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Analysis of the Efficiency of  
Commercial Vehicle Tours:  
Data Collection,  
Methodological, and Policy  
Implications

By

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**TITLE:** Analysis of the Efficiency of Commercial Vehicle Tours: Data Collection, Methodological, and Policy Implications

**ABSTRACT:** The emphasis of this research is on the analysis of commercial vehicle tours. Tours are disaggregated by their routing constraints. The generation of Vehicle Kilometers Traveled (*VKT*) by tour type is analytically modeled and analyzed. The relative influence of the number of stops per tour, tour duration, and time window constraints on *VKT* is discussed using an analytical framework. Multistop tours are proven to generate more *VKT* than direct deliveries even for equal payloads. Intuition about the impacts of network changes and policy implications on *VKT* is derived. Implications for the calibration of trip generation and distribution models are discussed. It is proved that the percentage of empty trips has no correlation with the efficiency of the tours regarding *VKT* generation. The shape of Trip Length Distributions (TLD) is discussed. It is shown that the average trip length and the TLD shape are strongly dependent on the tour type, distance from the depot/distribution center to the service area, density of stops, and number of stops per tour. Implications for data collection needs are analyzed. Data and indicators that are needed to estimate and forecast truck *VKT* are proposed.

**KEY WORDS:** *Freight transportation, urban freight demand, carrier behavior, shipper behavior, commercial vehicle traffic, city logistics, commercial vehicle tours, truck trip generation, truck trip distribution, freight data collection, empty truck trips, truck trip length distribution*

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## 1. Introduction

It is increasingly recognized that urban freight movements play a critical role in the quality and performance of urban transportation systems. A recent USA based study of 13 cities indicates that commercial vehicles account on average for 8.8% of the *VKT*<sup>1</sup>; a predominant share of trips that contribute to freight *VKT* originate at distribution centers (DC) or warehouses (Outwater et al., 2005). However, the overall impact of urban freight on congestion can be significantly higher than the sheer number suggested by the *VKT* alone. This is indicated by the Highway Capacity Manual with the use of equivalency factors for light and heavy vehicles. A commercial vehicle impact on congestion can be equivalent to the impact of several cars depending on the truck dimensions, engine power and truck weight, geometric design, and prevalent traffic conditions (TRB, 2000). A similar statement can be said about the relatively higher impact of commercial vehicles on such urban issues as noise, pollution, accidents, and transport infrastructure damage costs.

Urban freight transportation modeling is not yet a mature field (Regan and Garrido, 2001). In particular, urban commercial vehicle tours or trip chains are completely ignored in traditional four-stage transportation modeling approaches borrowed from the passenger modeling literature or in most urban freight models. A recent and comprehensive survey of urban freight modeling efforts across nine industrialized countries of America, Europe, Oceania, and Asia<sup>2</sup> confirms the absence of urban commercial vehicle tour analytical models (Ambrosini and Routhier, 2004).

Incipient work regarding commercial vehicle tour data collection and modeling has recently begun. Data collection efforts that aim to capture the complex logistical relationships of commercial tours have been undertaken in Canada (Stefan et al., 2005), USA (Holguin-Veras and Patil, 2005), and the Netherlands (Vleugel and Janic, 2004). In the modeling arena and to the best of the author's knowledge, if commercial vehicle tours are taken into account they are simulated. The tour simulation can combine a tour optimization embedded in a dynamic traffic simulation environment (Taniguchi and van der Heijden, 2000) or the simulation can be combined with discrete choice modeling (Stefan et al., 2005). In the latter, tour stops (number, purpose, location, and duration) are modeled using regression and logit models and then micro-simulated. To the best of the author's knowledge, the only research that attempts to study properties of urban tours analytically was performed by Figliozzi (2006b). This work classifies tours according to the commercial activity that generates the tour and routing constraints faced by the carriers. The likely impacts of information and communication technologies on commercial vehicles tours are discussed using an analytical framework.

Despite these advances in tour modeling and data collection, there is still no theoretical understanding of the properties of urban freight tours in relation to their efficiency and contribution to *VKT*. This research will contribute by filling this gap in the urban freight literature; however the emphasis of this research is not on trip or tour generation models or methods but on the mathematical analysis of tour characteristics and *VKT* generated. The contributions of this research are threefold: a) study commercial vehicle tours in relation to

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<sup>1</sup> Vehicle kilometers traveled (VKT) and vehicle miles traveled (VMT) differ only by a constant factor

<sup>2</sup> USA, Canada, Japan, Australia, Germany, UK, Netherlands, France, and Switzerland

the  $VKT$  generated, b) explore the impact of certain network and policy changes by commercial tour types, and c) discuss data collection, empty trips, trip length distributions (TLD), and trip generation/distribution modeling implications. The research is organized as follows: section two defines the modeling framework and notation used in the research. Section three classifies and analyzes tour types. Section four studies the impact of tour types on  $VKT$ . Section five discusses relevant policy implications. Section six analyzes empty trips, TLD, implications for trip generation and distribution models, and data collection issues. Section seven ends with conclusions.

## 2. Tour Definition, Assumptions, and Notation

This research focuses on one type of structure: a distribution or service center that provides to several retailers or customers. Within this basic distribution structure, the number of retailers/customers in a given route can increase or decrease in order to satisfy routing constraints. This configuration has been chosen because recent studies in urban areas in the United States have shown that deliveries from DCs or warehouses have one of the largest impacts on  $VKT$  in urban areas and can account for 80-98% of the commercial  $VKT$  related to the distribution of products or packages. (Outwater et al., 2005). On the service side, the commercial vehicles with the largest impact on  $VKT$  (excluding rental cars) are also business and public service vehicles which mostly operate from a central depot (Outwater et al., 2005).

An urban tour is defined in this research as the path that a commercial vehicle follows since it leaves its depot or DC and visits different destinations (two or more destination or stops) in a sequence before returning to the depot or DC during a single driver shift. These tours usually amount to less than 300 kms from the DC since they are restricted by the average travel speed, loading/unloading time, number of stops, and number of working hours in a shift. USA data estimates that warehouse delivery vehicles have an average of 105 kms (approximately 65 miles) per day per vehicle (Cambridge Systematics, 2004).

