European Journal of Operational Research 227 (2013) 216–226

Contents lists available at SciVerse ScienceDirect

European Journal of Operational Research

journal homepage: www.elsevier.com/locate/ejor

Innovative Applications of O.R.

# Combining linear programming and automated planning to solve intermodal transportation problems

Javier García [a,*], José E. Florez [a], Álvaro Torralba [a], Daniel Borrajo [a], Carlos Linares López [a], Ángel García-Olaya [a], Juan Sáenz [b]

[a] Computer Science Department, Universidad Carlos III de Madrid, Avenida de la Universidad 30, 28911 Leganés, Madrid, Spain
[b] Acciona I+D+i/Acciona R&D, Valportillo II 8, 28108 Alcobendas, Madrid, Spain

ARTICLE INFO

*Article history:*
Received 9 March 2012
Accepted 17 December 2012
Available online 27 December 2012

*Keywords:*
Logistics
Intermodal transport
Linear programming
Heuristic planning

ABSTRACT

When dealing with transportation problems Operational Research (OR), and related areas as Artificial Intelligence (AI), have focused mostly on uni-modal transport problems. Due to the current existence of bigger international logistics companies, transportation problems are becoming increasingly more complex. One of the complexities arises from the use of intermodal transportation. Intermodal transportation reflects the combination of at least two modes of transport in a single transport chain, without a change of container for the goods. In this paper, a new hybrid approach is described which addresses complex intermodal transport problems. It combines OR techniques with AI search methods in order to obtain good quality solutions, by exploiting the benefits of both kinds of techniques. The solution has been applied to a real world problem from one of the largest spanish companies using intermodal transportation, Acciona Transmediterránea Cargo.



## 1. Introduction

Nowadays, intermodal transportation plays a key role in international logistics. Intermodal transport commonly refers to the combination of two or more modes of movement of goods, such as road, rail, or sea [1,2]. In this type of task, the use of Operations Research (OR) is still limited. Research on logistic problems usually focuses only on one mode of movement of goods, whether by road [3–5], rail [6], or sea [7]. However, there are two observations that make intermodal transportation problems more challenging than the uni-modal one: on one hand, the optimal path is not the shortest path anymore; instead, additional costs have to be considered at the nodes where a new transportation mean is applicable e.g., money and/or time. On the other hand, a new class of constraints has to be observed, which (to make things harder) is dependant on each node e.g., operating an exchange of transportation mean can actually involve other subproblems as it happens when moving goods from a truck to a ship. Thus, it provides very interesting and challenging tasks for researchers working in OR and related areas, such as heuristic search.

This paper deals with a real-world problem and in particular it focuses on the specific intermodal transportation problem of the spanish company Acciona Transmediterránea Cargo. As presented in the Related work section, in the literature, we did not find any article describing the same intermodal transport problem. This particular problem fits into the *intermodal* chain of *container*-transportation services described in the literature [1]. This chain usually links the initial pick-up point to the final delivery point of the container, visiting in between different pick-up and delivery points. Transportation is provided by several carriers. Our contribution attempts to provide a new application, TIMIPLAN, to solve problems of this kind. The planning component of TIMIPLAN consists of two phases: in phase one, for each set of goods to be picked up and delivered, the containers and trucks with minimum estimated cost to complete the service are selected. In this phase, several assignment models are constructed and solved as linear programming problems. In phase two, an Artificial Intelligence (AI) planner is used to select the best (cheapest) plan to serve each service: from a first pick-up point to the last delivery point over the service. The plan should fulfill a given set of constraints (temporal and regulatory), and will include the sequence of the transportation modes to be used. Although some of the application areas addressed in AI and OR are very similar (e.g., planning, scheduling), the methods that are used to solve these problems are substantially different. This paper describes the application we have developed for a big logistics company, and provide some experimental results that evaluate the software in real situations extracted from the customer database.

The remainder of the paper is organized as follows. Section 2 gives a brief summary of the transportation problem in its

* Corresponding author. Tel.: +34 637967331.
*E-mail addresses:* fjgpolo@inf.uc3m.es (J. García), jflorez@inf.uc3m.es (J.E. Florez), atorralb@inf.uc3m.es (Á. Torralba), dborrajo@ia.uc3m.es (D. Borrajo), carlos.linares@uc3m.es (C.L. López), agolaya@inf.uc3m.es (Á. García-Olaya), jsaenz@acciona.es (J. Sáenz).

