The Impact of Last Mile Parking Availability on Commercial Vehicle Costs

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Abstract. This research analyzes how parking availability levels affect commercial vehicle parking costs in congested urban areas. For commercial vehicles, parking availability has an impact on route characteristics and fleet sizes. Hence, commercial vehicles parking costs cannot be captured solely by estimating delays, distance traveled searching for parking, and/or the cost of parking fines. This research combines logistics and queuing models to estimate generalized commercial vehicle parking costs. Scenarios are built to study the impact of parking availability on typical less-than-truckload (LTL) and courier service costs. Results indicate that parking availability levels do impact commercial vehicle costs significantly but that the impacts magnitude are a function of customer and route characteristics.

Keywords: commercial vehicles, last mile, economic analysis, parking costs

1 Introduction

On-street parking spaces and freight loading zones (FLZs) are insufficient during certain periods of the day in many dense and congested urban areas (1, 2). Commercial drivers prefer not to park in available FLZs that are located away from customers (3, 4). When nearby parking is not available, the cost of double parking and parking fines can be substantial. For example, in New York City large delivery fleets such as FedEx and UPS paid $550 million in 2013 (5). Since repeated parking fines increase delivery costs, urban freight distributors and service providers raise service fees to customers in areas where deliveries or pick-ups are more difficult; for example, UPS charges a surcharge in some areas (such as zip codes 10000 – 10292) of Manhattan in New York City (6).

This research addresses the following research question: what is the impact of parking availability levels on delivery costs? The first section presents a brief literature review. Later sections present the modeling framework and data for less-than-truckload (LTL) and courier delivery scenarios. Scenario results are presented and analyzed; the impacts of parking availability levels on delivery costs and driver behavior are discussed. The paper ends with conclusions.

2 Modeling Commercial Parking

Assuming that there are S freight loading zones 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 utilized. 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)
μ : commercial vehicle service rate (vehicles per hour)
P(N=0) = probability that all FLZs are empty

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

$$P(t|N \geq S) = \frac{t_s}{t_{ef}}$$

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 for a FLZs, 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. An average parking utilization level (ρ) is defined as the ratio of parking demand to parking supply ($\rho = \lambda/S\mu$). *Parking utilization and parking availability are inversely related*, low parking utilization (low ρ) is associated with high parking availability or ease to find empty loading zones.

2.1 Modeling Service Costs and Constraints

Continuous approximations have been successfully used by many research efforts to model urban distribution systems (7). This study utilizes a continuous approximation model successfully used in the past (8, 9) to estimate the average route distance of commercial vehicles.

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

where VRP (V) = average distance travelled for a fleet of m vehicles (km)
k_l = local service area coefficients
n = the number of customers
m = the number of vehicles
A = the size of a service area (km^2)
$\bar{r}$ = average distance between customers and a depot (km)

Long-term variable service costs include vehicle depreciation, energy/fuel, vehicle maintenance, driver wage, double parking fines, and waiting time costs. In addition, there are fix costs such driver annual costs (driver health insurance, social security tax, medicare tax, and pension/retirement) and truck annual costs such as vehicle registration and insurance.

The optimization problem minimizes long-term vehicle costs by selecting the best vehicle type i and parking behavior j. The decision variable is the fleet size $m^{i,j}$ (integer) of vehicles type i following parking behavior j and the number of customers n^{ij} assigned to vehicle type i following parking behavior j. The binary variable y_{ij} is 1 when the vehicle double parks (j = 1) and zero when the driver waits (j = 0) if parking is not available when $N \geq S$.

Sets
I = set of vehicle types, $i \in I$
J = set of parking behaviors, $j \in J$ (e.g. double park or wait/cruise for parking)
K = set of years of the planning horizon, $k \in K$

Parameters
C = Total cost over the planning horizon (dollar)
c_p^i = Unit purchase cost for vehicle type i (dollar/vehicle)
c_r^i = Unit resale cost for vehicle type i (dollar/vehicle)
c_e^i = Unit energy cost for vehicle type i (dollar/ gallon or dollar/kWh)
c_m^i = Unit maintenance cost for vehicle type i (dollar/mile)
c_l^i = Hourly driver wage for vehicle type i (dollar/hour)
c_t = fine of receiving one parking fine (dollars)
c_a^i = Unit annual cost for vehicle type i (dollar/vehicle)
f_d = Discount factor (%)
f_e = Rate of inflation for diesel fuel (%)
$L^{i,j}$ = Tour distance of vehicle type i (miles/tour) and behavior j
$T^{i,j}$ = Tour duration of vehicle type i (hours) and behavior j
T_{max} = Maximum tour duration(hours)
w_d = Average customer demand (lb./stop)
t_s = Average service time (minute/stop)
n = Number of daily customers or stops

