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Conceptual Model of a Decentralized Transport Organization in the Increasingly Uncertain Transport Environment of the Physical Internet

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Abstract: *In recent literature, it is indicated that freight transportation via trucks is still insufficient in terms of efficiency and sustainability. Reasons for such inefficiency are poor utilization of capacities (drivers, trucks, containers etc.), high shares of empty mileage, as well as lacking flexibility when responding to an increasing market volatility. It is assumed that future transport systems will have to deal with higher urgencies and with smaller lot sizes. In course of this, the assignment of transport orders will be characterized by increasing spontaneity and an uncertain planning environment for logistics service providers.*

Thus, the objective of this paper is to present a conceptual model that combines a dynamical price prediction model and an approach for the dynamical assignment of freight flows through a network of hubs. Due to a constantly changing environment (e.g. demands, capacities, and/or prices), freight assignment will be updated continuously. As a result, the operational freight flow will evolve over time and choose the most cost-efficient route through the network by dynamically bundling and unbundling itself.

After a brief introduction on recent Physical Internet (PI) research, this paper will give a description of the proposed model, for a continuous and dynamic freight flow assignment. Eventually, we will discuss the results and conclude with the implications on our research.

Keywords: *capacity management, dynamic pricing, freight transportation planning, Physical Internet*

1 Introduction

In recent literature, it is indicated that logistics networks are still insufficient in terms of efficiency and sustainability with respect to economical, ecological and social aspects (Montreuil, 2011). To overcome these challenges, Montreuil (2011) exploits the Digital Internet metaphor to develop the Physical Internet (PI) vision. With the characteristics of that vision, he tries to address the current challenges of the logistics system. Since these days, the idea of the PI in particular was further developed by Montreuil himself (Georgia Tech, USA), E. Ballot (Mines ParisTech, FR), T. Crainic (Université du Quèbec à Montréal, CAN) and Y. Sallez (University of Valenciennes and Hainaut-Cambrès, FR) (Montreuil, 2012; Montreuil et al., 2012a; Montreuil et al., 2012b; Sallez et al., 2015; Sallez et al., 2016; Crainic and Montreuil, 2016; Domanski et al., 2018). Since 2004, several publications have outlined the general concept of the PI; since 2013, approaches with application character have been published (Domanski et al., 2018). Main research areas are the standardization of logistical units (Ehrentraut et al., 2016; Sallez et al., 2016), the sharing of resources and the operational handling and control of freight flows (Domanski et al., 2018). Further research interests lie in urban logistics (Crainic and Montreuil, 2016) and the design of suitable terminal infrastructure and processes (Sallez et al., 2015; Walha et al., 2016).

In our research, we focus on rising uncertainties in the assignment of transport requests in transport networks. Firstly, we will outline challenges going along with a dynamic transport environment. Furthermore, we will analyse recent PI literature on how the addressed challenges are solved. Moreover, we will give a description of the proposed model for a continuous and dynamic assignment of transport requests, followed by an exemplary application of the model. In a last step, we will give a conclusive outlook on our main findings and our next research steps.

2 Problem Statement

Due to increasing volatility in the freight transport market, the transport sector is developing ecologically, economically and socially unsustainably:

- Typically, a high share of fixed costs characterizes the cost structure of carriers (Lohre, 2007). Additionally, capital coverage (i.e. capital assets that are covered by equity and long term loans) is low. Therefore, under- and overcapacities resulting from higher probabilities of demand fluctuations directly increase the risk of liquidity shortages and/or lost sales (Wittenbrink, 2014).
- In the Austrian freight transport sector, greenhouse gas emissions (GHG emissions) have been rising more than 60% since 1990. In 2015, the transport sector was responsible for approximately 28% of the Austrian GHG-emissions, which equates 22.1 Mio. t CO2-Equivalent (Umweltbundesamt, 2017). Especially road freight transportation contributes to that significant rise. Since 1990, GHG-emissions in road freight transportation have been rising to 128%; between 2014 and 2015, they still rose for more than 1.4%. In 2015, road transportation was responsible for 27.7% of total GHG-emissions. Specifically, road freight transportation contributes to 12.1% to Austrian GHG-emissions (Umweltbundesamt, 2017). Similarly, the transport sector is responsible for 33.1% of the energetic end consumption and is 80% dependent on oil products as primary energy source (BMWFW, 2015). In a dynamic transport environment, logistics service providers tend to use the road instead of the more ecologically friendly rail due to high flexibility requirements (Bühler, 2006; Wittenbrink, 2014, pp. 9–10). Additionally, these means of transport are still utilized in an insufficient way (Bundesamt für Güterverkehr, 2017). As modal shift and the high use of transport capacities directly influence ecological efficiency (Keller and Helmreich, 2011), an increasingly dynamic transport environment contradicts such development.
- The availability of handling and driver personnel is essential for efficient freight transportation. Many transportation and logistics service providers find it increasingly difficult to fill open positions with appropriate staff (Wittenbrink, 2014). Furthermore, logistics service providers find themselves in a public debate over low pay and poor working conditions. Low pay and a high number of on-call hours are unattractive especially for truck drivers (Lohre et al., 2015). Uncertainties in necessary deployment, poor personnel-planning and high flexibility requirements for the staff contribute to a reduction of normal working relationships, enforce precarious employment situations and thus lead to personnel shortage (Lohre et al., 2015).

