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A new statistical method of assigning vehicles to delivery areas for CO_2 emissions reduction

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ABSTRACT

Transportation CO_2 emissions are expected to increase in the following decades, and thus, new and better alternatives to reduce emissions are needed. Road transport emissions are explained by different factors, such as the type of vehicle, delivery operation and driving style. Because different cities may have conditions that are characterized by diversity in landforms, congestion, driving styles, etc., the importance of assigning the proper vehicle to serve a particular region within the city provides alternatives to reduce CO_2 emissions. In this article, we propose a new methodology that results in assigning trucks to deliver in areas such that the CO_2 emissions are minimized. Our methodology clusters the delivery areas based on the performance of the vehicle fleet by using the k-means algorithm and Tukey's method. The output is then used to define the optimal CO_2 truck-area assignment. We illustrate the proposed approach for a parcel company that operates in Mexico City and demonstrate that it is a practical alternative to reduce transportation CO_2 emissions by matching vehicle type with delivery areas.

Introduction

Transportation is one of the main contributors of anthropogenic carbon dioxide (CO_2) (Intergovernmental Panel on Climate Change, 2007), and predictions indicate an increase in the next 20 years (European Commission, 2011). Road transportation accounts for a large share of freight transport emissions. In the European Union (EU), for instance, road transport accounts for more than 65% of EU transport-related greenhouse gases (GHG) and over 20% of the EU's total emissions of CO_2 (EU Transport GHG, 2007). In the United States, road transport accounts for approximately 30% of GHG and it is the fastest-growing major source of CO_2 emissions (EPA Road, 2011). In addition to these figures, cities in developing countries are becoming relevant in terms of their potential impact on transportation CO_2 emissions. For example, studies indicate that by 2030 there will be more vehicles in developing countries than in developed nations (Wright and Fulton, 2005) and therefore the GHG due to transportation will increase as well, probably as the largest contributor in emissions.

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Transportation CO_2 emissions are affected by a variety of conditions related to the type of vehicle (e.g. engine power, torque, fuel type, aerodynamic drag coefficient, etc.) and the characteristics of the delivery operation (e.g. type of road, slope, vehicle speed, load, etc.) (Akçelik and Besley, 2003). In addition, other variables that also affect CO_2 emissions include traffic, driving style (McKinnon et al., 2010) and weather conditions (RACQ, 2015) (Fuel Consumption Guide, 2014). Demir et al. (2011) study six emission models for road freight transport. (An instantaneous, a four-mode elemental and a running speed fuel consumption models (Bowyer et al., 1985), a comprehensive modal emissions model (Barth et al., 2005), MEET model (Hickman et al., 1999) and COPERT III model (Ntziachristos et al., 2000).) Using simulation and by comparing their differences under a variety of scenarios, they show that the main drivers of CO_2 emissions on road transportation are mainly explained by the type of vehicle, speed and road conditions.

Some studies have provided different alternatives to reduce transportation CO_2 emissions. McKinnon (2010) presents five freight transport parameters (transport intensity, modal split, vehicle utilization, carbon intensity and energy efficiency) and analyzes the potential savings of CO_2 emissions by modifying them in the logistics operation. Piecyk and McKinnon (2010) discuss that in order to achieve a 10% emissions reduction in freight transport in 2020, substantial improvements in vehicle utilization and fuel efficiency will be required. Therefore, the challenge consists in including information concerning these parameters in the logistics decision models with the aim at increasing fuel efficiency and thus, reducing CO_2 emissions.

