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Reducing port-related empty truck emissions: A mathematical approach for truck appointments with collaboration

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A B S T R A C T

Port-related emissions are a growing problem for urban areas often located directly next to maritime container terminals highly frequented by container trucks. Empty truck trips, caused by a lack of coordination among truckers, are responsible for a significant share of these emissions, and collaboration among truckers is seen as the major opportunity to address this issue. Truck appointment systems (TASs) schedule truck activities and enable collaboration for transportation between terminals and client locations. The aim of this work is to introduce a collaborative planning model to be operated within a TAS and to investigate its impact on emission and cost objectives. Starting with a review of requirements for a TAS with collaboration, an optimization model based on the multiple traveling salesman problem with time windows is developed, leveraging collaboration to reduce costs and emissions. The results for a real-world case demonstrate that the developed approach provides appropriately coordinated truck schedules and effectively reduces truck emissions and costs.

1. Introduction

Urban port areas increasingly struggle with port-related emissions–mainly caused by trucks moving full and empty containers between ports and the hinterland. At many ports empty container truck trips are a major cause for those emissions (Englert et al., 2011; Islam et al., 2013; Islam and Olsen, 2014). These trips relate to the non-utilization of available slot capacities (i.e., the number of empty or laden containers a truck can carry) of trucks in import- and export-related trips (Islam et al., 2013). Moreover, international trade imbalances aggravate the problem. Shipping companies based at import-dominated ports accumulate large amounts of empty containers, while those at export-dominated ports are in need of containers for export, requiring additional empty container transportation on the sea- and land-side. Fig. 1 illustrates the occurrence of empty truck movements on different routes. Both, not fully utilized slot capacity and empty repositioning trips, increase the number of total trips in a port region and thus cause avoidable emissions. As demonstrated in the figure, empty trips can be avoided if services are combined. This motivates collaboration among truckers in order to coordinate container activities.

Although the scheduling of truck activities within truck appointment systems (TASs) has been studied (Giuliano and O'Brien, 2007; Zehendner and Feillet, 2014), sharing of empty truck capacities has hardly been considered. Furthermore,

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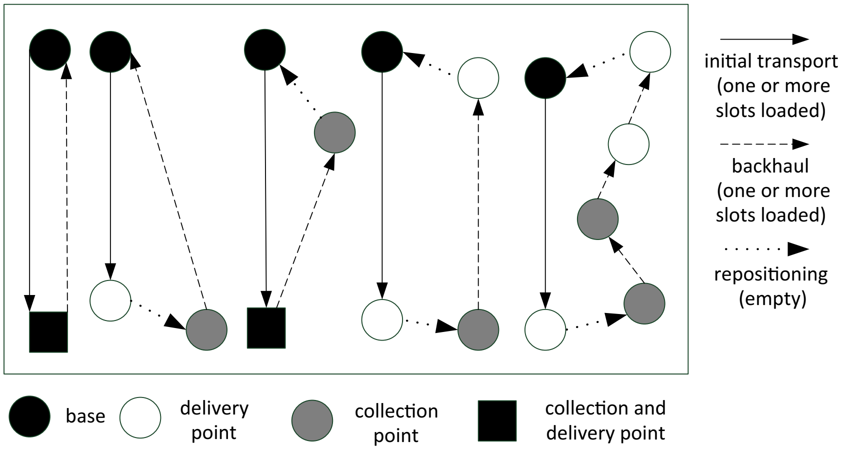

Fig. 1. Basic empty and loaded container truck movements (as defined in McKinnon and Ge, 2006).

there are mathematical formulations that model related problems from a single trucker perspective (Zhang et al., 2009; Agarwal et al., 2009). Nevertheless, participants of a collaborating group of truckers may not accept the collaboration agreement if their rational decisions are not considered appropriately. Game theoretic allocation mechanisms have been proposed to address this issue, but these approaches often require significant simplifications to provide feasible solutions for related problems (Özener and Ergun, 2008). Simulation approaches are another option to evaluate collaboration based on TASs (Islam and Olsen, 2014); however, they do not explicitly provide optimization with respect to emissions and costs.

In this work, we aim to introduce and evaluate an optimization approach that leverages collaboration options to reduce emissions and costs within a collaborative TAS. Thus, we seek to evaluate the impact of a group of truckers deciding to collaborate based on a TAS, instead of conventionally optimizing their individual operations. We develop a graph-based mathematical model, optimizing collaboration within a TAS. The solution approach considers CO_2 emission reduction and cost objectives for a collaborating group of truckers. Additionally, we include soft time windows in two cases (with and without collaboration) in order to consider late arrivals and their impact on the earnings of truckers. The experimental results, using the developed model and instances based on real-world data, demonstrate that the model effectively enables a collaborative TAS to reduce port-related truck emissions and leaves a community of truckers and individuals significantly better off in terms of emissions and costs. This article is structured as follows. Section 2 reviews the relevant literature with respect to collaboration approaches in transport, truck scheduling and TASs as well as emission-related port logistics. Section 3 introduces requirements for a collaborative TAS and a graph-based mathematical model, complemented by numerical experiments in Section 4. Finally, Section 5 concludes the study and gives an outlook on future research.

2. Literature review

There is a limited amount of specific literature available on TASs focusing on collaboration or emission reduction. Subsequently, we review collaboration approaches in transport (Section 2.1) and truck scheduling problems as well as TAS literature (Section 2.2).

2.1. Collaboration in road transport

Road transport allows various forms of collaboration. Agarwal et al. (2009) have examined different problems with collaboration in the industry, including collaboration set-ups with freight bundling and break-bulk terminals, the formation of alliances to reduce load imbalances, and approaches of carriers to jointly reduce the cost of asset repositioning. From the perspective of a single trucker, the considered problems could be modeled mathematically and the resulting linear programming models could be solved with reasonable computational effort. In cases of collaboration, game theoretic approaches have been proposed, but often need to be relaxed significantly for application to real-world problems (Özener and Ergun, 2008). Lozano et al. (2013) have developed a game theoretic approach for a related problem and have conducted extensive numerical experiments, comparing different solution concepts of cooperative game theory. The authors have demonstrated how to encourage coalitions to collaborate using game theoretic allocations, but also have emphasized that further practical requirements would need to be incorporated for entirely realistic modeling. Guajardo and Rönnqvist (2016) have reviewed allocation approaches for costs and profits resulting from collaborative transportation. The authors have considered a wide scope of methods, from proportional rules to approaches based on cooperative game theory. They have stressed that, though often well accepted among practitioners, proportional allocation methods usually show a weak performance and more sophisticated allocation approaches are needed to establish profitable and sustainable collaboration.

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