2015 16th IEEE International Conference on Mobile Data Management

An Interactive Freight-pooling Service for Efficient Last-mile Delivery

Panagiotis Liakos and Alex Delis
University of Athens, GR15784, Athens, Greece
Email: {p.liakos, ad}@di.uoa.gr

***Abstract*—The existing practices of the urban section of freight transport chain result in traffic congestion, air pollution and resources being wasted. We focus on the final stage of freight distribution and propose an interactive *freight-pooling* service, in an effort to reduce the undesirable effects and the cost of freight transport in urban areas. Our service empowers city and state authorities to orchestrate the distribution network through interactive interfaces. We break the problem into three distinct phases that collectively helps us set constraints related to the quality of service and find inexpensive routes. In this regard, our proposed *freight-pooling* approach becomes an attractive option for efficient distribution, that guarantees cost minimization without sacrificing the level of quality.**

Keywords—Intelligent Transportation Systems, Vehicle Routing Problem, Algorithms, Design.

I. Introduction

Urban Freight Transport (UFT) refers to the movement of freight vehicles whose primary purpose is to carry goods into, out of and within urban areas. The freight transport industry concerns sectors including, but not limited to retail, parcel/courier delivery, Hotel/Restaurant/Café, and delivery of construction material. The term *last mile* is used to describe the final leg of the supply chain, when goods are transported to the final customer. This last step is usually the least efficient one in distribution networks. The increasing significance of UFT in the economic welfare of modern cities raises the issue of providing economically and environmentally efficient *last mile* delivery.

The challenges involved in UFT are numerous. Deployment from suppliers to re-sellers and to ultimate customers is typically performed by a very large number of small carriers performing similar itineraries with partially filled trucks. This leads to a high concentration of truck activity in city areas and contributes to road congestion. Studies indicate that freight vehicles represent no more than 15% of total traffic flow in urban areas [1], but due to their size and frequent stops for deliveries have a more significant impact than passenger vehicles. Apart from traffic congestion, this behavior leads to high distribution cost and increases the infrastructure maintenance. Moreover, freight vehicles are diesel-powered and their engines generate emissions that are harmful to people. The total carbon dioxide emitted by all forms of transport in London in 2006 was 9.6 tonnes, of which an impressive 23% was produced by freight vehicles alone [2]. The negative impact of these emissions to public health and climate change can be faced with the use of low emission urban trucks to carry out deliveries as well as by increasing the filling rate of trucks to cut down the total number of trucks. Minimizing the total mileage required to carry out the necessary deliveries will reduce traffic congestion, air pollution and unnecessary costs that are, in the long term, passed onto the final consumers. This however should not become an end in itself as carrier companies build their reputation by offering secure and on time deliveries.

To this end, we consider here a *freight-pooling* Intelligent Transportation System (ITS) that integrates existing technologies to provide an innovative service. The idea of car-pooling has been around for quite a while and was very successful during energy crises. However, its popularity dropped significantly due to improved fuel economy and social trends [3], and the recent technology-enabled ride-matching has only slightly boosted the percentage of car-poolers [4]. In the context of UFT, an efficient *freight-pooling* service can find the balance between social cost and social benefit by synchronizing supply chains of multiple shippers and transferring the same number of goods using significantly less resources, as it is depicted in Figure 1. Properly equipped freights are able to issue their precise location throughout their trip. Therefore, a monitoring service can collect this information and be aware at any time of the shipments that will arrive in a depot point to then be delivered in urban areas. This problem is similar to a well studied [5] generalization of the *NP-hard Vehicle Routing Problem* (VPR) [6], namely the *Capacitated Vehicle Routing Problem* (CVRP), as freights have a limited carrying capacity. However, here we consider additional constraints. To tackle the issues of preserving quality of service and imposing a fair pricing policy for all involved parties, a neutral body, or *trustee*, is responsible for monitoring the distribution network and applying labels to delivery points to control certain aspects of the route calculation.

