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ARTICLE

Impact of last mile parking availability on commercial vehicle costs and operations

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ABSTRACT
Logistics, queuing and optimisation models are combined to study the impact of last-mile parking availability on commercial vehicle costs and operations. Parking availability levels affect commercial vehicle parking costs and operations and has an impact on route characteristics and commercial vehicle fleet sizes. The magnitude of the parking availability impacts on costs is a function of customer and route characteristics. Elasticity values indicates that only a few variables have a significant impact on commercial vehicle parking behaviour. Productivity improvements like service time reductions may result in undesirable changes in commercial vehicle parking behaviour.

KEYWORDS
Commercial vehicles; last mile; parking costs; economic analysis; elasticity

Introduction

There is a growing awareness regarding problems associated with commercial vehicles in congested urban areas. Efforts to increase downtown or neighbourhood livability can result in costly restrictions. Typical restrictions include commercial vehicle bans at certain times of the day, limited parking and/or loading and/or unloading zones for commercial vehicles, commercial vehicle noise level limits (when loading and unloading), commercial vehicles pollution constraints and commercial vehicles size limits. For example, in New York City, commercial vehicle size, routes and parking areas are restricted for urban freight distributors and service providers (City of New York 2013).

On-street parking spaces and freight loading zones (FLZs) are typically insufficient during certain periods of the day in most dense and congested urban areas; for example, in the USA, these urban areas include New York City, San Francisco, Los Angeles, Boston, Chicago and Washington D.C. News organisations frequently report on the problems caused by double-parked commercial vehicles or the high parking fines that delivery companies must pay (NBC News 2006; Gordon 2007; Halsey 2013; Hawkins 2013; Berezin 2014).

Although anyone who lives in a dense and congested city is familiar with the problems associated to commercial vehicle parking, there is limited research in this area. In particular, there is scant research related to models that attempt to understand the impacts of FLZ availability on commercial vehicles costs and behaviour. This study addresses the following research questions: how does parking availability affect distribution companies' parking behaviour? and (ii) what are the key variables that affect parking costs?

The next section discusses key aspects of the problem under study and presents a brief literature review. Later sections present a modelling framework that includes queuing, logistics and cost optimisation models. A case study that includes different delivery services types is analysed and cost elasticity and break-even values are discussed. The final sections discuss policy and managerial implications and summarise the main conclusions that can be derived from this research effort.

Background and brief literature review

When all parking spaces near delivery destinations are occupied, commercial drivers prefer not to park away from the delivery destination (Pluvinet et al. 2012). Several factors explain this preference. It is difficult to move bulky or heavy products over long distances or across intersections even if the driver or delivery person is utilising a hand truck (Allen et al. 2000). In some cities or neighbourhoods, drivers may prefer to see their vehicles to prevent theft and/or vandalism (Morris, Kornhauser, and Kay 1999). In addition, parking away from the delivery points adds time per delivery and small delays quickly become significant for drivers or companies that have to serve many customers along the route (Figliozzi 2007; Figliozzi and Tipagornwong 2016).

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When there is no parking available nearby, the delivery point commercial drivers may double-park. If commercial drivers double-park frequently, the cost of parking fines can be substantial. For example, in New York City, large delivery fleets including FedEx, UPS and the U.S. Postal Service paid $550 million in 2013 (Hawkins 2013). Since repeated double-parking fines increase the final delivery cost, urban freight distributors and service providers may raise service fees to customers in areas where deliveries or pickups are more difficult. For example, UPS charges a surcharge in some congested or difficult delivery areas (such as zip codes 10000–10292) of Manhattan, New York City (United Parcel Service of America 2015).

