Quantifying the impact of next-generation modes of delivery

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Project Objective

The purpose of this project is to apply quantitative tools from geospatial analysis, geometric probability theory, and mathematical optimization to predict the impacts that new delivery paradigms will have on traffic congestion and carbon emissions. Thanks to recent innovations in telecommunications and location-based services, there is currently an unprecedented expansion of last-mile delivery services that transport products to households within a short time frame, often within the span of a few hours. The net impact of the introduction of these services is that a person's trip to the store is now replaced by a trip taken by a third party, which might benefit from an economy of scale by (for example) taking an efficient route through multiple households at once, thereby aggregating demand more efficiently. This project will model this change within a mathematical optimization framework to determine the circumstances under which these services can provide the greatest social benefit.

Problem Statement

One of the fundamental concerns in the analysis of logistical systems is the trade-off between localized, independent provision of goods and services versus provision along a centralized infrastructure such as a backbone network. The introduction of new last-mile delivery services is a very recent instance of this dichotomy, and very little is currently known about the fundamental costs and benefits that are incurred as a result of such technology. One of many complicating factors is the presence of *trip chaining*, which is itself a challenging optimization problem that has seen little attention in existing literature. When one introduces delivery services, there are two fundamental questions that arise:

1. How much congestion is saved by removing the person's trip to the store?
2. How much congestion is added by using the coordinated route?

This project will answer these two questions by formulating a person's trip-chaining problem as a *Generalized Travelling Salesman Problem*, a mathematical program that has received little attention by the transportation community.

Research Methodology

We first formulate a person's trip chaining problem as a *Generalized Travelling Salesman Problem*, in which one is given n sets of points (representing n different classes of destinations, such as grocery stores, banks, pharmacies, and so on), and one seeks the shortest path that visits one point from each set. We then study the *asymptotic* behavior of the solution to this problem in the limit as n becomes large, which gives a simple algebraic expression that approximates the actual length of this tour. We then use this algebraic expression in various scenarios representing different adoption patterns of delivery services to predict the impact that these services will have vis-à-vis carbon footprint reduction.

Results

We developed several mathematical models representing adoption of delivery services. In each model, we assume that each person has n "tasks" that they must complete each day (such as going to work, the grocer, and so forth), and each of these tasks can be performed at k different locations. We then compute the difference in carbon footprint between the scenario where some of those people use delivery services versus the scenario where no services are used. In an extreme example, we have a population of N people, and each person belongs to one of two classes, either "luddites" or "shut-ins", distinguished as follows:

- A *luddite* performs all of their tasks by themselves and drives to each of the n locations.
- A *shut-in* shops for everything online and remains stationary while packages are delivered to them.

Using our algebraic expressions for the Generalized Travelling Salesman Problem, we then determine the "critical threshold" of adoption of delivery services such that the carbon footprint is reduced. Our model shows that, for most metropolitan regions, the rate of adoption must be between 10% and 20% to realize emissions reduction. This suggests that there is an initial period in which delivery services actually produce *more* carbon emissions, because the efficiencies due to their economies of scale have not yet been realized.