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Urban form and last-mile goods movement: Factors affecting vehicle miles travelled and emissions

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ABSTRACT

There are established relationships between urban form and passenger travel, but less is known about urban form and goods movement. The work presented in this paper evaluates how the design of a delivery service and the urban form in which it operates affects its performance, as measured by vehicle miles travelled, CO_2, NOx, and PM10 emissions.

This work compares simulated amounts of VMT, CO_2, NOx, and PM10 generated by last mile travel in a number of different development patterns and in a number of different goods movement structures, including various warehouse locations. Last mile travel includes personal travel or delivery vehicles delivering goods to customers. Regression models for each goods movement scheme and models that compare sets of goods movement schemes were developed. The most influential variables in all models were measures of roadway density and proximity of a service area to the regional warehouse.

These efforts will support urban planning for goods movement, inform policies designed to mitigate the impacts of goods movement vehicles, and provide insights into achieving sustainability targets, especially as online shopping and goods delivery become more prevalent.

1. Introduction

Worldwide, awareness has been raised about growing greenhouse gas emissions. In the United States, transportation contributes approximately 25% of all greenhouse gas emissions (US EPA, 2008). While addressing the impact of transportation on greenhouse gas emissions is critical, transportation also produces significant levels of criteria pollutants such as NOx and PM10, which impact the health of those in the immediate area (US EPA, 2013a, 2013b). These impacts are of particular concern in urban areas, which due to their constrained land availability increase proximity of residents to the roadway network and resulting pollutants. In the United States, heavy vehicles (those typically used for deliveries) produce a disproportionate amount of NOx and particulate matter – heavy vehicles represent roughly 9% of vehicle miles travelled but produce nearly 50% of the NOx and PM10 from transportation (US EPA, 2008; Davis et al., 2013).

Researchers have identified a potential to reduce greenhouse gas emissions by replacing passenger vehicle travel with delivery service (see Wygonik and Goodchild, 2012; Siikavirta et al., 2002). These reductions are possible because, while delivery vehicles have higher rates of greenhouse gas emissions per mile than private light-duty vehicles, the routing of delivery vehicles to customers is far more efficient than those customers traveling independently. Delivery vehicles can

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travel directly from one final destination to another, while passenger trips require unique round trips. In addition to lowering travel-associated greenhouse gas emissions, because of their more efficient routing and tendency to occur during off-peak hours, delivery services have the potential to reduce congestion. Thus, replacing passenger vehicle travel with delivery service provides opportunity to address global concerns - greenhouse gas emissions and congestion. Unfortunately, work by Wygonik and Goodchild (submitted for publication) indicates criteria pollutants are increased through the use of delivery schemes due to their increased reliance on larger, diesel vehicles for longer distances. These types of vehicles generate more criteria pollutants per mile than passenger vehicles.

While researchers have found relationships between passenger vehicle travel and smart growth development patterns, similar relationships have not been extensively studied for goods movement. In rural areas, where shopping choice is limited, goods movement delivery is relatively more important than in urban areas. As such, this work examines the relationships between goods movement and development pattern characteristics including density and distance from warehousing. This research answers the question: do the impacts from last mile goods movement strategies differ with urban form characteristics?

This work considers the amount of CO_2, NOx, and PM10 generated by personal travel and delivery vehicles in a number of different goods movement structures, including different customer densities and various warehouse locations. The results allow for a comparison of the impacts of greenhouse gas emissions in the form of CO_2 to local criteria pollutants (NOx and PM10) for each goods movement structure. These efforts increase integration of goods movement into urban planning, inform policies designed to mitigate the impacts of goods movement vehicles, and provide insights into achieving sustainability targets. This research is especially important as online shopping and goods delivery becomes more prevalent.

The next section examines the existing research to identify gaps and likely contributing factors. The third section explains the evaluated goods movement structures and the data. The fourth section documents the methods used to develop the fifth section – results. As simpler models more easily support implementation in practice, the fourth and fifth sections examine the number of influencing variables required to produce an explanatory model. In the sixth section, concluding points are presented.

2. Literature

2.1. Influence of urban form

While the relationship between urban form and automobile travel has been well studied (see for example: Smart Growth Network, 2011; Moudon et al., 2003; Porter et al., 2005; Cervero, 1989, 1996; Cervero and Landis, 1997; Frank et al., 2007, 2006; Ewing et al., 2002; Ewing and Cervero, 2001; Handy et al., 2005; TRB, 2009), less is known about its relationship to goods movement. Klastorin et al. (1995) documented a relationship between number of truck trips and density, Wygonik and Goodchild (2011) evaluated the cost and CO_2 per delivery order related to density, and Wygonik and Goodchild (submitted for publication) evaluated the vehicle miles travelled, CO_2, NOx, PM10, and travel time for goods movement over three different development patterns. Both Siikavirta et al. (2002) and Wygonik and Goodchild (2012) examined the impact on CO_2 emissions for passenger travel replacement for grocery shopping for distributed and clustered customers. These papers illustrate while some efforts have been made to document if there is a relationship between urban form and goods movement impacts, minimal research has considered what the influencing factors might be.

Daganzo (2010) is one example of an effort to tie urban form to goods movement impacts, relating customer density to vehicle miles travelled. In discussing the traveling salesman problem, he proposes an approximation where the approximate travel length for a single delivery vehicle serving a set of customers is a function of the number of customers and service area size (or customer density) along with a factor for the type of road network connectivity (straight line paths – Euclidean/L2 or grid connections – Manhattan/L1). He extends that approximation for the vehicle routing problem (in which more than one vehicle serves a set of customers) where, in addition to the number of customers and the size of the service area, he includes the capacity of the vehicle and the distance from the depot to the service area centroid.

2.2. Warehouse locations

Since warehouses (including storage and distribution centers) are frequently an end point for commercial trips, their location can significantly influence the distances travelled by goods movement vehicles. Extensive research has evaluated the optimal locations for warehouses. Crainic et al. (2004) found that the use of 'satellite' warehouses to coordinate movements of multiple shippers and carriers into smaller vehicles reduced the vehicle miles travelled of heavy trucks in the urban center but increased the total mileage and number of vehicles moving goods within the urban center. These results illustrate the close relationship between warehouse location and the vehicle choice. Likewise Dablanc and Rakotonarivo (2010) found terminal locations have moved further from the city center over the past 30 years resulting in an estimated increase in 15,000 tonnes of CO_2 per year. They compare this with estimated gains from smaller consolidation centers located close to city centers and found the increase in CO_2 from the relocated terminals was 30 times greater than the savings from the smaller consolidation centers. Filippi et al. (2010) found greater potential environmental savings through urban distribution centers than through changes to the vehicle fleet, though both were successful.

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