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Invited Review

A review of recent research on green road freight transportation

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ABSTRACT

Road freight transportation is a major contributor to carbon dioxide equivalent emissions. Reducing these emissions in transportation route planning requires an understanding of vehicle emission models and their inclusion into the existing optimization methods. This paper provides a review of recent research on green road freight transportation.

1. Introduction

Road freight transportation is essential for the economic development, but it is also harmful to the environment and to human health. Until recently, the planning of freight transportation activities has mainly focused on cost minimization (see, e.g., Crainic, 2000; Forkenbrock, 1999, 2001). With an increasing worldwide concern for the environment, logistics providers and freight carriers have started paying more attention to the negative externalities of their operations. These include pollution, accidents, noise, resource consumption, land use deterioration, and climate change risk (Schreyer et al., 2004).

At the local and regional levels, a significant portion of freight transportation is carried out by trucks, which emit a large amount of pollutants. While transportation technologies and fuels have improved over the years, most trucks run on diesel engines, which are major sources of emissions of nitrogen oxides (N_2O), particulate matter (PM) and carbon dioxide (CO_2). Repeated exposure to N_2O-based smog and PM has been linked to a wide range of health problems. At the global level, greenhouse gases (GHGs) significantly contribute to global warming. In the transportation sector, GHG emissions are dominated by CO_2 emissions from burning fossil fuels. These cause atmospheric changes and climate disruptions which are harmful to the natural and built environments and pose health risks. Until recently, GHGs were not classified as a pollutant in the classical sense. However, the United States Environmental Protection Agency (EPA) has recognized in 2009 that GHGs pose a danger to human health and welfare. GHGs absorb and emit radiations within the thermal infra-red range in the atmosphere and significantly raise the Earth's temperature. As of October 2013, the level of atmospheric CO_2 emissions is estimated to be equal to 393.66 parts per million and is still increasing (ESRL, 2013).

The carbon dioxide equivalent (CO_2e) measures how much global warming a given type and amount of GHG may cause, using the functionally equivalent amount or concentration of CO_2 as the reference. The selection of GHGs to include in the carbon footprint is an important issue. Wright, Kemp, and Williams (2011) suggest that a significant proportion of emissions can be captured through the measurement of CO_2 and CH_4, which are the most prominent anthropogenic GHGs. The emissions of CO_2 are directly proportional to the amount of fuel consumed by a vehicle, which is in turn dependent on a variety of vehicle, environment and traffic-related parameters, such as vehicle speed, load and acceleration (Demir, Bektaş, & Laporte, 2011). On the other hand, CH_4 emissions are a function of many complex aspects of combustion dynamics and of the type of emission control systems used.

Freight transportation planning has many facets, particularly when viewed from the multiple levels of decision making. Arguably the most famous problem at this level is the well-known Vehicle Routing Problem (VRP), which consists of determining least cost routes for a fleet of vehicles to satisfy the demands of a set of customers, subject to side constraints. The traditional objective in the standard VRP is to minimize the total distance traveled by all vehicles, but this objective can be enriched through the

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inclusion of terms related to fuel consumption (Bektaş & Laporte, 2011; Demir, Bektaş, & Laporte, 2012).

Recent developments in green road freight transportation have heightened the importance of operations research techniques in this area (see, e.g., Dekker, Bloemhof, & Mallidis, 2012; Dobers et al., 2013; Lin, Choy, Ho, Chung, & Lam, 2013; Salimifard, Shahbandarzadeh, & Raeesi, 2012; Touati & Jost, 2012). In the last decade, the body of knowledge on the reduction of CO_2e emissions from road transportation has grown notably. As of August 2013, we are aware of at least 58 papers on this topic. In this study we focus on the green logistics literature related to total energy consumption.

The scientific contribution of this study is threefold: (i) to analyze the factors affecting fuel consumption, (ii) to extensively survey the available vehicle emission models, (iii) to review the scientific literature on green road freight transportation. The remainder of this paper is organized as follows. Section 2 reviews the factors affecting fuel consumption. Section 3 lists the available tools to estimate CO_2e. In Section 4, we investigate routing problems with regard to fuel consumption. Section 5 presents an extensive body of literature of CO_2e emissions in routing and scheduling. Conclusions and future research directions are stated in Section 6.