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)
P_t^i = Probability of receiving a double parking fine of vehicle type i
d = Days of service per year
K = Years in planning horizon
w_C^i = Load capacity of vehicle type i (lbs)
r_e^i = energy consumption rate of vehicle type i (gallon/mile or kWh/mile)

2.2 Problem Formulation

Minimize C where

$$C = \sum_i \sum_j \left(c_p^i - (1 + f_d)^{-K} c_r^i\right) m^{ij} + \sum_i \sum_j \sum_k [\,(1 + f_d)^{-k} (c_e^i L^i r_e^i m^{ij} d + c_m^i L^{ij} m^{ij} d + c_l^i T^{ij} m^{ij} d + c_t p^{ij} nd + c_a^i m^{ij})] \quad (1)$$

$$L^{ij} = \bar{r} + \frac{k_l \frac{n^{ij} - m^{ij}}{n^{ij}} \sqrt{n^{ij} A}}{m^{ij}} + \bar{r} \quad (2)$$

$$T^{ij} = \frac{\bar{r}}{v_a^i} + \frac{k_l \frac{n^{ij} - m^{ij}}{n^{ij}} \sqrt{nA}}{m^{ij} v_b^i} + \frac{\bar{r}}{v_c^i} + n^{ij} t_s^i + (1 - y_{ij})\left(n^{ij} W_q(\rho)\right) \quad (3)$$

$$p^{ij} = y_{ij} P(N \geq S) \leq 1 \quad (4)$$

Subject to:

$$m^i \geq n^{ij} \cdot w_d / w_C^i \qquad \forall i \in I \quad (5)$$

$$T_{max} \leq T^{ij} \qquad \forall i \in I \quad (6)$$

$$n^{ij}, m^{ij} \geq 0 \qquad n^{ij}, m^{ij} \in \text{Set of Integers} \qquad \forall i \in I,\ \forall j \in J \quad (7)$$

$$m^i = \sum_j m^{ij} \qquad n = \sum_i \sum_j n^{ij} \quad (8)$$

Equation (1) is the objective function, minimization of total cost. Equation (2) estimates the length of a delivery tour that starts from a depot, serves customers, and returns to the depot. Equation (3) estimates tour duration. Equation (4) estimates the probability of receiving a fine. Equation (5) is a weight/capacity constraint. Equation (6) is a route duration constraint. Equation (7) is an integer non-negativity constraint. Equations (8) set total fleet size and customer constraints. Average parking utilization levels ρ affect the value of waiting time W_q and therefore can affect fleet size (equation 6).

3 Case Study

To better understand the impacts of parking availability on service costs, two types of services are analyzed: less-than-truckload (LTL) and courier deliveries. LTL deliveries are heavier and require more time per delivery than courier deliveries. LTL shipments can range between 600 and 1,200 lbs. (10) with service times ranging between 15 and 25 minutes per stop (11). Courier services are lighter ranging from 1 to 170 lbs. (10). Courier service time ranges from 1 to 5 minutes (11). Due to space constraints, only one type of vehicle is assumed in this research.

LTL and courier deliveries are classified into two types: type "A" deliveries are heavier with longer service time and a longer tour duration than type "B" deliveries. The characteristics of customers LTL A, LTL B, Courier A and Courier B are summarized in Table 1. The characteristics of the vehicle are shown in Table 2.

Table 1. Logistics Characteristics of the Case Studies

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 (minutes)	20	6	3	3
Time window (hours)	8	6	4	2
Planning horizon (years)	5	5	5	5
Average speed (mph) - Inside service area - Outside service area	 10 30	 10 30	 10 30	 10 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%

4 Impacts of Parking Availability on Costs

Long-term costs are estimated and the results show that the impacts of parking availability are different for the double parking and waiting strategies.

Figure 1 shows, as a function of parking utilization levels ρ, the expected probability that FLZs are occupied and the expected waiting time. 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 Figure 1; the other two scenarios (LTL B and Courier A) fall in between these extreme scenarios.