SteadieSeifi et al. (2014) also indicates an ongoing trend of higher flexibility and increasing delivery urgencies in the logistics service sector. Additionally, a concept asking for high flexibility from transport service providers is Sharing Economy. From a microeconomic point of view, companies acting in such an environment have business concepts characterized by the shared and temporary use of resources that are not permanently required (Puschmann and

Alt, 2016). Therefore, carriers can apply for desired transport orders and shippers can bid for available resources without having to make long-term contracts. This leads to a highly dynamic and hardly predictable environment within the concept of PI (Qiao et al., 2016). Additionally, increasingly dynamic and digitized value chains place new requirements on logistics operators. Due to the digitization value creation, networks will be more segmented, freights-sizes are decreasing and quality requirements (e.g. punctuality, speed) are increasing (BMVIT, 2016; Scheucher, 2014). Another trend having effects on the freight transport sector is a visible shift of the structure of freight. Freight is increasingly becoming of high value, high quality, low volume and rather low weight (König and Hecht, 2012). Consequently, future transport systems will have to deal with higher urgencies of shipments (higher value of goods, same day delivery) in smaller lot sizes (individualization, lot size 1). Therefore, the assignment of transport orders is characterized by an increasing volatility and spontaneity leading to an uncertain planning environment for logistics service providers.

In summary, the mentioned changes tend to lead to economically, ecologically and socially unsustainable developments. Time consuming transport mode choices and implementations of bundling concepts are more unlikely to be implemented due to rising transport urgencies. Rising volatility of freight transportation demand leads to under- and overcapacities in means of transportation leading to lost sales and liquidity shortages at logistics service providers. Furthermore, a lack of planning competencies in an increasingly uncertain transport environment results in an unsecure work environment for drivers and logistics personnel. Our research aims to tackle the mentioned challenges by providing a solution in terms of a model that allows the dynamical planning of freight flows through a network of hubs and the constant surveillance of these freight flows. The approach helps to gain transparency over planned freight flows and helps to realize economic, ecological and social potentials.

3 Literature Review

In terms of a PI literature review, relevant publications regarding concepts of vehicle routing, routing of goods and dynamic pricing strategies in recent PI literature are considered. In general, planning problems are clustered in operational, tactical and strategic planning levels (Caris et al., 2008; Crainic and Bektas, 2007; Hoff et al., 2010; SteadieSeifi et al., 2014). A synonym for the strategic planning level is “system design” (Crainic and Bektas, 2007); long-term decisions are made, as for the number and locations of terminals and the capacity level of (transport) equipment. On tactical planning level, three essential planning domains are described: The Network Flow Planning (NFP) problem results in a plan, how goods are routed through a defined network. The Service Network Design (SND) problem defines what kind of service (type, frequency and quantity) is provided between network elements (SteadieSeifi et al., 2014). Additionally, decisions on the capacity level of labour are generally summarized on the tactical planning level (Caris et al., 2008). On operational level, the optimal means of transportation is selected for a pending transport order and the vehicle routing is made for the set of transport orders assigned to a means of transportation (Hoff et al., 2010). For the taxonomy of the analysis of the literature review, we follow the general structure of Crainic et al. (2017). We focus on the following questions:

- Addressed stakeholder: Who is the focused stakeholder of the proposed model?
- Objective: What kind of added value does the model aim for?
- Addressed objects: What are the focused objects considered within the defined model?
- Addressed modes: What transport modes are taken into account?
- Predictive modelling: Are there any forecast procedures proposed?
- Demand modelling: How is the initial data for the model defined?

- Application modelling: How do changing framework conditions influence the model?
- Period Type: Is the planning horizon discretized and how many planning periods are considered?

