Collaborative Vehicle Routing when Agents have Mixed Information Sharing Attitudes

Los, Johan; Schulte, Frederik; Spaan, Matthijs; Negenborn, Rudy

DOI
10.1016/j.trpro.2020.02.014

Publication date
2020

Document Version
Final published version

Published in
Transportation Research Procedia

Citation (APA)
Los, J., Schulte, F., Spaan, M., & Negenborn, R. (2020). Collaborative Vehicle Routing when Agents have Mixed Information Sharing Attitudes. *Transportation Research Procedia*, *44*, 94-101. https://doi.org/10.1016/j.trpro.2020.02.014

Available online at www.sciencedirect.com

ScienceDirect

Transportation Research Procedia 44 (2020) 94–101

Transportation Research Procedia

www.elsevier.com/locate/procedia

LOGI 2019 – Horizons of Autonomous Mobility in Europe

Collaborative Vehicle Routing when Agents have Mixed Information Sharing Attitudes

Johan Los[a,*], Frederik Schulte[a], Matthijs T. J. Spaan[b] and Rudy R. Negenborn[a]

[a]*Delft University of Technology, Department of Maritime and Transport Technology, Mekelweg 2, 2628CD, Delft, The Netherlands*
[b]*Delft University of Technology, Department of Software Technology, Van Mourik Broekmanweg 6, 2628XE, Delft, The Netherlands*

Abstract

The transportation market requires collaboration to improve efficiency and reduce emissions. Individual carriers, however, might be hesitant to share their private information on a transportation platform. Although a few articles have investigated the value of information sharing, they assume identical behaviour of all carriers. In practice, nonetheless, some carriers are open to share more information than others. We consider such a hybrid information sharing setting and investigate the value of information sharing dependent on what other carriers are willing to share. We propose a Multi-Agent System in which carriers and customers interact and vary carriers' willingness to share information about vehicle locations and marginal costs. The results show that sharing full route plans is always beneficial for individual carriers, independent of what position information other carriers share. However, to increase the total profit in scenarios with limited interaction, at least 50% of the carriers need to share full plans instead of only current positions. Furthermore, about 60% of the carriers need to be stimulated to share full cost information for solutions with maximal service level, although it might be unprofitable for themselves.

Keywords: Collaborative Vehicle Routing; Information Sharing; Heterogeneous Carriers; Platform-Based Transportation; Multi-Agent System.

1. Introduction

Cooperation in the transportation market is important for realizing efficient vehicle routes (Gansterer & Hartl, 2018) and has been studied within different contexts, from urban to synchromodal transportation (Verdonck et al., 2013; Cleophas et al., 2019; Li et al., 2017). The rise of the platform economy increases the need for cooperation: while customers had a long-term contract with a carrier in the past, they might now subscribe to one of the rapidly

* Corresponding author. Tel.: +31 (0)15 27 88249.
E-mail address: J.Los@tudelft.nl

10.1016/j.trpro.2020.02.014

growing transportation platforms (e.g., UberFreight, BlackBuck, and Quicargo) to find the cheapest contract for transportation. Hence, it is important for carriers to provide their services via the platform as well.

Carriers, however, might have different attitudes towards cooperation in reality. Although cooperation in larger coalitions may result in individual profit increases of up to 800% (Schulte et al., 2019), it requires the revelation of some private information, such as intended routes or marginal costs for individual requests (see Fig. 1). Not all carriers are equally prepared to share such confidential information due to competitive reasons. Larger companies, for example, might be more concerned with their confidentiality, while smaller firms could have larger collaboration advantages.

Earlier studies that investigated the value of sharing different types and amounts of information have shown that more information is in general beneficial, but that full information sharing is not always necessary (Los et al., 2019; Gansterer et al., 2019; Li et al., 2018). These studies, however, assumed that all carriers share the same types and amounts of information.

