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Combining pickups and deliveries in vehicle routing – An assessment of carbon emission effects ☆

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ABSTRACT

This paper studies the effect on carbon emissions of consolidation of shipments on trucks. New positioning and communication technologies, as well as decision support systems for vehicle routing, enable better utilization of vehicle capacity, reduced travel distance, and thereby carbon emission reductions. We present a novel carbon emission analysis method that determines the emission savings obtained by an individual transport provider, who receives customer orders for outbound deliveries as well as pickup orders from supply locations. The transport provider can improve vehicle utilization by performing pickups and deliveries jointly instead of using separate trucks. In our model we assume that the transport provider minimizes costs by use of a tool that calculates detailed vehicle routing plans, i.e., an assignment of each transport order to a specific vehicle in the fleet, and the sequence of customer visit for each vehicle. We compare a basic set-up, in which pickups and deliveries are segregated and performed with separate vehicles, with two consolidation set-ups where pickups and deliveries may be mixed more or less freely on a single vehicle. By allowing mixing, the average vehicle load will increase and the total driven distance will decrease. To compare carbon emissions for the three set-ups, we use a carbon assessment method that uses the distance driven and the average load factor. An increase in the load factor can reduce part of the emission savings from consolidation. We find that emission savings are relatively large in case of small vehicles and for delivery and pickup locations that are relatively far from the depot. However, if a truck visits many demand and supply locations before returning to the depot, we observe negligible carbon emission decreases or even emission increases for consolidation set-ups, meaning that in such cases investing in consolidation through joint pickups and deliveries may not be effective. The results of our study will be useful for transport users and providers, policymakers, as well as vehicle routing technology vendors.

1. Introduction

Freight transport has a considerable negative environmental impact in the form of local pollutants, such as particular matter, and global pollutants, such as greenhouse gases. Worldwide, the movement of freight is responsible for about 10% of energy related carbon emissions; In domestic situations, much of these emissions are due to road transportation

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(92% in the United Kingdom) (McKinnon et al., 2015). One way to reduce these emissions is by using existing vehicle capacity better: McKinnon et al. (2015) report that around 20–25% of the hauls are performed with empty vehicles and that the average degree of vehicle utilization in the European Union ranges from 28% in Ireland to 45% in Denmark.

Our study is motivated by the current aim of reducing carbon emissions through more efficient routing in freight transport. Léonardi and Baumgartner (2004) note that four freight transport efficiencies should be improved in order to reduce emissions: routing, logistics, driving and vehicle. Routing efficiencies refer to the route that the vehicles follow with the implication that a shorter route yields lower emissions. Logistic efficiencies refer to capacity utilization on-board a vehicle with the implication that greater load consolidation will reduce emissions. Driving efficiencies refer to the way the vehicle is driven in terms of speed and idling. Finally, vehicle efficiencies relate to the design of the vehicle itself in terms of fuel efficiency or alternative technologies. In this paper, we focus on the interrelated routing and logistics efficiencies. Specifically, we study the routing and load consolidation implications on carbon emissions in two pickup and delivery scenarios - one in which the vehicles perform all deliveries prior to commencing the pickups and one in which deliveries and pickups can occur freely.

There are studies on the effect of improving vehicle utilization on a large scale, e.g., in a region or a country, as in Walnum and Simonsen (2015). Such studies typically measure fuel usage or carbon emissions and relate the observed levels to input variables such as the load on the vehicle and the speed. However, it is then difficult to disentangle the improvements from better vehicle utilization from improvements in vehicle technology or routing tools. In our approach we model the decisions of an individual transport provider and determine the carbon emission savings resulting from consolidation of shipments. This allows us to assess the impact of vehicle utilization in isolation.

We can draw on techniques from the field of *green logistics*, where one minimizes fuel consumption or carbon emissions, often alongside other objectives such as costs; see Demir et al. (2014a). Even though we do not optimize carbon emissions or fuel consumption, we compare the emissions of set-ups with different load factors, and need a similar method for computing emissions. In this paper, we use the simple but reasonable carbon emission computation method from Turkensteen (2016), see Section 3.

If shipments are consolidated in such a way that the vehicle route does not change, vehicle utilization is increased. One consequence is that we need fewer hauls to serve the transport demand, thus reducing the distance driven. However, the effect of higher average payload will counteract the resulting carbon emission savings. We call this the *payload effect*.

An interesting side-effect occurs when consolidation is performed in such a way that new locations are added to the original route. In that case, the average distance traveled by each item can increase, for example because items destined to the end of a route have to go on a detour through locations that are not in the set-up without consolidation. In such cases, the emissions due to the payload on the vehicle can increase. We call this the *detour effect*.

As indicated above, we consider a specific case of consolidation, namely the possible combination of deliveries from a depot and pickups destined to the same depot on the same vehicle. This case is interesting for two reasons. First, both the payload and the detour effect can occur: When pickup locations are added to a delivery route, the items to be delivered may travel over a longer distance. The same applies for the addition of delivery locations to a pickup route. Second, there are several situations where combined deliveries and pickups on the same vehicle are attractive in practice.

In an overview, McLeod et al. (2008) focus on urban areas in the United Kingdom, mainly of the collection of packaging waste. They mention that retailers such as ASDA, Sainsbury, and Next use trucks to return recyclable packaging materials. Anily and Federgruen (1990) argue that grocery stores have discovered cost-cutting potential by allowing vehicles to collect large volumes of inbound materials on their delivery routes. In forestry, studies such as Carlgren et al. (2006) consider the usage of a return haul from a factory to a forest to carry a load in the opposite direction for another forestry company.

Another interesting application arises from a trend towards the 'circular economy' where materials and products are reused (CircularEconomy.com, 2016). One manifestation of this could be that a company sells a service, e.g. clothing or printing, to companies rather than physical products such as clothes or printers. The company would then be responsible for replacing or refilling products at given points in time. A well-known example is Eastman Kodak (Krumweide and Sheu, 2002). In clothing, the upcoming Danish company Vigga.us leases children's clothes to customers, takes them back after usage, and replaces them with larger size clothes (Vigga.us, 2015). The examples from McLeod et al. (2008) fall in the same category. In all these cases, used materials or products could be collected by the vehicles that perform the deliveries.

In order to perform our analysis we construct a model of the decisions taken by the transport provider. This model and its underlying assumptions are presented in Section 2. We consider two consolidation options, namely *backhauling*, a set-up in which all deliveries should take place before any pickup, and *mixing*, a set-up in which deliveries and pickups can be mixed freely, as long as the vehicle's capacity is not exceeded. We analyze the carbon emission effects of the three different levels of flexibility regarding consolidation. Through computational experiments on a diverse set of instances, we consider the effect of different characteristics of the situation, such as the number of delivery and pickup locations and their distribution in an area.

The environmental effect of combining deliveries and pickups has not been given much attention in the literature. To the best of our knowledge, the only study that provides numerical results on carbon emission savings is the one by Ubeda et al. (2011). The authors consider the case of backhauling within a case company during one week, and compare this to a (current) set-up with separate delivery and pickups and the set-up with the lowest cost, as well as a set-up with minimal carbon emissions. It is found that the backhauling option yields about 15% less carbon emissions than the current set-up and around 5% less than the set-up that minimizes total costs. A more integrated set-up with mixing is not considered, and the results