We build on the idea of cluster-first, route-second approaches [7] and consider a three-phase method that enables the specification of constraints regarding scheduled deliveries, constructs groups of delivery points to reduce the total number of freights and finds the best route for each freight. In the following, we outline our approach (Section II), suggest a fair pricing policy (Section III), present our evaluation approach (Section IV), and conclude this presentation.

II. Overview

The problem we address here (CVRP) involves K freights of fixed capacity C, that have to deliver quantities of goods q_i to n delivery points. Additionally, each shipment is associated with a time e_i that represents the moment it becomes available and we consider constraints such as shipments that should be grouped or handled with an exclusive route. We tackle the

978-1-4799-9972-9/15 $31.00 © 2015 IEEE
DOI 10.1109/MDM.2015.60

IEEE computer society

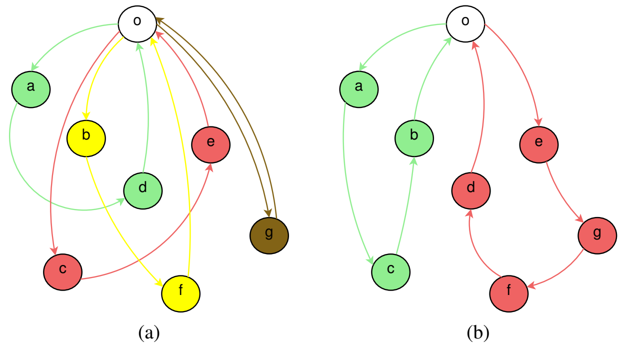

Fig. 1: An example of a freight-distribution network for the *last-mile* delivery. Freights deliver goods from the depot (*o*) to several customers (*a-g*). In (a) the shipments are delivered using 4 freights that pass through similar paths. In (b) *freight-pooling* reduces the number of freights and the total mileage.

problem by decomposing it into three phases: (i) collecting user-specified constraints, (ii) clustering the delivery points, and (iii) constructing the actual routes.

A. Collecting user-specified constraints

The first step of our approach allows a *trustee*, a role that can be assigned to city authorities in the context of UFT, to orchestrate the process by specifying constraints. As *freight-pooling* involves different parties, it is often the case that the most cost-effective schedule will be unfair to those parties who wait in the depot for other shipments or whose goods are delivered last. The solution is to charge each party based on the total delay in the delivery of its shipment. To allow the involved parties to determine if they prefer faster deliveries in exchange for higher charges, the *trustee* can apply different time windows for the delivery of each shipment. Additionally, the *trustee* can mark delivery points to be excluded from the *freight-pooling* network and have an exclusive freight assigned to them, or label them to ensure a proper mixture of goods in each freight. Interactive visualizations of the network enable the *trustee* to make appropriate labellings intuitively.

B. Clustering

The clustering phase determines the number of freights that will be needed for all shipments and the delivery points that each freight will be assigned to. At this stage we are not interested in the actual routes the freights will follow. Our goal is to find the *Minimum Spanning Trees* (MST) of the delivery points that make best use of the freights' capacity. We also do not need to consider grouping a shipment with the ones that become available at significantly different time and, lastly, we possibly already have some groups partly specified by the *trustee*. We approach this problem by applying a variation on the *Esau-Williams* heuristic [8] for the *Capacitated Minimum Spanning Tree* problem. This provides us with a very good approximation of the optimal solution. In every step, when choosing the closest point in a different subgroup, we also ensure that our additional constraints are satisfied. In particular, we verify that: (i) assuming a maximum delay for each shipment the time windows of the points in each subgroup overlap, (ii) the points to be grouped bear the same label, and (iii) the points that are marked for exclusive delivery are not grouped with other points.

