An Analysis of the Competitiveness of Freight Tricycle Delivery Services in Urban Areas

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ABSTRACT

This research analyzes the competitiveness of freight tricycles, low-capacity freight delivery vehicles, as compared to diesel vans in urban areas. Freight tricycles, also known as electric-assisted trikes, are low-emissions vehicles powered by a combination of human effort and an electric engine. This research develops a cost model incorporating vehicle ownership and operation models as well as logistics constraints such as time windows, cargo capacity, fuel consumption, and energy use. Unlike previous research efforts, the model has been tailored to the unique characteristic of freight tricycles and diesel van deliveries in urban areas. The model is used to analyze the competitiveness of freight tricycles against diesel-powered delivery vans. Cost breakeven points and elasticity for several vehicles and route-related variables are estimated. The results provide new insights regarding the “last mile” delivery characteristics and logistical constraints that may affect tricycles competitiveness. Freight tricycle competitiveness is sensitive to urban policies and design variables such as on-street speed limits and parking policies. Tricycle’s competitiveness is also greatly affected by drivers’ costs but barely affected by electricity or diesel costs. Unlike electric trucks, the competitiveness of tricycles is not driven by the value of vehicles and their utilization.

Keywords: urban areas, freight, tricycles, green, delivery, policy implications
INTRODUCTION

There is a growing awareness regarding the problems associated with urban freight deliveries in congested urban areas. Efforts to increase downtown or neighborhood livability can pose severe limitations for urban freight deliveries. Typical restrictions include ban at certain times of the day, a reduction of parking and/or loading/unloading zones, noise level and pollution constraints, and vehicle size limits. For example, there are some restrictions to heavy goods vehicles on weekends in the European Union (1) and truck size, routes, and parking are restricted in New York City (2). In this context, despite its limitations, freight tricycles are increasingly appealing.

Freight tricycles are ideal vehicles for congested and dense urban areas due to their small size and smaller carbon footprint, lack of tailpipe emissions, and relatively easy access to congested areas with limited parking facilities. In many urban areas freight tricycles can legally use bicycle paths/lanes which allows for faster access to congested downtowns or pedestrian areas. In addition, customer service times can be reduced because tricycles can be parked inside businesses or at nearby bicycle parking racks during deliveries. Besides practical considerations, the political environment in many states and countries encourages the utilization of environmentally friendly vehicles through tax credits or policies that aim to reduce greenhouse gas emissions.

There are also limitations associated to freight tricycles, chiefly their limited cargo capacity and relatively low operating speed. From the viewpoint of shippers and truck companies, total logistic cost is a crucial factor when making decisions or thinking about any changes to their supply chains. Utilizing publicly available data from an existing freight tricycle delivery company in Portland, Oregon, key factors that affect tricycles’ cost competitiveness are analyzed. The goal is to compare the competitiveness of freight tricycles against diesel powered delivery vans. Because the freight that is delivered by tricycles is often light and small, diesel vans are the natural competitor – single unit trucks, the other dominant urban delivery vehicles, are more expensive than vans and would have a high percentage of underutilized capacity. Efforts are made to present a realistic case study. However, the goal of this research is not to represent the costs of one company but to study the key factors that affect tricycle competitiveness analyzing cost elasticity values and the sensitivity of breakeven values. The ultimate goal is to derive insights that are applicable to cities and companies outside Portland, Oregon.

To compare tricycle and van costs, we develop a model that incorporates vehicle ownership and operation models, logistics constraints such as time windows and cargo capacity, and fuel consumption and energy use. The next section presents a brief literature review and the following sections present the cost/logistics model, case study assumptions, and results.

LITERATURE REVIEW

There are many bodies of literature that are relevant to the topic of freight tricycle delivery. Because of the high number of relevant papers and to facilitate the review of key factors, three subsections are introduced; freight tricycle characteristics, last mile deliveries in urban areas, and urban delivery costs models.
Freight Tricycle Characteristics

Most freight tricycles are electric-assisted. Tricycle payloads are typically between 330 and 600 lbs. and their volume capacities are typically between 42 and 55 cubic feet. Their speed is approximately 10 miles per hour (3). Although most freight tricycles are electronically assisted, the riders still have to pedal (4). The specifications of a typical freight tricycle and van are shown in Table 1.