Previous research efforts have modelled parking availability by analysing a parking demand-to-supply ratio that is defined as the ratio between parking demand and parking supply rates. Some publications define the parking demand rate as a freight trip generation rate multiplied by the average parking time; for example, Jaller, Holguín-Veras, and Hodge (2013) studied off-peak-hour deliveries and evaluated commercial parking availability with the parking demand-to-supply ratio at different times of day in New York City. The freight trip generation rate has been traditionally estimated as a function of the number of employees by type of industry, commercial sector or land use (Fischer and Han 2001). The parking supply is defined as the number of parking spaces or FLZs. The literature based on the analysis of empirical demand/supply data largely agree that at peak times there is insufficient parking capacity in commercial districts and along urban arterials (Wenneman, Habib, and Roorda 2015) and even in neighbourhoods (Chen and Conway 2016).

Another line of research has utilised simulation models (e.g. Aiura and Taniguchi 2006; Cherrett et al. 2012) to study commercial vehicle parking in urban areas. These models can accurately represent transportation networks and FLZs, generate commercial vehicle trips and their parking time and estimate commercial vehicles delays. A recent model to analyse parking policies in specific locations combines parking choice models and traffic simulation models (Nourinejad et al. 2014).

The third approach is a statistical model. For example, a statistical model (based on queuing theory) has been used to study how *personal* or *passenger* parking demand responds to pricing and parking availability in San Francisco (Millard-Ball, Weinberger, and Hampshire 2014). This type of modelling effort can be used to investigate the impact of pricing on parking arrival rate, parking duration and parking availability. Unfortunately, there is no similar dataset that can be utilised to study the impacts of pricing and parking availability on commercial vehicles. A previous paper by the same authors was preliminary (conference proceedings) and did not include a discussion of elasticity values and policy/managerial implications (Tipagornwong and Figliozzi 2015; Figliozzi and Tipagornwong 2016).

Unlike previous research efforts, this research focuses on modelling parking availability combining queuing models and logistical models based on continuous approximations. Unique contributions of this research are the addition of real-world routing constraints such as load capacity or route time durations, the analysis and comparison of courier and less-than-truckload (LTL) and ranking the impact of logistics and policy variables as a function of their elasticity values. The next section presents the modelling framework integrating queuing and continuous approximations for long-term logistic costs.

Modelling commercial parking

This research models parking availability utilising queuing models. Routing constraints are modelled utilising continuous approximations. Service costs include all the relevant long-term (vehicle and driver) costs. Finally, all the models are integrated within an optimisation framework that can be utilised to determine the optimal number of vehicles, vehicle type and parking behaviour.

Parking availability

Convenient access is important for both consumers and carriers (Durand and Gonzalez-Feliu 2012), hence the number of available parking spots is usually limited. Assuming that there are (S) FLZs available on a first-come-first-serve basis and that inter-arrival times and FLZ occupation times follow exponential distributions, a M/M/S queuing model can be utilised. The expected probability of double-parking ($P(N \geq S)$)can be estimated as follows:

$$P(N \geq S) = 1 - P(N \leq S-1) = 1 - \sum_{N=0}^{S-1} \frac{(\lambda/\mu)^N}{N!} P(N=0)$$

$$P(N=0) = \frac{1}{\sum_{N=0}^{S-1} \frac{(\lambda/\mu)^N}{N!} + \frac{(\lambda/\mu)^S}{S!} \cdot \frac{1}{1-\lambda/S\mu}}$$

where

$P(N \geq S)$ = probability that all FLZs are occupied

N = number of commercial vehicles in the system

S = number of FLZs

λ : commercial vehicle arrival rate (vehicles per hour)

$P(N=0)$: probability that all FLZs are empty

If a commercial driver waits when FLZs are fully occupied, the expected waiting time of the driver can be estimated as follows:

$$W_q = \frac{P_o(\lambda/\mu)^S(\lambda/S\mu)}{S!(1-\lambda/S\mu)^2\lambda}$$

When a commercial driver waits until an FLZ is available, it is assumed that the driver waits inside the vehicle and since the vehicle is never left unattended, the 'waiting' driver will not receive a parking fine.

