Can Tolling Schemes Really Reduce Emissions of Freight Transportation in Urban Area?

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Municipalities across the world have become concerned about the level of emissions in their city centers. As urbanization increases, they have become aware of the negative impacts of road-based transportation. Transportation causes traffic congestion, air pollution and can create health problems for the citizens of metropolitan areas. As a result, several cities have introduced tolling schemes to discourage vehicles from entering the inner city to reduce congestion and pollution, especially during peak hours. However, little research has been done to examine the impact of tolling schemes on commercial fleets, especially on resulting costs and emissions. In this study, we investigate a vehicle routing problem considering different tolling schemes for several city types. We compare how they impact a company's total costs, fuel usage (which drives emissions), and the routes of their vehicles. Comprehensive computational experiments allow for a detailed analysis of what impact tolling schemes can have on the structure and cost of routes for logistics service providers. Furthermore, with our experiments, we can analyze whether the various types of tolling schemes work in the way municipalities are expecting it.

First, we summarize the existing tolling schemes around the world. To date, only a few cities and towns are applying congestion charges to their urban roads. The list includes Singapore, London, Milan, Stockholm, Gothenburg (Sweden), Valletta (Malta), and Durham (England). The types of existing tolling schemes include per gantry fee (Singapore), per-day fee (London, Milan, and Durham), per-entry fee (Stockholm, Gothenburg), and per-minute fee (Valleta). The tolling schemes we investigate in this paper are based on these existing schemes.

We model the vehicle routing problem based on a standard single-depot vehicle routing problem, where each vehicle starts and ends its route at the same depot. All drivers begin their day at a pre-specified time and work for a maximum duration. We assume that each customer can be visited at any time during the day. We assume that the travel time between locations is known, but depends on the time the vehicle starts its travel, i.e., time-dependent travel times. We assume that the vehicles do not need to wait at customers. After arriving at a customer, each vehicle incurs the service time and then immediately begins to travel to the next customer in the sequence. The total costs consist of the labor cost, fuel cost, and the congestion charge. We consider four types of congestion charges in this study: daily fee, per entry fee, per minute fee, and per gantry fee. For per entry, per minute and per gantry fees, we consider a fixed version and a time-dependent version. That is, a higher fee will be collected if the vehicle is traveling during peak hours. To solve the vehicle routing problem, we adapt and apply the LANCOST heuristic proposed by Wen and Eglese (2015), which is based on a tabu search heuristic and is applicable to solve multiple vehicle routing problems with time-dependent travel times.

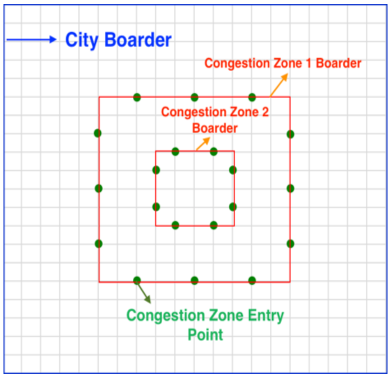

Figure 1: City and Congestion Zones

In the computational experiments, we experiment with three different city sizes (large, medium, and small cities). For each city size, we experiment with two different congestion zone sizes, one at a time. Figure 1 provides an example of a city and its two congestion zones. We assume that a vehicle can enter a congestion zone via one of the entry points located on the border of the zone. We consider instances with 100 customers. We investigate how different tolling schemes may impact the total costs, the distance traveled by the vehicles (in and outside the congestion zone), the travel time, total working time of the drivers, and the emissions. Also, we compare the impacts of the same tolling scheme on different geographies, i.e., different city and congestion zone sizes.

Scheme	Obj	Labor Cost	Total Emissions	Emissions in Zone	Dist. in Zone	Dur. in Zone	Vehicles enter zone
$18/day	14.39%	0.84%	0.92%	2.25%	2.47%	0.87%	-15.22%
$17/entry (fix)	13.38%	0.53%	0.86%	-1.89%	-1.73%	-0.78%	-15.22%
$17/entry (t-d)	13.49%	0.29%	0.48%	-0.94%	-0.74%	-0.40%	-15.22%
$0.06/minute (fix)	14.37%	0.04%	0.40%	-3.67%	-3.70%	-1.46%	2.17%
$0.06/minute (t-d)	14.53%	-0.03%	0.16%	-3.84%	-3.82%	-1.54%	2.17%
$0.42/gantry	12.44%	-0.05%	0.50%	-5.83%	-5.80%	-2.34%	-2.17%

Table 1: Computational Results

Table 1 presents an example of the computational results. The results are for a scenario with medium city and large congestion zone. The first column of the table presents the types of tolling schemes. For per entry fee and per minute fees, there are versions of a fixed charge (rows 2 and 4) and a time-dependent charge (rows 3 and 5). The second through the last columns present the changes (compared with the cases where no congestion fees are collected) in the total cost, labor cost, fuel cost, distances traveled by vehicles in the congestion zone, total time vehicles spending in the zone, total emissions in the zone, and the number of vehicles entering the zone, respectively. From the results, we can see that the introduction of congestion tolls can help to reduce the number of vehicles entering the congestion charge zone, the distances that vehicles travel within the zone, and the time vehicles spend in the zone. However, results also show that many of the congestion pricing schemes can actually increase total emissions (as in the fourth column), because vehicles drive farther distances to avoid the zone in the city center. For instance, the per day charge in the above results increases the total costs by 14.39%, but rather than reducing emissions in the congestion zone, it increases the in-zone emissions by 2.25%.

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