| TABLE 1 Specifications of Typical Van and Tricycle. |
|---------------------------------|------------------|------------------|
|                                  | Tricycle         | Diesel Van       |
| Make                             | Cycle Maximus    | Dodge Promaster  |
| Price                            | 6,200 dollars a  | 34,000 dollars c |
| Battery size / Tank size         | 864 watt-hour a  | 24 gallon d      |
| Range                            | 30 miles a       | 288 miles d      |
| Max Speed                        | 10 mph b         | 50 mph e         |
| GVW                              | 715 lbs a        | 8,900 lbs f      |
| Tare                             | 165 lbs a        | 4,781 lbs f      |
| Payload                          | 550 lbs a        | 4,119 lbs f      |

a Cycle Maximus (4)  
b Conway, et al. (3)  
c Commercial Truck Trader (5)  
d Based on the fuel economy of 12 mpg (6) (7)  
e Typical urban area maximum speed limit  
f AOL Autos (8)

Wilson et al. (9) state that an average fit man or woman could pedal a bicycle with the power output of 75 watts without suffering fatigue for seven hours. The human contribution is not negligible since human power could reduce necessary battery size by roughly 500 watt-hours over a 7-hour day and the battery capacity is approximately 850 watt-hours.

Compared to a diesel delivery van, there are many advantages of a freight tricycle. First, a tricycle is relatively small, requires a small parking space, and can park both on and off-street as shown in Figure 1. Second, in some cities, there are dedicated bicycle lanes a tricycle can use to bypass traffic congestion. Third, a tricycle does not directly emit greenhouse gases or other air pollutants though there are likely upstream emissions caused by electricity generation. Finally, the purchase cost of a tricycle can be roughly 4.5 times lower than the purchase cost of a diesel van as shown in Table 1. However, there are several crucial disadvantages of freight tricycles. A tricycle’s payload and volume capacity are limited. Sometimes freight cannot be delivered by a tricycle if the cargo weight and/or volume exceed the tricycle capacity. Moreover, its traveling range is limited and its travel speed in free-flow conditions is much lower as shown in Table 1.

Last Mile Deliveries in Urban Areas

Freight tricycles are typically used in the “last mile of supply chains”, i.e. the movement of goods from a distribution center or warehouse to final stores and customers. Tozzi et al. (10) analyzed the characteristics of freight delivered by trucks from a local urban distribution center to shops and retailers in Parma, Italy. They collected data on 2,595 delivery tours, corresponding
Tipagornwong and Figliozzi
to 19,582 deliveries. They discovered that, on average, each end-user of a downtown urban
delivery tour receives 5 parcels or 45 kg and each end-user of a whole-city tour receives 13
parcels or 161 kg. They also discovered that delivery frequencies are between 2 and 7 days and
that 74 percent of all goods are delivered in the morning time.

![Image](http://www.neighborhoodnotes.com)

(a) A tricycle parks off-street

![Image](http://b-linepdx.com)

(b) Tricycles run on a dedicated bike lane

FIGURE 1 Urban Freight Delivered By a Freight Tricycle

Image sources: (a) http://www.neighborhoodnotes.com (b) http://b-linepdx.com

Products delivered by freight tricycles are often food, bakery products, beverage, daily
products, grocery products, office supplies, electronics, and pharmaceutical products (11). B-
line, a freight tricycle delivery company in Portland, Oregon, delivers food, bakery products, daily
products, office supplies, and bicycle parts to more than 100 locations (12). Because of just-in-
time systems and small store inventory sizes, many businesses have increased the frequencies of
their replenishment and decreased order size (13). In addition, many shops and stores prefer
urban deliveries in morning peak hours (13, 14).

Most freight tricycle delivery areas are in dense downtowns or commercial business
districts. For example, the freight tricycle delivery area in Paris includes 154,000 businesses and
430,000 residents within 9 square miles (3). The main freight tricycle delivery area in Portland is
downtown and two miles around the urban center of the city (12). The sizes of freight tricycle
companies are typically medium or small. The fleet of La Petite Reine in France consists of 50
tricycles. The fleet of Gnewt Cargo in London consists of 6 tricycles and 3 electric vans (3). The
B-line company in Oregon comprises 6 tricycles (15).

Urban Delivery Costs Models

To incorporate routing constraints and costs, continuous approximation models have been
successfully used in the past such as Davis and Figliozzi (16), and Tozzi et al. (10). Continuous
approximation models are based on the model originally proposed by Daganzo (17) for a
capacitated vehicle routing problem (CVRP).

\[ CVRP = 2\bar{m} + 0.57\sqrt{nA} \]

where \( CVRP = \text{average distance travelled (km)} \)
\[ \bar{r} = \text{average distance between customers and a depot (km)} \]

\[ n = \text{the number of customers} \]

\[ C = \text{a capacity of a vehicle that is the number of customer visits per a vehicle} \]

\[ m = \text{the number of vehicles that is the ratio of } n \text{ to } C \text{ or } m = \frac{n}{C} \]

\[ A = \text{the size of a service area (km}^2\text{)} \]

A vehicle capacity is assumed to be equal to the demand of at least 6 customers \((C \geq 6)\). The number of customers is assumed to be at least 24 \((n \geq 24)\). Daganzo’s approximation works better in elongated areas as the routes were formed following the strip strategy.

