (or less decisive factors) to trucking costs for ancillary small businesses.

Table 1: Impact of model inputs on cost parameters

	Distance based costs					Time based costs						
Model input	C_{fuel}	$C_{service}$	$C_{maintenance}$	C_{tyre}	$C_{depreciation1}$	C_{driver}	$C_{insurance}$	$C_{registration}$	$C_{administration}$	C_{depot}	$C_{interest}$	$C_{depreciation2}$
Vehicle classification	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Operator type		✓	✓	✓	✓	✓			✓	✓	✓	✓
Freight type					✓		✓				✓	✓

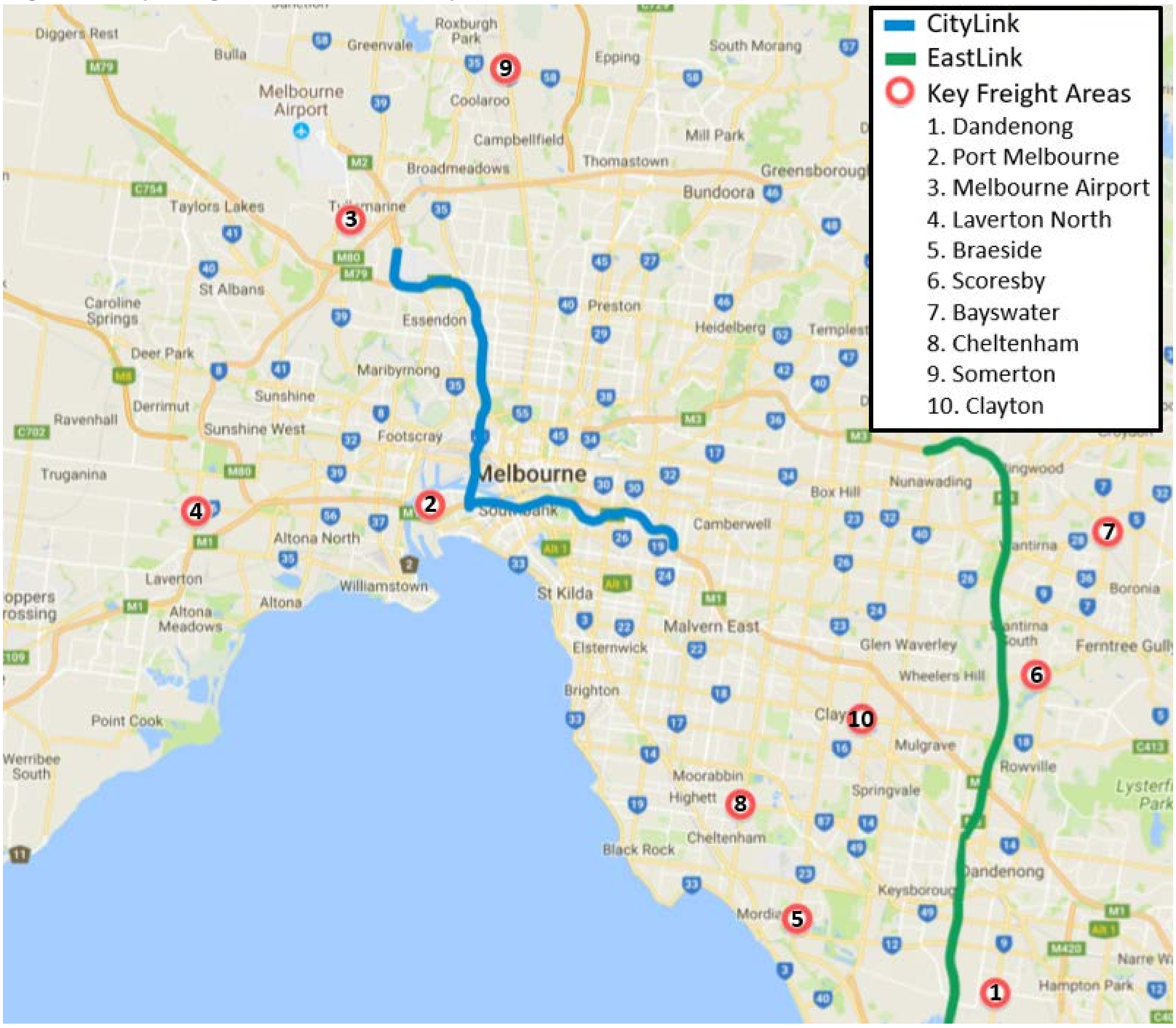
Note: ✓ Has impact on cost parameter

Using outcomes from previous steps, the model is developed to calculate total trip costs for both toll and non-toll routes. Comparisons between toll trip costs for toll routes and non-toll routes are made, and the optimal route can then be determined. Due to uncertainties around assumptions made, a 5% confidence interval will be provided for. Where the total trip cost for the toll route is smaller than the cost for the non-toll route, the toll route will be the optimal route. Furthermore, if the total trip cost for the toll route is greater than the non-toll route but is still within a 5% confidence level of the non-toll route cost, the toll route will still be considered as the optimal route. For hire & reward operators, the toll route will always be the optimal route as long as its travel time is less than 5% greater than the non-toll route travel time. Model outputs can then be analyzed and discussed against literature.

3. Case Study in Melbourne

To give the study some scope, routes between ten Key Freight Areas (KFAs) in Melbourne will be considered, as shown in Figure 1. KFAs are numbered from 1 to 10.

