Recovery Plans for Synchromodal Transport Systems

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Abstract

In this research, we provide an algorithm for dynamically adjusting a transport plan in the case of disturbances in a synchromodal transport system. Recently several research projects have introduced decision support tools to solve planning problems in the synchromodal network that can handle the vast amount of information, but recovery planning in case of disturbances is underrepresented. Our aim is to explore when adjustments to the plan are necessary in case of a disturbance in a network, maximizing expected revenue. Disturbances are categorized right upon their occurrence and the category is updated as new information becomes known. We model the progress of a disturbance by a Markov Chain and define a Markov Decision Process to obtain a recovery strategy. We focus on a single chain of freight transport, employing different modes, and provide solutions for reacting to unplanned disturbances. A case study from industry provides validation of this algorithm.

Keywords: Freight transport planning, Synchromodality, Dynamic Algorithm, Disturbances, Recovery planning, Markov Decision Process

1. Introduction

We propose this research aligned with the targets of the United Nations in the 2030 agenda for sustainable development. The United Nations posed 17 sustainable development goals (SDGs) as blueprint for a more sustainable future for a fast growing worldwide population, and aims at strengthening the means of implementation and revitalization of the global partnership for sustainable development. This objective encourages multi-stakeholder partnerships that mobilize and share knowledge, expertise, technology and financial resources to tackle the challenges relates to achieve the SDG targets in all countries. In supply chains, efficient movement and timely availability of goods is of vital importance, making freight transportation a key component and a main contributor to costs (Crainic, 2003; Ghiani, Laporte and Musmanno, 2004).

Synchromodal transport facilitates efficient connections between hinterland destinations, deep-sea terminals and *extended ports*, hinterland terminals that act as extension of a deep-sea terminal (Roso et al., 2009; Veenstra et al., 2012). Carriers and customers select the best mode of transport, given the operational circumstances at terminals at any time during the transport, synchronizing the demand for transport with the available capacity. This allows for flexible planning of transport

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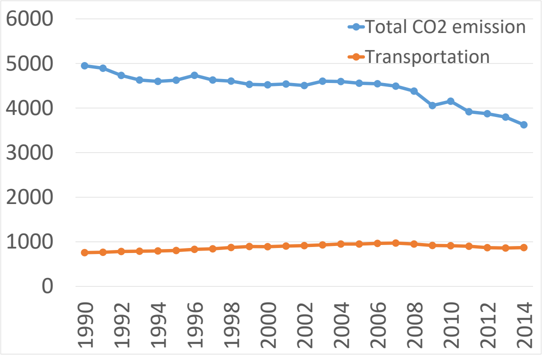

Figure 1: CO2-emissions in EU-28 (MtCO2) (World Resources Institute, 2017)

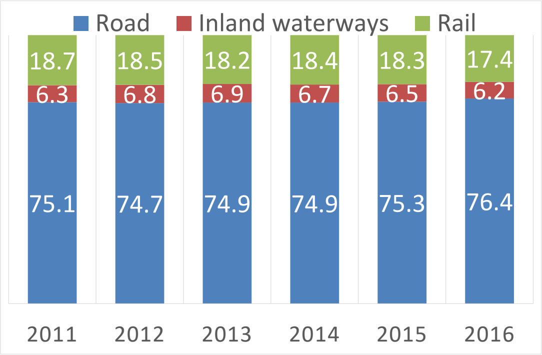

Figure 2: Modal split of continental freight transport in EU-28 (Eurostat, 2018)

and real-time switching between modes (SteadieSeifi et al., 2014; Behdani et al., 2014; Tavasszy et al., 2015; Pfoser et al., 2016; van Riessen, 2018).

The concept of synchromodality has great potential for promoting modal shift in freight transport and working towards the goals set by the EU for the reduction of CO2 (Pfoser et al., 2016). Research interest in the area of synchromodal transport is growing, but the focus has been on the strategic and tactical areas of transport planning (SteadieSeifi et al., 2014). Despite the stimulation from authorities, the technological developments and spiking research interest in synchromodal transport, the implementation of synchromodality in the current transport planning operations is difficult. One of the reasons is the lack of decision tools to support shippers, carriers and Logistics Service Providers (LSP) to act on real-time information efficiently.