C. Constructing the actual routes

Having determined the groups of delivery points we can construct each individual freight route by solving the corresponding *Traveling Salesman Problem* (TSP). TSP is also an *NP-hard* problem in combinatorial optimization that has been studied extensively. We employ the algorithm in [9] to find a good approximation. In addition to this, we use the priorities associated with the delivery points to determine the direction the vehicle will follow, i.e., which delivery point will be visited first. This last step allows the *trustee* to orchestrate the cost of each party involved and provide a fair schedule.

III. Cost Model

The cost of hiring a carrier is mostly associated with the time the freight remains engaged. *Freight-pooling* minimizes the total miles the freights travel and as a result reduces this cost significantly. A benefit also occurs regarding other charges, such as the minimum charging fee for each truck, as the total number of freights involved is reduced as well.

In this section, we study the effect a *freight-pooling* service has on the cost that is related to the traveled distance. We build a cost model that utilizes the money saved to encourage suppliers to participate in this collective effort. In addition to this, we suggest that a portion of the total benefit should finance the orchestration process. We do not consider a compensation for carriers, whose interests will be seriously hurt, as they not in the position to enforce suppliers to work independently.

A. Freight-pooling profit

Figure 2 depicts the delivery of three shipments from the depot point $\circ$ to points 1, 2, and 3. Each shipment is associated with a cost c_i that depends on the distance of the delivery point from the depot (original route). Assuming that the load of all three shipments can be accommodated in a single truck, we also assign the minimum *freight-pooling* cost c_i', i.e., the cost of delivering the shipments by following the shortest route that passes through all three delivery points (*freight-pooling* route). The total profit of *freight-pooling* is:

$$totprof = \sum_{i=1}^{n} (c_i - c_i') \tag{1}$$

Using (1) for the example of Figure 2, we can calculate a total profit of: $(5-5)+(17-15)+(14-7) = 9$, for the example of Figure 2. We note that c_i' is never greater than c_i, as shipments are grouped only in an effort to reduce mileage. However, as each supplier's contribution in the total profit is different, we propose in the following a model that allocates charges fairly. We also suggest that part of this profit should be utilized to cover the expenses of the *freight-pooling* service.

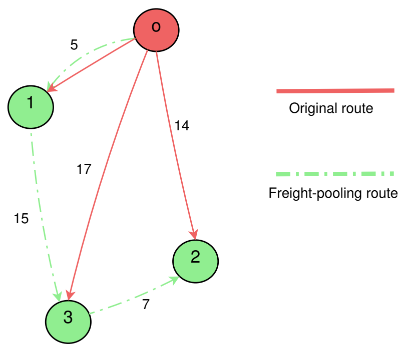

Fig. 2: An example of the distance-related costs involved in a freight-distribution network for the *last-mile* delivery. Through *freight-pooling* we manage to reduce the total cost of this example from 36 $(5 + 14 + 17)$ to 27 $(5 + 15 + 7)$.

B. Freight-pooling charges

In the case of suppliers hiring freights individually, the calculation of each supplier's charges is straight forward as each one deals directly with a carrier. However, in the case of *freight-pooling*, the presence of a fair charging policy is essential. In the example of Figure 2, we observe that the first segment of the *freight-pooling* route is identical with an original route and induces no profit, as opposed to the other two. However, to encourage all suppliers to get involved in *freight-pooling*, we must ensure that they all benefit from their participation. Therefore, to achieve fairness we consider that their charge for the new route should be determined using the original cost c_i for each delivery point. We define $charge_i$ for each supplier i to be:

$$charge_i = \sum_{j=1}^{n} c'_j * \frac{c_i}{\sum_{j=1}^{n} c_j} \quad (2)$$

Using (2) for the example of Figure 2, we end up with: $charge_1 = 3.75$, $charge_2 = 10.5$, and $charge_3 = 12.75$.

