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Cutting fuel consumption of truckload carriers by using new enhanced refueling policies

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ABSTRACT

This study proposes a new fuel-saving approach for the U.S. truckload (TL) industry from the operations-research perspective. Our approach is inspired by the idea given by multiple industry experts that, when trucks are heavy, their fuel consumption rates are notably worse in uphill and congested segments than in other segments, so that trucks should avoid buying large amounts of fuel before entering uphill and/or congested segments. We show both theoretically and numerically that our approach requires lower fuel consumption than other (existing) approaches to move a truck in a given (fixed) origin-destination route. Although, at a glance, the savings given by the proposed approach might seem small, it may actually save noticeable amount of carbon dioxide (CO_2) emissions and fuel cost for the U.S. TL industry, if implemented properly.

1. Introduction

During the last few decades, green supply chain network distribution problems, which involve suppliers, manufacturers, distributors, and retailers, have received much attention from researchers (Tiwari and Chang, 2015; Konur, 2014). One of the most important parts of these green supply chain problems is the transportation of materials, because transportation, in particular truck transportation, is known to account for large amounts of pollutants emission (Tiwari and Chang, 2015; Ericsson et al., 2006). To date, many studies have investigated the methods of reducing environmental costs of trucks by means of operations research techniques. These studies are typically conducted within the context of vehicle routing and scheduling, and often focus on formulating and solving the green vehicle routing problem (GVRP) or pollution routing problem (PRP) (Demir et al., 2014a). These problems are similar to the standard vehicle routing problem (VRP), except that the cost is measured by fuel consumption or pollutants emission, instead of distance or time. These studies have shown that notable savings in trucks' fuel burn can be attained by (1) avoiding costly arcs (e.g., long, uphill, or congested arcs that require increased fuel consumption), and (2) controlling the trucks' cargo (shipment) weight such that the heaviest items are unloaded at the early phase of the route (for delivery instances) or loaded at the late phase of the route (for pick-up instances).

These GVRP or PRP studies, however, can provide rather limited benefits to the trucking industry as a whole. This is because, in general, they can be applied only to the less-than-truckload (LTL) industry, and not to the (larger) truckload (TL) industry, for two reasons. First, TL carriers typically do not perform “milk runs” (package deliveries and/or pick-ups) that are represented by the GVRP or PRP. Instead, TL operations are described by the “point-to-point” truck movement from origin (O) to destination (D), where the movement is restricted only along the shortest route from O to D (as TL carriers are paid by “billed miles” or shortest-route miles). This means that TL carriers do not have the flexibility to choose arcs (their routes are fixed). Second, TL carriers usually load their trucks only at O and unload only at D (i.e., no loading/unloading occurs between O and D). This means that, in no part of the route between O and D, can TL carriers control their trucks' cargo weight.

The above suggests that TL carriers have little control over the two key decision variables of the GVRP and PRP (route and cargo weight), which makes it difficult for them to benefit from the use of these techniques. In fact, given that both the route and cargo weight are fixed, it may be difficult for TL carriers to benefit from any operations research technique to reduce fuel consumption. Recently, however, two studies (Suzuki, 2008; Suzuki et al., 2014) have tried to reduce a truck's fuel burn in the TL industry by formulating and solving a mathematical model called the *fixed route vehicle refueling problem* (FRVRP). The FRVRP seeks, for a given (fixed) O-D route, the optimal refueling policy (sequence of fuel stops to use, along with the refueling quantity at each stop) that minimizes a vehicle's refueling cost along the route. While the standard FRVRP minimizes the refueling cost, the above two studies minimized

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not only the refueling cost, but also the truck's fuel burn.

Suzuki (2008) proposed a formulation that imposes penalties (opportunity costs) for using truck stops that are located far from the main route (require a vehicle to deviate considerably from the shortest route) to reduce "out of route" miles. Suzuki et al. (2014) proposed a formulation based on the idea that if a truck possesses more fuel than necessary in its fuel tank (e.g., beyond that needed to reach the next refueling location or destination, whichever comes first), it must burn additional fuel to carry this "unnecessary" fuel to the next station, so that such surplus fuel should be eliminated. These studies showed that fuel savings between 0.062% and 0.435% may be possible.

These studies, however, did not consider the following two effects which, according to our focus-group studies conducted with TL carriers, may have non-trivial impacts on the fuel consumption rate of heavy-duty trucks. First is the mixed effect of fuel weight and road congestion. Carrier managers believe that a truck burns more fuel in congested areas if it carries a large amount of fuel because: (1) it is known that more fuel is required to accelerate a heavier truck, so that (2) a truck with more fuel (more weight) will require more fuel burn during the repetitive "stop-and-go" movements that are typically observed in congested areas. Given this insight, we posit that it may be best to avoid buying large amounts of fuel before entering congested areas (note that fuel capacity of TL trucks is typically 200–500 gallons, so that full fuel can weigh nearly 3500 lbs.). Second is the mixed effect of fuel weight and road gradient (slope). Carrier managers believe that a truck burns more fuel in uphill (positive gradient) segments if the truck carries a large amount of fuel because: (1) it is known that a heavier truck needs more fuel burn while climbing hills, so that (2) a truck with more fuel (more weight) will need to burn more fuel in these segments. Given this insight, we posit that it may be best to avoid buying large amounts of fuel before entering uphill segments.