In this article, we consider a scenario in which agents have mixed information sharing attitudes: we investigate the influence of different information sharing policies by different carriers. We develop a Multi-Agent System (MAS) for solving a Dynamic Pickup and Delivery Problem (DPDP) by iterative auctions between order agents and vehicle agents. We vary 1) the ratio of carriers that share full route plan information and carriers that share only current vehicle positions, and 2) the ratio between carriers that share marginal costs through their bids and carriers that hide their marginal costs sometimes. While full plan sharing turns out to be profitable for individual carriers, cost sharing does not increase individual profits but contributes to the total solution quality.

2. Problem Description

We consider a platform that assists in connecting transport supply and demand in real-time. Hence, we build upon the DPDP with time windows and capacities. A problem instance consists of a set C of orders and a set K of vehicles, each representing one carrier. Each order $c \in C$ has a release time, a pickup location, a delivery location, a load quantity, and a price g_c that it pays if it is transported. Contrary to standard DPDPs, vehicles' availability is also dynamic, i.e., each vehicle has a release time and an availability time window, besides its start and end location and capacity. All locations have a service time window and a service duration, and for each pair of locations, travel time and travel costs are defined.

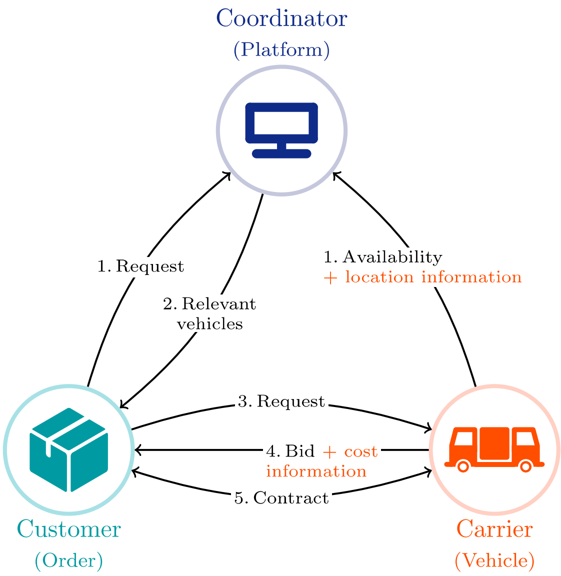

Fig. 1. Communication between customers, carriers and coordinator in the developed Multi-Agent System. Location information and cost information are variable.

A (temporary) solution for a problem instance is a set of routes, each consisting of a sequence of locations, representing the (partially completed, partially planned) path of a vehicle, subject to standard time, capacity and precedence constraints. Routes can change during operational time, since vehicles may deviate from their plans if new information becomes available.

We focus on two objectives, namely:

- maximizing the service level $SL = \frac{|C_S|}{|C|}$, where C_S is the set of orders that are served by a vehicle in the final solution, and;
- maximizing vehicle profits $PR^k = \sum_{c \in C_S^k} g_c - TC^k$, where C_S^k is the set of orders that are served by vehicle k and TC^k represents the travel costs for the final path of vehicle k.

While individual carriers might only focus on PR^k, customers, platform owners or authorities will focus more on service level and on the total system profits $PR = \sum_{k \in K} PR^k$.

3. Hybrid Information Sharing within a Multi-Agent System

To model carriers with different attitudes towards information sharing in one system, we develop a MAS for solving the DPDP in a distributed manner (see Fig. 1). Each order is represented by an order agent that tries to make a transportation contract with a vehicle agent, while each vehicle agent tries to make profit by accepting and serving orders efficiently.

We introduce two types of vehicle agents differing in their attitude towards sharing location information with the platform (see Fig. 2):

- **Full Plan Sharer (FPS)**: The vehicle agent shares its complete route plan with the platform when it connects to it, and provides complete updates if its plan changes.
- **Current Position Sharer (CPS)**: The vehicle agent shares only its position with the platform when it connects to it, and provides updates of its actual position upon request. No information regarding future plans is shared.