Figliozzi (18) proposes a modification of the approximation model to deal with fewer customers per route, the vehicle routing problem (VRP):

\[ VRP (V) = k_l \frac{n-m}{n} \sqrt{nA} + 2\bar{r}m \]

where

\[ VRP (V) = \text{average distance travelled for a fleet of } V \text{ vehicles (km)} \]

\[ k_l = \text{local service area coefficients} \]

\[ n = \text{the number of customers} \]

\[ m = \text{the number of vehicles} \]

\[ A = \text{the size of a service area (km}^2\text{)} \]

\[ \bar{r} = \text{average distance between customers and a depot (km)} \]

The equation above can be used for distribution areas with random (R), clustered (C), and mixed random and clustered (RC) customers and time windows. The values of the \(k_l\) coefficients can be calibrated empirically using regression analysis (18).

Davis and Figliozzi (16) propose a cost minimization model to compare electric and diesel trucks. The model includes the delivery distance, the power consumption rate, and the cost minimization model. The distances are estimated with the approximation vehicle routing problem model proposed by Figliozzi (18). A total of 243 scenarios are analyzed; these scenarios are a combination of an average distance from factories to customers, the number of customers, customer service time, per-customer demand weight, and a service area size. The circumstances that make electric trucks viable are high annual utilization, low traffic speeds, numerous customer stops, reduced purchase price (tax subsidies), long planning horizon, and more assistance on roadways such as high grade. Wei and Figliozzi (19) examine the economic and technological factors affecting the cost competitiveness of electric commercial vehicles. They analyze emissions costs assuming a CO\(_2\) cost of $18/ton and find that CO\(_2\) emission costs represent a small percentage of delivery costs.

Compared to delivery diesel or electric trucks, tricycles have unique characteristics. For example, tricycles can deliver/park faster than conventional vehicles. In addition, the minimum number of required vehicles/drivers is unlikely to be the same for tricycles and vans. In order to incorporate the unique characteristics of tricycles, it is necessary to introduce changes to the previous models utilized to compare vehicles with different engine/drivetrain types. The next section describes the cost and logistics model developed in this research.
COST AND LOGISTICS MODEL

As in previous continuous approximation models the delivery tour is segmented into 3 legs: leg A (a vehicle going from a depot to a service area), Leg B (the vehicle delivering goods in the service area), and Leg C (the vehicle returning to the depot).

Unlike previous modeling efforts, we have added a term to account for time spent searching/finding parking. In dense and congested commercial/downtown areas trucks sometimes cannot find available parking spaces when they reach their delivery point; even if loading zones are provided, the available parking space(s) may be already taken. In this case, trucks may have to circumnavigate delivery points in order to find available parking or wait until a loading zone is vacant. As a result, there is a penalty associated with the time and average distance traveled to find an available (empty) parking space. This penalty is directly added it to the distance formula because the average extra parking distance to find an empty parking space is not dependent on the route itself.

\[ Leg \ B^i = k_l \frac{n - m^i}{n} \sqrt{nA} + 2\bar{r}m^i + n\bar{t}_{park}^i \]

Where \( t_{park}^i \) = average distance to find an available parking space of a vehicle type \( i \); similarly, a time penalty \( t_{park}^i \) associated to parking a motorized vehicle and loading/unloading its cargo is included a part of the average customer service time \( t_{serv}^i \) in the tour duration equation (3).

Unlike previous costs comparisons, the model presented in this research includes driver costs. Previous research effort (e.g. comparing electric and diesel vehicles) assumed that the same number of vehicles and drivers were necessary. This is not the case in the present research since, for example, in some cases two vans may be replaced by three tricycles. The cost minimization model is shown below.

