Optimising Container Transports in Collaborative Roundtrip Scenarios

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Abstract: *Within this paper, we discuss the importance of combinatorial optimisation problems arising in the context of the Physical Internet. We focus on one specific problem originating in one of the four demonstration pilots of the Austrian PhysICAL project which develops and demonstrates four best practice examples to path the way to the Physical Internet. It will be shown that the Collaborative Roundtrip Problem is similar to the well-known machine scheduling problem. Conclusions are drawn with respect to the computation solution approach as well as the importance with respect to the implementation of the Physical Internet.*

Conference Topic(s): *From Logistics Networks to Physical Internet Network; Interconnected freight transport, logistics and supply networks.*

Keywords: *Freight Transportation Planning; Horizontal Collaboration; Optimisation*

1 Introduction

In 2020, the Austrian model project PhysICAL (Physical Internet through Cooperative Austrian Logistics) has been started (PhysICAL, 2021). The main goal of the project is to showcase Physical Internet (PI) applications such that best practices examples are generated, and other companies and practitioners start to actively follow the PI idea. Hurdles and reservations shall be reduced by implementing four PI demonstration pilots. Ecological and economical assessment shall show the benefits on an individual (company) and general (societal) level.

The four PI demonstration pilots pursued within the PhysICAL project are:

- **Wood Logistics**: In Austria, the harvesting of wood is one significant economic branch as up to 40% of Austria’s land is covered by woods (Statistik Austria, 2010). However, the transport of the harvested wood from forest to consumers is mostly done via trucks. While for the first-mile this is obvious (in most cases no other mode of transport is available in forests), the long-distance transports could be shifted towards rail (or even inland waterways). However, transhipment of wood from trucks to trains is rather cost-extensive as no intermodal transport unit is (currently) available. The goal is therefore to develop an appropriate hardware container which is capable of intermodal transports. In addition, digital service shall be provided to ease the ordering and implementation of these intermodal wood transports.
- **Intermodal Transport Platform**: The main goal of the intermodal transport platform is to provide a digital solution for ordering, processing and following intermodal transports. The idea is that the platform operates like a one-stop-shop where the shipper can order the whole supply chain like searching Google and clicking on the best result. That is, after specifying when to transport from where to where a list of feasible transport chains is presented. The shipper then only needs to click on the chosen one (e.g., the cheapest) which is then booked and (later) processed. All necessary intermediate steps (e.g., transhipments, coordination among the individual legs of the transport, etc.) are organised by the platform via direct (digital) links to the operators. In addition, the shipper can follow (in real-time) the processing of the transports. This platform is developed to be open to all participants following the given rules.

- **Supply Chain 3.0**: The main idea is to install a wholesale logistics supply chain for e-commerce. Currently, producers are either directly selling to end customers via their own online shops or via e-commerce platforms like Amazon or Alibaba. They have, however, to handle all logistics on their own. Even when selling on (large) online platforms, at least logistics up to the warehouses of the online platforms have to be organized by the producers themselves. In most cases, this is not the core competence of the producers and unnecessarily binds resources. Therefore, the idea is to install a wholesale logistics supply chain where the wholesaler takes over all (digital and physical) processes necessary starting at the loading ramp of the producer. This involves all physical transports but also digital registration of the products at platforms (including all eventually necessary accreditation processes). Obviously, this allows for horizontal collaboration as logistics processes (and therefore also transportation) is organized by one company. Furthermore, intermediate storages are shared among each other as well.
- **The New CEP Last-Mile**: In Courier, Express and Parcel (CEP) logistics the last-mile is known to be the most cost-extensive part of the transport chain with up to 53% share of the total costs (Honeywell, 2016). In addition, it is discussed that negative traffic-oriented impacts are existent (Accenture, 2021). Therefore, several projects exist focusing on collaborative white-label logistics for the CEP last-mile. However, we experienced in many discussions with CEP service providers that the white-label delivery is not desired as some questions are still open. Among others, transition of liability among CEP service providers is not yet fully regulated. Therefore, the main idea of this demonstration pilot is to come up with hardware and logistics process innovations enabling collaborative CEP last-mile services.

The whole concept is rounded up with the introduction of a Digital Twin (DT) of the (Austrian) transport system. Although the main focus is laid on a replication of those parts that are relevant for the four PI demonstration pilots. The main intention of the PhysICAL DT is on the one hand to objectively show the impacts of the collaborative logistics. On the other hand, the DT provides a decision support tool for decision makers (e.g., shippers) as they can easily see the impacts induced by their decisions. In addition, the DT presents historic data to decision makers. It is therefore easier for them to assess past decisions and their implication on the transports.

Within this paper, we focus, however, on just one specific optimisation problem arising in the context of the intermodal transport platform. As transport demand is automatically matched to possible transport offers (which are envisaged to be also booked automatically in the future), horizontal collaboration is fostered since decision makers are not aware of other goods to be transported on the same truck/train/vessel. That is possible as the platform itself is neutral (i.e., not operated by any company involved in the transport sector other than providing an open booking platform). Therefore, decision makers can decide on the (for them) best transport option without any resentments against other competitors.