This location information becomes important when an order agent sends (at its release time) a request for transportation to a well-selected group of vehicles. While this request is sent to all available vehicles in other MAS approaches (Máhr et al., 2010; Gath, 2016), a lot of computational and communicational effort may be saved if only the most promising subset of vehicles is involved in the auction. Hence, the platform proposes as candidates the vehicles with least spatiotemporal distance to the pickup and delivery locations of the order. While future plans can be taken into account to compute this distance for FPSs, only current positions can be used for CPSs.

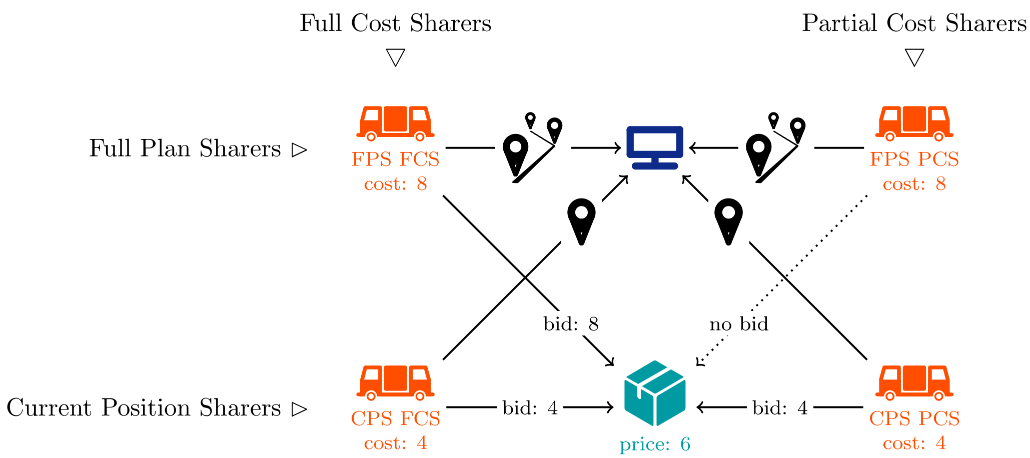

Fig. 2. Different types of carriers: Full Plan Sharers (top) share their full route plans with the platform, while Current Position Sharers (bottom) only provide their actual locations upon request; Full Cost Sharers (left) always share their marginal costs with a requesting order, while Partial Cost Sharers (right) only share their marginal costs if the order is profitable, i.e., the order price is higher than the marginal costs.

A vehicle agent receiving a request from an order agent computes the marginal travel cost for this order with respect to its current route plan, i.e., the minimum additional travel cost for including both the pickup and the delivery into its route, subject to time and capacity constraints. If serving the order is feasible, the vehicle agent responds to the order agent by placing a bid (or not), according to its attitude towards cost information sharing. Again, we analyze two types of agents (see Fig. 2):

- **Full Cost Sharer (FCS)**: The vehicle agent always shares the marginal cost, even if the payment it can obtain from the order (g_c) is lower than the marginal cost.
- **Partial Cost Sharer (PCS)**: The vehicle agent shares the marginal cost only if accepting the order is profitable, i.e., g_c is higher than the marginal cost. Otherwise, no bid is placed.

After the auction deadline, the order agent selects the bid with lowest marginal costs, and proposes to make a contract with the corresponding vehicle agent. If this is no longer feasible (due to the dynamics of the system), the vehicle agent of the second-best bid is chosen, and so on, until a contract is made or no bids remain. Iterative auction rounds are scheduled since more suitable vehicles can appear in the future.

4. Computational Study

For the computational experiments, we use the set of 10 DPDP instances of Los et al. (2019). Each instance consists of 1000 dynamic orders on an approximately 1000×1000 area, and 150 vehicles. Half of the vehicles is available during the complete time horizon of 10h, the other half has randomly selected release and availability times. Average order quantities of 20, average service durations of 2 min and average time window lengths of 2.5h are used. All vehicles have capacity 100. Travel times are equal to the Euclidean distance between locations, travel costs are 0.011 times this distance, and order prices are 0.014 times the distance between pickup and delivery location.