Distribution centers are increasingly located in the outskirts or low-density suburban areas. The efficient operation of DCs requires affordable tracts of land, good connectivity to the highway system, and reduced congestion. Therefore, it is increasingly common that tours from a DC to a service area start with a connecting distance, often along a primary highway system. This is followed by the tour itself in the service area and by the final return trip to the DC. A crucial requirement to study urban freight tours analytically is to find a mathematical expression that can link tour length with the number of customers (stops) per tour, the proximity among the customers, and the proximity of the DC to the customers. The expression proposed in this research for the length of a tour  $l(n)$  starting and ending at the DC or depot is the following:

$$l(n) = 2r + k \frac{n}{\sqrt{\delta}} + \frac{k'}{\sqrt{\delta}} = 2r + k\sqrt{an} + k'\sqrt{a/n} \quad (1)$$

where:

$r$  : the connecting distance from the DC to the border of the delivery region  $a_s$ ,

$n$  : the number of stops,

$\delta$  : the density of stops,

$k, k'$ : constants that depend on the network characteristics and area shape respectively, and

$a$  : the extent of the area of service comprised by the  $n_s$  customers

The first component represents the connecting distance to the border of the delivery area, the second component is the local tour connecting the customers or stops, and the third component the average distance between the tour and the border of the delivery area; figure 1 illustrates the three components. As the number of customers increases, the length of the *TST* per customer is proven to converge in a convex area where customers are randomly and independently dispersed (Stein, 1978). However, the distance between the ends of the *TST* and border of the service area quickly decreases as  $n$  increases; which is intuitively correct as this distance is related to the minimum distance from a point to  $n$  random points (Figliozi, 2006a). The value of  $k'$  increases as the area is less compact; for example, the value of  $k'$  increases in rectangular areas as the ratio between long and short sides increases.

In compactly shaped service areas (e.g. circular and square) this TST approximation works strikingly well on average even for a small  $n$  such as  $n = 2$  (Daganzo, 1984). Simulations performed by Chien (1992) show that expression (1) is a robust and accurate approximation to the length of a traveling salesman tour. The constant or a circuitry factor in compact areas is estimated to be  $k \approx 0.765$  for euclidean distances and  $k \approx 0.98$  for Manhattan or L1 travel distances (Larson and Odoni, 1981). As intuitively expected, more constrained problems have equal or larger solution costs, as shown by Haimovich and Kan (1985), for the capacitated vehicle routing. Expression (1) is used in this research as a continuous approximation of the length of TSP tours in order to determine analytically different tour properties. A similar modeling approach has been used to solve and gain insight into numerous logistics problems; a detailed compilation of such models is presented by Daganzo (1991).

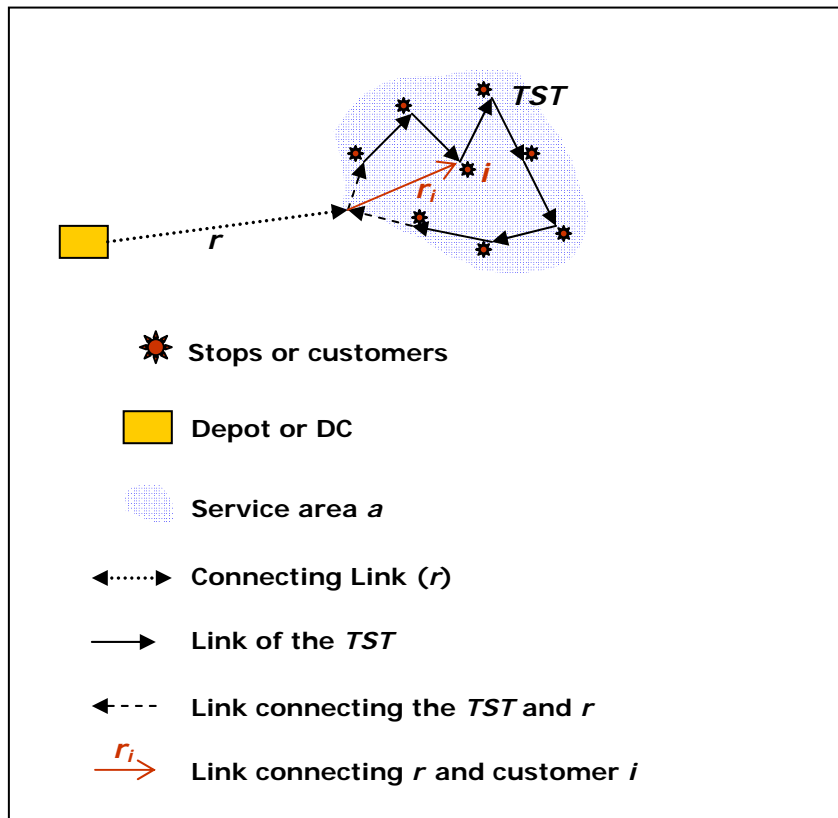


Figure 1

Fixed routes are assumed in this research. This assumption is congruent with practice; the configuration of tours is in many cases linked to sales or driver's territories which have been predefined in advance (Assad, 1988). This is confirmed by data from the The Netherlands where fixed routes comprise 70 - 80% percent of the truck trips (Vleugel and Janic, 2004). It is assumed that retailers, customers, or specific business settings articulate the characteristics of the service through such terms as order size, frequency, or time windows; the demand for freight transportation is a derived demand. Accordingly, routes are delineated in order to satisfy these requests by the central distribution or service center; a fleet operator must plan tours that satisfy tour constraints such as vehicle capacity, route time length, driver-working hours, allowed delivery windows, etc. as appropriate. Additional notation used throughout the paper follows.

## 2.1 The Basic Model

This research considers a system with one DC or depot and  $n$  stops or customers. Let customer  $i, i \in I = \{1, \dots, n\}$  with a location in the plane  $x_i, i \in I$ . The demand of location  $x_i, i \in I$  is denoted  $d(x_i)$  and the size of the order requested by  $q(x_i)$ . Let

$X = \{x_1, \dots, x_n\}$  be the set of demand locations, with  $r_i$  the distance from location  $x_i$  to the connecting link  $r$ .

The set of demand locations is partitioned into service regions. Each time a customer is serviced in a given region, the service is made by a vehicle that services during a tour all other customers in the region as well. Let  $\mathbf{p} = \{X_1, \dots, X_R\}$  denote a partition of  $X$ . The set of corresponding tours is denoted  $J = \{1, \dots, z\}$ , where  $z$  indicates the number of zones or service regions and  $X_j (j \in J)$  denotes the collection of demand locations. Let  $m_j = |X_j| (j \in J)$  be the number of stops or demand points in tour  $j$ . Let  $\{a_1, \dots, a_z\}$  denote the set of service areas generated by partition  $\mathbf{p}$ .

Let:

$b$  = vehicle capacity

$f$  = minimum delivery or service frequency

$d_j$  = annual demand for tour  $j$ , with  $\sum_{i \in X_j} d(x_i) = d_j$ . Total demand is  $\sum_{j \in J} \sum_{i \in X_j} d(x_i) = D$

$q_j$  = payload for tour  $j$ , with  $\sum_{i \in X_j} q(x_i) = q_j$

$t_l$  = Time to load a unit of product into the truck

$t_u$  = Time to unload a unit of product from the truck (loading/unloading times are highly dependent on the loading/unloading equipment used -- manual, forklift, conveyor, etc -- and the distance to/from the truck to the receiving area).

$t_o$  = Fixed time needed for order receiving when stopping at the retailers (this time includes order receiving, order checking/inspection, paperwork and documentation, etc).