Figure 1: Key Freight Areas in case study (with reference numbers)



These locations are selected from major areas of freight transfer and interchanges, including Port Melbourne and Melbourne Airport. The clustering of KFAs in the eastern and northern regions of Melbourne is attributed to the strong presence of industrial works and warehouses in the area. CityLink (denoted in blue color) and EastLink (denoted in green color), the two toll roads in Melbourne area are located among those KFA (as shown in Figure 1) to facilitate intra city freight trips as they intended. The markers on the toll road indicates the entry/exit point on the toll road. The KFAs form origins and destinations for routes and yield a total of 90 different combinations of O-D pairs. Each O-D will have an optimal route according to its specifications; which include time of day, vehicle classification, operator type and freight type. This study considers: time of day to the nearest whole hour to reflect the data sets extracted from the Google API. Nine vehicle classifications for urban areas have been considered, with two Light Commercial Vehicle (LCV) and seven Heavy Commercial Vehicle (HCV) categories. HCV includes both articulated or rigid trucks, as well as b-doubles of up to 8 axles. Road trainers are not considered in this study as they are more appropriate for rural roads. In addition, three operator types will be used in the study to highlight differences between hire & reward operators, and two sub-divisions of ancillary operators: small businesses and franchise (larger businesses). Eight freight types are considered, to represent the commodities that are most dominant in driving the Australian economy. They include dry goods, construction material, and liquid bulk.

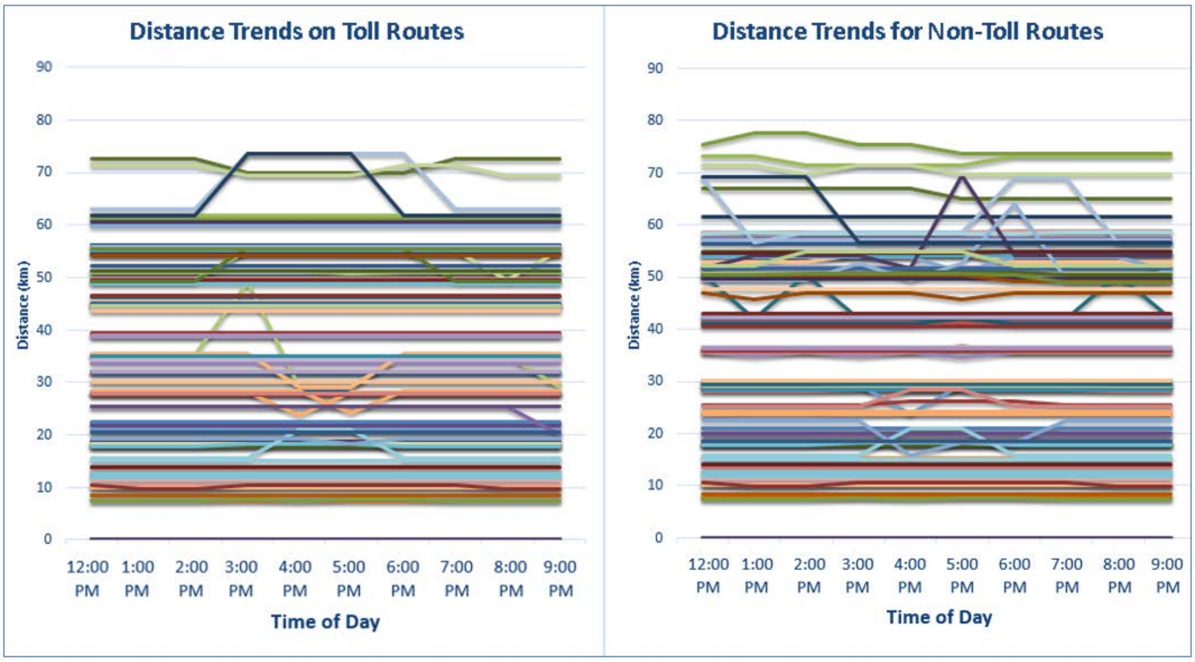
In order to integrate the CityLink and EastLink tolling schemes into the freight vehicle model, the format of the tolls has to first be evolved from what is found on their home websites. CityLink’s format that prices travelled road segment between an entry and exit point, is determined to be most appropriate for applying to Excel functions. The EastLink tolls are changed to match the CityLink format. Since tolls change based on vehicle classification and time of day (only for CityLink), the toll generators are linked to the appropriate primary inputs for the model. O-Ds are inputted into the Google Maps to (1) verify the O-Ds that are determined to only utilize a non-toll route, (2) identify the most probable toll route for the rest of the O-Ds. For Part 2, the toll route options presented by the Google Maps for each O-D pair are compared to the Google API data, and the route is chosen by selecting the option that aligned best with the data. In most cases, there is a stand-out option on the Google Maps and the tollways used are able to be clearly identified. Since tolls from CityLink and EastLink are charged in accordance to stationed toll points, the entry and exit points of the links are recorded down for each O-D toll route. These points are then applied to the toll generator to find the toll for each O-D. Note that for this study, each O-D will only be assigned a single toll route option.

4. Results and Discussion

4.1 Data Analysis

A key sample time was chosen between 12:00pm and 9:00pm, and data for both toll route and non-toll route was extracted from the Google API data sets for Thursday. Only one day of the week was selected, in order to allow for detailed analysis within the specified study period. Since data trends between peak periods (AM and PM peaks) and off-peak periods are the focus of this analysis, only one of the peak periods is required to be looked at in more detail. The chosen sample time between 12:00pm and 9:00pm considers trends for PM peak and off-peak periods. The graphs in Figure 2 and Figure 3 were produced for analysis.