The MAS is implemented in Go and the experiments are performed on a 3.30 GHz Intel i5-4590 CPU with 8GB of RAM running Linux. All reported results are averages over 10 instances and 10 runs of the MAS per instance, with a maximum of 10 auctions per order agent. To be able to compare profits over different instances, we define the normalized total profit for a solution R by $PR(R)/PR(\text{BKS})$, where BKS is the best solution out of 10 runs of the MAS with only FCSs, 100% vehicle interaction, and a fast reauctioning time of 60s. Analogously, the normalized profit for a single vehicle $k \in K$ is given by $PR^k(R)/PR(\text{BKS})$.

First, we vary the position sharing policies of the vehicles. In Fig. 3, we compare results for an increasing share of the vehicle fleet consisting of FPSs. We let order agents interact with 10%, 40%, 70%, or 100% of the available vehicles, and marginal costs are always shared by the vehicles (i.e., all vehicle agents are FCSs).

Fig. 3a shows that the service level is almost always 1, i.e., hardly any orders are rejected, indifferent of the position sharing policy. In Fig. 3b, we observe that the normalized total profit is higher for higher vehicle interaction percentages (VIPs), and generally increases with increasing share of FPSs for lower VIPs (10% and 40%). However, a share of at least 50% of FPSs is then needed to obtain a higher total profit than a fleet consisting of only CPSs obtains. For higher VIPs (70% and 100%), there is no influence of position sharing policy. In Fig. 3c, we show the average normalized profit per vehicle, broken down to position sharing attitude. FPSs obtain higher average profits than CPSs, and this difference is larger for lower VIPs. The individual profits generally decrease a bit if more vehicles share full route plans.

Second, we vary the cost sharing policies of the vehicles. Fig. 4 shows the results for an increasing share of the vehicle fleet consisting of FCSs. Again, order agents interact with 10%, 40%, 70%, or 100% of the available vehicles, and route plans are always shared by the vehicles (i.e., all vehicle agents are FPSs).

Fig. 4a shows an increasing service level when a larger share of FCSs is present. Furthermore, there is a large gap between a VIP of 10% on the one hand, and a VIP of 40% or more on the other hand. This gap is visible as well for the normalized total profit in Fig. 4b. While the total profit increases with increasing share of FCSs from 0.4 on for a VIP of 10%, it does so from 0.1 on for higher VIPs. Fig. 4c shows the average normalized profit per vehicle, broken down to cost sharing attitude. The average profit for PCSs is in general higher than the average profit for FCSs, but this difference becomes smaller when the share of FCSs is larger and when higher VIPs are used. Average profits slightly increase for both FCSs and PCSs if the share of FCSs increases.

