PORT-IO: A MOBILE CLOUD PLATFORM SUPPORTING CONTEXT-AWARE INTER-TERMINAL TRUCK ROUTING

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PORT-IO: A MOBILE CLOUD PLATFORM SUPPORTING CONTEXT-AWARE INTER-TERMINAL TRUCK ROUTING

Research in Progress

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Abstract

The role of ports goes far beyond the traditional function of a pure transport node linking sea and landside transportation. Rather, many ports offer value-added logistics and auxiliary services leading to a network of container flows. Moreover, containers may need to be transferred between different areas within the port. Information exchange and optimization is necessary to efficiently coordinate actors and container movements involved in respective inter-terminal transports in order to avoid empty trips and thus high costs, emissions, and additional traffic volume. In this paper, we describe a novel optimization problem for addressing inter-terminal truck routing in ports and propose two greedy heuristics and a hybrid simulated annealing algorithm. The computational results are evaluated in terms of costs, empty trips, and utilized number of trucks and they indicate that the proposed hybrid simulated annealing algorithm is able to report feasible and improved routes within seconds. The optimization component is embedded into a cloud platform integrating truck drivers based on a mobile application. Beyond common functionalities, the proposed platform enables a flexible real-time assignment of truck drivers to container movements by considering the current position of trucks with the objective to better manage and coordinate inter-terminal transports. As such, our approach contributes not only with a valuable approach for vehicle planning in ports, but also presents an accessible, scalable, and multi-tenant system prototype of a mobile cloud platform for handling the interactions with truck drivers in practice, demonstrated with an example for the Port of Hamburg, Germany.

Keywords: Inter-terminal transport, truck routing, hybrid simulated annealing, cloud computing, mobile application.
1 Introduction

Due to growing transport volumes and infrastructure constraints, many ports face traffic problems leading to a lower efficiency, significant costs, and higher vehicle emissions (see, e.g., Giuliani and O’Brien, 2007). Especially in metropolitan areas, the additional truck traffic generated at ports and related logistics centers highly impacts other road users and surrounding neighborhoods. A considerable proportion of port-related traffic is produced by inter-terminal transportation (ITT). ITT refers to any kind of land and sea transportation moving containers and cargo between organizationally separated areas within a port (Heilig and Voß, 2016; Tierney et al., 2014). This includes the transport of containers between container terminals, empty container depots and repair stations, value-added logistics facilities (e.g., warehouses, container freight stations), dedicated transport terminals (e.g., barge and rail terminals, dry ports), and shipping procedure facilities (e.g., for container screening, customs clearance). Whereas the main goal of efficient ITT systems is a punctual delivery of containers, for example, to minimize the outgoing vessels’ time in port, it becomes increasingly important to consider the economic and environmental impact of ITT.

Recent research activities focus on the evaluation of different types of ITT vehicles and vehicle fleet configurations for minimizing delivery delays proposing integer programming (Tierney et al., 2014; Nieuwkoop et al., 2014) and simulation (Duinkerken et al., 2006; Schroer et al., 2014) approaches (for an extensive overview, the reader is referred to Heilig and Voß, 2016). However, empty vehicle trips, generating unproductive vehicle emissions and traffic load, are not considered by these studies. Evers (2006) firstly mentions the importance of information systems that gather (near) real-time information to better coordinate ITT-related vehicle movements. The author suggests establishing a third-party ITT provider that maintains a fleet of vehicles to handle and coordinate ITT demands of different organizations within a port and emphasizes the importance of developing an information system to interact with those organizations. He et al. (2013) further investigate the sharing of vehicles between container terminals to reduce vehicle capacity bottlenecks. Note that extra vehicle capacity may also be offered by external truck companies that are temporarily available in the port. Besides regarding available vehicle capacities and transport costs, opening hours of facilities and required delivery times of containers need to be considered. The transport of containers, consisting of a paired container pickup at an origin location and a container delivery at a destination location, can be seen as a Pickup and Delivery Problem (see Parragh et al., 2008) with additional constraints devoted to represent ITT, such as the time-windows of locations, the due dates of transport orders, and the maximum availability time imposed by the trucks devoted to perform the deliveries. Moreover, in the related literature, the movement of containers between trucks and customers’ locations can also be referred to as container drayage (see, e.g., Macharis and Bontekoning, 2004). Related optimization problems, such as the ones proposed by Zhang et al. (2011) and Braeckers et al. (2013), aim to solve the container drayage problem by either reducing the service times, the total distance, or the number of vehicles. In this paper, we address the container drayage problem within an ITT scenario that aims to assign and route owned and non-owned trucks pursuing to reduce costs and contemplating context information by considering initial truck positions.