Two papers related to dynamic pricing in the PI are identified. Qiao et al. (2016) investigate how bidding prices for requests based on an auction mechanism should be determined by carriers regarding less than truckload orders in the PI. Thus, two pricing strategies for a one-leg problem are taken into consideration: a unique bidding price and a variable bidding price. The objective of each of these strategies is to maximize the carrier's profit. They use a dynamic programming model. After all, they conclude that both strategies could be used as a decision making tool, especially since the two approaches both lead to very comparable results. This research issue is further studied by Qiao et al. (2017). They extend the work mentioned earlier by taking a multi-leg problem and corresponding routing of vehicles into account. Furthermore, besides request selection and pricing strategies for less than truckload capacity of a carrier, the possibility of having full capacity to load is investigated. Again, the objective of the strategies is to maximize the carrier's profit. However, restrictions of the model are that a carrier could only select one type of request to bid for as well as static request quantities in the hub. They compare two scenarios – on the one hand taking full capacity and on the other hand partially loaded vehicles into account. Altogether, they concluded that the main difference of these scenarios is the way future request information is taken into consideration. Regarding carriers with fully utilized capacity, only the hub the carrier will arrive next is considered, while all hubs between the original and destination hub of an LTL utilized vehicle are taken into account. A limitation of the paper is that the request quantity emerging in each hub is static and not dynamically solved. Thus, the very dynamic environment of logistics services is not fully described by this model.

The remaining results of the literature research are related to routing of either vehicles or goods in the Physical Internet. In the course of the study by Montreuil, Hakimi et al. (2012) a mobility web simulator was developed. The purpose of this simulator is to plan various tasks of the supply chain manager, transport agent and routing agent. Thus, it is realized via a multi-agent based model. Furthermore, the task of a routing agent in the simulator also includes vehicle routing of trucks and trains. This vehicle routing problem is approached via a simple two-step method. First, fixed costs are assigned to each route between nodes. Second, a shortest path algorithm is executed from origin to final destination. Altogether, they come to the conclusion that the implemented PI-scenario results in shorter but yet more hopping trips as well as a significantly lower overall travel distance compared to the current logistics network. The paper of Furtado (2013) deals with a simulation for a decentralized transport planning and thus vehicle routing within the PI. Since the network is decentralized, each hub plans the route for a vehicle to the next hub. The trucks are linked to single hubs and hence have to travel back to those after delivering. In terms of vehicle routing optimization, the objective function is to minimize the total costs. Additionally, the possibility of container consolidation was also taken into account. From the obtained simulation results they concluded that consolidation reduces overall costs of logistics network and leads to an increase in efficiency regarding empty mileage as well.

Sarraj et al. (2014) is currently the most cited article related to PI. It deals with the definition of transportation protocols with respect to the Physical Internet, which includes the definition of new container loading, routing and consolidation protocols in that context. Regarding the container routing not only trucks, but also trains were considered. Moreover, the objective function of the routing algorithm is to minimize besides the costs also the time and environmental impact. Furthermore, in terms of solving the vehicle routing problem the A* heuristic for calculating the shortest path for each destination at each hub is used. From the obtained results, they deduced that the fill rate of transportation capacity has significantly increased. Moreover, the implementation of the PI concept into the observed network leads to a CO2-emission reduction of 60% due to a significant share of rail transportation. Consequently, also the costs are lower than in the current logistics networks.

Moreover, Yang et al. (2017) investigated the resilience of freight transportation – trucks and trains are considered – with respect to the Physical Internet. Thus, they implemented a VRP regarding the hub disruptions with the help of dynamic and resilient routing protocols. The objective function of the VRP does not only imply cost minimization, but also reduction of CO2-emissions and the overall travel time of the goods. Again, a multi-agent simulation model was implemented as well as the A* heuristic for solving the VRP. Overall, Yang et al. deduce from their simulation results (4.3% of additional costs, an increase of 9.6% of CO2-emissions and 1.83 hours of delay in the worst considered case of disruption), that PI can be seen as a resilient transportation system. Other PI literature is not described in this literature review as it does not fit into the problem statement or the taxonomy described above.

