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Real-time container transport planning with decision trees based on offline obtained optimal solutions

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ABSTRACT

Hinterland networks for container transportation require planning methods in order to increase efficiency and reliability of the inland road, rail and waterway connections. In this paper we aim to derive real-time decision rules for suitable allocations of containers to inland services by analysing the solution structure of a centralised optimisation method used offline on historic data. The decision tree can be used in a decision support system (DSS) for instantaneously allocating incoming orders to suitable services, without the need for continuous planning updates. Such a DSS is beneficial, as it is easy to implement in the current practice of container transportation. Earlier proposed centralised methods can find the optimal solution for the intermodal inland transportation problem in retrospect, but are not suitable when information becomes gradually available.

The main contributions are threefold: firstly, a structured method for creating decision trees from optimal solutions is proposed. Secondly, an innovative method is used for obtaining multiple equivalent optimal solutions to prevent overfitting of the decision tree. And finally, a structured analysis of three error types is presented for assessing the quality of an obtained tree. A case study illustrates the method's purpose by comparing the quality of the resulting plan with alternative methods.

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1. Introduction

Continuous growth of global container volumes puts increasing pressure on the inland road, water and rail connections, especially in developed countries with limited public support for infrastructural expansion. Simultaneously, shippers require more reliable inland connections because their supply chain demands for just-in-time delivery, and the environmental impact of the inland transportation is increasingly bound by restrictions from governments and from shippers themselves. In this study, we consider decision support for the planning of inland transportation. The problem is based on the situation of European Gateway Services (EGS), an inland transportation network providing transportation between the deepsea ports in Rotterdam and various *extended gates* in the European hinterland [43,45]. Although the inland network has sufficient capacity in general, temporary congestion occurs frequently on all inland modes: road, water, and rail connections. Most inland transportation of containers is carried out by operators that are dedicated to specific modes. In the light of these developments, an integral approach for the routing and planning of all inland container transportation is vital. In this study we propose a real-time DSS for providing improved planning support. In particular, we propose to use decision trees as method in the DSS. Decision trees are a way to represent rules underlying data with hierarchical, sequential structures that recursively partition the data [23]. In our method, the routing decision is made per container, by applying the tree to the properties of the container transportation order (i.e. booking). Fig. 1 gives an example of a decision tree supporting the routing decision for a container.

1.1. Characteristic intermodal decision problem

For a particular corridor (i.e., the set of available transportation options between two locations), a set of inland services is available, characterised by the mode of transport (barge, rail or truck), cost per container, departure time, arrival time, and vehicle capacity (volume and weight). Naturally, the time between departure and arrival of a service depends on the mode's travel speed. Typically, speed and cost are high for trucking and low for barge transport. Volume capacity is high for barge transportation and low for a truck. The weight capacity for both barge and truck is mostly not restrictive. The mode train has intermediate levels for speed, cost and capacity, but typically has a restrictive weight capacity, especially in mountainous regions. In this setting, we consider scheduled barge and train services with fixed capacities,

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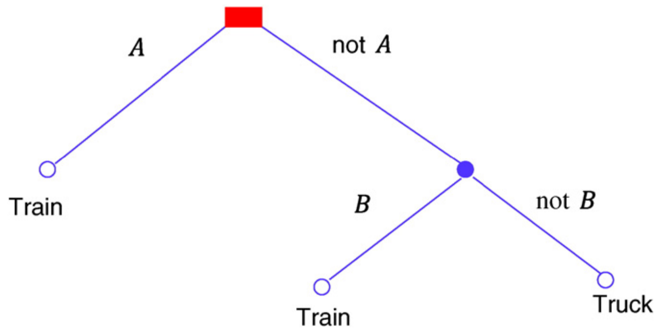

Fig. 1. Example decision tree for deciding on the mode of transportation for a container. The first decision is based on whether or not the container has property A. If not, a second decision follows, based on whether or not the container has property B.

while trucks can be ordered at any time without limits. Generally, in a transportation setting, orders arrive sequentially at a transportation network planning department. Each order has several attributes, such as the client name, the number of containers for the order, the booking lead time, the transport lead time and the size and weight of each container in the order. The number of containers is measured in standard container sizes of Twenty feet Equivalent Units (TEU). The booking lead time is the time between the arrival of the order and the availability of the container; the transport lead time is the time between the availability of the containers and the due time at the destination (see Fig. 2). The planner's goal is to transport the containers at the lowest possible total cost, ideally before the due time of the containers, but often it is allowed to deliver a little later, indicated by the overdue time. In practice, overdue delivery can sometimes be negotiated with customers, in our modelling overdue delivery is allowed at a penalty cost for the network operator. The characteristics of this decision problem do not change over time, giving rise to periodicity, e.g. weekly. Therefore, analytics on historic information can be used to find patterns and create a decision tree (DT). Subsequently, this decision tree can be used for decision support in future periods.