2. Factors affecting fuel consumption

The factors influencing fuel consumption have been studied by Ardekani, Hauer, and Jamei (1996), Bigazzi and Bertini (2009), Demir et al. (2011) and Alwakiel (2011). A summary of these works is provided in Fig. 1. These factors can be divided into five categories: vehicle, environment, traffic, driver and operations. Most fuel consumption models concentrate on vehicle, traffic, and environmental influences, but do not capture driver related issues which are relatively difficult to measure. Moreover, operations related factors are often seen as an externalities affecting fuel consumption.

One important work by Eglese and Black (2010) studies the emissions arising in routing and lists some of the factors affecting fuel consumption. In contrast to the existing literature, the authors argue that speed is more important than distance traveled when estimating emissions. In another study, Demir et al. (2011) have compared several emissions models, and mentioned other relevant factors such as load weight and distribution, engine type and size, vehicle design, and road gradient.

Road freight is mostly carried by internal combustion vehicles. In order to move a vehicle, an engine must provide power to overcome the effects of inertia, rolling resistance, wind resistance, road

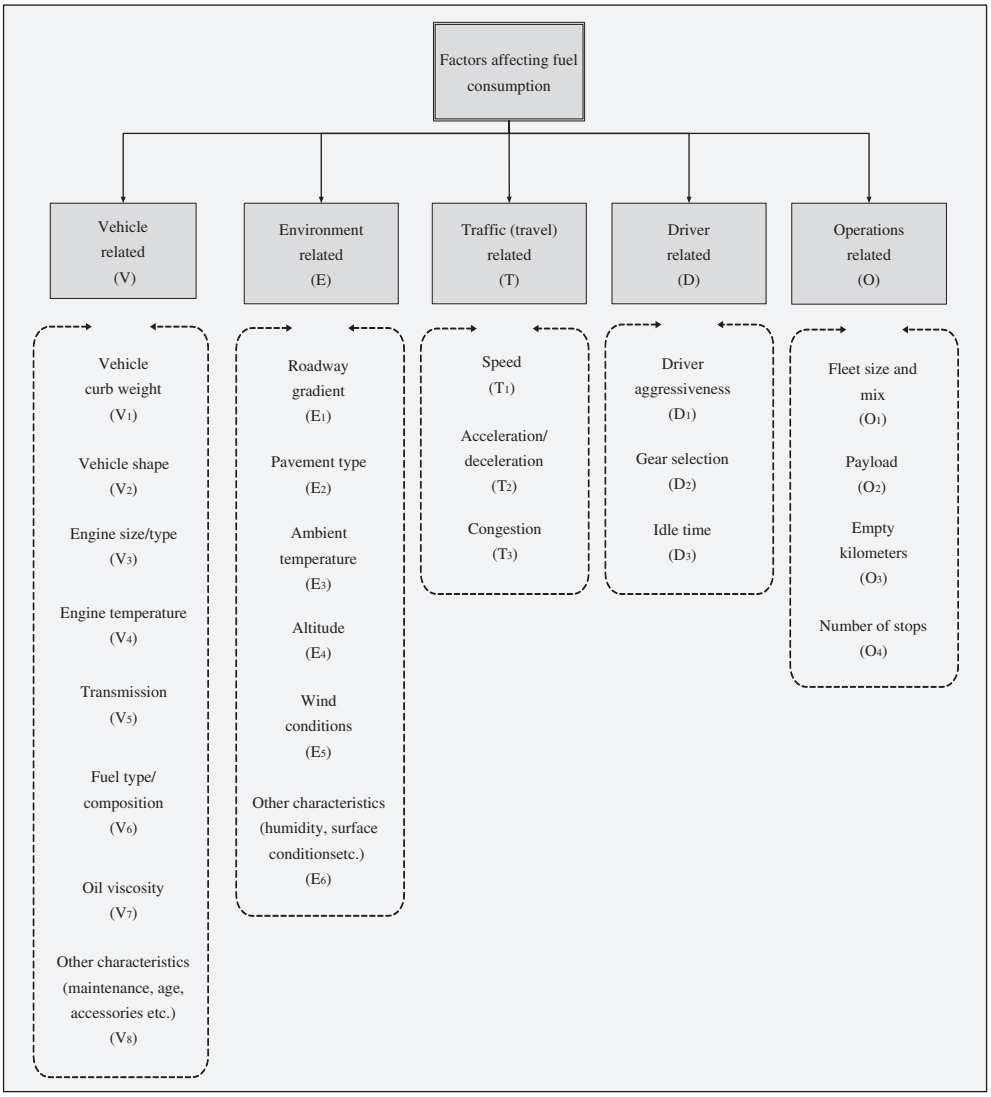

Fig. 1. Factors affecting fuel consumption.