$s$  = Average truck speed

$w$  = driver effective working hours or time available for truck operations (i.e. driver maximum working hours per day minus lunch or mandatory breaks)

$\rho$  = time window factor, representing the ratio between time window delivery length and working shift length,  $0 < \rho < 1$

$\rho w$  = time window length for any given customer

$\theta_j = q_j / b$  = tour  $j$  fill rate

## 2.2. Notation Convention

The upper bar is used to indicate an average; for example  $\bar{q}_x$  indicates the average order size across all customers and  $\bar{q}_j$  indicates the average order size only for the customers in tour  $j$ . A subscript is used to denote the type of tour; 0 to 3, as indicated in the next section. For example,  $p_1$  denotes the partition generated by tour type 1 and  $J_2$  is the set of type 2 tours.

## 2.3 Tour Example

Tour data from different cities indicate that the average number of stops per tour is significantly higher than two stops. The city of Calgary reports approximately 6 stops per tour (Hunt and Stefan, 2005), Denver reports 5.6 (Holguin-Veras and Patil, 2005) and data from Amsterdam indicate 6.2 stops per tour (Vleugel and Janic, 2004). In the case of Denver, approximately 50% of single and combination truck tours include 5 to 23 stops per tour. Further data collection is needed to generalize these results but it appears that the average number of stops per tour ranges between 5 and 6 for midsize to large cities.

Data from Amsterdam indicate that the amount of time that is taken during unloading/loading stops is 21 minutes on average (mode 10 min.) and that the average time to reach the service/delivery area is 25 minutes (mode 10 min.). The data suggest a skewed distribution which may be due to the impact of congestion and delays at stops. Using the previously defined notation in Amsterdam:  $t_u \bar{q}_{(x_i)} = 21$  min,  $(r/s) = 25$  min, and  $m_j = 6.2$ . Assuming that the average time between customers (includes driving, waiting/parking, and loading/unloading) is  $k/(s\sqrt{\delta}) + t_o + t_u \bar{q}_{(x_i)} = 55$  minutes and with  $m_j = 7$ , the tour duration in route  $j$  is of approximately 7.25 hours. In such a tour, assuming 1/2 hour for the driver lunch break, the length of the tour is 7.75 hours. Approximately 11% of the time is spent driving to the service area, 32% loading/unloading, and 51% waiting or driving between customers, and 6% for the driver's lunch time or personal needs. Clearly, these values are city dependent and are related to such factors as city density/shape, average speeds, distance between warehouse/distribution districts to delivery areas, driver working hours, etc. In the case of service tours (no deliveries or pickups), the same logic applies but replacing time unloading/loading for in situ service time.



### 3. Tour Classification and Properties

For a given set of customer requests, the fleet operator delineates routes that satisfy these requests taking into account routing constraints such as vehicle capacity, route time length, driver-working hours, allowed delivery windows, etc. as appropriate. Adapting the classification suggested by Figliozzi (2006b), tours are classified in four different types according to the binding constraint that determines the characteristics of the tour:

- (a) truck capacity,
- (b) frequency of service,
- (c) length of tour, and
- (d) time window lengths.

If each order is equal to the capacity of the truck there is space for just one customer per tour, case (a) is also called direct delivery truckload (TL) tour or type 0 tour. In case (b) the required replenishment frequency or high inventory costs preclude the use of TL order, a tour can service two or more customers; this is called a type 1 tour. In type 1 tours, customers request less-than-truckload (LTL) order sizes. In case (c), if the constraints are not only the replenishment frequencies but also the length of the tour, the tour is of type 2. In addition, if the number of stops per tour is limited by time windows, case (d), the tour is of type 3.

The type of constraints used in this research is congruent with the constraints found in vehicle routing literature in urban areas where models are mostly constrained by the capacity of the vehicles or the temporal dimensions of the tours and the customer requests (Bodin et al., 2003).

#### 3.1 Type 0 – Direct Delivery

As indicated in section two, tours are defined as the path that a commercial vehicle follows from the DC to visit a series of destinations in a sequence before returning to the depot during a single driver shift. Type 0 is a degenerate type of tour since it is characterized by visiting *only one* destination before returning to the depot. It is included in the analysis since it is a basic point of reference regarding *VKT* and tour efficiency as explained in section four. The binding constraints in this type of tour are:

$$\begin{aligned} q(x_i) &= b & \forall x_i \in X \\ m_j &= 1 & \forall j \in J_0 \end{aligned}$$

Since there is one customer per tour, there are  $n$  different tours. Tours are trivially identified by the only customer served in the tour,  $X_j = \{x_j\}$  and  $n = z_0$ . For any customer  $i$  the total number of trips per year is equal to  $d_i/b$ . For any tour  $j$ , the annual *VKT* is:

$$VKT_{0,j} = \frac{d_j}{b} (2r + 2r_j)$$

The total distance traveled per year in the region is obtained summing across the set of

$$\text{tours: } VKT_0 = \sum_{j \in J_0} VKT_{0,j} = \sum_{j \in J_0} \frac{d_j}{b} (2r + 2r_j) = 2r \frac{D}{b} + \sum_{j \in J_0} \frac{d_j}{b} r_j \quad (2)$$

Expression (2) indicates that distance  $VKT_0$  is influenced by the ratio between total demand and truck capacity as well as individual customer demands and truck capacity. In the special case where demand levels are the same for all customers,  $d = d_i = d_i, \forall i, i' \in I$  or the demand is uniformly distributed, expression (2) becomes:

$$VKT_0 = 2 \frac{nd(x_i)}{b} (r + \bar{r}_i) = 2 \frac{D}{b} (r + \bar{r}_i) \quad (2')$$

### 3.2 Type 1 – Less-than-Truckload – frequency constrained

In this type of tour customer requests are less than truckloads (LTL). Due to the low demand of customer  $i$  and/or the characteristics of the commercial activity (e.g. perishable products, organizational issues, or storage area capacity) full truckloads are not a viable alternative; a higher frequency of service would be required (Figliozzi, 2006b). The frequency constraint in this type of tour determines the order size:

$$d(x_i) / q(x_i) = f > d(x_i) / b \quad \forall i \in I$$

Tours still satisfy capacity constraints but tours can have more than one customer:

$$\sum_{i \in X_j} q(x_i) = m_j \bar{q}_j \leq b \quad \forall j \in J_1$$

The average order or delivery size tends to decrease as the number of customers in the tour increases since  $m_j \bar{q}_j \leq b$ . The optimal partition of the  $n$  customers into tours that minimizes total distance traveled is equivalent to solving a vehicle routing problem. This is a generalization of the traveling salesman problem.

The  $VKT$  per year per tour  $j$  is equal to:

$$VKT_1 = \sum_{j \in J_1} \frac{d_j}{q_j} (2r + k \sqrt{a_j m_j} + k' \sqrt{a_j / m_j})$$

Tours are balanced if the numbers of stops, payloads, and service areas are the same across tours; figure 2 presents an example of a partition that is tour balanced and subareas are not overlapping.