Table 1: Other reviewed PI Literature

Author	Title
Ballot and Montreuil (2012)	Analysis of the Physical Internet vs. supply chains
Meller et al. (2013)	Functional Design of Physical Internet Facilities: A Road-Rail Hub
Oktaei et al. (2014)	Designing Business Models for Physical Internet Transit Centers
Rouges and Montreuil (2014)	New interconnected business models to reinvent delivery
Montreuil et al. (2015)	Modular Design of Physical Internet Transport, Handling and Packaging Containers
Pan et al. (2015)	Perspectives of inventory control models in the Physical Internet
Crainic and Montreuil (2015)	Physical Internet Enabled Interconnected City Logistic
Gasperlmair et al. (2016)	Go2PI - Practically proved steps to implement the Physical Internet
Maslarić et al. (2016)	Logistics Response to the Industry 4.0. The Physical Internet
Colin et al. (2016)	A proposal for an open logistics interconnection reference model for a Physical Internet
Ounnar and Pujo (2016)	Holonic Logistics System: a novel point of view for Physical Internet
Pan et al. (2016)	Physical Internet and interconnected logistics services
Venkatadri et al. (2016)	On Physical Internet logistics: modeling the impact of consolidation on transportation and inventory costs
Fazili et al. (2016)	Physical Internet, conventional and hybrid logistic systems. A routing optimisation-based comparison using the Eastern Canada road network case study
Pal and Kant (2016)	F2π: A physical internet architecture for fresh food distribution networks
Simmer et al. (2017)	From horizontal collaboration to the physical internet - a case study from Austria

Zhong et al. (2017)	Big Data Analytics for Physical Internet-based intelligent manufacturing shop floors

Overall, the main part of the papers regarding concepts of vehicle routing, routing of goods and dynamic pricing strategies in the PI focus on modelling and solving vehicle routing problems. Additionally, two research papers deal with pricing strategies of freight transportation in the PI regarding not only a one-leg but also a multi-leg problem.

As a result, to the best of our knowledge, there is no modelling approach for a dynamical and continuous assignment of transport requests in the context of the PI. We have not found a model that allows a continuous surveillance of freight assignments to carriers and a dynamical update of these assignments under consideration of changing framework conditions. Therefore, freight forwarders are not able to identify available capacities within the network and do not continuously rearrange the assignment of freight due to a constantly changing transport environment (e.g. demands, capacities, and/or prices). Finally, they are not able to constantly bundle and unbundle freight transport orders, which leads to poorly utilized transport capacities, unsustainable transport mode choices, under- and overcapacities as well as spontaneous and socially unsustainable working conditions.

4 Conceptual Model

We introduce a conceptual model for dynamically and continuously (re-)assigning transport requests to carriers within an abstract network of origins, destinations and hubs. The objective is to reduce costs and GHG emissions by dynamically bundling transport requests and fully utilizing transport capacities. More specifically, the underlying problem can be described as the following: Given a transport network consisting of a set of customers and an arbitrary number of transshipment points, a set of transport requests has to be assigned to transport routes such that all goods are picked up at their origin and delivered at their destination at minimal costs.

