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Delivery by drone: An evaluation of unmanned aerial vehicle technology in reducing CO_2 emissions in the delivery service industry

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ABSTRACT

This research paper estimates carbon dioxide (CO_2) emissions and vehicle-miles traveled (VMT) levels of two delivery models, one by trucks and the other by unmanned aerial vehicles (UAVs), or "drones." Using several ArcGIS tools and emission standards within a framework of logistical and operational assumptions, it has been found that emission results vary greatly and are highly dependent on the energy requirements of the drone, as well as the distance it must travel and the number of recipients it serves. Still, general conditions are identified under which drones are likely to provide a CO_2 benefit – when service zones are close to the depot, have small numbers of stops, or both. Additionally, measures of VMT for both modes were found to be relatively consistent with existing literature that compares traditional passenger travel with truck delivery.

1. Introduction

In March 2012, Silicon Valley startup TacoCopter made headlines as it publicly announced plans for the delivery service of tacos within the City of San Francisco via unmanned aerial vehicles (UAVs), otherwise known as "drones" (Gilbert, 2012) Interested customers would be able to place their order on a smartphone application and comfortably wait as a drone delivers their food to them from above. However, the idea never was able to get off the ground as shortly after the announcement, the U.S. Federal Aviation Administration (FAA) quickly enacted and has since enforced a national moratorium on all commercial activities utilizing drone technology. Nevertheless, interest in the nonmilitary use of drones has increased dramatically with successful operations outside the United States in the delivery of medicine, food, and mail orders. In light of these successes, as well as pressure from the private sector seeking to exploit the potential benefits of drone technology, the FAA has recently created legal and physical space for experimentation, although full commercial operation authorization is not expected for some time (United States Federal Aviation Administration, 2015).

As with past penetration of technology in markets and industries, focus has been heavily placed on the economic and social impacts that the introduction of drone technology may bring. For instance, companies anticipate a reduction in transportation costs (D'Andrea, 2014), concerns exist regarding individual privacy rights (Olivito, 2013), and airspace congestion. As these benefits and costs are weighed, however, little assessment currently exists on the environmental consequences that drone technology may possibly have if fully adopted by industries.

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This research paper seeks to answer this question, specifically in terms of CO_2, which is the most documented and well-known greenhouse gas, and vehicle miles traveled (VMT), a measurement of movement often used to calculate pollution and energy impacts. This paper will first discuss existing literature and then describe the methodology used to model delivery routes while incorporating real-world emission parameters. The resulting estimates on the effects that the replacement of delivery trucks by delivery drones will have on operational CO_2 emissions and VMT, as well as identified patterns by these results, are presented at the end of this paper.

2. Literature review

To understand past efforts in research with regards to the impacts of delivery modes and comparisons amongst them, a literature review was conducted. Ample articles were identified in regards to delivery trucks, each with generally similar results showing significant reductions in CO_2 emissions and/or VMT when delivery trucks replace personal travel. However, when focus was shifted onto the environmental impacts of delivery drones, little could be found. While drones are not as well-studied as trucks, comparisons between delivery trucks and personal light-duty travel models are relevant and telling in how methodology and results could assist or be applied towards this research.

2.1. Evaluations of impacts of delivery trucks

Some of the earliest work comparing delivery services to personal travel was conducted by Cairns, with several papers spanning from the late 1990s to the mid-2000s. Focusing on VMT impacts of grocery delivery services in the United Kingdom, she finds significant reductions when a delivery-by-truck system replaced typical passenger travel, often estimating savings of 70–80% (Cairns, 1997). She also finds it possible to have increased VMT savings as the number of customers simultaneously increases (Cairns, 1998). While these results were pertinent only to the United Kingdom, she later expands her research, examining international results of modeling assessments, and again sees a 70% or more potential savings in VMT (Cairns, 2005). Unfortunately, Cairns work has been limited to estimated changes in VMT only and does not examine emission impacts.

This gap, however, was quickly filled by Kim, et al. as they compare the energy consumption and air emissions of three different delivery systems (Kim et al., 2008). Using U.S. Environmental Protection Agency (EPA) standards and route modeling, they suggest that a system that utilizes centralized drop-off locations has the least CO_2 emissions, closely followed by an e-commerce network in which packages are delivered to customers along a designated route. The third, representing traditional passenger travel, performs the worst with almost 40 times more CO_2 emissions than the e-commerce network. Results of Kim, et al. reflect closely to those of Cairns with a 68% reduction in VMT between the passenger travel and e-commerce delivery models.

McKinnon and Edwards also examine the last mile stage for small non-food items, contrasting home delivery operations with conventional personal travel shopping in the United Kingdom (McKinnon and Edwards, 2009). Even when considering additional factors, such as trip chaining, product returns and redelivery, and customer bus travel, they still find that goods delivery via coordinated delivery trucks almost always results in less CO_2 emissions than via individual trips of personal vehicles. This was further substantiated by Edwards, et al. with the caveat that environmental impacts may favor private vehicles if enormous amounts of goods are purchased by the customer per trip (Edwards et al., 2010).

Nevertheless, for the purposes of this research, it is Wygonik and Goodchild that provides the most meaningful methodology framework for a comparison between two delivery modes (Wygonik and Goodchild, 2012). On a detailed level, the team constructs proximity and random assignment models using ArcGIS and EPA parameters, and with guiding assumptions, they assess the differences in VMT and CO_2 emissions between passenger travel and delivery vehicles. Their findings of a 95% reduction in VMT with trucks and 86% less CO_2 are similar to previously mentioned studies, but it is their illustrative and easily replicable methodology that has most useful – it was adopted and slightly altered for this research's comparison between delivery trucks and drones, as described in the methodology portion of this paper.

2.2. Evaluations of impacts of delivery drones

D'Andrea provides helpful approximations of drone energy usage in his work calculating hypothetical operational costs of a drone delivery system (D'Andrea, 2014). Using reasonable assumptions in payload, lift-to-drag ratio, headwind, and other variables, D'Andrea determines a worst-case energy requirement for a drone. While his situational parameters and resulting value are too specific for the purposes of this research, the magnitude of the energy requirement creates an insightful scale that has been helpful in this research for comparative analysis once data was collected.

Beyond D'Andrea, however, literature regarding impact assessments of drones is scarce. This is mainly due to the relatively recent introduction and little operational usage of drone technology in the delivery industry, as well as drone diversity and proprietary information barriers. Online publications and editorials exist and have speculated various impacts, but most focus on financial and operational elements (Wang, 2016). Those that discuss possible environmental impacts either do not incorporate CO_2 or VMT calculations (Eng, 2016) or are focused on drones in fields of conservation and wildlife protection

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