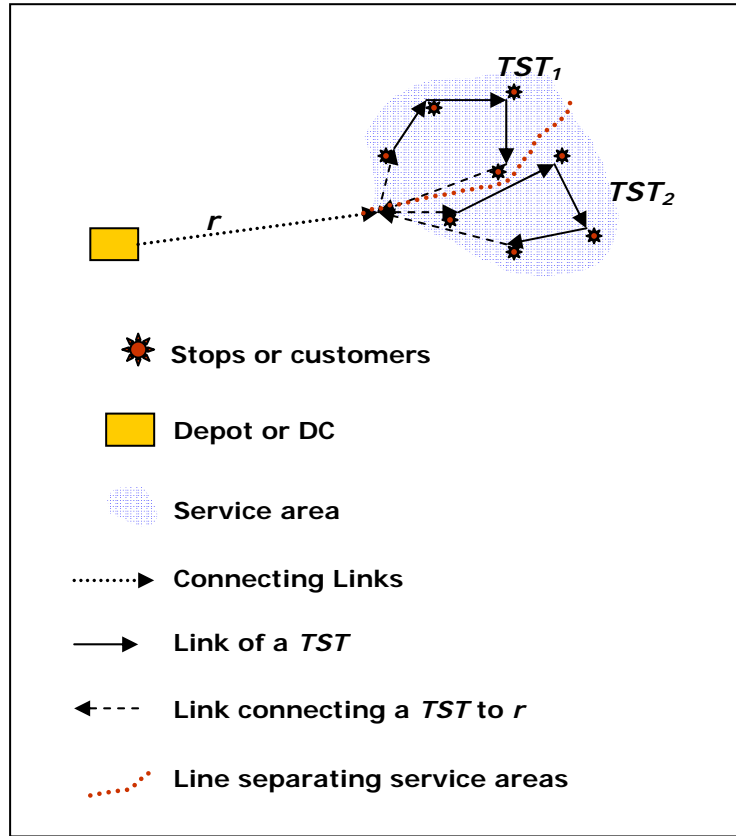


Figure 2

Achieving balanced tours is an important objective in practical applications (Tang and Miller-Hooks, 2006). It is highly desirable that service areas are compact and tours do not cross, especially when drivers are responsible for their own service areas or when service areas correspond to sales districts. Assuming balanced tours:

$$VKT_1 = \frac{d_j}{\theta_j b} \sum_{j \in J_1} (2r + k\sqrt{a_j m_j} + k'\sqrt{a_j / m_j}) = \frac{d_j}{\theta_{1,j} b} (2rz_1 + k\sqrt{m_j} \sum_{j \in J_1} \sqrt{a_j} + k'\sqrt{1/m_j} \sum_{j \in J_1} \sqrt{a_j})$$

With fixed service tours, overlapping leads to higher  $VKT_1$ . Assuming that subareas are not overlapping and that tours are balanced, then  $a_j = a/z_1$ ,  $m_j = n/z_1$ ,  $\theta_1 = \theta_j$ ,  $D/z_1 = d_j \forall j \in J_1$ :

$$VKT_1 = \frac{D}{\theta_1 z_1 b} (2rz_1 + kz_1 \sqrt{n/z_1} \sqrt{a/z_1} + k' z_1 \sqrt{z_1/n} \sqrt{a/z_1})$$

In the last expression the  $VKT_1$  is minimized if the number of delivery regions is one,  $z_1 = 1$ . Thus the  $VKT$  in the most efficient type 1 tour can be expressed as:

$$VKT_1 = \frac{D}{\theta_1 b} (2r + k\sqrt{an} + k'\sqrt{a/n}) \quad (3)$$

This is intuitively expected. One tour that services all  $n$  customers has two additional advantages: (a) higher delivery frequency and smaller average order size since  $\bar{q} \leq b/n$  and (b) it is easier to reach high fill rate ratios  $\theta_1$  as a higher number of smaller orders can be consolidated into one tour. A higher delivery frequency is in general beneficial for customers as inventory holding costs are reduced. A high fill truck ratio is a measure of the efficiency of the tour regarding the utilized truck capacity.

### 3.3 Type 2- Route length constrained

In this type of tour the customer demands are also less than truckloads (LTL), however, the binding constraint is the length of the tour. Not all customers can be served in the same tour; hence, the service area  $j$  must be split into two or more delivery regions. The binding constraint for each tour  $j$  with  $m_j$  stops can be expressed as:

$$\frac{1}{s}(2r + k\sqrt{a_j m_j} + k'\sqrt{a_j / m_j}) + m_j t_o + t_u q_j \leq w \quad \forall j \in J_2 \quad (4)$$

$$d(x_i)/q(x_i) = f > d(x_i)/b \quad \forall i \in I \quad (4')$$

Expression (4) can be interpreted as the sum of two terms  $t_r$ , or time spent to/from the service area and  $t_c$  the time spent in the service area per customer:

$$t_r = 2r / s$$

$$m_j t_c = k\sqrt{a_j m_j} + k'\sqrt{a_j / m_j} + m_j t_o + t_u q_j.$$

The term  $(k/s)\sqrt{a_j m_j} = k/(s\sqrt{\delta})$  measures the average ‘‘routing proximity’’ between two stops and it is mostly determined by network and geography characteristics of the service area. The average routing proximity of stops or customers can have an important impact on the trip length distributions as seen in section six.

The solution to the vehicle routing problem in this type of tour is finding the optimal partition (tours) that minimize expression (5) subject to tour length constraint (4) and customer frequency constraints (4'):

$$J_2 \in \arg \min VKT_2 = \sum_{j \in J_2} \frac{d_j}{\theta_{2,j} b} (2r + k\sqrt{a_j m_j} + k'\sqrt{a_j / m_j}) \quad (5)$$

If tours are balanced, expression (5) becomes:

$$VKT_2 = \frac{D}{\theta_2 z_2 b} (z_2 2r + k\sqrt{na} + k' z_2 \sqrt{a/n}) \quad (6)$$

The average number of customers per tour is  $\bar{m}_2 = n / z_2$ .

If tour length is binding, the fleet operator can increase the average number of stops by reducing the time spent per customer. This could be achieved: a) with handling equipment to reduce  $t_u$ , e.g. using a forklift, b) with technology to reduce fixed processing times  $t_o$ , e.g. RFID<sup>3</sup> tags and readers to reduce paperwork and inspection time, and c) with better facilities to reduce  $t_c$ , e.g. a loading/unloading bay that can reduce time searching for parking and shorten distance between truck and customer. In tours with a large number of stops, time reduction per customer can have a significant impact on the efficiency of the tour. If the median number of stops in the soft drink industry is 25 (Golden and Wasil, 1987), a 5 minute saving per stop represents a saving of 26% of the total eight hour driver working day. The time that a truck spends in a delivery/pickup area can be increased by adding DCs and reducing the average distance between DCs and service areas.

### 3.4 Type 3- Time Window Constrained

The main constraint in this type of tour is the time window length. Time windows have a significant impact on decreasing the efficiency of tours. A time window not only reduces the proportion of time available per service area but also can decrease the density of customers per tour. To illustrate the latter assume that all locations in a set  $X$  are initially served in a driver's eight-hour tour. Let's assume that customers start demanding shorter time windows: either morning (8 to 12 am) or afternoon (12am to 4pm) service. Further, assume that customers are split evenly between the two service times but they are still randomly dispersed across the whole service area. With the introduction of morning and afternoon time windows, at least two tours are needed. With two tours, the customer density is reduced to  $\delta/2$  and the average distance between stops increases as indicated by expression (1).