Apart from this, an effective coordination requires a common information sharing platform as well as efficient mechanisms to plan and coordinate ITT movements and involved actors. Information systems for supporting the interaction between a third-party ITT provider and a fleet of owned and temporarily hired vehicles were considered to be essential in the literature, but, to the best of our knowledge, have not been implemented so far. In this context, given the current knowledge basis, we identify a lack of integrative approaches focusing on both information exchange and decision support. Integrative approaches aid the planning and management of ITT by tackling empty trips, vehicle unproductivity, emissions, and traffic load. The need for this type of platform has further become apparent in recent projects, such as in the Maasvlakte area of the Port of Rotterdam (see, e.g., Heilig and Voß, 2014).
In this paper, we present a novel approach to address the inter-terminal truck routing problem (ITTRP) by considering specific requirements and constraints of ITT. For solving this problem, we propose two greedy heuristics and a hybrid simulated annealing approach allowing to provide feasible schedules within short computational times. This performance characteristic is an important requisite in the context of a real-time application as the one proposed in this work. Moreover, following the design science research paradigm (Peffers et al., 2007), we include the solution approaches in an optimization component artifact and propose a prototype artifact in the form of a cloud-based information system for managing and planning ITT in ports as well as a mobile application for supporting the interaction with truck drivers. Thus, the three main design objectives of the artifacts are to achieve a (1) more efficient resource usage by proposing a planning method for collaborative ITT operations, (2) to increase the flexibility by allowing real-time planning and information exchange, and (3) to design an accessible, scalable, and extensible mobile cloud platform used to purposefully integrate port actors and to process various sources of information. More specifically, the proposed vehicle planning mechanism considers the current positions of trucks and thus enables a context-aware ITT planning. Thus, it facilitates an on-going re-planning of container movements based on current data (e.g., transport requests) and real-time vehicle positions. For evaluating the performance of the proposed algorithm, we conduct computational experiments based on an example in the Port of Hamburg. Our approach further represents an important milestone towards the development of information sharing platforms gathering real-time information through mobile devices and sensor technologies. Note that the integration of mechanisms for securing information access as well as aspects of organizational governance in such collaborative platform is left to future research. The data collection and scalability features of the proposed cloud platform build a profound and robust foundation for applying big data analytics in order to further explore coherencies between port-related traffic and external factors (e.g., traffic situation, weather) as well as to improve forecasting of travel and service times.

The paper is structured as follows. Section 2 formally explains the proposed ITTRP. After describing the proposed greedy heuristics and hybrid simulated annealing approach, we present the results of the computational experiments conducted for evaluating their performance. In Section 3, we present the implemented mobile cloud platform prototype. This includes a brief explanation of the main components embedding the proposed hybrid simulated annealing approach. An example is given using real-world data from the Port of Hamburg in order to demonstrate the functionality of the prototype. Finally, we draw conclusions from our results and identify activities for further research.