Table 2. Characteristics of a Single Unit Truck

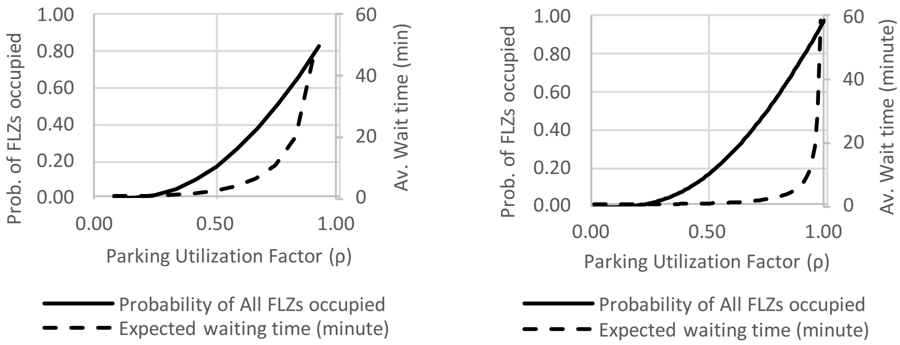
Parameter	Truck
Make	Isuzu N-series
Fuel tank / battery size	25 gallon
Fuel / electricity consumption rate	10 mpg
Gross vehicle weight	12,000 lbs.
Tare	5,672 lbs.
Payload	6,328 lbs.
Lifetime	12 years
Purchase cost	$ 50,000
Maintenance cost	$ 0.20 / mile
Vehicle insurance	$ 2,336 /year
Vehicle registration	$ 391 /year
Diesel / electricity cost	$ 2.689 / gal
Driver wage	$ 16.28 / hour
Driver health insurance	$ 7,000 / year
Driver Social Security/Medicare taxes	7.65% of driver compensation
Driver pension/retirement	25% of driver compensation

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

The cost per customer (per stop) is shown in Figure 2. For the sake of simplicity, only LTL A and Courier B graphs 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.

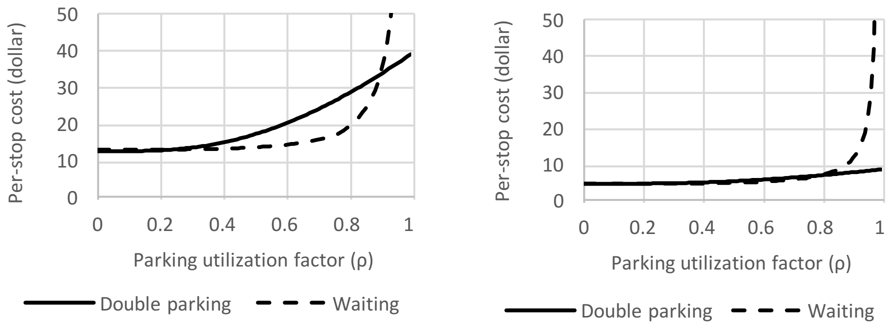
The comparison of the costs of double parking and waiting strategies are less straightforward. For LTL A deliveries, it is better to "wait" than to double park when $\rho < 0.93$; for Courier B deliveries, it is better to "wait" than to double park when $\rho < 0.82$. The results indicate that for Courier B double parking is a nearly optimal strategy for most ρ values, since the difference between the cost of double parking and waiting can be barely perceived in the interval $0 < \rho < 0.82$; on the other hand, for LTL A the difference between the cost of double parking and waiting are noticeable in the range $0.40 < \rho < 0.90$.

These results indicate that the impact of parking availability on LTL and Courier services differs significantly. In areas with a reduced number of loading zones and high parking demand it is expected that courier vehicles will double park instead of waiting for parking. For LTL vehicles, waiting is a more attractive option. LTL vehicles have longer service times and hence the probability of parking fines are high if the vehicles are not legally parked. The parking utilization must be high ($\rho > 0.93$) and waiting times very long to outweigh parking fine costs.



LTL A (service time = 20 min) Courier B (service time = 3 min)

Fig. 1. Expected waiting time and probability all FLZs are occupied (N≥S)



LTL A Courier B

Fig. 2. Long-Term Truck Costs

5 Conclusions

The objective of this study was to investigate the impact of parking availability on commercial vehicles service costs. A model where fleet size is affected by changes in parking waiting time and parking behavior was formulated.

Results show that as parking availability decreases, costs increase more rapidly for LTL services than for Courier services. The differences in costs per customer for LTL and courier deliveries are related to customer service times and route structures. LTL vehicles have longer service times and hence the probability of parking fines are higher if the vehicles are not legally parked. The parking utilization must be high and waiting times long to outweigh expected parking fine costs.

It is also observed that LTL services are more likely to wait for parking than Courier services. The results also indicate that double parking can be a company's rational response in some circumstances, especially for courier type services.

Future research avenues include the optimization of FLZ locations (12) and an analysis of the impacts of parking availability on CO_2 emissions by vehicle type (13).

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