This section analyzes the reduction in the number of stops when a time window is introduced. For the sake of simplicity and without loss of generality, let us assume that  $\rho$  is the time window reduction factor,  $0 < \rho < 1$  and  $\rho \in \{1/2, 1/3, \dots, 1/15, 1/16\}$ . The smallest time window is  $1/2$  hour for an eight hour shift and  $\rho = 1/16$ . The delivery time window is equal to  $\rho w$  and the reduction in customer density is approximated by  $\rho \delta$ . It is assumed that customers split evenly between the service times but they are still randomly dispersed across the whole service area:

$$\frac{1}{s} (2r + k\sqrt{am_j} + k'\sqrt{a/m_j} + m_j t_o + t_u q_j) \leq \rho w \quad \forall j \in J_3 \quad (7)$$

Notice in (7) that the left hand side increases since the whole service area is used and the right hand side decreases; tour time length constraints are tighter. The solution to the vehicle routing problem in this type of tour is finding the optimal partition (tours) that

<sup>3</sup> RFID stands for Radio Frequency IDentification

minimize expression (8) subject to tour length constraint (7) and customer frequency constraints (4<sup>o</sup>):

$$J_3 \in \arg \min VKT_3 = \sum_{j \in J_3} \frac{d_j}{\theta_{3,j} b} (2r + k\sqrt{am_j} + k'\sqrt{a/m_j}) \quad (8)$$

If tours are balanced, expression (8) becomes:

$$VKT_3 = \frac{D}{\theta_3 z_3 b} (2rz_3 + k\sqrt{z_3}\sqrt{an} + k'z_3\sqrt{z_3}\sqrt{a/n}) \quad (9)$$

The average number of customers per tour is  $\bar{m}_3 = n / z_3$ .

#### 4. Comparison between $\bar{m}_2$ and $\bar{m}_3$ when time constraints are binding

If tour length constraints (4) and (7) are binding, it is possible to compare them as follows:

$$\frac{1}{s} (2r + k\sqrt{\bar{a}_j \bar{m}_2} + k'\sqrt{\bar{a}_j / \bar{m}_2}) + \bar{m}_2 t_o + t_u \bar{m}_2 \bar{q}_2 \approx \frac{1}{s\rho} (2r + k\sqrt{a\bar{m}_3} + k'\sqrt{a/\bar{m}_3}) + \bar{m}_3 t_o + t_u \bar{m}_3 \bar{q}_3$$

The average times spent in the service area per customer are  $t_{2c}$  and  $t_{3c}$ :

$$\bar{m}_2 t_{2c} = k/s\sqrt{\bar{a}_j \bar{m}_2} + k'/s\sqrt{\bar{a}_j / \bar{m}_2} + \bar{m}_2 t_o + t_u \bar{m}_2 \bar{q}_2$$

$$\bar{m}_3 t_{3c} = k/s\sqrt{a\bar{m}_3} + k'/s\sqrt{a/\bar{m}_3} + \bar{m}_3 t_o + t_u \bar{m}_3 \bar{q}_3$$

It follows that  $t_{2c} < t_{3c}$  given that  $\bar{m}_2 \geq \bar{m}_3$ ,  $a > a/z_2 = \bar{a}_j$ , and the service frequency is the same ( $\bar{q}_2 = \bar{q}_3$ ). Since time constraints are less tight in tours type (2), then  $\bar{m}_2 \geq \bar{m}_3$ .

Replacing  $t_{2c}$  and  $t_{3c}$ , then solving for the value of  $\bar{m}_3$ :

$$\begin{aligned} \frac{2r}{s} \left( \frac{\rho-1}{\rho} \right) + \bar{m}_2 t_{2c} &= \frac{\bar{m}_3}{\rho} t_{3c} \\ \frac{2r}{s} (\rho-1) + \rho \bar{m}_2 t_{2c} &= \bar{m}_3 t_{3c} \\ \bar{m}_3 &= \rho \bar{m}_2 \frac{t_{2c}}{t_{3c}} - \frac{2r}{st_{3c}} (1-\rho) \end{aligned} \quad (10)$$

Since the second term in (10) is always positive and  $t_{2c} < t_{3c}$ , the reduction of customers is larger than the value of  $\rho$  itself,  $\bar{m}_3 < \rho \bar{m}_2$  and  $z_2/z_3 < \rho$ . Shortening time windows has

a severe impact on the number of stops that can be served per tour; therefore, it may have a negative impact on the number of truck tours and  $VKT$  that are needed to satisfy the same number of customers.

The value of  $\bar{m}_3$  cannot be negative; a lower bound on the feasible values of  $\rho$  is obtained setting  $\bar{m}_3 = 1$  in expression (10) and solving for the lower bound  $\underline{\rho}$ :

$$\underline{\rho} \bar{m}_2 \frac{t_{2c}}{t_{3c}} - \frac{2r}{st_{3c}} (1 - \underline{\rho}) = 1$$

$$\underline{\rho} \left( \bar{m}_2 \frac{t_{2c}}{t_{3c}} + \frac{2r/s}{t_{3c}} \right) = 1 + \frac{2r/s}{t_{3c}}$$

$$\underline{\rho} = \frac{t_{3c} + 2r/s}{(\bar{m}_2 t_{2c} + 2r/s)}$$

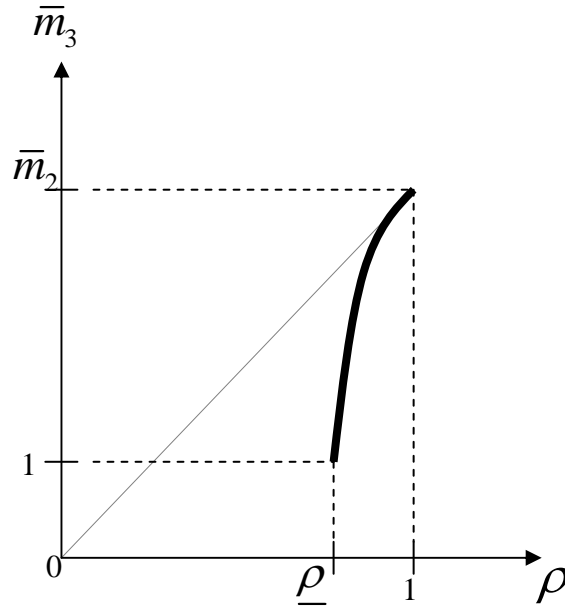


Figure 3

The feasible values of  $\rho$  are closer to 1 when the importance of the connecting time grows in relation to the delivery time; if  $\underline{\rho}$  is closer to 1 the curve has a steeper slope and the feasible values of  $\bar{m}_3$  quickly decrease as seen in figure 3. Therefore, urban areas with considerable urban sprawl tend to suffer a higher reduction in the number of customers per tour as the time windows shorten.