2 Inter-Terminal Truck Routing Problem

The ITTRP aims to address the problem of a third-party ITT provider that connects transport orders for moving containers between facilities (e.g., container terminals, empty container depots and repair stations, value-added logistics) within a port. The ITT provider may maintain an owned fleet of vehicles and can hire external truck drivers that offer their capacity temporarily. Consequently, we have a set of $n$ locations, $L$, a set of $t$ trucks, $T$, and a set of $m$ customers, $C$, where each customer $c \in C$ has a set of requesting orders $R^c = \{j^c_1, j^c_2, ..., j^c_{|R^c|}\}$. Moreover, each order $j^c_i$, $c \in C$, $i \in R^c$ has a given origin location $o(j^c_i) \in L$ and destination location $d(j^c_i) \in L$. Each order involves a service time at each location, namely, $s_{o(j^c_i)}$ and $s_{d(j^c_i)}$. Additionally, each transport order has to be completed before a given due date $du(j^c_i)$. The latter is important to avoid delays of subsequent activities, which may have a negative impact on the performance of the whole supply chain. On the other hand, each truck $t \in T$ has an initial position, $pos_t$, a maximum number of working hours, $max_t$, a prefixed cost for using it, $cost_t$, and variable costs per hour, $hour_t$. A truck driver of an external company, for example, may charge a higher initial price for using the truck’s capacity. Finally, each location $l \in L$ has a working time window $[a_i, b_i]$ for the arrival of trucks. Whereas container terminals often work 24/7, other facilities (such as empty depots, value-added logistics) have limited working hours. Since for each pair order-truck the company receives a fixed revenue, the objective of this problem, from the
point of view of the ITT provider, is to reduce the costs related to the use of trucks. The objective of this problem, therefore, can be illustrated with the following objective function

\[ \text{Minimize } \sum_{t \in T} y_t \cdot \text{cost}_t + \sum_{t \in T} \text{time}_t \cdot \text{hour}_t \]  

(1)

where \( y_t \) is equal to 1 if the services of the truck \( t \) are hired, 0 otherwise. The service time required by a truck \( t \) to perform all its assigned transport orders is denoted as \( \text{time}_t \). A solution for the ITTRP has to satisfy some feasibility restrictions:

- The trucks have to arrive at the origin and destination location imposed by each order within their given time windows. They can arrive in advance, but in that case they will have to wait until the opening time allows them to perform the pickup or delivery.

- Since we consider that trucks may be in various locations at the time of planning, each route starts and ends at the initial position of the respective truck. Nevertheless, the time required to return to the initial position is not taken into account in the objective function.

- The fixed and variable costs of each truck are known in advance and depend on the type of truck (internal, external) and the duration of the overall route.

- The traveling time between two locations as well as service times and time windows are known in advance.

- Each truck can only carry at most two containers at the same time.

- Each transport order \( j \) has to be performed before its due date, including the service time for activities within the destination location.

### 2.1 A Hybrid Simulated Annealing Approach for the ITTRP

Simulated Annealing (SA; Kirkpatrick, 1984) is a popular meta-heuristic that consists of extending the local search through allowing movements leading to worse solutions in terms of objective function value. Basically, in an SA algorithm a candidate move from a given neighborhood structure is randomly selected. In case a better solution is reached, the candidate move is accepted. On the other hand, if the candidate move does not lead to an improvement of the objective function value, it may be accepted according to a probability that depends on the deterioration \( \Delta \) of the objective function value.

The probability of acceptance is computed as \( e^{-\frac{\Delta}{\text{Temp}}} \), where \( \text{Temp} \) is used as a control parameter.

For solving this problem, we propose an SA approach using different neighborhood structures which are changed dynamically during the search according to its evolution by means of a variable \( k \) establishing the used neighborhood. That is, if an improvement is obtained by means of the current neighborhood structure, \( k \) is reset to 1. Otherwise, it is increased and establishes the use of another neighborhood structure. This strategy allows avoiding local optima when the probability of accepting a worse candidate move is very low. Note that this concept incorporates a novel idea of combining SA with a simple variable neighborhood approach (VNS; see, e.g., Hansen and Mladenović, 2001).
Algorithm 1 shows the pseudo-code of the proposed hybrid SA. The parameters of the algorithm are the initial temperature \(Temp_{\text{start}}\), the stopping temperature \(Temp_{\text{min}}\), and the cooling rate \(\beta\). The initial solution is generated (line 1) by using one of the heuristics proposed in this work (see Section 2.2). The variable \(k\) devoted to determine the neighborhood structure and used for generating the random neighbor is initialized in line 3. A neighbor solution, \(S'\), is randomly generated using a given neighborhood structure depending on \(k\) (line 5). The neighborhood structures implemented in this algorithm are based on (i) reinsertion movement, that is, an order is removed from the route of a truck and reinserted into the route of another and (ii) interchange movement, that is, two different orders swap their positions within their corresponding routes. For each temperature, after updating the current and best solution in lines 7-14, if applicable, \(Temp\) is decreased \(Temp \leftarrow Temp \cdot \beta\), where \(0 < \beta < 1\) (line 15). The complete SA algorithm is executed until the temperature reaches a certain threshold, \(Temp_{\text{min}}\) (line 4). The best solution reached during the search \(Temp_{\text{best}}\) is finally presented (line 17).