The remainder of the paper is organised as follows: First, we give an introduction into the actual collaborative roundtrip optimisation problem. Then, we outline possible parallels with other well-known combinatorial optimisation problems and discuss possible solution approaches. Finally, we conclude on the importance of research in this sector for a successful implementation of the PI vision.

2 The Collaborative Roundtrip Problem

The problem as arising in our intermodal transport platform PI demonstration pilot is as follows: Assume a container train connection between two major cities, e.g., Hamburg, Germany, and Vienna, Austria. Further assume that this train connection is operated for economic reasons like a block train, i.e., no waggons are un/coupled at intermediate stops, cf. (Jänsch, 2016). The obvious advantage of this approach is that ordering a block train is in most cases cheaper (on average per container) than ordering individual container transportation (VCÖ, 2020). That is, in general, the train is ordered by a freight forwarder. Shippers are ordering individual container slots from the freight forwarder. Therewith the prices for shippers can be reduced (compared to direct ordering at the carrier).

Now, further assume that along the trip from Hamburg to Vienna an intermediate stop is scheduled at Enns, Austria. Although the train is operated like as block train for the carrier, un/loading of containers at the intermediate stop are possible. That means, however, that even though the train might be fully loaded with 40 40-feet containers when leaving Hamburg only a part of them might be scheduled for Vienna while the other part is unloaded in Enns. In an optimal scenario, additional containers have to be transported from Enns to Vienna such that the then empty waggons can be used for these additional containers. Of course, additional containers might have to be transported from Enns to Hamburg, others from Vienna to Enns and even further ones from Vienna to Hamburg. In an even more complex scenario, one can imagine that there more than three cities along the roundtrip.

In a more general setting, we define the (basic) collaborative roundtrip problem (BCRP) as follows. We are given:

- a roundtrip for a train with n stops in cities $(c^1, c^2, \ldots, c^n, c^{n+1} = c^1)$;
- a train schedule for this roundtrip, i.e., actual departure times for each of the n cities;
- a capacity, i.e., number of containers, for each scheduled train;
- travel times between city c^i and c^{i+1};
- transport demands, i.e., a set of containers, from city c^i to c^j;
- for each container, an earliest departure date and a latest arrival time, specifying when the container is earliest available at its departure city and has to arrive latest at its destination city;
- with each container costs for lifting and transporting are associated;
- each container has a weight.

The goal is now to find a transport schedule such that each container arrives before its latest arrival time at its destination city. In addition, the number of needed roundtrips shall be minimised, i.e., the latest arriving container should arrive as early as possible. As a second, subordinated optimisation goal the number of container lifts should be minimised. Furthermore, the (total) costs should be minimised.

Figure 1: Example of a simple roundtrip A-B-C-A with three cities.

An extended version of this BCRP is the what we call subtour collaborative roundtrip problem (SCRP). For the SCRP, at least on pair of cities c^i and c^j exists, with $i \neq j$; $i, j \neq 1$; $i, j \neq n$, such that $c^i = c^j$. For example, a roundtrip of type A-B-C-B-A, cf. Fig. 1.

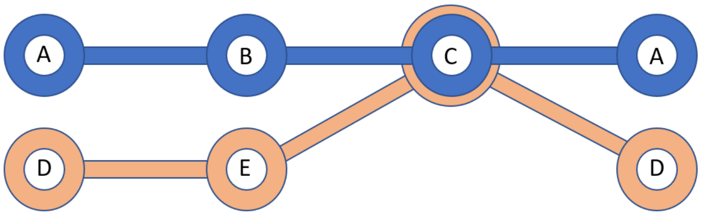

Figure 2: Example of a two overlapping roundtrip A-B-C-A and D-E-C-D.

A further extended version of the BCRP (and SCRP) is when multiple roundtrips exists with at least one common city. For example, roundtrip 1: A-B-C-A and roundtrip 2: D-E-C-D, cf. Fig. 2. Container transport from all cities to all other cities might occur such that transhipment from one roundtrip to another roundtrip at the common cities have to take place. We refer to this variation as multiple collaborative roundtrip problem (MCRP).

So far, we have no theoretical results on the computational complexity of these problems. However, some similarities with well-known combinatorial optimisation problems can be identified. We will discuss in more detail in the next section together with possible (algorithmic) solution approaches.

3 Computationally Solving the Collaborative Roundtrip Problem

3.1 Similarities with Well-Known Combinatorial Optimisation Problems

Rather obvious is a close relation to classical scheduling problems. Especially machine scheduling (Lenstra et al., 1977). The main goal of machine scheduling problems is to schedule a given set of jobs on a given set of machines. The goal is to find a schedule such that the make span, i.e., the finishing time of the latest job, is as early as possible. When considering now that containers are jobs and waggons are machines, the similarities are obvious. However, due to the site constraints, it is not so easy to directly link these two problems with each other. As extensively illustrated in (Lenstra et al., 1977), there are different version of machine scheduling which are computationally easy, i.e., are member of the class P of deterministic polynomial solvable problems. Other variants are, however, member of NP, i.e., there are no deterministic polynomial time solution approaches (unless $P = NP$).