When the driver double-parks, a parking enforcement officer can issue a parking fine. However, an illegally parked vehicle does not always receive parking fines. This study models the expected probability of receiving a parking ticket or fine given that all FLZs are occupied p_t as a function of service time (t_s) and the parking enforcement cycle duration (t_{ef}). The inverse of μ is the duration of the average parking zone utilisation or t_s.

$$p_t = \text{probability}(\text{ticket}|N \geq S)) = \frac{t_s}{t_{ef}}$$

An average parking utilisation level (ρ) is defined as the ratio of parking demand to parking supply$(\rho = \lambda/S\mu)$. Parking utilisation and parking availability are inversely related, low parking utilisation$(\text{low}\rho)$ is associated with high parking availability or easiness to find empty loading zones.

Routing constraints

Continuous approximations have been successfully used by many research efforts to model urban distribution systems (Langevin, Mbaraga, and Campbell 1996; Daganzo 2005). This study utilises a continuous approximation model, successfully used in the past (Figliozzi 2008; Figliozzi 2010) to estimate the average route distance of commercial vehicles.

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

where vehicle routing problem (VRP) (V) = average distance travelled for a fleet of m vehicles (miles)

k_l = local service area coefficients
n = number of customers
m = number of routes
A = the size of a service area (km^2)
$\bar{r}$ = average distance between customers and a depot (km)

The following parameters are utilised to formulate long-term service costs.

L^i = tour distance of vehicle type i (miles / tour)
T^i = tour duration of vehicle type i (h)
$T_{\max}$ = maximum tour duration (h)
w_d = Average customer demand (lb / stop)
t_s = Average service time (minute / stop)
v_a^i = Average speed of vehicle i going from a depot to the service area (mph)
v_b^i = Average speed of vehicle i running inside the service area (mph)
v_c^i = Average speed of vehicle i returning to the depot (mph)
w_c^i = Load capacity of vehicle type i (lb)

Route duration and vehicle capacity constraints can be expressed as follows:

$$L^{ij} = \bar{r} + \frac{k_l \frac{n^{ij}-m^{ij}}{n^{ij}}\sqrt{n^{ij}A}}{m^{ij}} + \bar{r}$$

$$T^{ij} = \frac{\bar{r}}{v_a^i} + \frac{k_l \frac{n^{ij}-m^{ij}}{n^{ij}}\sqrt{nA}}{m^{ij}v_b^i} + \frac{\bar{r}}{v_c^i} + n^{ij}t_s^i + \left(1-y_{ij}\right)\left(n^{ij}W_q(\rho)\right)$$

$$\left(m^{ij} \geq n^{ij} \cdot w_d / w_C^i \forall i \in I, \forall j \in J\right)$$

$$T_{\max} \geq T^{ij} \forall i \in I, \forall j \in J$$

The binary variable y_{ij} indicates whether the vehicle double-parks $(y_{ij} = 1)$ or waits for parking $(y_{ij} = 0)$. These equations estimate the length of a delivery tour that starts from a depot, serves customers and returns to the depot as well as tour duration. Average parking utilisation levels ρ and parking behaviour affect waiting time W_q and can indirectly also affect fleet size when T^{ij} increases over the maximum tour duration.

Service costs

Long-term service cost includes vehicle depreciation cost, energy/fuel cost, vehicle maintenance cost, driver wage, driver annual costs, truck annual costs and double-parking fines. In the USA, drivers' annual costs include driver health insurance, social security tax, Medicare tax and pension/retirement; the truck annual costs include vehicle registration and insurance. The following indices are utilised to formulate long-term service costs.

$i \in \{\text{set of vehicle types}\} = I$

$j \in \{\text{setofparkingbehaviors}\} = J$ j = 1 for double-park ing and j = 0 for waiting or cruising for parking

$k \in \{\text{set of years of the planning horizon}\} = \{1, 2, \ldots, K\}$

The following parameters are utilised to formulate long-term service costs.