### 2.2 Initial Solution Generation Algorithms

In order to generate an initial schedule two constructive heuristics are proposed, namely Greedy Insertion Heuristic (GIH) and Greedy Location Targeted Heuristic (GLTH). GIH aims to allocate iteratively the orders to trucks yielding the minimum increase of the objective function of the solution. On the other hand, GLTH first determines the order to be assigned according to the closeness to a target location \(l\) and, once that, it assigns the best truck allowing the minimum increase on the objective function.

Algorithm 2 depicts the pseudo-code of GIH. This algorithm is a constructive greedy algorithm where at each step an order has to be assigned to a truck until all the orders have been assigned (line 3). Hence, at each iteration the order-truck assignment \(order_{\text{sel}} \leftarrow truck_{\text{sel}}\) yielding the minimum increase of the overall objective function value of the solution is selected. Note that the position that the order occupies within the truck sequence is denoted as \(pos_{\text{sel}}\); in this regard, the one allowing the best increment in the overall objective function value of the solution is selected. The sequence of orders of the selected truck \(S'_{\text{sel}}\) is updated by including order \(order_{\text{sel}}\) at position \(pos_{\text{sel}}\) (line 11). Finally, the already assigned order is removed from \(O\) (line 12).

Algorithm 3 depicts the pseudo-code of GLTH. This algorithm is similar to GIH and only differs in the way the assignment of orders to vehicles is conducted. While in GIH we evaluate the objective function value of all the available orders in all the vehicles, in GLTH we select an order according to a distance criterion and determine the best truck to perform that order. That is, initially a random location \(l\) is generated (line 3). This location is then used to find the order with the nearest origin to \(l\) (line 5). Once the order is fixed, we select the truck and position within the route providing the minimum increase in the objective function value of the solution (lines 6-9). This assignment is selected and included in the solution (lines 10-11). The target location \(l\) is updated to the destination of the above assigned order, \(order_{\text{sel}}\), in line 12. Finally, the already assigned order is removed from \(O\) (line 13).

To evaluate the performance of the proposed algorithms, we conduct computational experiments with five different scenarios. In Table 1, we present the results of the performance assessment. The column “Instance” contains five combinations of the number of transport orders (“Orders”) and available...
trucks ("Veh"). The other columns include the results of the greedy heuristics and the hybrid SA algorithm, which depend on the initial solution generation method. The results are disclosed in objective value ("Obj"), the total time required to serve all orders ("Acc Time"), actual number of appointed trucks ("Veh"), and the number of empty trips ("Emp"). Regarding the objective value, we see that the use of a more versatile algorithm, such as the SA for improving the results provided by the greedy heuristics, leads to an enhancement in all the cases. When the two heuristics are compared, GLTH exhibits a better performance than GIH in terms of objective function value, total time, and number of vehicles. However, it requires performing more empty trips than GIH. In this regard, compared to the other algorithms, GIH needs more trucks to perform all the orders. The use of the SA algorithm jointly with GLTH provides, on average, the best objective value. The reason is the reduction of empty trips and number of vehicles leading to a better utilization of trucks. The effect of empty trip reductions is further reflected in the accumulated service times.

Furthermore, besides the ecological benefits derived from the reduction of empty trips in terms of emissions, the reduction of used vehicles can also have a positive effect on the traffic situation in the port in general by taking off the load of a considerable number of trucks. In this sense, if we scale the results provided in this section to ports that face serious traffic congestion problems, we can obtain higher reductions leading to both economic and ecological benefits.