As machine scheduling is closely related to knapsack problems (Lenstra et al., 1977) the similarities of the collaborative roundtrip problems to them is obvious.

3.2 Algorithmic Solution Approaches

Based on the observations in the previous subsection, i.e., the similarities with machine scheduling, it is obvious that (successful) computational approaches for machine scheduling should be followed. Therefore, we will examine them in more detail. Especially the basic variant of the CRP – or at least instances with, e.g., limited number of cities, are very likely to be polynomial solvable. Therefore, solution approaches based on integer linear programming (Nemhauser and Wolsey, 1999) or on dynamic programming are promising (Bellman, 1954).

However, for those variants which cannot be tackled via exact algorithms, local search-based approaches seem to be promising as local search operators can be naturally defined for this problem. Therefore, we propose to use metaheuristic approaches like variable neighbourhood search (VNS) and variable neighbourhood descent (VND), cf. (Mladenović, and Hansen, 1997). Operators which can be used for (efficiently) defining a (large) set of the necessary neighbourhoods will be based on swapping (exchanging container-to-waggons-assignments) and shifting (circular exchanging multiple container-to-waggons-assignments) operations.

4 Conclusions

Within this paper, we formulated the collaborative roundtrip problem (CRP) and variants of it. It arises in scenarios where containers need to be transported from one city (hub) to another one on an individual level, the carrying train, however, is operated on a roundtrip. The goal is to best possible utilise the train, i.e., to minimise the number of empty waggons such that the number of totally needed roundtrips/trains can be minimised. Due to its similarities to machine scheduling, it might be assumed that some variants of these problems can be time-efficiently solved via exact algorithmic approaches like inter linear programming or dynamic programming. However, more complex variants, e.g., those involving multiple roundtrips, are most likely too complex such that only (meta-)heuristic approaches can be meaningfully be applied as for larger real-world sized problem instances exact approaches will not come to an end.

The herein formulated CRP is not new as this problem already arises for (rail) carriers and/or freight forwarders on a daily basis. However, to the current status quo, the scheduling of containers on the train is on the one hand not very flexible and on the other hand only basically optimised. That is, a first-come, first-serve strategy is mainly applied when booking containers slots.

We, however, suggest that based on the complexity which can be easily handled via a (automated) digital transport mediation and booking platform efficiency of transportation can be increased. This increase in efficiency will, obviously, result in reduced transportation costs. At the same time the emitted CO_2e can be reduced as the increase in efficiency is mainly related to a higher utilisation rate of trains. Furthermore, the attractiveness of trains over trucks is increased and further shift towards trains can be expected. Finally, and not to neglect, is the positive impact on the society as a whole. Due to a modal shift towards train, it can be expected that negative by-products of (long-haul) road transports like decreased air quality and therefore deaths (WHO, 2021) are reduced.

We want to furthermore highlight that intermodal transport booking platforms ease the process of intermodal booking through their one-stop-shop mentality. Therefore, the hurdles of booking intermodal transports are significantly reduced. E.g., for a standard intermodal transport of first-mile, long-haul, last-mile only one instead of five bookings (first-mile, transhipment, long-haul, transhipment, last-mile) are necessary. Even though already nowadays the booking of intermodal transports could be outsourced to freight forwarders, there is still a person at the freight forwarder who has to organise all of the five bookings. That is, making intermodal as easy as unimodal transport one can expect a major impact.

In addition, it is essential that the booking platform is neutral. That is, that it is not operated, financed, or owned by one (or more) companies having a major interest in the transport sector. E.g., if a large freight forwarded or shipping company would operate such a platform it is most likely that other players on the market would not provide their transport capacities on this platform. This is since then the platform operator would have access to additional (and sensitive) data about capacities and transport operations of competitors.

The major goal of such a transport platform must be, however, that the booking processes are fully automated. That is, that it is not necessary for humans to interact with the platform on a daily basis. As soon as this fully automated booking process could be realised it will become easy to step forward from intermodality towards synchromodality. That is, since as soon as an interruption occurs on one of the booked transports the platform can automatically decide whether another transport option leads to better (e.g., more reliable) results. Furthermore, the platform can objectively decide whether a shift is beneficial for the system (and not only for the individual transport). It is therefore possible to optimise towards a system optimum (compared to a user equilibrium which is known to be inferior from a societal perspective), cf. (Wardrop, 1952).

However, in order to be able to automate the booking processes, it is essential that the needed computations in the background can be performed efficient (and fast). Therefore, it is crucial to investigate the underlying optimisation problems in more detail and to come up with fast, yet good solutions. We therefore suggest to further investigate the CRP (and other optimisation problems) arising in the context of the PI.

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