The above paragraph suggests that we may be able to save a truck's fuel burn along a given (fixed) route by adopting a refueling policy that avoids (or minimizes) buying fuel before entering the congested and/or uphill segments. Given this inspiration, we perform both a theoretical work and numerical experiments that attempt to answer the following questions: "Can the policy based on this idea really save fuel consumption of trucks?" and "If so, how much savings are possible?" If the saving is found to be respectable, this paper makes a contribution by introducing a new approach to the TL industry that cuts trucks' fuel consumption without changing the route or cargo weight. The proposed approach is not mutually exclusive, but rather complementary, with the existing approaches (Suzuki, 2008; Suzuki et al., 2014), so that, if proven to be useful, the approach can be used in conjunction with these other approaches.

2. Literature review

Two types of research are relevant to this study. The first is the FRVRP studies, which represent the focal problem of this study. The second is the research that investigated the impact of various factors (e.g., vehicle weight and road gradient) on fuel consumption rates of vehicles.

2.1. FRVRP studies

To date, several FRVRP forms and solution techniques have been developed. Although the FRVRP has been applied to multiple transportation modes, our review here focuses on those studies that considered the FRVRPs in the trucking industry, as they are most relevant to this study. Readers that are interested in the FRVRPs of other transportation modes are referred to Stroup and Wollmer (1992) (air), Besbes and Savin (2009) (sea), and Nourbakhsh and Ouyang (2010) (rail).

Graphical representation of the most popular FRVRP form used in the TL industry is shown in Fig. 1. This form is widely used by both scholarly FRVRP studies and commercial software products (several software products exist in the TL industry that solve the FRVRP, which are often called "fuel optimizers" by practitioners; e.g., *ProMiles*, *Expert Fuel*). The problem is defined by a set of truck stops $\Omega = \{1, 2, \ldots, i, \ldots, n\}$ on the fixed route from origin to destination, each element of which is characterized by (1) p_i (fuel price per gallon), (2) e_i (out-of-route miles, or the extent to which a vehicle must divert from the route to reach truck stop i), and (3) $d_{i-1,i}$ (miles between truck stops $i-1$ and i, excluding e_{i-1} and e_i). Given the initial fuel level at origin and the required fuel level at destination, the FRVRP seeks the minimal-cost refueling policy $\Phi = \langle \phi_1, \phi_2, \ldots, \phi_i, \ldots, \phi_n \rangle$ for a vehicle, where $\phi_i \geq 0$ is the amount of fuel to be purchased at truck stop i. The problem is subject to the constraints that: (1) the vehicle must maintain the minimum fuel level of $l \geq 0$ at all times, (2) the fuel level at any point in the route must not exceed the tank capacity, and (3) refueling quantity at every truck stop must not be less than the minimum purchase quantity.

Perhaps the first study that considered the FRVRP in the trucking industry is Lin et al. (2007). This study considered a reduced version of the FRVRP shown in Fig. 1, in which every truck stop is assumed to be located "on the route" (i.e., $e_i = 0\ \forall\ i$). An interesting aspect of this study is that it considered the FRVRP as a special case of the capacitated lot-sizing problem (CLSP), which is widely used in the production literature, and developed an efficient optimal algorithm by modifying the existing CLSP methods. A similar (essentially identical) FRVRP form was considered by Khuller et al. (2008). This study formulated the FRVRP as a dynamic program in which the problem is divided into n sub-problems, and developed an efficient optimal algorithm.

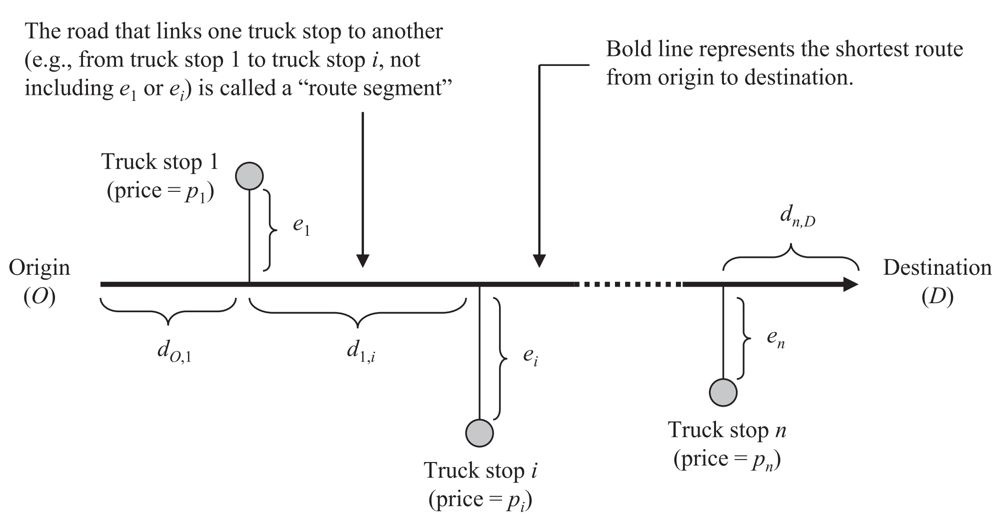

Fig. 1. A sample refueling problem (source: modified from Suzuki et al., 2014).