<table>
<thead>
<tr>
<th>Instance</th>
<th>GIH</th>
<th>SA-GIH</th>
<th>GLTH</th>
<th>SA-GLTH</th>
</tr>
</thead>
<tbody>
<tr>
<td>Orders</td>
<td>Veh</td>
<td>Obj</td>
<td>Acc Time</td>
<td>Veh Emp</td>
</tr>
<tr>
<td>5</td>
<td>4</td>
<td>277.12</td>
<td>11h 48m</td>
<td>2</td>
</tr>
<tr>
<td>10</td>
<td>5</td>
<td>720.79</td>
<td>31h 23m</td>
<td>5</td>
</tr>
<tr>
<td>15</td>
<td>6</td>
<td>870.46</td>
<td>38h 01m</td>
<td>5</td>
</tr>
<tr>
<td>20</td>
<td>7</td>
<td>1012.31</td>
<td>44h 09m</td>
<td>7</td>
</tr>
<tr>
<td>25</td>
<td>8</td>
<td>1157.53</td>
<td>50h 03m</td>
<td>8</td>
</tr>
<tr>
<td>Average</td>
<td></td>
<td>807.64</td>
<td>5.4</td>
<td>5.4</td>
</tr>
</tbody>
</table>

Table 1. Performance assessment of GIH, SA-GIH, GLTH, SA-GLTH

3 Prototype for Real-Time Planning and Managing ITT

As information exchange is as important as the optimization itself, we further aim to develop an information platform that allows the interaction between ITT providers and truck drivers based on mobile and cloud technologies in order to facilitate a context-aware coordination of container movements by using the proposed hybrid SA algorithm.

The implemented prototype utilizes characteristics of the cloud computing paradigm (for an overview on cloud computing the reader is referred to, e.g., Armbrust et al., 2010). Specifically, we follow the concept of mobile cloud computing to derive the underlying system architecture (see, e.g., Dinh et al., 2013). The prototype connects truck drivers by providing a fully integrated mobile application that can be installed on a mobile device (e.g., smartphone, tablet). Thus, the proposed prototype represents a multi-tenancy, accessible, and scalable mobile cloud platform that can be used by an ITT third-party provider to plan and manage ITT movements. The cloud-based prototype does not only facilitate that different truck drivers, including subcontractors, can use a central, accessible information exchange platform, but also offers greater flexibility in terms of computing infrastructure scaling as well as attractive economic aspects (e.g., no upfront investments for computing resources, usage-based pricing). The implemented functionality can be used by different ITT providers in several ports thus generating economies of scale. At this point, it can be highlighted that external data services, providing additional information such as on the current traffic in a port, can be integrated easily as the system architecture follows common web standards. In the following, we explain the main components and demonstrate the prototype as well as the embedding of the proposed solution approach (see Section 2).

The AJAX (Asynchronous JavaScript and XML)-based web app represents a rich web application providing functionality to plan and manage activities related to ITT movements. It is offered as soft-
ware as a service (SaaS) solution. The home screen contains important functionality to track the current position of vehicles and to interact with the truck drivers by sending and receiving messages. It further contains the location of registered ITT facilities (e.g., container terminals, empty container depots and repair stations, etc.). Other functionality, such as to maintain customers, is implemented as well. We used the Google Web Toolkit (GWT) to implement the web app.

The mobile app facilitates the interaction between truck drivers and ITT providers, containing all functionality to share positioning data, to receive ITT-related transport order lists, to write and receive messages, and to report the fulfillment of transport orders. The transport list is the result of the optimization component and thus represents the optimized order of jobs that need to be fulfilled in time. An asynchronous task manages the synchronization of data and frequently announces the current location of truck drivers. In the current version, we implemented the mobile app by using the Android SDK.