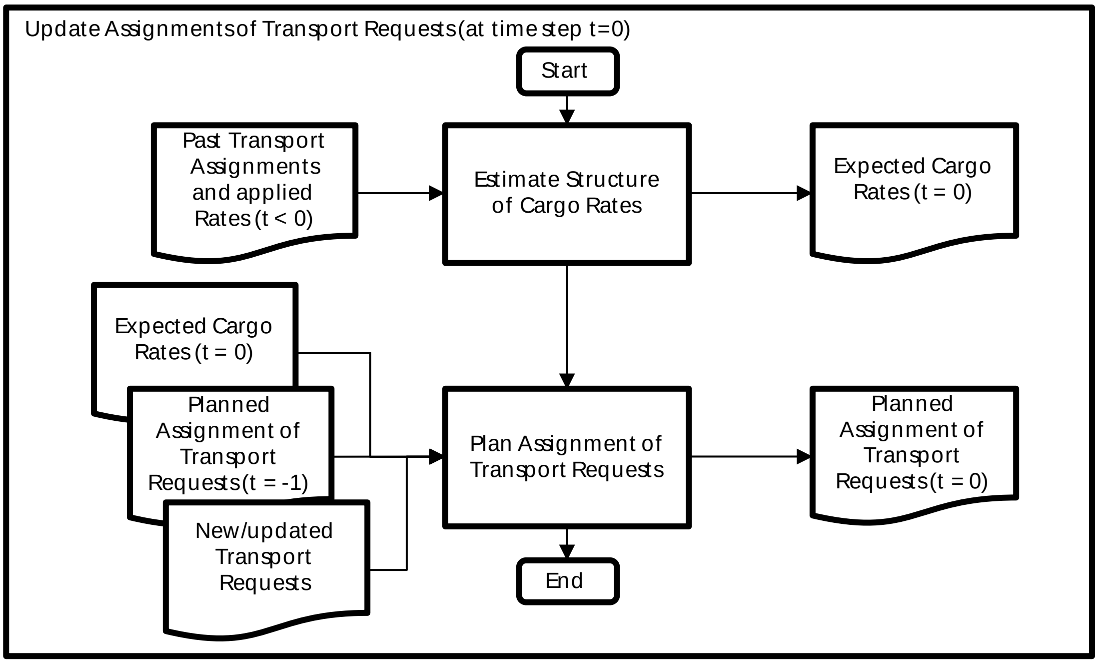

Figure 1: Approach to update planned assignments of transport requests continuously

Thereby, the assigned carriers have to service each customer within the given time windows and the cargo may not exceed the maximal transport capacity of the carriers. In addition, new requests are dynamically added to the system and framework conditions (e.g. time windows) are changed. As a result, the assignment has to be updated continuously. The approach should help to fully utilize available capacities, reduce GHG emissions and to minimize the overall transport costs. The proposed model is defined as a multi-step approach. It consists of a model to estimate the structure of expected freight rates within a transport network, a model to (re-)assign transport requests and a model to continuously update the planned assignment of transport requests. Schematically the approach is depicted in Figure 1.

The continuous application of the model results in an updated plan of assignment of transport requests. The following components of the model are described in this chapter:

- Estimate structure of cargo rates: A pricing model evaluates the expected costs of different transport variants between origins, destinations and hubs in an abstract transport network.
- Assign transport requests: A routing model optimizes the assignments of the transport requests in order to generate cost minimal freight flows through the network.
- Update assignments of transport requests: A planning algorithm continuously updates the transport routes of all requests when new transport requests are added or framework conditions are changed (e.g. time windows).

4.1 Estimate Structure of Cargo Rates

The first component of the model is a transport-pricing model. To optimize the assignment of transport requests, we want to estimate expected transport costs for each request. In order to do so, a model describing expected freight rates of transports between all relevant locations (e.g. origins, destinations, hubs) as well as individual framework conditions (e.g. type of freight, fill rate, urgencies) is needed. Depending on the respective use case, a suitable pricing model has to be developed. Several formulations can be found in literature:

Zhang et al. (2015) consider the case of a third-party-logistics provider that provides warehousing and transportation services. They developed a stochastic nonlinear programming model to find the optimal freight rates for different delivery dates considering the provider's holding cost and available transportation capacity.

Budak et al. (2017) developed a model for forecasting the spot market prices. They introduced two methodologies, a quantile regression model and an artificial neural network, to estimate the transport costs between two locations depending, among other things, on the distance, the freight type, the possibility of a return load from the arrival town and the tonnage.

In section 5.2, we present a two-stage regression model for the use case of a freight forwarder, specialized on arranging transports from Scandinavia to South-East Europe. Thereby, we use similar parameters as Budak et al., but introduce a new way tonnage is included in the model.

4.2 Plan Assignment of Transport Requests

The second component of the model is the optimized assignment of transport requests to carriers in a given network under consideration of the estimated cargo rates. Given is a set of customers and a list of transport requests from origins to destinations. The objective is to find cost minimal freight flows, in order to fulfil all transport requests under consideration of a certain transport demand for each request. Therefore, the set of transport requests is assigned to a set of carriers. The cost of each transport is determined by a transport pricing model of section 4.1.

For each customer, time windows are given determining pickup and delivery times. It is possible to transport multiple requests by the same carrier, if the transport capacity of the carrier is sufficiently large. It is also possible to transship the cargo at certain transshipment points as well as to organize groupage or distribution traffics.

The problem described can be classified as Pickup and Delivery Problem with Transshipment (PDPT). Cortés et al. (2010) introduced a mixed integer-programming formulation of the problem, but as the problem is NP-hard (Rais et al., 2014), finding the optimal solution is computationally not efficient.

Therefore, heuristic approaches were developed for finding a reasonable good solution within acceptable time limits. Qu and Bard (2012) and Masson et al. (2013) proposed Large Neighbourhood Search (LNS) algorithms to solve the problem efficiently. Danloup et al. (2018) extended their idea and introduced a Genetic Algorithm (GA).