**Set**

\( I = \) set of types of vehicle \( i \) \{van, tricycle\}

**Decision variables**

\( m^i = \) number of vehicles of type \( i \) to service all the average daily customer demands

**Parameters**

**Cost**

\( C_{tot}^i = \) Total cost for vehicles \( i \) (dollar)

\( c_p^i = \) Unit purchase cost for vehicle \( i \) (dollar/vehicle)

\( c_r^i = \) Unit resale cost for vehicle \( i \) (dollar/vehicle)

\( c_e^i = \) Unit energy cost for vehicle \( i \) (dollar/gallon or dollar/kWh)

\( c_m^i = \) Per-mile maintenance cost for vehicle \( i \) (dollar/mile)

\( c_l^i = \) Unit labor cost for vehicle \( i \) (dollar/hour)

\( c_{co2} = \) Unit \( CO_2 \) emission cost (dollar/ton)
Inflation factors
\[ f_d = \text{Discount factor (\%)} \]
\[ f_e = \text{Rate of inflation for diesel fuel (\%)} \]

Other parameters
\[ e^i = \text{Per-tour fuel/electricity consumed by vehicles of type } i \text{ (gallons/tour or kWh/tour)} \]
\[ e^i_{\text{cap}} = \text{Battery capacity for vehicle type } i \text{ (kWh)} \]
\[ d_{\text{year}} = \text{Days of service per year} \]
\[ l^i = \text{Per-tour distance travelled to serve route of vehicle } i \text{ (miles/tour)} \]
\[ w_d = \text{Average unit customer demand (lbs)} \]
\[ w^i_{\text{cap}} = \text{Payload capacity for vehicle } i \text{ (lbs)} \]
\[ v^i_a = \text{Average speed of vehicle } i \text{ going to the service area (Leg A) (mph)} \]
\[ v^i_e = \text{Average speed of vehicle } i \text{ traveling inside the service area (Leg B) (mph)} \]
\[ v^i_c = \text{Average speed of vehicle } i \text{ returning to the depot (Leg C) (mph)} \]
\[ e^i_{\text{co2}} = \text{Per-mile fuel/electricity consumption rate of vehicles of type } i \text{ (gallon/mile or kWh/mile)} \]
\[ r^i_{\text{co2}} = \text{CO}_2 \text{ emission rate of vehicle type } i \text{ (kg/gallon or kg/kWh)} \]
\[ t^i_{\text{serv}} = \text{average time needed to serve a customer from vehicle } i \text{ (hours)} \]
\[ t^i = \text{Total tour time of vehicle } i \text{ (hours)} \]
\[ t_{\text{max}} = \text{Maximum tour time window (hours)} \]
\[ K = \text{Years in planning horizon} \]

Objective
Minimize
\[ \text{Total cost} = \text{purchase} - \text{resale} + \text{energy} + \text{emission} + \text{maintenance} + \text{labor} \quad (1) \]

\[ c^i_{\text{tot}} = c^i_p m^i - (1 + f_d)^{-K} c^i_c m^i + \sum_{k=1}^{K} (1 + f_d)^{-k}(1 + f_e)^k [c^i_{\text{dyear}} m^i e^i] + \sum_{k=1}^{K} (1 + f_d)^{-k} [c^i_{\text{dyear}} m^i t^i] + \sum_{k=1}^{K} (1 + f_d)^{-k} [c^i_{\text{dyear}} m^i t^i] \]

\[ l^i = \bar{r} + \frac{k_i n - m^i}{n \sqrt{nA + n t^i_{\text{park}}}} + \bar{r} \quad (2) \]

\[ t^i = \frac{\bar{r}}{v^i_a} + \frac{k_i n - m^i}{n \sqrt{nA + n l^i_{\text{park}}}} + \frac{\bar{r}}{v^i_c} + n t^i_{\text{serv}} \quad (3) \]

\[ e^i = l^i e^i \quad (4) \]

Subject to
\[ m^i \geq \frac{n w_d}{w^i_{\text{cap}}} \quad \forall i \in I \quad (5) \]
\[ e^i \geq e^i_{\text{cap}} \quad \forall i \in I \quad (6) \]
\[ t_{\text{max}} \geq t^i \quad \forall i \in I \quad (7) \]
\[
\begin{align*}
v_a^i & \leq 60 \text{ mph} \quad i \in \{\text{truck}\} \\
v_c^i & \leq 60 \text{ mph} \quad i \in \{\text{truck}\} \\
v_b^i & \leq 30 \text{ mph} \quad i \in \{\text{truck}\} \\
v^i & \leq 10 \text{ mph} \quad i \in \{\text{tricycle}\}
\end{align*}
\]
\[
\begin{align*}
m^1 & \geq 0 \quad \forall i \in I
\end{align*}
\]
\[
m^i \in \text{Set of Integers}
\]

Equation (1) is the objective function. Equation (2) is the length of a vehicle tour, starting from a depot, servicing customers, and returning to the depot. Equations (3) and (4) are the time spent and the energy consumed for the whole vehicle tour. Equation (5) is the vehicle weight capacity. Equation (6) is the energy constraint. Equation (7) is the driver time constraint. Equations (8) set the speed limits. Equations (9) and (10) restrict the number of vehicles to the set of positive integers.