c_p^i = Unit purchase cost for vehicle type i (dollar / vehicle)
c_r^i = Unit resale cost for vehicle type i $\left(\frac{\text{dollar}}{\text{vehicle}}\right)$ in year K
c_e^i = Unit energy cost for vehicle type i (\$ / gal or \$ / kW h)

r_e^i = energy consumption rate of vehicle type i ($ / mile or kW h / mile)
c_m^i = unit maintenance cost for vehicle type i ($ / mile)
c_l^i = hourly driver wage for vehicle type i ($ / h)
c_t = parking fine ($)
p_t^{ij} = probability of receiving a parking for vehicle type i and behaviour type j
c_a^i = unit annual cost for vehicle type i (dollar / vehicle)
f_d = discount factor (%)
f_e = rate of inflation for diesel fuel (%)
d = days of service per year
K = years in planning horizon
m^{ij} = fleet size $m^{i,j}$(integer) of vehicles type i following parking behaviour j

The sum of purchasing, resale, energy/fuel, maintenance, driver wages, parking tickets and vehicle fixed annual costs can be expressed as follows:

$$C = \sum_i \sum_{j=1}^{J} \Big[(c_p^i - (1+f_d)^{-K} c_r^i) m^{ij} + \sum_{k=1}^{K} (1+f_d)^{-k}(1+f_e)^k (c_e^i r_e^i L^{ij} m^{ij} d) + \sum_{k=1}^{K} (1+f_d)^{-k} (c_m^i L^{ij} m^{ij} d) + \sum_{k=1}^{K} (1+f_d)^{-k} (c_l^i T^{ij} m^{ij} d) + \sum_{k=1}^{K} (1+f_d)^{-k} (c_t p_t^{ij} m^{ij} d) + \sum_{k=1}^{K} (1+f_d)^{-k} (c_a^i m^{ij}) \Big].$$

Optimisation problem

The optimisation problem minimises long-term vehicle costs by selecting the best vehicle type i and parking behaviour j. The decision variable is the fleet size $m^{i,j}$(integer) of vehicles type i following parking behaviour j and the number of customers n^{ij} assigned to vehicle type i following parking behaviour j. The binary variable y_{ij} is 1 when the vehicle double-parks ($j = 1$) and 0 otherwise ($j = 0$) when the driver waits until a parking space is available.

$C =$ Total cost over the planning horizon (dollars)

$$\text{Minimise } C \tag{1}$$

Subject to:

$$m^{ij} \geq n^{ij} \cdot w_d / w_C^i \forall i \in I, \forall j \in J \tag{2}$$

$$T_{max} \geq T^{ij} \forall i \in I, \forall j \in J \tag{3}$$

$$p_t^{ij} = y_{ij} p_t \leq 1 \forall i \in I, \forall j \in J \tag{4}$$

$$n^{ij}, m^{ij} \geq 0 n^{ij}, m^{ij} \in \text{set of integers} \forall i \in I, \forall j \in J \tag{5}$$

$$m^{ij} \leq n y^{ij} \ \forall i \in I, \ j = 1 \tag{6}$$

$$m^{ij} \leq n(1 - y^{ij}) \forall i \in I, \ j = 0 \tag{7}$$

$$n \leq \sum_i \sum_J^{j=1} n^{ij} \tag{8}$$

Equation (1) is the objective function, minimization of total cost. Equation (2) is a weight/capacity constraint and Equation (3) is a route duration constraint. Equation (4) estimates the probability of receiving a fine. Equation (5) is an integer non-negativity constraint. Equations (6) and (7) are logical constraints that link parking behaviour and fleet size. Equation (8) ensures that all customers are served.

The reader should note that the threshold for waiting or double-parking is purely monetary. The model attempts to explain what factors may support a waiting or double-parking strategy. It is assumed that loading zones are convenient for commercial vehicle drivers; another dimension of the problem is the situation when commercial drivers stop in the closest place (double-park) even when loading zones are free but not close enough to the final delivery location (a trade-off that is not analysed in this research).

Case study

It is hypothesised that logistics constraints and route characteristics have an impact on parking costs, operations and behaviour. Two types of delivery services are analysed: LTL and courier deliveries. LTL deliveries are heavier and require more time per delivery than courier deliveries. LTL shipments can range between 600 and 1200 lb (Morris and Kornhauser 2000) with service times ranging between 15 and 25 min per stop (Muñuzuri et al. 2012). Courier services are lighter, ranging from less than 1 to 170 lb (Morris and Kornhauser 2000). Courier service time ranges from 1 to 5 min (Muñuzuri et al. 2012). Four route types are studied in this is research but due to space constraints, only one vehicle type (a typical small delivery truck) is utilised in this research.

