Carbon emission effects of consolidating shipments

- taking topological effects and temporal constraints into consideration

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1 Introduction

In this study we consider the emissions savings that can be achieved by combining pickups and deliveries on the same vehicle. A previous paper [9] presents the effect of many factors, such as the size of the vehicle, on the carbon emission savings. One of the striking results is that, although emission savings are often between 10% and 40%, there are situations where consolidation leads to carbon emission increases. However, the study contains several simplifying assumptions, namely the usage of Euclidean distances and the absence of temporal constraints.

In this paper, we extend our previous work by removing simplifying assumptions to accommodate important real-life aspects: road distances, tour duration constraints, and time windows. The results are not trivial. For example, one may expect that time windows and tour duration constraints limit the distance savings from combining deliveries and pickups, but they also reduce the load on the vehicle, meaning that the overall effect on emissions is not clear.

We compare a *non-consolidated set-up* where deliveries and pickups are performed on separate but identical vehicles and a *consolidated* set-up, where outbound and inbound items can be mixed freely on the vehicle, as long as capacity and temporal constraints are adhered to.

2 Literature and hypotheses

In [9], two key factors that determine the carbon emissions from coordination shipments are the distance and *the average load factor* of vehicles, i.e., the share of the vehicle's capacity that is on average occupied by the vehicle's load (measured in weight units). In this section, we consider literature on the impact of using road distances or travel times as objectives, and of adding time-windows and tour duration restrictions.

The focus of the vehicle routing literature is on designing better and more accurate models and efficient solution algorithms. Studies on the impact of factors such as geography and temporal constraints on vehicle routing are mainly from the field of continuous approximation, on locations that are uniformly distributed in an area.

Boscoe et al. [1] find a high correlation between Euclidean and *road distances* in the US but warn that features such as bridges, islands, and irregular shorelines may lead to clearly longer distances. Cooper [3] finds that there is strong correlation between Euclidean distances and vehicle routing costs in the British Midlands. However, the shape and the geometry of the area can affect the tour length [4]. It is found in [8] that a *tour duration limit* has in principle a similar effect as a capacity constraint, assuming that the density of locations does not change. However, the tours covering a certain area in the consolidated set-up in [9] tend to be longest, so tour duration limits would affect this set-up most. Regarding *time windows*, Daganzo [5] studies the impact of having *m* different intervals that serve as time windows for different demand points and finds that the total distance is a square root function of *m*. If constraints on the capacity make that closely located pickups and delivery locations with similar time windows cannot be visited together, this could have the same effect as increasing the number of intervals *m* in the consolidated set-up.

Based on the literature review, we expect that 1) road distances have little impact, and 2) temporal constraints lead to reduced distance savings and possibly emission savings in the consolidated set-up.

3 Models and experimental design

In our experiments, we mimic the decisions of a real transport provider who has to serve a given set of delivery and pickup locations from a given depot with a fleet of homogeneous vehicles with given capacity. The provider minimizes the number of vehicles as the primary objective, and the total distance driven as the secondary objective.

To this end, we use a commercial VRP solver ([2], [6]) to find approximate solutions. We find a solution to the non-consolidated set-up by solving two instances of the Vehicle Routing Problem with Time Windows (VRPTW): one for the deliveries and one for the pickups. For the consolidated set-up, we find a solution to the corresponding Vehicle Routing Problem with Pickups and Deliveries and Time Windows (VRPPDTW). We obtain the distance and the average load factor, which determine the total carbon emissions as in [9].

Our benchmark consists of the Li & Lim PDPTW instances [5] with approximately 100 pickup and delivery pairs.[i] We modify the instances such that all deliveries originate from a single depot and all pickups are destined for the same depot. The road distances are taken from the databases Denmark (DK), the Dutch province of South Holland (SH), and Illinois (IL) from Mileage Charts[ii] and cover different topographies. We distribute the delivery and pickup quantities of the Li & Lim instance lc106 over randomly selected locations in these three areas, with a central location for the depot, so that differences across geographies only are due to the mutual distances between locations, and not the number of locations. The maximum tour duration T is modeled through a time window on visiting the depot in the interval $[0,T]$, where we both consider tight and loose tour durations. We use the time windows from the regular Li & Lim instances, but since pickups tend to precede deliveries, we create instances where each pickup location is changed into a delivery location and vice versa.

4 Experimental investigation

Our preliminary computational experiments cover in total 55 instances. We compare the results to the corresponding Euclidean instances without temporal constraints.

The usage of *road distances* instead of Euclidean distances appears to reduce the emission and distance savings from consolidation to up to 10% for the DK database. The question is how general this characteristic is; we plan further experiments on different geographical datasets. The emission savings typically decrease with the tightness of the *tour duration constraint*, as expected: Consolidated tours are longest and more affected. However, in several cases, we obtain the surprising result that the addition of a tour duration limit increases emission savings from consolidation. We find that having more tours to satisfy the duration constraints has a small effect on the total distance, and that average load factor is often lower than in the non-consolidated set-up. These effects may give the counterintuitive result that the lower vehicle utilization may lead to larger carbon emission savings than in the unconstrained case. The addition of *time windows* has unpredictable effects because the minimization of vehicles has the highest priority. In some cases, when the consolidated set-up requires few vehicles, the resulting tours may be long in order to satisfy time windows. We have observed carbon emissions increases in such cases up to 8%, in particular when pickups tend to precede deliveries. As for the tour duration constraints, there are instances for which the distance savings are larger than in the unconstrained case.

5 Conclusions

We extend a previously investigated model with real-life aspects to more accurately measure the carbon emission effect of consolidating pickups and deliveries, namely real road distances and temporal constraints. Typically, there is a clear impact on emission savings: for road distances, emission savings appear to be lower than for Euclidean instances, whereas temporal constraints reduce the emission savings of consolidation. However, we have seen several cases where the resulting lower load factor resulting from such constraints can increase savings. Detailed results, including additional experiments, will be presented during the conference.

References

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[i] The Li & Lim instances can be retrieved on https://www.sintef.no/projectweb/top/pdptw/li-lim-benchmark/

[ii] The MileageCharts Database is available on http://www.mileage-charts.com/