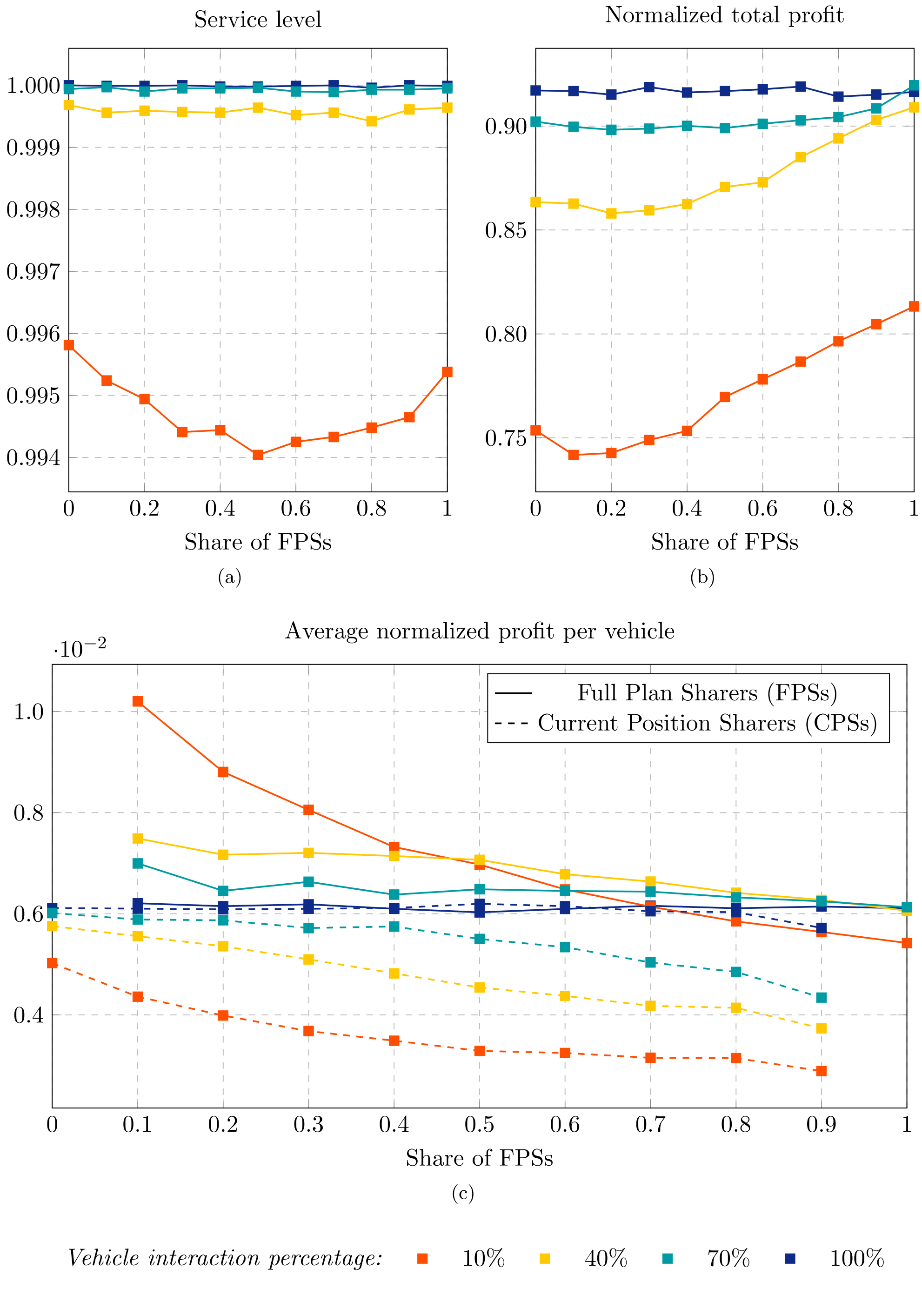

Fig. 3. Results for varying mixes of Full Plan Sharers (FPSs) and Current Position Sharers (CPSs).