As a first and novel intention of accounting for CO_2 emissions on transportation logistics models, Bektaş and Laporte (2011) present the Pollution-Routing Problem (PRP), which considers the cost of emissions in the vehicle routing model. The model was later extended by Demir et al. (2012) by including the consideration of low speeds. The PRP formulation considers the comprehensive emissions model of Barth et al. (2005) but with the assumptions of constant road angle, average speed and rolling resistance, in each arc. The study presents relevant insights regarding the effect of distance, load, speed, variation of demand and vehicle size, on CO_2 emissions under a variety of conditions. However, the effect of road factors is out of the scope of the study (e.g. in all the experiments a road angle of zero is assumed). In addition, because vehicle routing models typically assume homogeneous fleet, the PRP holds the same assumption, and thus, the impact of the type of vehicle (size, type of fuel, frontal area, engine power, load capacity, etc.) on CO_2 emissions is not formally considered into the model. While these assumptions (homogenous fleet and road angle equals zero) may not cause a significant impact on defining routes, we notice that the assignment of the vehicle to the delivery area may still provide alternatives to reduce transportation CO_2 emissions during the delivery operation. In a review on road green transport, Demir et al. (2014) show that the assignment of the right vehicle is a promising research area to reduce transportation CO_2 emissions. To illustrate this concept, consider a comparison between a low and high torque trucks. A low torque truck performs better in long level distances under constant average speed, while, under pronounced slopes, the high torque truck outperforms the low torque truck. Thus, we notice that the impact of CO_2 emissions can be substantial mainly in regions with vehicle constraints and variety of types of roads.

Road conditions include the roughness of the road pavement. This affects the vehicle fuel efficiency and hence CO_2 emissions (Greene et al., 2013). In addition, other road factors such as slopes, number of lanes, traffic lights and uneven surfaces, among others, also affect the engine performance of the vehicle, and therefore, the CO_2 emissions. Therefore, we notice that different types of vehicles (with specific type of tires, engine, etc.) may adjust better (in fuel efficiency) to a specific road condition than other. In other words, defining the proper match between the type of truck and the delivery area may increase the efficiency in fuel consumption and reduce CO_2 emissions.

In this article, we focus on studying the operation of the express delivery in Mexico City. We notice that for this type of delivery in a dense area as Mexico City, parcel companies assign a specific vehicle and driver to serve to a specific region within the city. This assignment is conducted by balancing the volume (packages), distance traveled and vehicle constraints. Companies then leave the routing decision to the drivers, who commonly have enough experience in driving the city; in that he or she is able to manage its dynamics, i.e. traffic time windows, change in street directions, weekly (and unexpected) street markets, riots, etc.

Although multinational parcel companies operating in big cities like Mexico City usually invest in having an efficient vehicle fleet to reduce fuel consumption (e.g. DHL Express Mexico, 2013; UPS Mexico, 2013; FedEx Mexico, 2009), the amount of CO_2 is still significant mainly due to the amount of deliveries and the high service level they provide. Because this high service level requires responsiveness to the customers, express delivery in dense urban areas has usually low truck utilization and diversity in the vehicle fleet. These conditions allow the possibility of exchanging trucks to serve different regions without compromising flexibility. Because the types of vehicle and road conditions explain the transportation CO_2 emissions (Demir et al., 2011), we are thus, interested in learning whether the truck-region assignment has an impact on transportation CO_2 emissions, and how this outcome can help decision makers to reduce CO_2 emissions.

In this article, we present a statistical–mathematical methodology that allows companies to reduce transportation CO_2 emissions when delivering in regions with a variety of landforms and road conditions (i.e. vehicle, traffic, etc.). Our approach works by analyzing the historical performance of the vehicle fleet in terms of its daily delivery operation and fuel consumption. This analysis allows us to build a statistical model that relates each vehicle with an emission factor (amount of CO_2 per vehicle-kilometer), and thus, we can identify regions within the city where the performance of a truck type is better. The output is then used to define the optimal CO_2 assignment of a particular truck type to a particular zone. Our research is based on an empirical study of the last mile express delivery by a multinational parcel company that operates in Mexico City. We include an illustration of our approach in the delivery operation for the parcel company and we show that our method provides a practical alternative to reduce transportation CO_2 emissions by matching vehicle type with delivery areas.