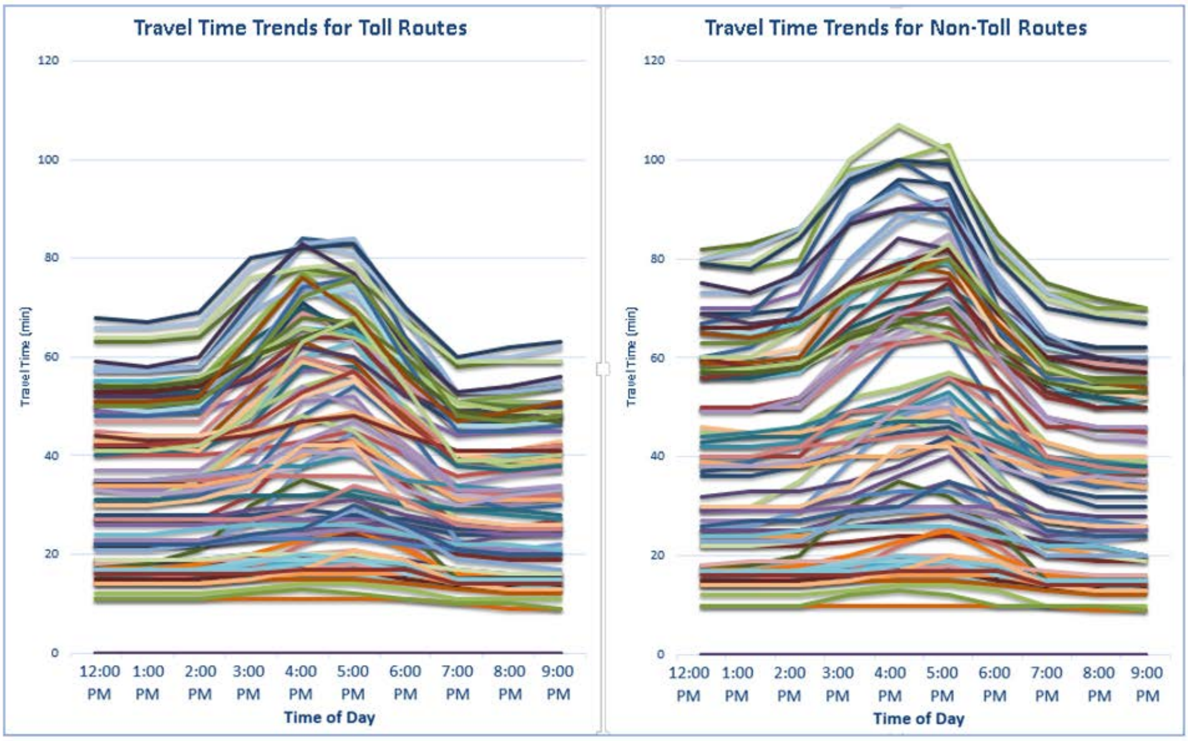
Figure 2: Distance trends from traffic data for 12PM-9PM



A comparison between the graphs in Figure 2 show that O-Ds that have a greater distance on their toll route, also have a greater distance on their non-toll route – this is already known intuitively. What is surprising is the relative similarity between the distances incurred on the toll routes and non-toll routes. Whilst peak hour is hinted at from the more drastic changes in distance seen between 2:00pm and 7:00pm, there are quite a number of O-Ds that remain relatively linear throughout the whole period of time displayed. This suggests that there are O-Ds that do not warrant route changes over the course of a day. In contrast, the O-Ds that show distance fluctuations may utilize slightly altered routes that involve detours and diversions, as a result of responding to congestion. They may also be O-Ds that are forced to have their optimal routes changed between toll and non-toll, depending on the hour of the day. O-Ds that show more drastic fluctuations are more likely to be akin to the latter case. There is also the possibility that they are derived from errors that may occur during data collection.

Figure 3 (below) clearly shows the presence of peak hour, and the time frame of peak hour is relatively consistent between the data collected on toll routes and non-toll routes. Whilst it does generally take longer to travel along a non-toll route, as shown by the peak at ~107 minutes, the O-Ds clustered at the bottom of the graphs show smaller variances between the corresponding toll and non-toll routes. In fact, they are almost exactly the same in some instances. It is expected that trucks travelling between these O-Ds will most likely always utilise the non-toll route option.

Figure 3: Travel time trends from traffic data for 12PM-9PM



A comparison between the travel times on an O-D's toll route and non-toll route show that time savings can range from 0 minutes to 25 minutes. Sample data sets at 9am and 9pm have been considered for peak hour and off-peak hour respectively. Results are summarized in Table 2.

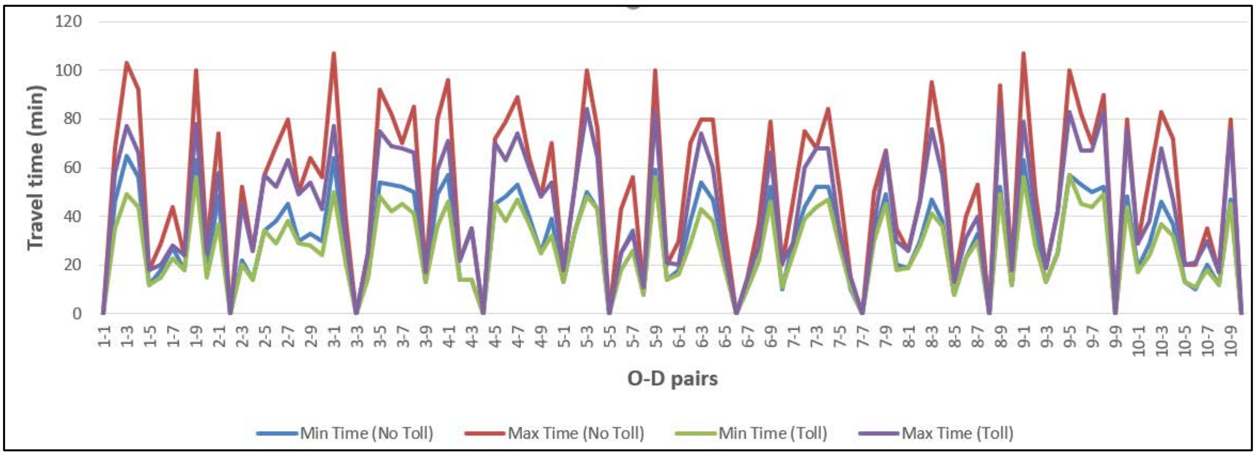
Table 2: Time saved by using toll routes

t minutes saved	No. of O-D Pairs (Peak – 9AM)	No. of O-D Pairs (Off-Peak – 9PM)
$t < 0$	25	24
$1 < t < 5$	17	26
$6 < t < 10$	17	22
$11 < t < 15$	15	15
$16 < t < 20$	14	3
$21 < t < 25$	2	0

It can be seen that there are around 25 O-D pairs that do not result in any time savings when using their toll route, and this is consistent for peak and off-peak hours. There are quite number of O-Ds that incur a decent amount of time saving, however, the corresponding toll costs will also have to be considered to determine whether or not they exceed the operator's cost threshold. A toll route that is only marginally faster than its non-toll equivalent is still not expected to be preferred by hire & reward operators if it is substantially costlier to travel along.