LTL and courier deliveries are classified into two groups: A and B. 'A' types have heavier shipment sizes, longer service times and longer tour durations than 'B' types. The characteristics of customers LTL A, LTL B, Courier A and Courier B are summarised in Table 1. The characteristics of the vehicle, a typical small delivery vehicle in the USA, are shown in Table 2.

The cost minimization model presented previously is utilised to minimise long-term service costs as a function of fleet size and changing demand and supply($\rho = \lambda / S\mu$) ratios but conditional on utilising one strategy (waiting or double-parking). Scenarios LTL A

Table 1. Route and service characteristics.

Parameter	Scenario: LTL A	LTL B	Courier A	Courier B
Number of daily stops	400	400	400	400
Service area size (sq. mile.)	8.5	8.5	8.5	8.5
Distance between a depot and a service area (miles)	4.5	4.5	4.5	4.5
Customer demand (lb/stop)	450	80	10	10
Service time (min)	20	6	3	3
Time window (h)	8	6	4	2
Planning horizon (years)	5	5	5	5
Average speed (mph)				
– Inside service area	10	10	10	10
– Outside service area	30	30	30	30
Delivery days per year	260	260	260	260
Discount factor (%)	6.5	6.5	6.5	6.5
Fuel/energy inflation (%)	2.5	2.5	2.5	2.5

Table 2. Characteristics of a single unit truck.

Parameter	Truck
Make	Isuzu N-series
Fuel tank/battery size	25 gal
Fuel/electricity consumption rate	10 mpg
Gross vehicle weight	12,000 lb
Tare	5672 lb
Payload	6328 lb
Lifetime	12 years
Purchase cost	\$50,000
Maintenance cost	\$0.20/mile
Vehicle insurance	\$2,336/year
Vehicle registration	\$391/year
Diesel/electricity cost	\$2.689/gal
Driver wage	\$16.28/h
Driver health insurance	\$7000/year
Driver social security/Medicare taxes	7.65% of driver compensation
Driver pension/retirement	25% of driver compensation

and LTL B are weight-constrained, whereas Courier-A and Courier-B scenarios are time-constrained.

Impacts of parking availability on costs

Long-term costs are estimated for each scenario as a function of parking availability. The results show that the impacts of parking availability are different for the double-parking and waiting strategies. Figure 1 shows the expected probability of no parking and the expected waiting time as a function of parking utilisation levelsρ. The rate of increase of the probability of no parking is steady and comparable across different service types. However, expected waiting time varies significantly across delivery types. For the sake of simplicity, only LTL A and Courier-B graphs are shown in Figure 1; the other two scenarios (LTL B and Courier A) fall in between LTL A and Courier-B scenarios and are not included for the sake of brevity.

For LTL A routes, with longer service times, the increase of expected wait times as a function of ρ starts to show high values – more than 5 min per customer – for parking utilisation values $\rho > 0.60$. On the other hand, for Courier-B routes, the increase of expected wait time as a function of parking utilisation values starts to show high values – more than 5 min per customer – for values $\rho > 0.90$. In the latter scenario, the increase is very sharp when $\rho > 0.90$.

Costs per customer (per stop) are shown in Figure 2. For the sake of simplicity, only the LTL A and Courier-B curves are shown. In terms of absolute costs, as expected, courier deliveries are several times more economical than LTL deliveries. This is expected because it is more difficult to deliver heavier loads that have longer service times; more routes, drivers and vehicles are necessary to accommodate fewer LTL customers per route. Courier routes are several times more efficient in terms of utilisation of resources such as vehicles and drivers.