Recently, several research projects have introduced decision-support algorithms and heuristics to solve logistics problems in synchromodal transport. However, the existing algorithms lack the ability to adjust solution concepts based on unexpected events, becoming known by real-time information. Disturbances in a transport plan are an example of unexpected events, and are of vital importance in transport planning as they can cause a ripple effect. The difficulty of reacting to disturbances is confirmed by the different stakeholders in the European hinterland freight network, e.g. stating that approximately only 80% of freight trains arrive on time. They emphasize the need for cost-efficient recovery planning support, without loss of service level for their customers.

Currently, most LSPs employ alternative modes of transport (mainly trucking) based on a first-come first-serve policy as recovery strategy when a disturbance occurs, which in general is cost-inefficient (van Riessen et al., 2016). However, within synchromodal operation there might be opportunities to adjust the original plan without driving up costs to deliver affected orders on time, employing the capacity of the network as a whole. How to find these opportunities using information about the disturbance, regarding the severity, duration and impact on the network, has not been studied before. Assuming that the state of a disturbance is regularly updated, the planning adjustments can be updated as well. The timing of information can be divided in different phases based on the amount of information available. This leads to a dynamic algorithm where the state of a disturbance is assessed at discrete time intervals and based on available information the expected recovery costs can be minimized.

2. Problem Description

For the scope of our research, we focus on recovery plans for a single chain of transport modes within a synchromodal network, considering two different modes in the chain. The orders shipped in the chain are assumed to be known; last-minute rush-orders are left out of scope. We assume that the information sharing is perfect between the involved stakeholders, i.e. shippers, who supply the orders, carriers, who facilitate the transport, LSPs, who have a responsibility of connecting shipments to carriers in a cost-efficient way from their origin to their destination, terminal operators, handling the orders and responsible for transferring between modes, and network operators. An algorithm is developed for minimizing the costs due to unexpected disturbances in the network, obtaining cost-efficient recovery solutions while maintaining the service level as much as possible. Under the said assumptions we aim to investigate the value of information sharing regarding disturbances. Under perfect information sharing we expect that recovery solutions need to be less focused purely on maintaining service level, employing alternative transport for any affected order, and more on cost-efficiency as the progress of a disturbance can be incorporated in the recovery decision.

We assume both the scenario of chains spanning only long-haul freight transport (between terminals) as well as the scenario of a chain where one connection is the pre- and end-haul truck delivery. A visual depiction of a chain of long-haul transport studied in this research can be found in Figure 3. The locations A and B are both origin and destination, T is a terminal in between where the shipments are transferred from one mode to another. Both between A and T and between B and T a fixed connection, such as train or barge, is the primary option for transport, visualized by bold arrows here. From all locations there is also an option for alternative transport (by truck) to service critical demand in order to be able to satisfy demand with minimal overdue delivery, visualized by dashed arrows. In the case one of the connections represents pre- and end-haulage, e.g. between T and B, B can be viewed as a set of destinations within a region to which orders must be delivered and from which demand orders originate.

For every connection a set of possible disturbances is identified. The mode of transport, as well as geographical characteristics of a connection are the main elements that influence the type of disturbances that can occur on a connection. Different types of disturbances vary in the expected duration, information availability and reliability, and impact on the network. A late departure of a train only affects the path of all orders and the assets used on that transport, but other trains using the same corridor need not be affected. A defect of a part of a rail on the other hand affects all trains on that corridor. Information availability can be different, illustrated by the following

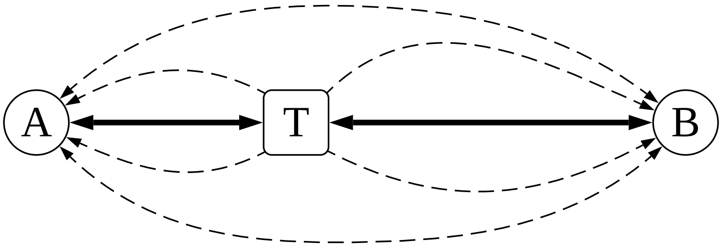

Figure 3: One intermodal chain, with freight moving both from A to B as from B to A, always via a transshipment terminal T. At each point it is always possible to reach the end-destination through an alternative route, indicated by dashed arrows.

example. The information-flow of a disturbance due to a defect on a rail track moving wagons equipped with GPS-tracking is much better than when it is dependent only on a local maintenance team.