Putting together the toll and non-toll time data sets from the Google API, the optimal travel times for the O-Ds can be found, and they are shown in Figure 4. This graph focuses on the minimum and maximum travel times found to occur across an entire day.

Figure 4: Maximum and minimum travel times using Thursday data



When comparing the travel times between routes with toll and no toll, it can be said that it is generally preferable to go via a toll route. However, there are quite a few O-Ds such as 2-8 (Port Melbourne to Cheltenham) and 9-10 (Somerset to Clayton) that show similar or marginally different travel time along their toll and non-toll routes. Thus, these O-Ds' optimal routes cannot be differentiated by travel time alone, and it likely that ***total cost*** incurred during travel will be the governing factor in whether the toll route or non-toll route will be most preferred. As stated in the previous section, the study by Cullinane and Toy (2000) pitches speed as one of the top most influential factors in determining route choice. However, the importance of speed and time saving is also trumped by costs, which may very well be the heart of the problem of freight vehicles diverting off toll ways. The same study by Cullinane and Toy (2000), ranks cost above speed when determining route choice.

The distance and time graphs analyzed above all point towards some O-Ds that always have their non-toll route as the optimal option. This means that for these O-Ds, the non-toll route is both faster and shorter to travel along 24 hours a day, 7 days a week. Since costs are comprised of time-based costs and distance-based costs (Drewello and Scholl, 2015), the top two influential factors of route choice (Cullinane and Toy, 2000) are satisfied. Using the method outlined, optimal route predictions were made. Results are summarized in Table 3, and it seems that there is potential for toll routes to be the optimal route for a large percentage of O-Ds. There is the possibility for up to 76% of O-Ds journeys to be undertaken via its toll route. O-Ds designated as "non-toll route only" were verified with the Google Maps, and it is clear that traffic data collected from the Google API very closely aligned with the outputs from the Google Maps.

Table 3: Optimal route(s) for O-Ds

Optimum route	No. of O-D pairs	Percentage of total
Non-toll route only	22	24%
Either toll or non-toll route (use model to determine)	68	76%
TOTAL	90	100%

4.2 Tollways and Tolls

It is known that CityLink and EastLink are priced differently, and the developed toll generators for both links show the higher pricing evident on CityLink. A representation of the toll charges on both links is shown in Figure 5 and Figure 6, and it is clear that in many instances CityLink tolls can be double of what is charged for EastLink, even for shorter road segments.

EastLink found to be charging more flat fare (per km) compared to CityLink which introduce the inconsistency to route choice for road users due to inconsistency in tolls applied (per km or per section). It is quite clear from Figure 6 that CityLink tries to charge higher tolls from shorter trips, which are quite frequent in Melbourne, and thus toll charge has become a critical factor deciding optimum route for freight when total cost is considered. In this case study, it was found that the more popular tollway used by the O-Ds is CityLink, which can be potentially used by up to 44 of the 90 O-D pairs. Since tolls on CityLink are much greater than the ones on EastLink, it is probable that diversions off tollways and onto arterial roads is more frequently experienced on adjacent routes to CityLink. O-Ds that involve segments from both links are likely to result in the largest total tolls, however, the number of O-Ds in this category is also a smaller cut of the total sample. Results from the case study are summarized in Table 4.

Figure 5: Toll charges per km for Heavy Commercial Vehicle on EastLink for different O-Ds (N-S Direction)

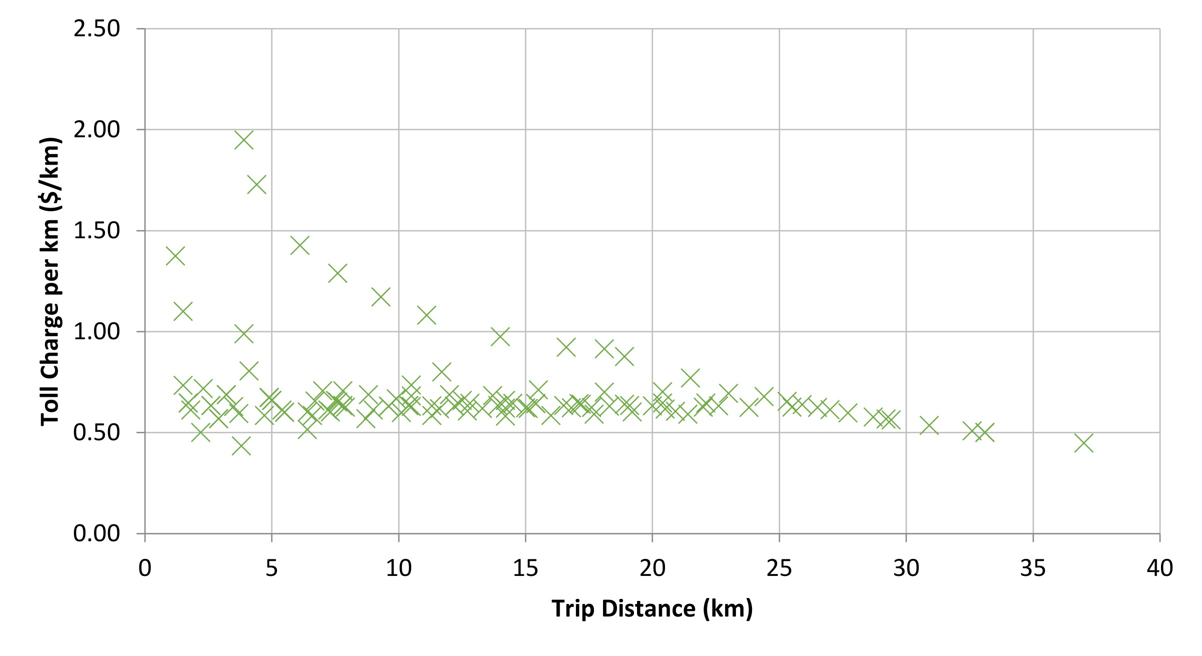


Figure 6: Toll charges per km for Heavy Commercial Vehicle on CityLink for different O-Ds (N-S Direction)