#### 4.1 VKT Relative Impact by Tour Type

This section explores the efficiency of commercial vehicle tours by  $VKT$  generated. Assuming the basic model of one DC serving a given set of  $n$  locations, changes in  $VKT$  are studied as the tour type changes *ceteris paribus*.

##### 4.1.1 Comparing VKT for types 0 and 1 - General case

Taking the ratio of expressions (2) and (3):

$$\mathcal{G}_{0/1} = \frac{VKT_0}{VKT_1} = \frac{2(r \frac{D}{b} + \sum_{j \in J_0} \frac{d_j}{b} r_j)}{\frac{D}{\theta_1 b} (2r + k\sqrt{an} + k'\sqrt{a/n})} = \frac{\theta_1 (2r + \frac{2}{D} \sum_{j \in J_0} d_j r_j)}{2r + k\sqrt{an} + k'\sqrt{a/n}}$$

Assuming that demand locations and levels are randomly but evenly distributed:

$$\mathcal{G}_{0/1} = \frac{\theta_1 (2r + 2\bar{r}_i)}{2r + k\sqrt{an} + k'\sqrt{a/n}} \quad (11)$$

Then the efficiency factor  $\mathcal{G}_{0/1} < 1$  as the length of the TST is always longer than the average distance to the locations for Euclidian distances and  $n > 1$ . Further, for a given area,  $\mathcal{G}_{0/1}$  decreases as  $n \rightarrow \infty$  since the TST distance increases proportional to  $\sqrt{n}$  but  $\bar{r}_i$  does not change. As expected, a reduction in the fill rate factor  $\theta_1$  increases the inefficiency of type 1 tours. Direct deliveries are more efficient than “complete” TLT tours that cover all the customers.

A critical fill rate factor  $\theta_1^c$  equalizes the efficiency of partially loaded direct deliveries and fully loaded complete LTL deliveries:

$$\theta_1^c = \frac{2r + 2\bar{r}_i}{2r + k\sqrt{an} + k'\sqrt{a/n}} \quad (12)$$

Whenever the minimum delivery frequencies allow fill rates to be higher than  $\theta_1^c$  direct deliveries are the most efficient delivery method regarding  $VKT$ . Otherwise, “complete” TLT tours that cover all the customers and depart from the DC fully loaded are more efficient regarding  $VKT$ . As the denominator grows faster than the numerator when  $n \rightarrow \infty$ , the critical fill rate factor  $\theta_1^c$  decreases as  $n$  increases.



Type 1 tours can satisfy minimum frequency constraints and higher fill rate factors since:

$$\begin{aligned} f &\leq d / \bar{q} \leq dn / b \\ n\bar{q} &\leq b \end{aligned} \quad (13)$$

Expression (13) indicates that as the number of customers per region increases, it is easier to satisfy minimum frequency delivery constraints departing from the DC fully loaded.

#### 4.1.2 Comparing VKT for types 1 and 2

Taking the ratio of expressions (3) and (6):

$$\mathcal{G}_{1/2} = \frac{VKT_1}{VKT_2} = \frac{\frac{D}{\theta_1 b} (2r + k\sqrt{an} + k'\sqrt{a/n})}{\frac{D}{\theta_2 z_2 b} (z_2 2r + k\sqrt{na} + k' z_2 \sqrt{a/n})} = \frac{z_2 \theta_2 (2r + k\sqrt{an} + k'\sqrt{a/n})}{\theta_1 (z_2 2r + k\sqrt{na} + k' z_2 \sqrt{a/n})}$$

Assuming same service frequency and order sizes  $\theta_1 = n\bar{q}_{x_i} / b$ ,  $\theta_2 = n\bar{q}_{x_i} / z_2 b$ , then  $\theta_1 / \theta_2 = z_2$ . Replacing:

$$\mathcal{G}_{1/2} = \frac{2r + k\sqrt{an} + k'\sqrt{a/n}}{z_2 2r + k\sqrt{na} + k' z_2 \sqrt{a/n}} \quad (14)$$

Then  $\mathcal{G}_{1/2} < 1$  as long as  $z_2 > 1$ , i.e. increasing the number of subareas decreases the efficiency regarding VKT generated; this is reinforced when the relative importance of the connecting distance  $2r$  is high. Since the ratio of fill rate is  $\theta_1 / \theta_2 = z_2$ , type 1 tours can satisfy simultaneously tighter minimum frequency constraints and higher fill rate factors than type 2 tours.

#### 4.1.3 Comparing VKT for types 2 and 3

Taking the ratio of expressions (6) and (9):

$$\mathcal{G}_{2/3} = \frac{VKT_2}{VKT_3} = \frac{\frac{D}{\theta_2 z_2 b} (z_2 2r + k\sqrt{na} + k' z_2 \sqrt{a/n})}{\frac{D}{\theta_3 z_3 b} (2r z_3 + k\sqrt{z_3} \sqrt{an} + k' z_3 \sqrt{z_3} \sqrt{a/n})} = \frac{\theta_3 z_3 (z_2 2r + k\sqrt{na} + k' z_2 \sqrt{a/n})}{\theta_2 z_2 (2r z_3 + k\sqrt{z_3} \sqrt{an} + k' z_3 \sqrt{z_3} \sqrt{a/n})}$$

Assuming same service frequency and order sizes  $\theta_2 = n\bar{q}_{x_i} / z_2 b$ ,  $\theta_3 = n\bar{q}_{x_i} / z_3 b$ , then  $\theta_2 / \theta_3 = z_3 / z_2$ . Replacing:

$$\mathcal{G}_{2/3} = \frac{z_2 2r + k\sqrt{an} + k' z_2 \sqrt{a/n}}{2rz_3 + k\sqrt{z_3}\sqrt{an} + k' z_3 \sqrt{z_3}\sqrt{a/n}} \quad (15)$$

Then  $\mathcal{G}_{2/3} < 1$  as long as  $z_2 / z_3 < 1$ , i.e. increasing the number of subareas due to time window constraints decreases the efficiency regarding VKT generated. When the relative importance of the TST increases the efficiency factor tends to  $\mathcal{G}_{2/3} \rightarrow 1/\sqrt{z_3}$ ; when the relative importance of the connecting distance increases the efficiency factor tends to  $\mathcal{G}_{2/3} \rightarrow z_2 / z_3$ , with  $z_2 / z_3 < \rho$ .

## 5. Policy Implications

This section applies the insights and expressions obtained in sections three and four to evaluate how policy changes or network changes may affect generated VKT. Changes are analyzed, *ceteris paribus*, and disaggregated by tour type. Four different changes are analyzed: 1) limitations in vehicle dimensions (i.e. reducing maximum truck size), 2) limitations to the free circulation of commercial vehicles (i.e. banning trucks in parts of the network, introduction of one-way streets, etc), 3) restrictions on commercial vehicle parking or loading/unloading zones, and 4) an increase in road congestion. The policy measures can be translated into the following notation:

- 1) a reduction in the truck capacity  $b$ ,
- 2) an increase of the circuitry factor  $k$  or distance to the service area  $r$ ,
- 3) an increase in the fixed delivery time and/or per unit loading time,  $t_o$  and  $t_u$  respectively, and
- 4) a reduction in the average speed  $s$ .