The relevant disturbances for each corridor are categorized based on these varying characteristics, grouping disturbances of similar gravity and expected duration. The timing of information is assumed to follow a similar path for all disturbances. First a disturbance becomes known as it occurs, upon which it can be immediately categorized and the availability of a mode is adjusted accordingly. A diagnosis of the demand regarding its severity and duration is supplied and the category of the disturbance as well as the expected time of it being cleared up are updated if needed. If any updates on the diagnosis are offered, the category and duration are updated accordingly. The final stage of a disturbance is its clearance after which a mode is fully operational. Note that even for disturbances without intermediate diagnoses, i.e. with only notification of a disturbance and its sudden clearance, can still be incorporated in this framework by assigning a separate category to this type of disturbance. Also, by categorizing disturbances, estimation of the gravity of unprecedented types of disturbances can be assessed as well by looking for similarities with the defined categories.

3. Approach

First, we obtain information about the type and frequency of disturbances and how they affect the rest of the network from various logistics companies in the Netherlands, dealing with intermodal transport. In order to build a framework for categorizing disturbances, we consult the varying stakeholders involved with freight transportation on different corridors. Their experiences provide information about possible disturbances based on historical data, as well as insights into how the different types of disturbance should be grouped. Based on this information different categories of disturbances can be identified. By assuming different phases of information regarding the disturbance, we can obtain insight in the value of updating the information.

Next, an algorithm is designed for recovery planning able to react to said categorized disturbances with the objective of minimizing the expected transportation costs. Overdue deliveries are penalized and incorporated in this minimization. Incorporating disturbances in an online transport planning algorithm is difficult due to the complex stochastic structure of disturbances, regarding their duration, their impact and their frequency. To deal with the stochasticity of occurred demands we employ a dynamic algorithm that categorizes disturbances at each time period to assess the best possible plan for all orders. Note that the prediction of occurrences of disturbances is not incorporated in this algorithm. The algorithm is designed to plan from an order point of view, choosing the best path for an order to reach its destination from its current location. Availability and feasibility of paths in the network are assessed dynamically, enabling to adjust a transport plan of an order, even if it is not directly affected by a disturbance (e.g. taking an earlier train because the order a wagon was booked for is too late or travels through a different route and is last-minute available).

The algorithm is dynamic in the sense that at discretized time intervals the categories of the disturbances in the chain are updated if new information is available. From this new information and the current duration of each active disturbance at these time intervals, probability distributions of the time left before clearing the disturbance can be obtained. The state of a disturbance can be modelled with a Markov Chain, where the state is defined by its category and duration up to now. Probabilities for jumping to other states, including the state of clearance, are derived for all states. Employing this method a Markov Decision Process of finite horizon can be defined for all orders, both currently in transport as well as soon to be starting shipments. The decision that is made is to either use alternative transport, use earlier available spots on the regular corridor (that can come available because of delayed shipments), or wait until the disturbance is cleared, taking expected availability of spots when the disturbance is cleared into account. The finite horizon can be defined as when an order becomes obsolete, e.g. the best-before-date of perishable items. Note that this is an offline optimization as the optimal policy can be defined based on the given Markov Chain.

The designed algorithm is validated by several experiments based on case studies provided by the industry. Different varieties of transport chains are incorporated, dealing with different types of disturbances. The performance of the algorithm is assessed by comparing the costs for recovery plans of the solutions to the costs that were realized. From these results we can obtain insights in the value of diagnosing disturbances and updating the status as well as finding a structure of business logic that can be applied in these circumstances. We expect that by incorporating more information about the status of disturbances in the recovery plans, less costs need to be made as the expected progress of a disturbance is taken into account. We believe that this algorithm is capable of handling the vast amount of data available in a synchromodal chain in a real-time setting, paving the way for efficient decision support for recovery planning.

Multiple corridors between two nodes in the chain will be incorporated in a later stage of this research. We see opportunities for future work by incorporating self-learning mechanisms in the categorization of disturbances. By comparing previous categorizations, i.e. the initial state a disturbance was assigned to plus the progress through the Markov Chain, to the progress it would have followed for a different initial state, the impact on the costs can be quantified. After the clearing of a disturbance the categorization rules can be modified, using reinforced learning techniques, if it turns out that a different categorization would have resulted in a better solution. This places the optimization in an online environment, and we expect the obtained solutions to significantly improve. We also see opportunities for extensions to multiple chains or a complete intermodal network. Also incorporating revenue management of shippers would be an interesting research opportunity, as this would make the calculation of expected costs much more complex. However, the insights in how services should be priced when a disturbance occurs can be very valuable.

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