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A downtown on-street parking model with urban truck delivery behavior

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ABSTRACT

In this study we present an on-street parking model for downtowns in urban centers that incorporates the often-neglected delivery demand of delivery trucks. The behavior of truck deliveries is distinctly different from commuter parking: trucks do not cruise for parking spaces, and demand for goods delivery is driven by customers and is practically inelastic to the delivery costs. We generalize the downtown on-street parking model from Arnott and Inci (2006) to study the relationship between passenger vehicles' parking and truck delivery behaviors, and provide tools for policy makers to optimize the trade-offs in parking space allocation, pricing, and aggregate network congestion. The social optimum can be obtained by solving a nonlinear optimization problem. The parking model is able to replicate the commuter-only scenario as a special case. It is shown that ignoring truck delivery behavior can significantly overestimate travel speeds and cruising stock. We applied the model to a case study of downtown Toronto and found that compared to a baseline scenario representative of Toronto in 2015, increasing parking fees from CAD $4/h to nearly CAD $7.85/h and assigning 4.1% of parking spaces to truck deliveries would eliminate cruising and truck double-parking, resulting in a social surplus gain of over CAD $14,304/h/mile^2. In a first-best allocation scenario where total parking spaces can also change, we found that increasing total parking spaces by 18%, having 3.5% truck delivery allocation, and reducing parking fees to CAD $2.47/h would eliminate cruising and double-parking while increasing social surplus by CAD $24,883/h/mile^2. These model findings are along the same level of effect as demonstrated in the literature.

1. Introduction

As the rate of urbanization increases, societies struggle to develop policies to make the most efficient use of space to cope with congestion. Parking management is one such policy. Poorly implemented parking policies can lead to "cruising" for parking spaces, which can account for more than 30% of downtown traffic in some cases (Shoup, 2005). On the other hand, parking pricing strategies can be more effective than road pricing strategies because of a greater public acceptance. The effectiveness of parking policies can also be enhanced by such engineered technologies as real time information systems (e.g. Cao and Menendez, 2015) like *SFpark.org* or data-driven parking pricing (Qian and Rajagopal, 2013; Mackowski et al., 2015).

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Researchers have developed analytical means of evaluating trade-offs in pricing, capacity, information technologies, and spatial-temporal allocation of parking spaces with respect to their welfare effects on cruising, traffic congestion, transit use, and activity patterns, among others. However, urban freight is largely neglected in these studies, despite the significant differences in freight delivery use patterns from commuter patterns, the high demand for freight loading/unloading, and the exacerbated effects that truck delivery inefficiencies have on multiple aspects of urban sustainability—congestion, safety, air quality, etc. (e.g. Chow et al., 2010; You et al., 2016). In a recent study of freight delivery demand in New York City, Jaller et al. (2013) confirmed that parking policies often overlook urban freight.

Urban freight delivery needs are inherently different from commuter parking. Unlike commuters, delivery trucks typically need spaces to temporarily park to load or unload goods at destinations in the central business district. Trucks take up more space, require close proximity to destinations (Tipagornwong and Figliozzi, 2015), and require access routes with greater turning radii. For example, parcel delivery services like FedEx, UPS, and Purolator accounted for more than CAD $1.5 M in parking fines in Toronto in 2006 (Haider et al., 2009). Jaller et al. (2013) highlight a list of example parking policies available to policy-makers: parking management systems, car-share provision, in-lieu fee, maximum parking standard, parking freeze, residential parking permits, transferable parking rights, variably priced parking, among others. These policies typically overlook freight or truck delivery demand.

In a focus group survey of thirteen industry sectors, Morris et al. (1998) identified deliveries as one of the key transportation barriers for freight mobility. Focus groups indicated congestion, inadequate docking space, inadequate curb space for delivery trucks, and oppressive parking regulations as examples. Recommendations included off-peak deliveries, reducing passenger vehicle traffic, improving mass transit to reduce private passenger vehicles, creating "truck only" areas like the garment district in New York City, using integrated information systems, or introducing consolidation centres outside the city. While some strategies like off-peak deliveries have been studied further (e.g. Holguín-Veras et al., 2011), there are generally no analytical downtown parking models that consider freight delivery activities. The few efforts that do exist are either traffic simulation-based (Nourinejad et al., 2014) or do not consider equilibrium interactions of truck deliveries and passenger parking (Marcucci et al., 2015; Tipagornwong and Figliozzi, 2015). As such, many of the recommendations or issues in urban freight and city logistics related to parking cannot be analytically addressed.

We propose a downtown on-street parking equilibrium model that incorporates the effects of urban freight. The model generalizes a state-of-the-art on-street parking model (Arnott and Inci, 2006, denoted AI06) to include effects of space allocation for truck deliveries, truck double parking, and consequences in traffic flow capacities. To the best of our knowledge, this is the first parking equilibrium model that considers all these trade-offs. We then apply the theoretical model to a case study of downtown Toronto to support first-best and second-best space allocation policies for truck deliveries. The model can be easily customized to other downtown regions around the world to support policy recommendations.

2. Literature review

Analytical commuter parking models are relatively new compared to other transportation models. Some of the earliest models of note examined the dual nature of parking as a private and public good. Glazer and Niskanen (1992) noted that economists (e.g. Vickrey, 1954) generally assumed curbside parking to be a private good to justify marginal cost pricing. On the contrary, the authors demonstrated that insufficient parking spaces lead to cruising behavior, which results in increased costs for both travelers looking for parking as well as in-transit travelers. When the roadway is sub-optimally priced or free, there should be a positive lump sum parking fee that covers that cost.

Another feature of the dual nature of parking observed by Arnott et al. (1991) and Anderson and de Palma (2004) is that the pricing by a market of private operators is both monopolistic and competitive. Each operator sets the price as profit-maximizing due to the all-or-nothing demand for a single space (this behavior has been empirically confirmed by Kobus et al., 2013), but is competitive with other parking spaces for a user. Because operators may ignore the costs they impose on cruising, it is possible that the competitive pricing may result in welfare reduction relative to no pricing at all.

Arnott et al. (1991) used Vickrey's (1969) bottleneck congestion model to derive insights on the spatial and temporal nature of parking pricing. When parking is free, the authors showed how driver behavior to naturally park "outwards"—occupy spots in order of decreasing accessibility—leads to increased inefficiencies. Time-varying road pricing may eliminate queueing and reduce schedule delay costs, but distance-based parking pricing is needed to induce a more efficient "inward" parking behavior. They concluded that it is easier to implement an efficient parking fee policy than efficient road tolling policy. Their bottleneck model of parking has been extended by Zhang et al. (2008) to consider both morning and evening commutes, by Zhang et al. (2011) to investigate the efficiency of parking permits, by Qian et al. (2012) to examine parking clusters, and by Yang et al. (2013) to add capacity constraints and parking reservations. Fosgerau and de Palma (2013) studied the effects of early bird specials with time-varying parking pricing. While Lam et al.'s (2006) work is not directly a bottleneck parking model, they considered departure time choice at a network level using variational inequalities. The model requires route enumeration, which makes it difficult to apply to large scale study areas.

Arnott and Rowse (1999) used a circular city structure to analyze the randomness of parking availability and cruising to examine dynamic parking pricing and justify parking information systems. The model structure resulted in non-unique equilibria, however, and required a number of assumptions including ignoring traffic congestion. Anderson and de Palma (2004) incorporated cruising in a simpler model to arrive at several major conclusions. First, the socially optimal parking configu-