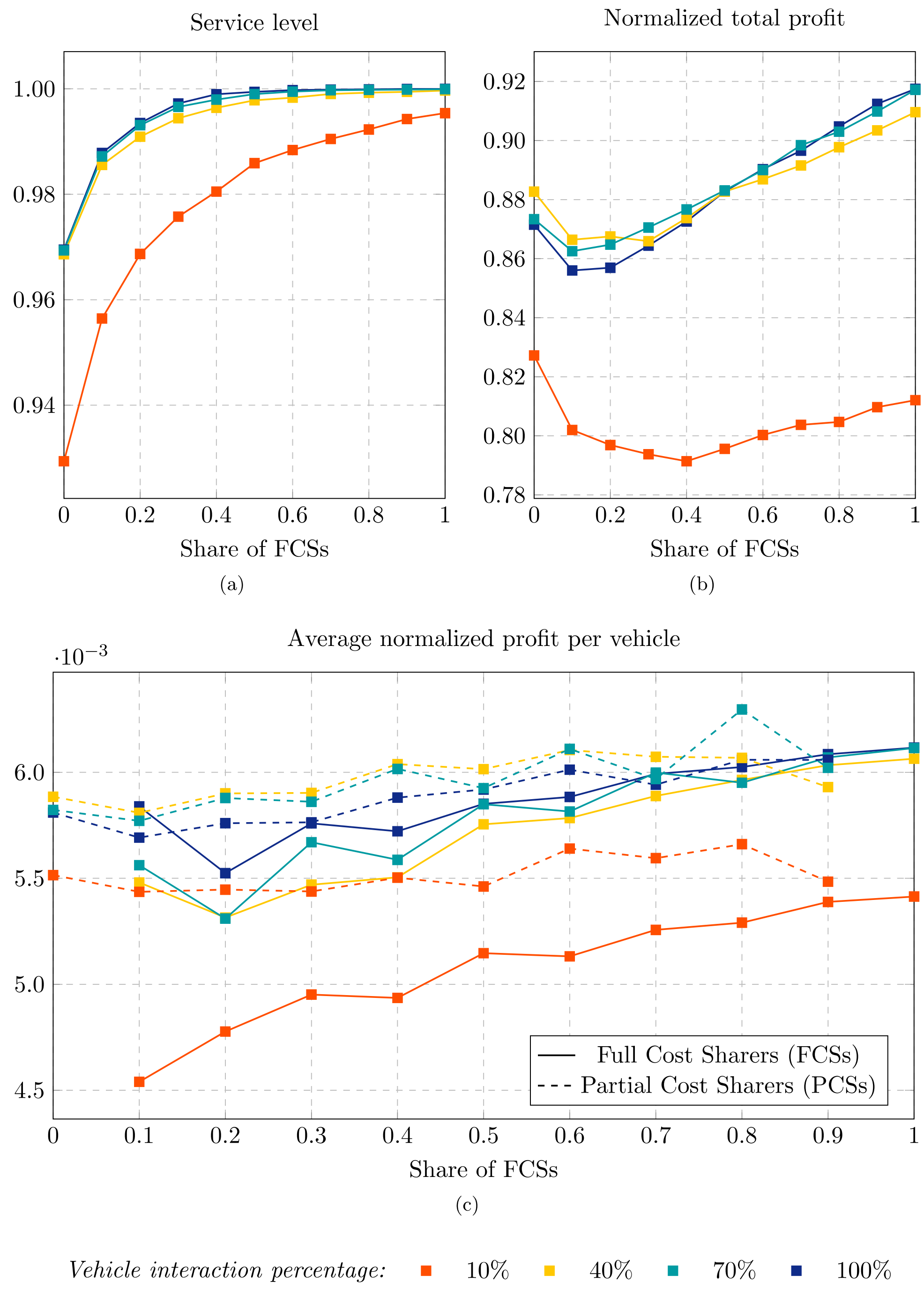

Fig. 4. Results for varying mixes of Full Cost Sharers (FCSs) and Partial Cost Sharers (PCSs).

5. Managerial Insights

Our comparison of different attitudes to information sharing yields the following insights for carriers and platform providers.

- **Sharing route plans is generally profitable from an individual perspective.** Platform providers may not be concerned with carriers' position sharing attitude, since the service level is not dependent on the position sharing policy. However, if only limited interaction is possible, platform providers may want at least 50% of the carriers to share their plans, since the total system profit (and related, the driven distance) is dependent on the position sharing policy. For carriers themselves, on the other hand, there is a strong monetary incentive to share full position information: individual profits can increase with up to 134% if future plan information is shared instead of only actual positions. In particular, if carriers know that the number of participants in auctions is limited, sharing full plans is beneficial.
- **Sharing route plans is profitable from a coalition perspective when interaction is limited.** With limited interaction, individual profits become lower if more carriers share their full plans. The global system profit, however, still increases, since the profits of plan sharing carriers are still higher than the profits of carriers sharing only their positions. Hence, although individual carriers benefit most from sharing route information if all competitors are hesitant to share it, it is better for the group if all plans are shared.
- **Platforms need to provide additional cost sharing incentives.** Cost sharing is highly important from the platform provider's point of view: the service level and the total profit generally increase if more carriers share their marginal costs. For individual carriers, however, always sharing costs is unprofitable: they might obtain a slightly higher profit if they hide their costs sometimes. Hence, introducing an additional incentive for cost sharing or a profit sharing mechanism by the platform is important.
- **Limited cost sharing is sufficient to achieve a high service level.** It is not necessary for a platform provider to motivate all carriers to share their costs. If about 60% of the fleet shares cost information and more than 40% of the fleet is involved in each auction, the service level is almost maximal. Hence, platform providers may want to motivate at least 60% of the carriers to share full cost information. Nonetheless, total profits increase if more carriers are willing to share full cost information.