4.3 Update Assignment of Transport Requests

The third component of the model is an algorithm to continuously update the planned assignment of transport requests to carriers. Therefore, the estimation of cargo rates as well as the planned assignment of transport requests is continuously re-evaluated. Whenever a new transport request is added to the existing plan of freight flows or other framework conditions change (e.g. time windows), the planned assignments are updated. Past requests as well as new requests are recalculated under consideration of relevant constraints (e.g. fixed time windows) and expected cargo rates (see section 4.1).

The model enables the freight forwarder to evaluate the transport costs of newly added requests and changing framework conditions (e.g. time windows) by comparing the overall costs of different transport bundling and unbundling alternatives:

- Variants of combining the newly added transport request with past transport requests.
- Variants of using one or more transshipment points as well as implementing groupage (collecting one transport order after another) or distribution tours (delivering one transport order after another).
- Variants of alternative time windows at the origins and/or destinations.

5 Application of the Model

In the upcoming section, we apply the proposed conceptual model to a use case of a freight forwarder, specialized on arranging transports from Scandinavia to South-East Europe with a central transshipment point (hub) in Budapest, Hungary.

5.1 Case Study: General Classification of the Available Data Set

The available data set consists of 8 158 full truckload (FTL) and less than truckload (LTL) transport orders between the years 2015 and 2017. It contains information about the carrier selected, assigned transport orders to each transport, pick-up and delivery due dates and locations as well as the type of cargo. Additionally, past transport costs per transport order are given.

To generalize and abstract the model, we cluster each location to its corresponding NUTS3-region (French: “Nomenclature des unités territoriales statistiques”). NUTS is a geocode standard from the European Union for abstracting European countries into smaller regions for statistical purposes. For countries like Bosnia-Herzegovina or Serbia, which are not member of the European Union, we define these regions manually. As an estimate for the travel distance we use the distance between the centers of the corresponding NUTS3-regions.

For clustering the types of cargo, we used the NACE classification of the European Union (French: “Nomenclature statistique des activités économiques dans la Communauté européenne”). According to NACE the transport orders are associated with the categories C17 (Manufacture of paper and paper products) and C24 (Manufacture of basic metals). Depending on the type of goods, either the length or the weight is the restricting factor regarding the maximal transport capacity. Products from the metal industry sector are usually restricted by their weight, while for paper products usually the size of the products restricts the maximal transport capacity.

According to the type of goods, we defined a degree of loading per transport order. The degree of loading is described by the percentage of the restricting factor related to an FTL transport order. Based on that definition, we call a transport order a FTL transport order, if the degree of loading is greater than or equal to 95 %. If the degree of loading is less than 95 %, it is defined as a LTL transport order. The considered data set contains 1726 LTL transport orders, what corresponds to 21.2% of all transport orders.

5.2 Estimate Structure of Cargo Rates: A Two Stage Regression Pricing Model

Based on the data set and the defined classifications, we developed a regression model to estimate cargo rates for the assignment of transport orders to carriers. For the estimation of cargo rates we identify significant attributes similar to Budak et al. (2017).

We propose a two-stage regression model. Firstly, we fit a regression model with using FTL transport data and their significant attributes only. After that procedure, in a second stage, we take the degree of loading for LTL transport orders into account. In this way, we overcome the problem that some interaction terms of the degree of loading with other attributes (e.g. distance) have a significant effect on the cargo rates.

5.2.1 First Stage: Cost Model for FTL transport orders

The first stage of the regression model for estimating the cargo rates of FTL transport orders includes the following significant attributes:

- Year and quarter variables: Dummy variables for the year and the quarter in which the transport has taken place to account for the overall seasonal and annual change of transport costs.
- Cargo type: Dummy variables indicating the type of the cargo (see NACE classification).
- Truck driver’s country of origin: Two dummy variables indicating whether the country of origin of the truck driver matches the country of the start respectively the endpoint of the tour. This is something we were told by experts working in the transport sector that it might have a significant effect on the transport pricing.
- Transshipment: Dummy variable, which is equal to 1, if the freight was transshipped.
- Way stops: Number of way stops of the tour other than a transshipment point.
- Distance between NUTS regions: Estimated travel distance using distance between the center points of the NUTS regions.
- Distance between NUTS regions squared: Square of the estimated travel distance.
- Start and end region: Dummy variables for each NUTS region indicating in which region the start and the endpoint of the tour is. These variables are used to account for the fact that transports to or from certain regions may defer in price due to the lack of return loads or due security reasons.

The coefficient of the travel distance is significantly positive while the coefficient of the squared distance is significantly negative. This implies that the impact of the change in distance on the transport costs becomes smaller the larger the travel distance is. Finally, the country of origin of the truck driver has an effect on the cargo rate: If it matches the country of the start respectively the endpoint of the tour, the transport costs become significantly lower. Obviously, carriers are willing to transport goods for a lower rate, if they have the option to start the tour at home or to return home.