We also model the service fee, an extra charge for each supplier that serves the purpose of financing the *freight-pooling* service. *Freight-pooling* adds a delay to the delivery of each shipment. Packages that are ready to be delivered are held until other shipments associated with the same freight become available. In addition to this, the sequential delivery of the shipments further stalls the procedure. As this delay has an effect on the reputation of each supplier, the orchestration service must compensate those that are more harmed by limiting their service fee. Therefore, the latter should be inversely proportional to the delay. Moreover, the service fee must not surpass the *freight-pooling* profit of any of the suppliers, as this would make their participation harmful. To address these constraints we model the service fee $sfee_i$ for each supplier i according to the following:

$$sfee_i = min(p_i * totprof * \frac{1/d_i}{\sum_{j=1}^{n} 1/d_j}, \quad p'_i * (c_i - charge_i)), \quad (3)$$

where d_i is the time period from the moment shipment i was made available until the moment it was delivered, p_i is the maximum percentage of the total profit that should be given to the orchestration service, and p'_i is the maximum percentage of each supplier's profit that should be used as a service fee.

For the example of Figure 2, assuming $d_1 = 20$, $d_2 = 27$, $d_3 = 70, p_i = 20\%$, and $p'_i = 50\%$, we end up with: $sfee_1 = min(0.9, 0.625) = 0.625$, $sfee_2 = min(0.252, 2.125) = 0.252$, and $sfee_3 = min(0.648, 1.75) = 0.648$.

IV. Evaluation approach

We are currently developing the web interface of our application that will enable users to manage shipment details, and the *trustee* to apply constraints and request route calculations. We are also building interactive maps to provide visualizations of the network of delivery points, to assist the *trustee's* decision making. A co-operating web service will construct the distribution plan which will also be available through a visualization. To evaluate our approach we will use publicly available datasets of the CVRP that have been studied extensively, to compare with the current best-known results.

V. Conclusion

In this paper, an interactive *freight-pooling* service is proposed. We model the problem as a CVRP but introduce further constraints that enable a *trustee* to orchestrate freight transport for efficient and effective last mile delivery. Additionally, we suggest a fair pricing policy that encourages the participation of suppliers. Our work is at an early stage and we plan to proceed by finalizing the web interface of our application and evaluating our approach for route calculation. We are also interested in making further use of geolocation data to design vehicle routes in an online fashion.

Acknowledgment

This work has been partially supported by the EU H2020 *"GALENA"* grant with agreement n. 641515.

References

[1] "European Commission: Study on Urban Freight Transport," Tech. Rep., April 2012. [Online]. Available: http://ec.europa.eu/transport/themes/urban/studies/urban_en.htm

[2] "London Freight Plan," Tech. Rep., 2012. [Online]. Available: https://www.tfl.gov.uk/info-for/freight/planning/london-freight-plan

[3] E. Ferguson, "The rise and fall of the American carpool: 19701990," *Transportation*, vol. 24, no. 4, pp. 349–376, 1997.

[4] N. D. Chan and S. A. Shaheen, "Ridesharing in North America: Past, Present, and Future," *Transport Reviews*, vol. 32, no. 1, pp. 93–112, 2011.

[5] D. Pisinger and S. Ropke, "A General Heuristic for Vehicle Routing Problems," *Computers & Operations Research*, vol. 34, no. 8, pp. 2403 – 2435, 2007.

[6] G. B. Dantzig and J. H. Ramser, "The Truck Dispatching Problem," *Management Science*, vol. 6, pp. 80–91, 1959.

[7] M. L. Fisher and R. Jaikumar, "A Generalized Assignment Heuristic for Vehicle Routing," *Networks*, vol. 11, no. 2, pp. 109–124, 1981.

[8] L. R. Esau and K. C. Williams, "On Teleprocessing System Design: Part II A Method for Approximating the Optimal Network," *IBM Systems Journal*, vol. 5, no. 3, pp. 142–147, 1966.

[9] N. Christofides, "Worst-case Analysis of a New Heuristic for the Traveling Salesman Problem," Graduate School of Industrial Administration, Carnegie Mellon University, Technical Report, 1976.