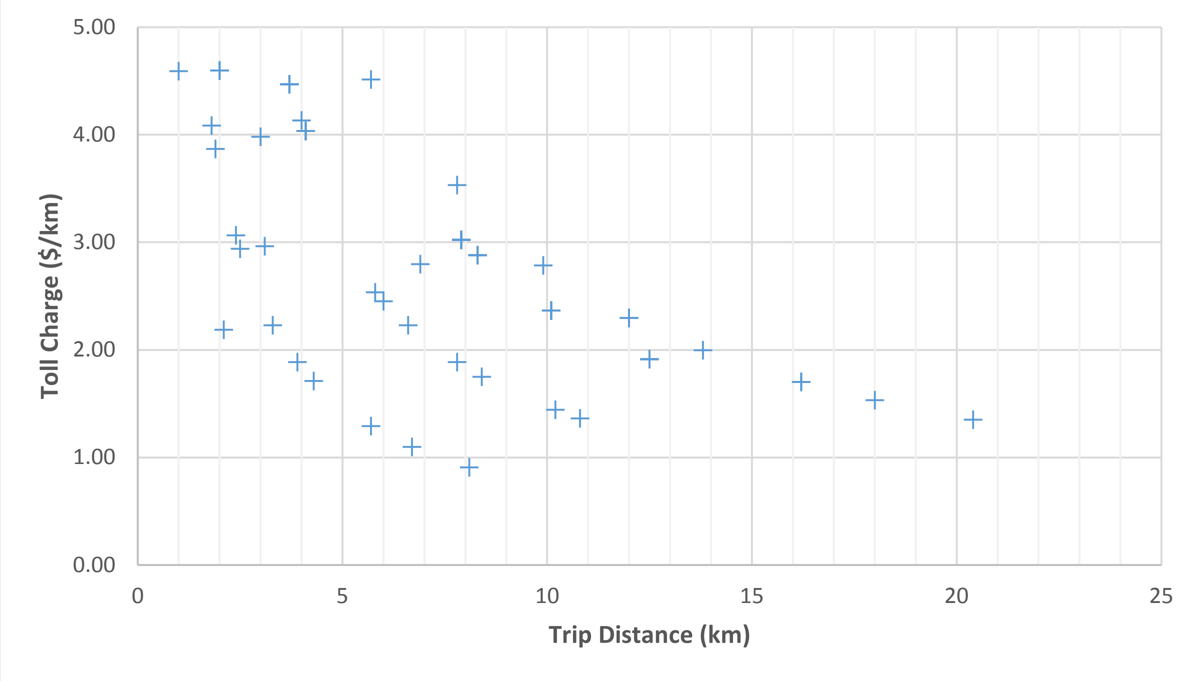


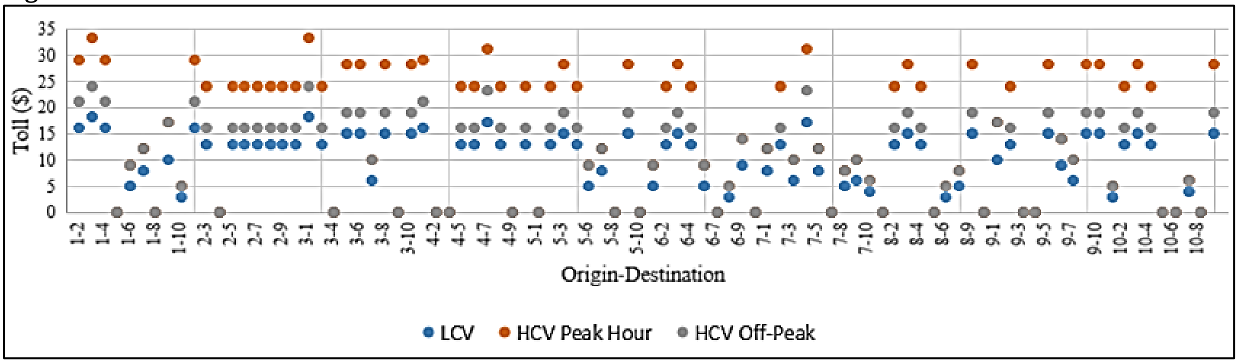
Table 4: Tollways used by O-D trips

Toll link used	No. of O-D pairs	Percentage
Only CityLink	36	53%
Only EastLink	24	35%
Both Links	8	12%
TOTAL	68	100%

Since it was found that up to 65% of O-D journeys could involve sections of CityLink, it is expected that tolls for these journeys will form a substantial factor in determining route choice. It is important to note the differences in pricing for HCV travelling on CityLink during peak hour and off-peak hour, as it is likely that more operators will be less resistant against toll pricing during non-peak hours when tolls are lower. For example, a HCV travelling between Tullamarine Freeway and Toorak Road pays $27.55 during peak hour, and $18.37 during non-peak hours; whereby the latter is much more accessible for more cost-sensitive operators such as ancillary small businesses. However, shifting trucks into night times is a different topic that needs to consider who makes the delivery time decision in the supply chain, which is not within the scope of this study.