**CASE STUDY**

To better understand the tradeoffs between tricycles and vans we tried to utilize real-world data from Portland, Oregon. The case study is based on the delivery area and customers of an existing tricycle delivery company, B-line (http://b-linepdx.com/). Most of the customers are located in or close to Downtown Portland, as shown in Figure 2. The goal is to understand the key tradeoffs and factors that affect competition between tricycles and delivery vans. Breakeven points and cost elasticity are then studied using data from public data sources associated with B-line delivery such as B-line (12) and Martin (15). This modeling exercise is not meant to represent the variability of customer demand or routes or more complex route structures such as combined delivery and pickup.

Only goods delivered from the distribution center to shops and retail stores are modeled. According to spatial distribution of the delivery locations, the locations could be segmented into 3 sub-service areas; Hillside-Northwest Portland, Downtown Portland, and East Portland. B-line averages 80 deliveries per day (15) and it is further assumed that the average number of deliveries is proportional to the number of the delivery locations in each sub-service area.
We assume that the products of the B-line’s partners arrive to B-line’s depot and then tricycles or vans deliver the cargo. As discussed previously, the service time per customer using a tricycle is likely to be less than that of a van due to parking availability and the ability of the tricycle to get closer to the customer delivery area. The assumed characteristics of the two vehicle types are summarized in Table 2. These characteristics are meant to represent a typical base case scenario; in a latter section the characteristics will be varied and their elasticity studied. On average, 8-10 tricycle tours are used to deliver goods to 80 customers per day (15).

Two distinct base case scenarios are analyzed: a) a cargo capacity constrained scenario and b) a time window constrained scenario; both scenarios require the same number of tours and tricycles. In the former scenario the average customer demand weight is 50 lbs.; in the latter scenario the maximum time window is 2-4 hours. The first scenario, “light urban delivery” is meant to represent food and office supplies delivery. The second scenario, “morning courier service” is meant to represents delivery in morning of more time-sensitive but smaller packages.
### TABLE 2 Assumed Vehicle Characteristics

<table>
<thead>
<tr>
<th>Vehicle</th>
<th>Freight tricycle</th>
<th>Diesel van</th>
</tr>
</thead>
<tbody>
<tr>
<td>Model</td>
<td>Cycle Maximus</td>
<td>Dodge Promaster</td>
</tr>
<tr>
<td>Resale price</td>
<td>$ 0 \textsuperscript{a}</td>
<td>$ 24,500 \textsuperscript{b}</td>
</tr>
<tr>
<td>Energy cost</td>
<td>10.46 cents/kWh \textsuperscript{b}</td>
<td>$ 3.866 / gal \textsuperscript{i}</td>
</tr>
<tr>
<td>Maintenance cost</td>
<td>$ 0.02 / mile \textsuperscript{c}</td>
<td>$ 0.20 / mile \textsuperscript{j}</td>
</tr>
<tr>
<td>Driver cost</td>
<td>$16.32 / hour \textsuperscript{d}</td>
<td>$16.32 / hour \textsuperscript{d}</td>
</tr>
<tr>
<td>CO\textsubscript{2} emission cost</td>
<td>$ 18 / ton \textsuperscript{e}</td>
<td>$ 18 / ton \textsuperscript{e}</td>
</tr>
<tr>
<td>Electricity / Fuel economy</td>
<td>29 watt-hour/mile \textsuperscript{f}</td>
<td>12 mpg \textsuperscript{k}</td>
</tr>
<tr>
<td>Battery size / Tank size</td>
<td>864 watt hour \textsuperscript{g}</td>
<td>24 gallons</td>
</tr>
<tr>
<td>CO\textsubscript{2} emission rate</td>
<td>0 kg / kWh</td>
<td>8.92 kg/gallon \textsuperscript{e}</td>
</tr>
<tr>
<td>Distance to find parking</td>
<td>0</td>
<td>200 feet (1 blocks)</td>
</tr>
<tr>
<td>Average speed inside service area</td>
<td>5 mph</td>
<td>10 mph</td>
</tr>
<tr>
<td>Average speed outside service area</td>
<td>5 mph</td>
<td>30 mph</td>
</tr>
</tbody>
</table>