A truck capacity reduction would increase the VKT as indicated by expression (3) for type 0 tours. Type 0 tours will be strongly affected since truck capacity is always binding (by definition). For type 1 tours, the increase in VKT would take place only in those tours where capacity is binding or where capacity becomes a binding constraint. No change is expected in those tours where capacity is not a binding constraint after the policy change.

An increase in the circuitry factor  $k$  or average distance  $r$ , would increase the VKT for all types as indicated by expressions (2), (3), (6), and (9). However, the highest impact would be on type 3 tours since they are more constrained. Restrictions on commercial vehicle parking or loading/unloading zones will increase the average time to serve a customer and the average tour length. The higher the number of stops per tour, the larger the additional time needed to serve the same number of customers per tour is. Type 2 and 3 tours will be

greatly affected if route length constraints are already binding. Type 0 tours are not affected.

An increase in congestion will reduce the travel speed and therefore increase the travel time. In this case, the impact on  $VKT$  alone is insufficient to describe the effects of congestion; the impact on  $VHT$  (vehicle hour traveled) must also be considered. Type 0 tours are not changed; the same distance is traveled and  $VKT$  remains constant. However, it may take longer to travel the same tour and then the  $VHT$  increases. Even though the distance traveled remains constant, the negative effect of commercial vehicle flows on the urban traffic flows is increased. The same reasoning can be applied to type 1 tours. Type 2 and 3 tours are severely affected since congestion reduces the ability to serve customers per working shift or time window.

Impacts by tour type are summarized in Table 1. A “+” sign indicates a likely simultaneous increase in  $VKT$  and  $VHT$  indicators. A “++” sign indicates a significantly higher increase in  $VKT/VHT$  indicators, and so on. A “=” sign indicates no change. The signs are to be interpreted as relative to each other on a row-by-row basis. When examining table 1, it is crucial to bear in mind that:

- 1) For a given fix route, a change in  $VKT$  takes place only when a constraint is violated but a change in  $VHT$  can take place even if the tour remains unchanged.
- 2) The number of stops per tour  $m$  is an integer variable, therefore the  $VKT/VHT$  change function is not continuous or proportional.
- 3) The higher the degree of “slackness” in the system, the higher the magnitude of the change needed to show an increases or decrease in  $VKT/VHT$ .
- 4) The final magnitude of the change in overall  $VKT/VHT$  across the whole urban area will depend on the relative significance of each tour type in the urban area; and
- 5) Second order effects have not been analyzed.

Change ↓	Tour Type →	0	1	2	3
1) Limit vehicle size		++	=/+	=	=
2) Limit circulation		+	+	++	+++
3) Reduce loading zones		=	=/+	++	+++
4) Increased congestion		= $VKT$ + $VHT$	= $VKT$ + $VHT$	++	+++

Table 1

Second order effects can be very important when the percentage of trucks in the network is significant. For example, a congestion related second order effect is the decrease in travel speed, which in turn increases the number of truck trips, which in turn reduces travel speed, and so on. A downward spiraling cycle is created even if the total demand in the service areas remains constant or decreases slightly, i.e. for activities that are largely inelastic to changes in transportation cost.

The four policy/network changes analyzed in this section do not pretend to be a complete or exhaustive representation of the changes that may take place in an urban area. However, their analysis is used to illustrate that policy/network shifts can have significantly different effects on the  $VKT$  generated disaggregating by tour type. Although  $VKT$  changes are network/area data dependent, helpful intuition can be derived from the proposed framework. The next section discusses the implications of tour type, the disaggregation on data collection, and efficiency measures.

## 6. Implications for Trip Generation and Distribution Models

Efficient truck repositioning, avoiding deadheading or long empty trips, is an especially important issue for the fleet operator who deals with long hauls<sup>4</sup>. In urban settings, reducing deadheading is not feasible in many cases and can be possible only in certain commercial trips such as the drayage of containers to/from a port. When the fill rate is less than one it is possible to combine or consolidate LTL shipments and reduce the length and frequency of deadheading, i.e. forming a tour consolidating LTL shipments reduces total deadheading.

Repositioning is in general not possible in urban pickup or delivery tours that originate and end at DCs or warehouses. Efficient repositioning requires a significantly higher degree of coordination and operational complexity and two or more depots/DCs in the urban area. With only one depot or DC, shipment consolidation is possible but not empty trucks repositioning.

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<sup>4</sup> When the trip duration exceeds a shift or working day it is not considered an *urban* trip in this research according to the definition provided in section 2. Truck repositioning is increasingly important as trip length grows.

Tour Type	Annual Trips	Trips per Tour (1)	Empty Trips per Tour(2)	Ratio (2)/(1)
Type 0	$\frac{D}{b} 2$	2	1	$\frac{1}{2}$
Type 1	$\frac{D}{\theta_1 b} (n+1)$	$n+1$	1	$\frac{1}{n+1}$
Type 2	$\frac{z_2 D}{\theta_2 b} (\bar{m}_2 + 1)$	$\bar{m}_2 + 1$	1	$\frac{1}{\bar{m}_2 + 1}$
Type 3	$\frac{z_3 D}{\theta_3 b} (\bar{m}_3 + 1)$	$\bar{m}_3 + 1$	1	$\frac{1}{\bar{m}_3 + 1}$

Table 2

The most efficient type of tour, type 0, generates one empty trip for each loaded trip. In many cases, loaded and empty trips are just the mirror image of each other (opposite directions but traveling over the same streets/highways). On the other hand, less *VKT* efficient multistop tours will generate several loaded trips and one return empty trip. Table 2 summarizes number of annual trips, number of empty trips, and their ratio by tour type. The number of “garage trips”, trips starting or ending at the DC or depot, can be expressed as  $2z_y D / (\theta_y b)$ ,  $y \in \{0, 1, 2, 3\}$ .

As can be observed in Table 2, the number of annual trips increases with the tour type, type 0 has the lowest number of annual trips while type 3 has the highest number of annual trips. As observed in section 4, *VKT* generation also increases with the tour type. Therefore, the percentage of empty trips has no correlation with the number annual trips or the efficiency of the tours regarding *VKT* generation. By simply observing changes in the percentage of empty vehicles it is impossible to ascertain whether efficiency has increased (higher percentage of type 0 tours) or decreased (higher percentage of type 2 and 3 tours). Therefore, the percentage of empty trips alone is a poor proxy for the efficiency of commercial vehicle tours or as a characterization of commercial vehicle activity in a given urban area. In urban areas, this is a *crucial observation* for estimation methods that generate truck trips from commodity tonnage flows after accounting for truck type and local data on average payload and percentage of empty trips per truck type. These models are frequently used in practice as indicated in the Truck Trip Generation manual (Fisher and Han, 2001). As seen in Table 2, the percentage of empty trips can widely vary widely by tour type and number of stops.