The comparison of the costs of double-parking and waiting strategies are less straightforward. For LTL A deliveries, it is better to 'wait' than to double-park until $\rho \cong 0.90$; for Courier-B deliveries, it is better to 'wait' than to double-park until $\rho \cong 0.70$. The results indicate that for Courier B, double-parking is a nearly optimal strategy for any ρ value, since the difference between the cost of double-parking and waiting can be barely perceived in the interval $0 < \rho < 0.70$. In other words, couriers are nearly indifferent between double-parking and waiting in the interval $0 < \rho < 0.70$. On the other hand, for LTL A services, the difference between the cost of double-parking and waiting is noticeable in the range $0.40 < \rho < 0.90$.

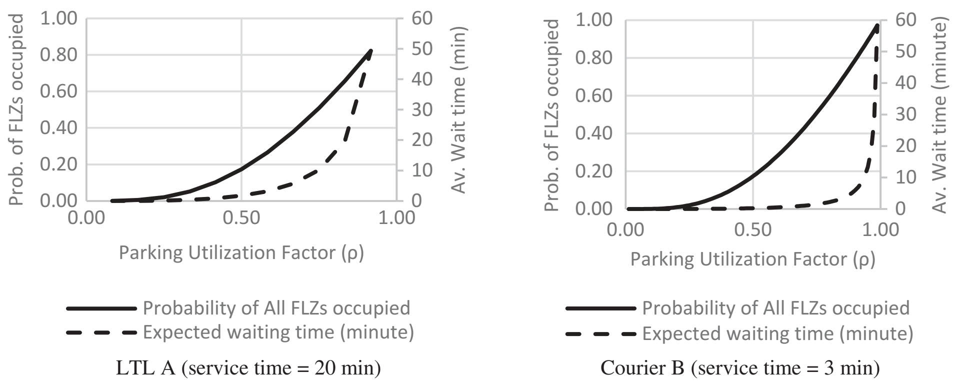

Figure 1. Occupancy and average waiting time vs. parking utilisation (ρ).

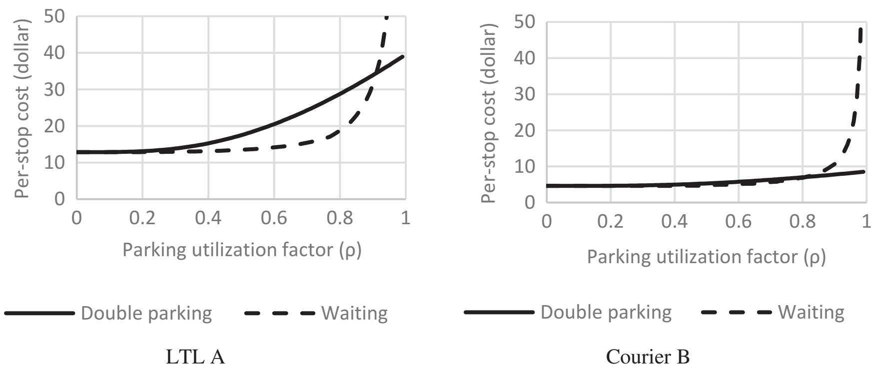

Figure 2. Long-term per-stop costs vs. parking utilisation (ρ).

These results indicate that the impact of parking availability on LTL and courier operations and behaviour are likely different. In areas with a reduced number of loading zones and high parking demand, it is expected that courier vehicles will show a tendency to double-park more than LTL vehicles. For LTL vehicles, waiting is a more attractive option. LTL vehicles have longer service times and hence the probabilities of parking fines are high when the vehicles are not legally parked. The parking utilisation must be high (ρ >0.90) and waiting times must be very long to outweigh the expected parking fine costs.

Per-stop elasticity analysis

Previous results are useful to highlight general trends regarding occupancy, waiting times, cost per customer, route type and parking demand/supply ratios. Elasticity values are calculated in this section to get an estimate of the relative importance of service, routing and parking variables on long-term cost per stop or customer.