\textsuperscript{a} Assumed to be is zero because a tricycle’s life time equals the planning horizon
\textsuperscript{b} U.S. Energy Information Administration (20)
\textsuperscript{c} Assumed to equal the maintenance cost of an electric vehicle multiplied by the ratio of the purchase price of a tricycle and an electric vehicle from Motavalli (21)
\textsuperscript{d} U.S. Bureau of Labor Statistics (22)
\textsuperscript{e} Feng and Figliozzi (19)
\textsuperscript{f} Calculated from the stated range and the battery size
\textsuperscript{g} Cycles Maximus (4)
\textsuperscript{h} Assuming depreciation of a van over 5 years, depreciation is low due to the low mileage driven (23)
\textsuperscript{i} U.S. Energy Information Administration (24)
\textsuperscript{j} Motavalli (21)
\textsuperscript{k} Freightliner (6)

Other parameters that are used for comparing diesel vans and tricycles are planning horizon and delivery days per year. The ownership time of delivery vehicles is approximately 12 years (25). However, the ownership time of freight tricycles is usually much shorter and assumed to be 5 years. As a result, the planning horizon is set to equal 5 years but the resale value of the diesel van after five years of relatively low utilization/mileage is taken into account. In addition, because goods are assumed to be delivered 5 days per week, there are 260 delivery days per year. Customer characteristics and planning parameters are summarized in Table 3.
TABLE 3 Customer Characteristics And Planning Parameters Of The Case Study

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Light urban delivery</th>
<th>Morning courier service</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of daily deliveries</td>
<td>74&lt;sup&gt;a&lt;/sup&gt;</td>
<td>74&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>Total area size (sq. miles)</td>
<td>8.5&lt;sup&gt;b&lt;/sup&gt;</td>
<td>8.5&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td>Distance from the warehouse (miles)</td>
<td>2.0&lt;sup&gt;c&lt;/sup&gt;</td>
<td>2.0&lt;sup&gt;c&lt;/sup&gt;</td>
</tr>
<tr>
<td>Customer demand (lbs.)</td>
<td>50&lt;sup&gt;d&lt;/sup&gt;</td>
<td>10&lt;sup&gt;e&lt;/sup&gt;</td>
</tr>
<tr>
<td>Time constraint (hours)</td>
<td>8&lt;sup&gt;f&lt;/sup&gt;</td>
<td>4&lt;sup&gt;g&lt;/sup&gt;</td>
</tr>
<tr>
<td>Van service time (minutes)</td>
<td>15&lt;sup&gt;h&lt;/sup&gt;</td>
<td>15&lt;sup&gt;h&lt;/sup&gt;</td>
</tr>
<tr>
<td>Tricycle service time (minutes)</td>
<td>10&lt;sup&gt;i&lt;/sup&gt;</td>
<td>10&lt;sup&gt;i&lt;/sup&gt;</td>
</tr>
<tr>
<td>Planning horizon (years)</td>
<td>6&lt;sup&gt;j&lt;/sup&gt;</td>
<td>6&lt;sup&gt;j&lt;/sup&gt;</td>
</tr>
<tr>
<td>Delivery days per year</td>
<td>260</td>
<td>260</td>
</tr>
<tr>
<td>Discount factor</td>
<td>6.5%&lt;sup&gt;k&lt;/sup&gt;</td>
<td>6.5%&lt;sup&gt;k&lt;/sup&gt;</td>
</tr>
<tr>
<td>Fuel/energy cost inflation</td>
<td>2.5%&lt;sup&gt;l&lt;/sup&gt;</td>
<td>2.5%&lt;sup&gt;k&lt;/sup&gt;</td>
</tr>
</tbody>
</table>

<sup>a</sup> Based on the delivery locations of B-line in the proposed service areas (12) and average daily deliveries (15)
<sup>b</sup> Total service area size of Hillside-Northwest, Downtown Portland, and East side of Portland
<sup>c</sup> Average distance from B-line’s depot to all three service areas
<sup>d</sup> 50 percent of an average customer demand weight of a city delivery from the study of Tozzi et al. (10)
<sup>e</sup> FedEx-type demand weight, Davis and Figliozzi (16)
<sup>f</sup> Whole-day delivery
<sup>g</sup> NCFRP 14 (14)
<sup>h</sup> Average customer service time, Davis and Figliozzi (16)
<sup>i</sup> Assumed to be less than van service time
<sup>j</sup> Assumed life time of a freight tricycle
<sup>k</sup> Feng and Figliozzi (25)

RESULTS AND DISCUSSION

This section presents the results of the transportation cost comparison in the two scenarios and this is followed by the breakeven and elasticity value analysis.