The inter-terminal truck routing optimization component is the core component of the proposed mobile cloud platform. It embeds the proposed optimization approach (see Section 2) to allocate requested container pickups and deliveries to available trucks. As depicted in Figure 1, the user is able to initiate an optimization task that triggers the hybrid SA algorithm in order to assign container transport orders to different trucks by considering constraints such as the maximum working hours, time windows of facilities, and container transport deadlines at the destination location. In this paper, we use data from real companies in the Port of Hamburg that frequently require ITT-related container movements. The planning results (see Figure 1, middle) indicate the assignment of container movements to available trucks. The results show the planned arrival time of a vehicle at the origin to pick up the container and at the destination to deliver the container. Moreover, the distances and durations between locations are shown. In the example, we can see that the algorithm reduces empty trips as containers are picked up at the delivery location in three cases (container transport 1, 2, 5). Note that we consider the current traffic situation in calculating the durations between locations by requesting additional information from the Google Maps API, providing traffic conditions in real-time on major roads and highways. The resulting costs and the number of reduced empty trips are declared separately so that the decision maker (i.e., ITT provider) can evaluate the economic and ecological impact of the optimization. Note that the decision maker is also able to manually allocate orders to trucks. As soon as a transport order has been fulfilled, it is removed from the planning interface, whereas new and unplanned orders can be flexibly integrated by re-planning all routes. In the latter case, the sequence of orders is automatically updated for each truck based on its current position. The truck driver is informed about all changes. Consequently, the prototype supports a very flexible ITT truck routing based on contextual information as well as an on-going interaction with involved truck drivers based on widely applied web standards.

Figure 1. Truck routing decision support interface (left: optimization task initialization, middle: result tableau, right: planning visualization for truck 2 with Google Maps API)
4 Conclusions and Future Research

Many ports around the globe are influenced by regional infrastructure constraints and factors. At the same time, ports have a huge impact on their environment and on the efficiency of supply chains in which they act as important ‘transport nodes’ and value-added logistics providers. An efficient planning of activities for reducing inefficient movements of vehicles, however, is highly dependent on an effective information exchange between involved actors.

In the course of this paper, we mitigate the impact of inter-terminal transports, representing a large percentage of container movements within the port area. According to the design objectives, the contribution of this paper is threefold. First, we address the inter-terminal truck routing problem to increase the utilization of available trucks and to reduce the number of empty trips based on specific requirements of ITT. Consequently, the approach is not only important from an economic perspective, but also contributes to a more ecological port environment. Second, we propose two greedy heuristics and an SA algorithm to achieve feasible solutions within short computational times. This is a main prerequisite of real-time applications and thus facilitates a flexible planning and management of ITT according to real-time conditions, such as in terms of order requests, truck availabilities, and traffic conditions. Finally, we embed the optimization component into an accessible, scalable, and multi-tenant cloud platform that facilitates, besides basic functionality, a real-time interaction with truck drivers as well as a central coordination and optimization of ITT movements. The proposed collaborative platform facilitates a purposeful integration and coordination of port actors and different sources of information taking into account important economic and ecological high-level objectives. Though, the establishment of information exchange in general implies several issues that are not considered in this paper (for instance, the resistance of actors to share information due to competition).

With respect to the maritime industry, our proposed approach could be transferred to the routing and scheduling of seaborne vessels within global shipping alliances (Armas et al., 2015) and to explore its joint application with berth planning operations (Lalla-Ruiz and Voß, 2015). Although designed for the conditions of ports, the approach can also be applied to other movements in transport networks, for instance, related to airports or car sharing. For future research, we aim to further consider vehicle emissions in the proposed optimization approach, based on vehicles’ properties (e.g., fuel type, weight, etc.). Moreover, the optimization component could be extended by a dynamic vehicle routing approach considering stochastic order requests. Regarding the cloud platform, we aim to integrate mechanisms to further control the information access and exchange between actors. The information access, for example for the ITT provider, should be defined in a more granular way following the need-to-know principle. In this regard, we aim to present a framework for security and privacy management, which defines different IT governance and management domains to address security and privacy concerns in both physical and cloud environments. Moreover, it is essential to evaluate the attractiveness of using the proposed collaborative platform, such as by applying game-theoretic methods to determine benefits of competing stakeholders operating in ITT coalitions.
References