Resulting from our analysis, neither the weekday of pickups or deliveries nor the transport duration has a significant effect on the cargo rates: The duration may be described by the distance assuming the average speed is similar on different routes. The fact that weekdays of pickups and deliveries have no significant effect on freight rates may coincide with the fact that customers do not have a clear preference regarding these weekdays. A fact, confirmed by the logistics experts of the application partner as well.

5.2.2 Second Stage: Accounting for the Degree of Loading

As we have little options, when it comes to bundling and unbundling FTL transport orders, we are interested in the LTL transport orders in the data set. These transport orders may be carried out as direct deliveries (direct transport from origin to destination), they may be collected in groupage tours (collect one transport order after another) and delivered in distribution tours (deliver one transport order after another) or they may transshipped at the transshipment points (unload and load transport orders).

We generalize cargo rates for LTL transport orders by performing a second regression analysis on the actual cargo rates using the following attributes:

- Predicted FTL costs of the first stage multiplied by the degree of loading
- Predicted FTL costs of the first stage multiplied by the square of the degree of loading
- Distance (between NUTS regions) multiplied by the degree of loading
- Distance (between NUTS regions)

The analysis is performed using the data set of LTL and FTL transport orders resulting in the coefficients shown in Table 2.

Table 2: Coefficients of LTL Model (Second stage)

pred. costs * degree of loading	pred. costs * degree of loading²	distance * degree of loading	distance
1.4078	-0.4066	-0.0820	0.0825

These results are consistent as the estimated costs of LTL transport orders (second stage model) converge towards the estimated costs for FTL transport orders (first stage model) when the degree of loading approaches 1. As the coefficient of the predicted costs times the square of the degree of loading is negative, the marginal costs for an LTL transport become lower with an increasing degree of loading. Furthermore, the predicted costs increase with a longer travel distance. However, this effect diminishes with an increasing degree of loading.

The results of the case study are promising: The median absolute prediction error for the whole data set, estimated by cross validation, is 3.42 %; the third quartile of the absolute prediction errors is 7.08 %. The median absolute prediction error for LTL transport is 10.27% compared to 3.04% for FTL transport orders. A test calculating the second stage separately for LTL transport orders did not significantly improve the results.

5.3 Plan Assignment of Transport Requests: Solving a Pickup and Delivery Problem with Transshipments

To determine the most cost efficient way to assign transport orders to a set of carriers, we solve a pickup and delivery problem with transshipments (PDPT) proposed by several authors in chapter 4.2. However, since the derived cost function of chapter 5.2 is cubic (the travel distance as well as the degree of loading of a truck depends on the route of the truck), exact algorithms cannot be applied to solve the problem efficiently. Therefore, we integrated our pricing model into the genetic algorithm proposed by Danloup et al. (2018). Schematically, the approach is depicted in Figure 2: Three transport orders are planned to be shipped directly from several origins to several destinations. (Request A from location 1 to location 2, request B from location 3 to location 4 and request C from location 5 to location 6). Furthermore, each transport order's time windows are defined, describing pickup and delivery due dates. Two options for transshipments are labeled with "T".

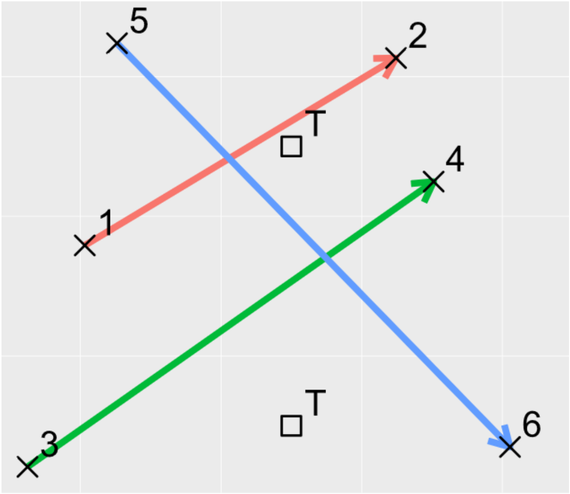

Figure 2: Illustration of the initial scenario

Solving the PDPT initially, each transport order is assigned to a direct delivery transport, as their framework conditions do not allow any other solution. (Request A by carrier "Red", request B by carrier "Green" and request C by carrier "Blue")

5.4 Update Assignment of Transport Requests

However, as framework conditions and the number of requests in the system is constantly changing, the sequence of modelling cargo rates and assigning transport requests is applied iteratively. By updating the assignment of transport orders, the freight forwarder is able to quantify the costs of a new request. Furthermore, the forwarder is able to evaluate changing time windows. As a result, he can generate a discount for altering or changing the time window of pickup and delivery due dates; new options for bundling and unbundling are occurring and he can carry out the transports more efficiently. The total travel distance of the used means of transportation decreases and their utilization increases.