A summary for tolls incurred along each O-D is shown in Figure 7. It is clear that tolls for HCV during peak hour is much greater than those for off-peak travel and trips made by LCV. Tolls for LCV reach its maximum at $20, and at $35 and $25 for HCV peak hour travel and HCV off-peak hour travel respectively. Whilst hire & reward operators will likely not be affected by tolls if time travel savings are found to be adequate, it is expected that for some O-Ds, ancillary operators may prefer to use LCV and only HCV during off-peak hours. In the case of ancillary small businesses, the types of vehicles likely to be utilized may be LCV anyway due their lesser demand for freight transportation.

Figure 7: Total toll for each O-D



O-Ds with CityLink segments use a total of three of the total nineteen available entries/exits, and the entry/exit points were found to be used quite prevalently. EastLink's set of entry and exit points had a bit more variety with eight of the total seventeen being in use, however, this is mostly due to the clustered positioning of the Key Freight Areas in the eastern region.

4.3 Findings from the Model

The total trip cost within the model is found based on the primary and secondary inputs of the model. Toll directions are also given where applicable. To help analyze the different cost components and their significance, two sample input sets are considered as per Table 5, to demonstrate the impact of operator type on route choice.

Table 5: Sample input sets during peak hour

Input Set	O-D	Route Type	Travel Time	Travel Distance	Operator Type	Vehicle Classification	Freight Type
1	Dandenong – Port Melbourne (1-2)	Toll	46min	45.1km	Hire & Reward	8 Axle B-Double	Liquid Bulk
		Non-toll	59min	41.2km			
2	Dandenong – Port Melbourne (1-2)	Toll	46min	45.1km	Ancillary (small business)	8 Axle B-Double	Liquid Bulk
		Non-toll	59min	41.2km			

Results for the two samples are shown in Figure 8 and Figure 9 in the form of stacked bar graphs. For both set 1 and 2, it is clear that fuel costs are a significant component of the total trip cost regardless of what vehicle is in use, and this is akin to literature found in the study by Perera et al. (2016). Of course, HCV will cost more to run due to a higher fuel burn rate, however, the proportion of fuel costs to total costs is actually higher in the LCV case. This is perhaps due to the irrelevance of driver costs for ancillary small businesses, which as demonstrated in set 1, can be a costly component of the total. By equally weighing the results in both sets, it can be seen that the top four most prominent costs are: (1) fuel costs, (2) driver's costs, (3) distance depreciation costs, and (4) maintenance costs. As such, distance based costs can be said to have more impact on the total cost than time based costs.

Figure 8: Cost comparison for input set 1 (Dandenong – Port Melbourne)

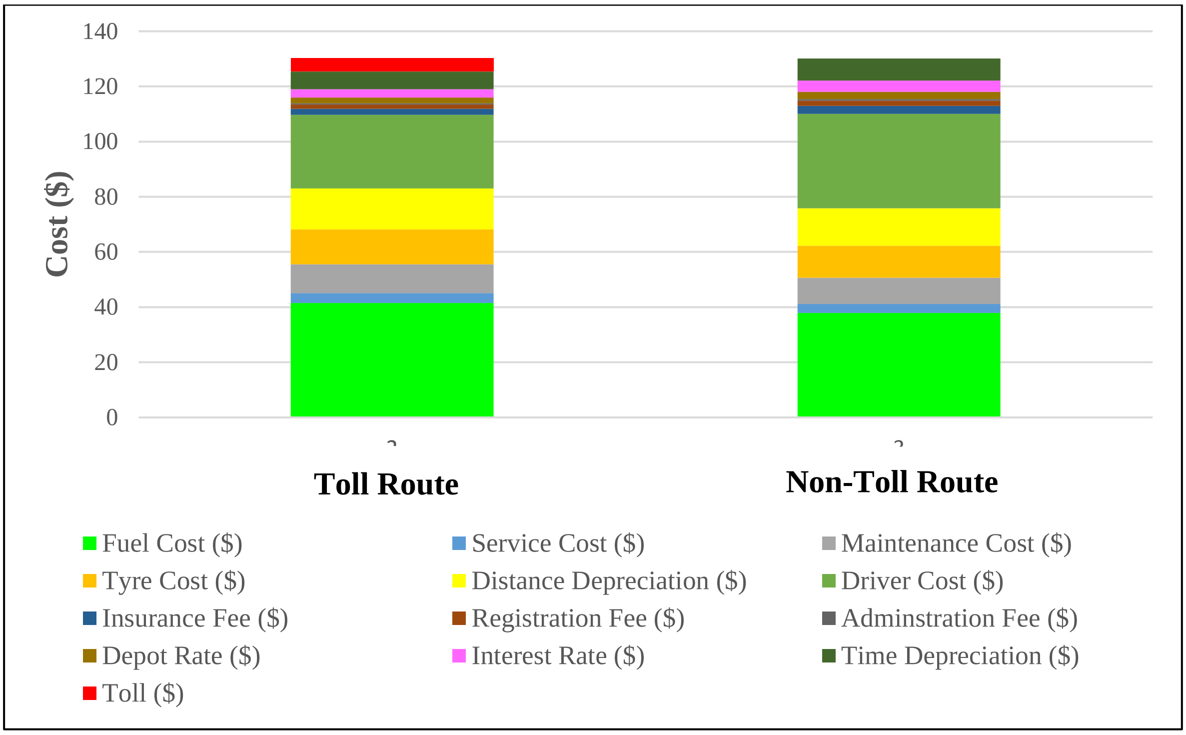
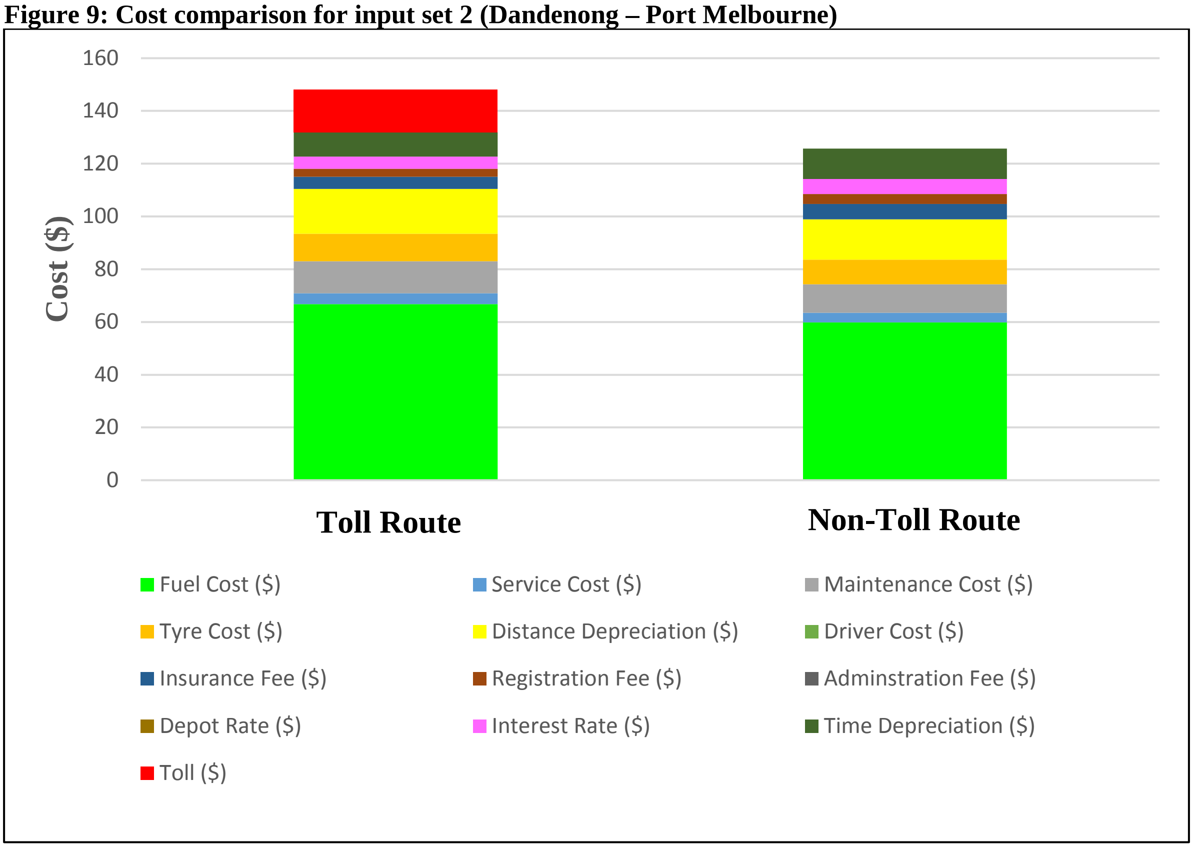