The elasticity analysis was conducted at break-even values (b) of ρ where the service cost of the double-parking behaviour equals the service cost of the waiting behaviour. The breakeven points were chosen because at these points small changes may result in behaviour reversals, for example, from waiting to double-parking or vice versa. The elasticities were obtained using numerical approximations of this function:

$$E(C/n,x) = \frac{\frac{\partial(C(x,b)/n)}{\partial x}}{\frac{C(x,b)/n}{x}}$$

where

$E(C/n,x) =$ variable x long-term service cost per stop elasticity

$C(x,b)/n =$ per customer or stop long-term service cost

b = breakeven point

Table 3 provides the elasticity values for the LTL-B scenario. To facilitate a comparison, elasticity values are sorted from highest to lowest value when j = 1 (double-park). A positive sign must be interpreted as an increase in per stop cost; for example, if the value of the parking fine increases 1% the per stop cost is going to increase 0.6% if the driver decides to double-park and 0.0 % if the driver decides to wait for an available parking space.

As expected, when ρ increases there is a major increase in service costs but at the breakeven point the increase is three times higher if the driver decides to wait instead of double-park. The ratio between $E(C/n,\rho)$ and $E(C/n,c_t)$ indicates that at the break-even point fines must increase more than 2.3 (1.37/0.6 ≈ 2.3) times faster than the demand/supply ratio (ρ) to make double-parking less appealing.

Service time has a high elasticity in the double-parking scenario, almost four times higher than in the wait scenario. This is may be explained by the fact that a service time increase also increases the probability of receiving a parking fine while double-parking. Hence, in the double-parking scenario, a longer service time creates an indirect cost increase related to parking fines and a direct cost increase related to longer route durations. The reverse, a reduction of service time leads to a decrease in service costs but because the decrease is much faster for companies that double-park, a decrease in service time moves the breakeven point between double-parking and waiting to the left or a smaller

Table 3. Elasticity values for the LTL-B scenario.

Variable	j = 1 (double-park)	j = 0 (wait)
Demand/supply ratio (ρ)	1.37	3.85
Service time, t_s	0.80	0.21
Parking fine, c_t	0.60	0.00
Driver wage, c_l	0.25	0.65
Purchase cost, c_p	0.06	0.13
Discount factor, f_d	0.02	0.04
Service area (SA) size, A	0.02	0.03
Distance depot to SA, r	0.02	0.05
Energy cost, c_e	0.01	0.02
Speed outside SA, v_a	−0.02	−0.03
Speed inside SA, v_b	−0.04	−0.04

Table 4. Elasticity values for the Courier-A scenario.

Variable	j = 1 (double-park)	j = 0 (wait)
Demand/supply ratio (ρ)	1.17	6.13
Service time, t_s	0.68	0.18
Parking fine, c_t	0.50	0.00
Driver wage, c_l	0.27	0.57
Purchase cost, c_p	0.08	0.16
Discount factor, f_d	0.04	0.05
Service area (SA) size, A	0.03	0.03
Distance depot to SA, r	0.03	0.07
Energy cost, c_e	0.02	0.03
Speed outside SA, v_a	−0.02	−0.03
Speed inside SA, v_b	−0.07	−0.07

demand/supply ratio (ρ). Driver hourly wage is the other variable that has a high impact on costs, especially in the waiting time scenario.

Variables related to route length such as service area size and distance depot-service area have a relatively small elasticity; the same can be said about the travel speeds. Vehicle purchase cost elasticity is more important in the wait scenario but it is five times smaller than the elasticity value for driver wages, $E(C/n, c_l) = 0.65$ and $E(C/n, c_p) = 0.13$. Other costs such as energy or the value of money (discount rate) have low elasticity values.

Table 4 provides the elasticity values for the Courier-A scenario. Overall, the same trends are maintained. However, a major jump is observed in the elasticity value for ρ if the vehicle waits. At the breakeven point, for any given increase in ρ the resulting increase in service costs per stop is 5.2 times higher if the driver decides to wait instead of double-parking.

The ratio between $E(C/n, \rho)$ and $E(C/n, c_t)$ indicates that at the breakeven point fines must increase more than 2.3 (1.17/0.5 ≈ 2.34) times faster than the demand/supply ratio (ρ) to make double-parking less appealing. The value of this ratio is similar to the value found in the LTL scenario.