In Figure 3 a schematic example of a changing number of transport requests and changing framework conditions (time windows) is shown. In figure 3a, only three transport requests need to be fulfilled. As indicated earlier, the best solution is, to carry out all transports separately. The estimated overall transport costs at this are 25.36 (for demonstration purposes, in this schematic example all cost figures are represented by the sum of the overall travel distance).

Next, a new transport request is added to the system and the assignment of all transport requests is updated. The result is shown in the figure 3b: Two trucks pick up requests from location 5 and 7 and deliver it to a transshipment point. From there, a single truck delivers these requests to their respective destinations 8 and 6. Due to the bundling, the transport costs are reduced to 31.90, compared to 32.93 if all transports would be carried out separately.

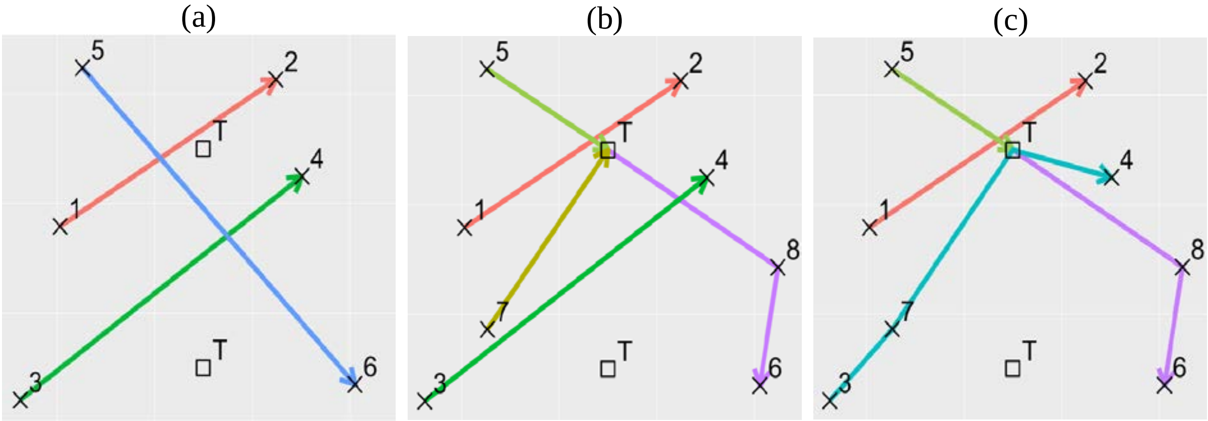

Figure 3 (a, b, c): Illustration of optimal assignment of transport orders in different scenarios

However, the total cost can be reduced to 27.95, if the given time window at location 7 is extended by one day. The freight forwarder is able generate a significant smaller transport price, while decreasing GHG emissions due to the shorter travel distance. The resulting routes are shown in the figure 3c.

6 Conclusion

In this paper, we introduced a conceptual model for a dynamical and continuous planning procedure for the assignment of transport request in the context of the PI. We developed a model that allows the continuous planning of freight flows through a network of hubs and the constant surveillance of freight assignments to carriers. Therefore, freight forwarders will be able to identify available capacities within the network and are able to rearrange the assignment of freight. Finally, they are able to bundle and unbundle freight transport orders, which leads to better utilized transport capacities, lower costs and fewer GHG emissions.

The model consists of three components building up on each other: A model to estimate cargo rates, a model to assign transport requests and a planning algorithm that continuously updates the expected assignments of transport requests. We introduced a use case of transport requests from Scandinavia to South-East Europe. The results of the developed model for the estimation of cargo rates are promising as the median absolute prediction error is only 3.42%. Furthermore, we demonstrated the feasibility of our approach as it is possible to quantify the costs caused by additional transport requests and changing time windows. Dynamic bundling and unbundling enables freight forwarders to generate lower costs per transport request. Our next steps are to evaluate the overall bundling potential of our conceptual model for the presented use case and to show the generated economic, ecological and social potential.

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