Figure 9: Cost comparison for input set 2 (Dandenong – Port Melbourne)



The significance of tolls is also something that is exemplified in the graphs, as there is a noticeable difference in the proportion of total costs it takes up between the two sets. For set 1, tolls make up a relatively small percentage of total costs and thus is unlikely to be a deterring factor. Cost differences between toll route and non-toll route travel is also quite minimal, and thus it is expected that the toll route will be the optimal route for set 1. In comparison, set 2 shows that the toll route is more than $20 more expensive to travel on than the non-toll route. Since the operator type is ancillary (small business) as well, it is expected that the major cost difference between the routes is likely to cause the operating vehicle to divert off the toll route and onto the non-toll route instead. Whilst there is a time-save of 13 minutes incurred from the toll-route option, it is unlikely that will be a swaying factor for these operators that are less concerned with time-saving.

To gain some understanding on how influential each model input is with route choice, different combinations of inputs were applied to the model to find the percentage of O-Ds that would take the toll route under those combinations. This was done for peak hour traffic which was set at 9:00AM, and off-peak traffic that was set at 9:00PM. Results are shown in Table 6.

Table 6: Percentage of O-Ds using toll route for different model input combinations

#	**Model Input Combinations**	**% of total O-Ds using toll roads during peak hour**	**% of total O-Ds using toll roads during off-peak**
A	Hire & Reward/Short Vehicle/Dry Goods	68%	58%
B	Ancillary/ Short Vehicle/Dry Goods	24%	8%
C	Hire & Reward/8 Axle B-Double/Dry Goods	68%	58%
D	Ancillary/8 Axle B-Double /Dry Goods	27 %	43%
E	Hire & Reward/8 Axle B-Double/Liquid Bulk	68%	58%
F	Ancillary/8 Axle B-Double /Liquid Bulk	29%	47%
G	Hire & Reward/Short Vehicle/Liquid Bulk	68%	58%
H	Ancillary/Short Vehicle /Liquid Bulk	24%	11%

We can see that for all combinations with a hire & reward type operator, results are stagnant and remain at 68% for peak hours and 58% for off-peak hours. This suggests that hire & reward operators always consistently use toll routes to the maximum level. The 10% difference between peak hour and off-peak results shows the importance of time saving for hire & reward operators. Earlier in section 4.1 (Table 3), it was found that there were 76% of O-Ds that could potentially use a toll route. Therefore, there is 8% of O-Ds that do not have significant enough travel time differences between its toll and non-toll routes for even hire & reward operators to consider.