Furthermore, the percentage of empty trips data will drastically change according to where the data collection is performed. For example, the percentage of empty trips will be very different in the connecting part of the tour (represented by  $r$ ) from the percentage of empty trips in the proper TST within the delivery region. For types 1, 2, or 3 the

percentage of “measured” empty trips in the connecting leg is fifty percent, but the percentage of “measured” empty trips in the TST (before the last stop) is zero.

### 6.1 Trip Length Distribution

The gravity model is still a popular technique to model trip distribution. This model is usually calibrated by comparing the trip length distribution (TLD) and trip length averages in the model against the observed trip length distribution and average. The average trip length in a tour type 1, 2, or 3 (using the appropriate  $m$  or number of stops per tour) can be expressed as:

$$\frac{l(m)}{m+1} = \frac{2r}{m+1} + \frac{k}{\sqrt{\delta}} \frac{m}{m+1} + \frac{k'}{m+1} \sqrt{\frac{a}{m}} \quad \forall m > 1$$

The average trip length with direct deliveries (type 0) can be expressed as:

$$\frac{l(m)}{m+1} = r + r_i \quad m = 1$$

All things equal, type 0 average trip lengths are longer than the average trip lengths of other types. The average trip length clearly depends on the number of stops per tour, which in turn depends on the type of tour and the routing constraints. In turn, the number of customers per tours can be limited by the commercial vehicle travel speed and the value of the time spent to/from the service area  $t_r$ , time spent serving customers or  $t_o + qt_u$ , and the average time proximity between stops  $k/(s\sqrt{\delta})$ .

If the magnitudes of the connection distance  $r_j$  and the average distance between stops  $k/\sqrt{\delta_j}$  are significantly different it is not surprising that the TLD is bimodal or even multimodal if all tour types are included in one TLD. In order to calibrate gravity models it is typically assumed that there is a decrease in the number of trips as distance or time between origins and destinations increases, i.e. a unimodal impedance function. However, if the magnitudes of the connection distance and the average distance between stops are significantly different, a unimodal impedance function may not be able to represent adequately the distribution of trip lengths. These observations strongly suggest that network assignment and calibration should be at least disaggregated by tour type or number of stops per tour.

Empirical observations confirm that multimodal TLD are found in practice (Holguin-Veras and Thorson, 2000). It is also clear that the relative location of major freight generators (i.e. large DCs, intermodal facilities, etc.) in relation to their service areas will also affect the shape of the TLD. In fact, that is also found using empirical data (Holguin-Veras and Thorson, 2000). Furthermore, the average distance between stops is likely to be related to the dispersion of the TLD around the modal points.

## 6.2. Implications for Data Collection

Truck trip generation tables are commonly based on linear regressions by land-use category and as a function of employment by industry sector (Fisher and Han, 2001). These aggregated methods are ill suited to study policy and network changes or for forecasting. In addition, the available linear models do not provide any information regarding the type of tours that is likely to be generated.

The logistics industry already uses truck payloads and fill truck rates as efficiency measures that indicate what percentage (Fernie and McKinnon, 2003); these measures capture what percentage of the available weight and volume truck hauling capacity is effectively utilized. To the best of the authors' knowledge, there have not been systematic data collection efforts to track payload and percentage fill truck time-trends by transportation planning agencies. Most of the truck weight and payload information is generated for pavement management purposes although it can be used to estimate the distribution of payloads as in Figliozi et al. (2000). However, disaggregation by tour type is necessary in urban areas since truck size is not always a binding constraint. Furthermore, if the product cubes out<sup>5</sup>, commercial vehicle utilization factors cannot be estimated by simply looking at the weight of the truck.

The temporal dimensions of the trips have also been largely neglected; however, the implementation of any commercial vehicle tour has always associated with it a temporal dimension. However, as the average travel speed is time dependent the impact of commercial vehicles will depend on the departure and return time to the depot. Tour departure time and time window constraints are therefore crucial to understand the impact of truck tours at different times of the day (e.g., peak and off-peak travel). To the best of the authors' knowledge, there are no systematic data collection efforts linking the number of stops, tour durations, and time windows. The only temporal information available is the distribution of trips during daylight hours from road surveys (Cambridge Systematics, 2003). However, this information is insufficient for explaining or predicting tour departure time.

Table 2 shows that the number of truck trips generated depends on the characteristics of the tour employed. In turn, tour types are a function of the commercial activity that generates the transport demand, network characteristics, and routing constraints. In addition, the analysis of expression (2), (3), (6), and (9) indicates that to understand changes in  $VKT$  in relation to network/policy changes, the following parameters need to be quantified:

- distribution of tour types by commercial activity;
- distribution of order sizes and vehicle types by tour type;
- distribution of the number of stops and tour lengths by tour type; and
- distribution of time windows, tour durations, and departure times.

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<sup>5</sup> Light commodities ordinarily "cube out" or reach the truck volume capacity before reaching the truck weight capacity or allowable axle weight limit

Freight behavioural analysis and data collection are particularly difficult due to the multiplicity of agents or decision makers (Hutchinson, 1985). Shippers, consignees, carriers, and third party logistics providers (3PLs) have different objectives, decision power, knowledge, and perceptions about supply chain and transport related choices. Commercial delivery tours are the materialization of service requests and service decisions across one or more supply chains and several decision makers. Keeping track of the observable tour parameters, such as number of customers per route, sequencing, time of service, vehicle used, distance, links traveled, etc, can provide valuable information and insights into supply chain agents' decision-making and behavior. Linking commercial activities to tour characteristics was first suggested by Figliozi (2006b). This work links the time sensitivity of the activity and the value of the activity itself to tour characteristics such as number of stops or time windows. Further research efforts are necessary to provide transportation analysts and practitioners with activity based data collection and modeling approaches.

## 7. Conclusions

The emphasis of this research is on the disaggregation of commercial vehicle tours by their routing characteristics. Although a few key assumptions are made about the distribution system including the one DC/depot structure and constant deterministic travel times and demand rates, valuable intuition can be obtained from the derived analytical expressions. In particular, the distinction between  $VHT$  and  $VKT$  and the discrimination of policy changes by tour type provide original insights.

It is proved that the  $VKT$  generated can be strongly influenced by the tour type. Direct deliveries are the most efficient type of tour up to a critical fill rate factor. As average order size decreases and time windows shorten, the efficiency of the tours also decreases. Multistop tours are proven to generate more  $VKT$  than direct deliveries even for equal payloads. The proposed analytical framework and tour classification seems a promising tool to derive insights regarding policy/network changes on  $VKT$  and  $VHT$  generated. Implications for the calibration of trip generation and distribution models are discussed. It is proved that the percentage of empty trips has no correlation with the efficiency of the tours regarding  $VKT$  generation or annual number of trips. The shape of Trip Length Distributions (TLD) is discussed. It is shown that the average trip length and the TLD shape is strongly dependent on the tour type.

A new level of urban commercial vehicle data collection and modeling efforts are needed to understand the workings of urban commercial vehicle tours. As illustrated in this research, efforts must be directed to comprehend the relationships between commercial activities, route designs and constraints, number of customers per route, and vehicle types in order to model the thinking and constraints faced by carriers and commercial vehicle fleet operators.



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