For the “light urban delivery” scenario, the number of tricycles needed is two times the number of required diesel vans. Because of its lower weight capacity a tricycle tour has fewer deliveries. As a result, the average tour time of a tricycle is 3.1 hours that are approximately 3 hours less than the average tour time of vans. For the “morning courier service” scenario, the number of tricycles needed equals the number of vans. With a tighter time window and with the capacity constraints not binding both vehicles have the same number of customer stops per tour. However, the tricycle tour time is a balance of both travel time and service time while the majority of the van tour time is comprised by the service time.

For the “light urban delivery” scenario, the transportation cost of diesel vans is approximately $4,000 lower while, for the “morning courier service” scenario, the transportation
cost of tricycles is approximately $9,000 lower. The cost structure of tricycles and vans are very different. In the case of tricycles, driver’s wages are the predominant cost followed by vehicle costs, as shown in Figure 3; approximate 150 dollars are spent in electricity. In the case of vans, drivers’ wages are important but with a lower share of the total annualized costs because vans are more expensive to maintain and fuel, as shown in Figure 4. The emission cost of diesel vans accounts for less than 0.2 percent of its costs.

![FIGURE 3 Proportions of Annual Costs of Freight Tricycles by Category](image1)

![FIGURE 4 Proportions of Annual Costs of Diesel Vans by Category](image2)

**Break-Even Analysis**

To analyze the feasibility of tricycles it is important to examine the breakeven values. The values of the variables that can equalize the costs of vans and tricycles (with all other variables set at their base case values) are shown in Table 4. The break even values can be used to find the logistics settings where tricycles can be competitive. First, either a small increase in vans service time or a small reduction in tricycle service times makes tricycles more competitive. Second, a decrease in distance between a depot and a service area or service time makes tricycles more competitive. In both scenarios, the parameters that potentially equalize the transportation costs with the reasonable ranges are service time, the distance between a depot and a service, service area, unit demand weight, time window, driver wage, and vehicle speed.

Overall, the changes needed to breakeven in both scenarios are relatively small and realistic. This relative parity between the two vehicles makes the elasticity analysis even more relevant.
### TABLE 4 Break-Even Analysis of Transportation Costs of Tricycles and Diesel Vans

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Light urban delivery(^a)</th>
<th>Morning courier service(^b)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Base case</td>
<td>Break-even</td>
</tr>
<tr>
<td><strong>Logistics elements</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Van service time (minutes)</td>
<td>15.0</td>
<td>15.5</td>
</tr>
<tr>
<td>Tricycle service time (minutes)</td>
<td>10.0</td>
<td>9.0</td>
</tr>
<tr>
<td>Distance between a depot and a service area (mile)(^c)</td>
<td>2.0</td>
<td>1.9</td>
</tr>
<tr>
<td>Service area (sq. mile.)</td>
<td>8</td>
<td>2</td>
</tr>
<tr>
<td>Unit demand weight (lbs.)</td>
<td>50</td>
<td>42</td>
</tr>
<tr>
<td>Time window (hours)</td>
<td>8.0</td>
<td>5.5</td>
</tr>
<tr>
<td><strong>Cost elements</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Van purchase price (dollar)</td>
<td>34,000</td>
<td>48,000</td>
</tr>
<tr>
<td>Tricycle purchase price (dollar)</td>
<td>6,200</td>
<td>4,200</td>
</tr>
<tr>
<td>Van driver wage (dollar/hour)</td>
<td>16.32</td>
<td>16.95</td>
</tr>
<tr>
<td>Tricycle driver wage (dollar/hour)</td>
<td>16.32</td>
<td>15.74</td>
</tr>
<tr>
<td>Diesel price (dollar/gallon)</td>
<td>3.87</td>
<td>7.05</td>
</tr>
<tr>
<td>Electricity price (cent/kW h)</td>
<td>10.46</td>
<td>-1,500</td>
</tr>
<tr>
<td><strong>Transportation element</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Van average speed (mph)</td>
<td>10</td>
<td>9</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

\(^a\) For the “light urban delivery scenario”, the transportation cost of vans is lower
\(^b\) For the “morning courier service” scenario, the transportation cost of tricycles is lower
\(^c\) Average distance from B-line’s depot to all three service areas

#### Per-mile Cost Elasticity Analysis

Given the importance of tour distance, an elasticity analysis is useful to find the variables that are more likely to affect per-mile costs. The parameters in the elasticity analysis are the same parameters in the breakeven analysis, as shown in Table 5.

The per-mile cost of tricycles is very sensitive to driver unit cost which is a key cost item. Similarly, the per-mile cost of vans is very sensitive to the driver unit costs. Any type of regulation that affects the relative value of driver costs is likely to swiftly change the relative competitiveness. Vans are more sensitive to vehicle cost changes and both vehicles are rather insensitive to changes in fuel/energy costs.
Among the transportation-related parameters, the per-mile cost of tricycles is sensitive to travel speed because the ratio of the total running time to tour time is high. Among the logistics-related parameters, the per-mile cost of vans and tricycles are sensitive to the service time (which includes parking) changes. Service times not only affect route durations but also drivers’ costs.