Fig. 3 illustrates an example of the characteristic intermodal decision problem schematically. We consider 1 origin, A, and 2 destinations: B and C. Both destinations can be reached by using a truck (T) or a rail connection can be used (R), for transport from A to B or from A via B to C. In the case of using rail transportation for containers with destination C, last mile trucking from B to C is required. In general, rail is cheaper than truck, but has limited capacity. Trucking capacity is abundant, and considered unlimited for this study. The train has a limited capacity, denoted by K. The costs for the four transportation options are denoted as c_{dm}, where d denotes the destination and m denotes the used mode, $d \in \{B, C\}, m \in \{R, T\}$. E.g., c_{BR} denotes the costs for transporting one unit from A to destination B by rail. Typically, the goal is to maximise the utilisation rate of the lower priced rail mode for the highest yielding destination. Because of different transportation restrictions between container classes and differences in costs, this decision problem is not straightforward.

For the planner, who must make decisions instantaneously for incoming orders, the question is how many slots to reserve for each destination, i.e., use a booking limit of K_B slots for containers to destination B and K_C slots for destination C, adhering to $K_B + K_C = K$.

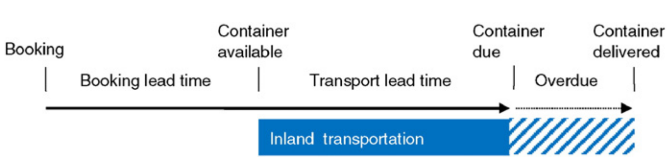

Fig. 2. Timeline of orders and inland transportation.

1.2. Real-time intermodal planning problem

Nowadays, in real cases (according to our experiences with EGS) often a greedy approach or first come, first serve (FCFS) approach is used for planning the container transportation. In case of a greedy approach, a container transportation order is assigned to the cheapest feasible service at the time of order arrival, i.e. the cheapest service with free capacity that travels within the container's time restrictions. In an FCFS approach, a booking is assigned to the earliest available service. In both methods, an order is assigned instantaneously at the time of order arrival.

The problem addressed in this study is to allocate an incoming order immediately to the most suitable inland service, as part of the optimization of the entire corridor. Existing scientific methods for real-time decision making for planning of inland container transportation focus on finding cheapest or shortest paths per transport order [49,50]. More advanced methods for solving the online problem require real-time automated data processing and are less insightful to human planning operators [22,25]. We propose a method for allocating orders to services based on optimal historical plans.

1.3. Proposed method for real-time decision support

In recent years, several studies have proposed optimisation methods for determining the optimal allocation of containers to all available inland transportation services, considering capacity, costs, lead times and emissions. The proposed methods are suitable for solving the *offline* planning problem, in which an optimal network plan is created for a batch of transportation orders collectively. In intermodal networks, such as the network of European Gateway Services, the implementation of a centralised offline approach is difficult for various reasons:

- Real-time decisions: The nature of the inland transport logistics requires a real-time approach, in which a customer can get immediate feedback on the selected mode, route, and most importantly, the estimated time of arrival. Consequently, updates in the planning of inland transportation have large influences on the subsequent production processes, possibly resulting in an undesired cascade of changes in earlier determined plans. An improved solution method must support real-time planning decisions, without continuous planning updates.
- Incomplete information: The operation of transportation systems is often not centralised, but depends on multiple cooperating decision makers, e.g. a logistics service provider and a transportation operator. The supply chain of container logistics lacks information integration [39]. Capacity and/or demand information for future periods is often not fully available. However, existing centralised optimisation methods depend strongly on complete information from integrated and automated processes, both for terminals, as for other parts of the supply chain. They lack the flexibility to deal with incomplete information. A method must therefore be able to provide decision support even with incomplete information.
- Human-aware decision making: In relation to the previous aspect, planning operators manually gather information ad hoc, such as real-time information on capacity and delays. Delays are common as the workloads in container terminals have a stochastic nature and are distributed unevenly in time [24]. For this, direct communication between manual operators is essential [12]. A transparent approach is required that allows the human operators to include manually obtained information in the decision process. We consider this the white box poperty of the desired solution method.

In this paper, we propose a general method for a real-time DSS that addresses the aforementioned issues, by meeting three main requirements. Firstly, the proposed method allows real-time decision support for allocating incoming transport orders directly to available inland services, resulting in a stable solution and instant feedback to the customer

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