Discussion

Two key policy insights can be derived from the results: (a) double-parking is unlikely to disappear from urban areas unless more dedicated freight and service parking spaces are available at peak times and (b) increasing parking fines and parking enforcement can discourage double-parking but it will not eradicate the problem for sufficiently high values of demand/supply ratios (ρ). In the long-term, urban policy may be more productive when the focus is on requiring enough on-street and off-street parking spaces for freight and service vehicles. These conclusions roughly agree with previous studies (Wenneman, Habib, and Roorda 2015; Chen and Conway 2016).

For managers at delivery or service companies, the options seem limited as well. Large package delivery companies such as FedEx or UPS understand that parking fine costs are just another element of the cost of doing business in congested urban areas. Pricing policies can reflect this additional cost (as in the cited case for UPS in Manhattan) which means that parking costs are eventually transferred to consumers in the forms of extra costs such as service or delivery fees. Alternatively, companies can try to lower service times or delivery costs. Some costs are not transferred to direct consumers of freight or commercial services; for example, double-parking severely restricts needed roadway capacity during peak hours which causes congestion and emissions; congestion impacts are mainly a function of service times or double-parking duration (Lopez et al. 2016).

For companies that double-park when parking is not available, the largest cost reduction is obtained when service times are reduced. For example, delivering packages to a package drop box at the ground-level entrance of a building can save valuable minutes otherwise spent at the elevator or carrying a hand truck through long hallways. For companies that usually wait or cruise until parking is available, the largest cost reduction is obtained when driver wages are reduced. Significant driver wage cuts an option in a competitive labour market and long-term cost reductions are usually achieved by decreasing service times or increasing driver productivity.

Managers have an incentive to increase productivity by reducing service times, but a reduction in service times makes (*ceteris paribus*) double-parking a rational response for a wider range demand/supply ratios (ρ). On the other hand, a reduction of driver wages makes (*ceteris paribus*) waiting a rational response for a wider range demand/supply ratios (ρ). Finally, it is worth noting that increasing passenger parking fees and assigning just a small percentage of parking to commercial vehicles produces a significant social surplus (Amer and Chow 2016). However, in practice, it also important to monitor that commercial vehicle zones are not taken by passenger vehicles; increased monitoring may increase (government) costs if parking fines do not cover the cost of enforcement.

For policy-makers, fostering the adoption of alternative vehicles that do not require street parking, such as tricycles (Tipagornwong and Figliozzi 2014), may provide a solution in dense urban areas. However, tricycles have important size/capability limitations and may not be a viable solution for most businesses.

Conclusions

This study addressed the following research questions: how does parking availability affect distribution companies' parking behaviour? and what are the key variables that affect parking costs? A model where long-term service costs and fleet size are affected by changes in parking demand/supply ratios was formulated. The model also accounts for different parking strategies such as double-park when necessary or wait/cruise until parking is available.

Results show that as parking availability decreases, costs increase more rapidly for LTL services than for courier services. The difference in cost changes is related to customer service times and route structures. It is also observed that LTL services are more likely to cruise or wait until parking becomes available than courier services. LTL vehicles have longer service times and hence the probabilities of parking fines are higher if the vehicles are not legally parked. The parking utilisation must be high and waiting times long to outweigh expected parking fine costs for LTL deliveries.

The results also indicate that double-parking can be a company's rational response, especially for courier type services, in urban environments with high parking demand/supply ratios. Parking policy options to tackle commercial vehicle double-parking are limited and perhaps bound to fail in the long-term unless development codes require enough on-street and off-street parking spaces for freight and service vehicles. A novel result is that increases in logistics or service productivity achieved through a reduction in service times makes (*ceteris paribus*) double-parking a rational response for a wider range of demand/supply ratios (ρ). This demonstrates the intricacy of the commercial vehicle parking problem, changes at the route or customer level (that are hard to observe for a public transportation agency), may result in undesirable (but rational from a private company perspective) changes in commercial vehicle parking behaviour.

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