In contrast, ancillary operators show changes in route choice based on vehicle size classification and freight type. Freight type is influential on the vehicle type, and this is exemplified by the use of tankers for transporting liquid bulk, and curtain sliders for transporting dry goods. The former being costlier to run than the latter. Overall, vehicle size classification seems to be most significant in varying the percentage of O-Ds using toll routes. By comparing Combination B and Combination D, it can be seen that larger vehicles with more axles are more likely to utilize toll routes. This is not as profound during peak hour as the percent only changes from 24% to 27%. In contrast, results from off-peak hour show a massive jump from 8% to 43% toll route usage. The large percentage for Combination D during off-peak times show that VOC for HCV can be high enough to encourage ancillary operators to seek time-saving toll routes. It is important to remember that the decrease in toll fees during off-peak hours also serves as a point of encouragement for toll route use. Results from Combination B suggest that VOC for LCV are much lower in comparison, and hence the non-toll route may still be preferred during off-peak hours.

5. Conclusions

Through the modelling of route choice between 10 Key Freight Areas in Melbourne, it was found that tollways can be a beneficial mode of travel. This is of course dependent on the model inputs which considers travel time saving (or operation cost saving), vehicle classification, operator type and freight type. Based on the forecasted travel time data an analysis was carried out to determine the optimum route for freight vehicles considering the other parameters. Whilst freight type was found to have some influence on route choice, its effects were found to be minor in comparison to the two other considerations. Vehicle classification has long been investigated in literature, and in this study, it was confirmed that heavier and larger vehicles were more likely to utilize tollways due to higher fuel and maintenance costs. In terms of operator type, hire & reward operators were found to be more tolerant towards toll charges in comparison to ancillary operators. In addition, they were also more likely to be attracted to time savings from tollway travel, due to the highly scheduled nature of their business.

As stated before, ~70% of operators own only one truck, and it is likely that most ancillary operators will fall under this category. Not much understanding, however, is made known on their operating preferences, which can dictate a lot of the time-based costs and distance-based costs. It is important to consider the needs and preferences of these operators as they make up a decent portion of the market, which may also lack uniformity in terms of standards of operation. Therefore, this study has proposed a methodology to select optimum route for freight vehicles in city logistics considering all major parameters.

5.1 Future Work

Future work that could be undertaken following this study is an investigation of confidence intervals for the cost model. More O-D pairings could also be considered to widen the scope, and the effects of travel across a whole week (Monday-Sunday) could be analyzed for any impacts on time and distance data. The current Excel model puts restrictions on the scope, hence further modelling could be done by integration into MatLab and/or an app form. In addition, travel time reliability can be improved by integrating with real time Google Map data since Google API data lack in real time aspects. In this manner an advanced algorithm can be developed to read road routes and toll sections used in order to automate the toll charge calculation.

Further, indirect costs (externalities) can be incorporated into cost model to provide an additional option for truck users to select. These options can be categorized as environmental friendly option and so on. For sustainable future consideration of externalities will be an essential factor beyond the direct cost based route choices.

References

Australian Trucking Association, 2004. Trucking– Driving Australia's Growth and Prosperity. Prepared by ACIL Tasman Pty Ltd.

Belenky, P., 2011. Revised departmental guidance on valuation of travel time in economic analysis. US Department of Transportation, Washington, DC Google Scholar.

Bennett, C.R., Greenwood, I.D., 2003. Volume 7: Modeling road user and environmental effects in HDM-4, Version 3.0, international study of highway development and management tools (ISOHDM), World Road Association (PIARC). World Road Association (PIARC), Paris.

Bureau of Infrastructure, 2011. Truck productivity: sources, trends and future prospects (No. 123). Transport and Regional Economics, Canberra, A.C.T.

Cullinane, K., Toy, N., 2000. Identifying influential attributes in freight route/mode choice decisions: a content analysis 13.

Drewello, H., Scholl, B., 2015. Integrated Spatial and Transport Infrastructure Development: The Case of the European North-South Corridor Rotterdam-Genoa. Springer.

Freight Metrics, 2016. Truck Operating Cost Calculator [WWW Document]. URL http://www.freightmetrics.com.au/Calculators/TruckOperatingCostCalculator/tabid/104/Default.aspx

Hensher, D.A., Ho, C.Q., Liu, W., 2016. How much is too much for tolled road users: Toll saturation and the implications for car commuting value of travel time savings? Transportation Research Part A: Policy and Practice 94, 604–621. https://doi.org/10.1016/j.tra.2016.10.012

King, D.A., Gordon, C.E., Peters, J.R., 2014. Does road pricing affect port freight activity: Recent evidence from the port of New York and New Jersey. Research in Transportation Economics 44, 2–11. https://doi.org/10.1016/j.retrec.2014.04.002

Li, Z., Hensher, D.A., 2012. Estimating values of travel time savings for toll roads: Avoiding a common error. Transport Policy 24, 60–66. https://doi.org/10.1016/j.tranpol.2012.06.015

Lu, W., Cregan, M., 2003. An Overview of the Australian Road Freight Transport Industry. Australia Bureau of Transport and Regional Economics (BTRE). Working Paper.

Naudé, C., Toole, T., McGeehan, E., Thoresen, T., Roper, R., 2015. Revised vehicle operating cost models for Australia, in: Australasian Transport Research Forum (ATRF), 37th, 2015, Sydney, New South Wales, Australia.

Perera, L., Thompson, R.G., Chen, Y., 2017. Understanding Road Freight Movements in Melbourne. Presented at the City Logistics Conference 2017, Thailand.

Perera, L., Thompson, R.G., Yang, Y., 2016. Analysis of toll charges for freight vehicles in Melbourne. Presented at the Australasian Transport Research Forum 2016, Melbourne, Victoria.

Quak, H., van Duin, J.H.., 2010. The influence of road pricing on physical distribution in urban areas. Procedia - Social and Behavioral Sciences 2, 6141–6153. https://doi.org/10.1016/j.sbspro.2010.04.026

Yang, H., Zhang, X., 2002. Multiclass network toll design problem with social and spatial equity constraints. Journal of Transportation Engineering 128, 420–428.

Yang, Y., Perera, L., Thompson, R., Liu, Z., 2016. Determining Optimal Toll Levels for Trucks for City Logistics. Presented at the 27th ARRB Conference, Melbourne, Victoria.