TABLE 5 Elasticity Analysis of Per-Mile Transportation Costs of Tricycles and Diesel vans

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Light urban delivery</th>
<th>Morning courier service</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Tricycle: Diesel van</td>
<td>Tricycle: Diesel van</td>
</tr>
<tr>
<td><strong>Logistics elements</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Service time (minutes)</td>
<td>0.473</td>
<td>0.739</td>
</tr>
<tr>
<td>Distance between a depot and a service area (miles)</td>
<td>-0.290</td>
<td>-0.297</td>
</tr>
<tr>
<td>Service area (sq. mile.)</td>
<td>-0.118</td>
<td>-0.211</td>
</tr>
<tr>
<td>Unit demand weight (lbs.)^a</td>
<td>-0.173</td>
<td>0.000</td>
</tr>
<tr>
<td>Time window (hours)^a</td>
<td>0.084</td>
<td>0.124</td>
</tr>
<tr>
<td><strong>Cost elements</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Purchase price (dollars)</td>
<td>0.090</td>
<td>0.255</td>
</tr>
<tr>
<td>Driver wage (dollar/hour)</td>
<td>0.908</td>
<td>0.873</td>
</tr>
<tr>
<td>Electricity price / diesel price</td>
<td>0.000</td>
<td>0.035</td>
</tr>
<tr>
<td>CO2 emission cost (dollar/ton)</td>
<td>n/a</td>
<td>0.002</td>
</tr>
<tr>
<td><strong>Transportation element</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Average speed (mph)</td>
<td>-0.394</td>
<td>-0.091</td>
</tr>
</tbody>
</table>

^a Large changes of these parameters change the per-mile costs because they increase vehicles.

Policy Discussion

Many urban areas are trying to increase the livability of downtown areas. In many cases road diets, marked pedestrian crossings and areas, and additional bicycle lanes or parking are introduced to increase the appeal of pedestrian and bicycle modes. These efforts can affect the competitiveness of tricycle delivery because they may slow down motorized traffic while increasing the speed or accessibility of tricycles.

Transportation infrastructure planning and regulation can promote tricycle delivery by reducing on-street speed limits, narrowing traffic lanes, limiting motor vehicle parking, and extending bicycle facilities. The same factors that improve pedestrian and bicycle mobility in urban areas
tend to improve the competitiveness of tricycle delivery. In turn, tricycle delivery increases livability by reducing emissions and noise and the number of heavier commercial vehicles.

CONCLUSIONS

The goal of this paper is to analyze the competitiveness of freight tricycle delivery services in urban areas. Two distinct scenarios are analyzed, a weigh constrained scenario (e.g. office staples) and a time constrained scenario representing a courier or small package delivery service.

The elasticity analysis and breakeven values indicate that driver costs are extremely critical. A small percentage change in drivers’ costs may rapidly change the relative competitiveness of tricycles and diesel vans. Service time is a logistical parameter that also has a great influence in the competitiveness of tricycles; tricycles will thrive in urban areas where parking or access to customers is difficult for conventional vehicles, where travel speeds are low, and with time constrained delivery windows. On the other hand, diesel vans thrive whenever capacity constraints or long travel distances increase significantly the number of required tricycles. Electricity or diesel costs in these scenarios are not the major factors affecting the relative competitiveness of tricycles and diesel vans.

Our findings are also useful for developing heuristics for fleet mix problems in central business areas, residential areas, and suburban areas. Each vehicle type should be assigned to the delivery conditions that better fit its relative strengths. Tricycles can be assigned to denser urban areas where depots are close to customers and where parking, access to businesses and travel are difficult; diesel delivery vans or trucks are better suited to situations where the depot is relatively far from the customer area and/or when travel time and access are not problematic. In addition, tricycles may not be competitive where capacity or time constrains demand an important increase in the number of additional drivers needed to operate the delivery fleet.

Transportation infrastructure planning and regulation can promote tricycle delivery by reducing on-street speed limits, narrowing traffic lanes, limiting motor vehicle parking, and extending bicycle facilities. The same factors that improve pedestrian and bicycle mobility in urban areas tend to improve the competitiveness of tricycle delivery. In turn, tricycle delivery increases livability and the appeal of active transportation modes by reducing emissions and noise and the number of heavier commercial vehicles in dense urban areas.
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