6. Conclusions and Future Research

In this article, we investigated the value of information sharing for platform-based collaborative vehicle routing, taking into account that carriers have different attitudes. This realistic assumption has not been explored by the few articles that explicitly consider information sharing, let alone that the majority of research on collaboration in transportation even assumes full information sharing. We described a Multi-Agent System for solving a dynamic Pickup and Delivery Problem in which carriers could share either separate positions or complete route plans with the platform, and could share either full cost information with order agents or hide it sometimes.

Based on our computational study, we can conclude that the solution quality (in terms of route efficiency) improves if more carriers share full route information, while these have incentives based on individual profits to do so. Furthermore, the service level improves if the share of carriers that share cost information increases up to approximately 60%, but individual carriers have no intrinsic monetary incentive to share this information. Hence, platform providers should provide additional incentives to convince at least 60% of the carriers to share cost information.

In this work, we assumed that carriers are cooperative in the sense that they do not manipulate the system by strategic bidding. Future work will address the question how a system can be designed such that carriers are individually motivated to share relevant information without being able to benefit disproportionately at the expense of the system efficiency.

Acknowledgements

This research is supported by the project "Dynamic Fleet Management (P14-18 – project 3)" (project 14894) of the Netherlands Organization for Scientific Research (NWO), domain Applied and Engineering Sciences (TTW).

References

Cleophas, C., Cottrill, C., Ehmke, J.F., Tierney, K., 2019. Collaborative urban transportation: Recent advances in theory and practice. European Journal of Operational Research 273, 801–816.

Gansterer, M., Hartl, R.F., 2018. Collaborative vehicle routing: A survey. European Journal of Operational Research 268, 1–12.

Gansterer, M., Hartl, R.F., Savelsbergh, M., 2019. The value of information in auction-based carrier collaborations. International Journal of Production Economics. DOI: 10.1016/j.ijpe.2019.09.006.

Gath, M., 2016. Optimizing Transport Logistics Processes with Multiagent Planning and Control. Wiesbaden: Springer.

Li, L., Negenborn, R.R., De Schutter, B., 2017. Distributed model predictive control for cooperative synchromodal freight transport. Transportation Research Part E 105, 240–260.

Li, S., Negenborn, R.R., Liu, J., 2018. Stimulating inland waterway transport between seaports and the hinterland from a coordination perspective. In International Conference on Computational Logistics, October 1-3, 2018, 67–85. Cham: Springer.

Los, J., Spaan, M.T.J., Schulte, F., Negenborn, R.R., 2019. The value of information sharing for platform-based collaborative vehicle routing. Technical report, Delft University of Technology.

Máhr, T., Srour, J., de Weerdt, M., Zuidwijk, R., 2010. Can agents measure up? A comparative study of an agent-based and on-line optimization approach for a drayage problem with uncertainty. Transportation Research Part C 18, 99–119.

Schulte, F., Lalla-Ruiz, E., Schwarze, S., González-Ramírez, R.G., Voß, S., 2019. Scalable core and Shapley value allocation methods for collaborative transportation. Technical report, University of Hamburg.

Verdonck, L., Caris, A., Ramaekers, K., Janssens, G.K., 2013. Collaborative logistics from the perspective of road transportation companies. Transport Reviews 33, 700–719.