0377-2217/$ - see front matter © 2012 Elsevier B.V. All rights reserved.
http://dx.doi.org/10.1016/j.ejor.2012.12.018

uni-modal and intermodal versions, introducing some of the main approaches used to solve it. Section 3 describes the intermodal problem in detail. Section 4 presents the TIMIPLAN algorithm. In this section, two ways to tackle the assignment problem of containers and trucks to services are described. In addition, in this section the planning module to select the best transportation modes is explained in detail. Section 5 shows the experiments performed. Also, it describes some comparative results of the two versions of the TIMIPLAN algorithm. Lastly, Section 6 presents the conclusions and further research.

## 2. Related work

Many approaches have dealt with the uni-modal transport problem. Coslovich et al. [5] focus on the container transportation problem taking into account the routing costs, the resources, and the container repositioning costs. Their approach has several similarities and analogies with our work (also in the solution approach, which uses the decomposition into subproblems). However, their approach focuses only on a fleet management problem that arises in a truck company, excluding the transport by ship or rail (significantly reducing the complexity of the problem). Powell et al. [3] tackle the problem of assigning drivers to loads in order to minimize the empty miles, but, again, only considering truck transportation. An interesting uni-modal solution for large transportation problems also is proposed by Sprenger and Monch [8].

There has also been some work in the intermodal transport problem [1,2]. Chang [9] focuses his study on how to select the best routes for shipments in an intermodal network. Because the entire problem is NP-hard [9], the original problem is broken into a set of smaller and easier subproblems, based on Lagrangian relaxation and decomposition techniques. However, in contrast with us, Chang assumes that the trucks drivers have no time constraints, and, additionally, Chang only reports results for problems carrying 10, 6, and 8 containers from the suppliers to the customer, over a small network graph of 112 nodes and only 407 links. Our biggest problem requires 300 containers movements over a network graph of 600 nodes and more than $3 \times 10^5$ links. Imai et al. [10] also propose to decompose the original problem into two different subproblems using a subgradient heuristic based on Lagrangian relaxation. However, they partially tackle the problem of intermodal transportation, as long as they only consider the problem of vehicle routing that arises in picking up and delivering full container load from/to an intermodal terminal (regardless of schedules of ships or trains). Bock [11] addresses a similar multimodal problem using LP techniques but with several important differences with the intermodal problem presented here. On one hand, Bock does not consider the containers in his multimodal problem and, hence, does not take into account the initial assignment of trucks to containers, which implies a significant reduction of the problem complexity. On the other hand, the biggest problem he considers has only 65 vehicles and 5 global transportation hubs. The biggest problem our approach deals with here has 300 trucks, 300 containers and more than 150 ship and train segments. Instead, Verma et al. [12] focus on the transport of hazardous material using truck-rail multimodal transportation (i.e. obviating the ship transportation mode) over a well-defined region of the US with only 37 shipper/receivers and 31 train segments and, additionally, assuming that the drivers have no time constraints. Gromicho et al. [13] propose an interesting and promising approach but considering only a single network to transport a container from a pick-up node to a delivery node. Therefore, they do not compute what container is the best to complete a service, and they not address the problem of solving multiple services sharing the same resources. Thus, all these approaches cannot be directly applied to our problem described in Section 3.

Also, there have already been some approaches that try to combine AI techniques with OR techniques. Bylander [14] uses linear programming as a heuristic that improves the search process in non-linear planning; Kautz and Walser [15] uses linear programming formulations for planning problems with different resources, action costs, and difficult objective functions; Fernández and Borrajo [16] solves the clustered-oversubscription problem by performing an action selection pre-processing to help the planning task using linear programming. In comparison with these works, we propose to use linear programming combined with planning in a different way. In our case, linear programming is used first to compute the assignment cost of resources to services in order to find the assignment with the least estimated cost. Later, we formulate each task as a planning problem where the previously selected resources are taken into account.

While OR techniques solve problems that can be modeled with linear constraints very efficiently, we advocate their combined usage with other general techniques like Automated Planning (AP) [17]. One of the main reasons is that Automated Planning actually starts by considering a very expressive language which usually overcomes some of the difficulties found when modeling a problem with linear constraints. Also, the standard language considered in AP (most likely PDDL [18] but also many other variants) is very well suited to represent a wider class of problems. These differences do not only apply to constraints, but also to the objective function, since AP can use non-linear optimization functions.

## 3. Problem description

This paper focuses on the container-based intermodal transportation problem (transportation of containerized cargo by a combination of truck, rail, and ocean shipping, to move massive quantities of containers) [1], but with the requirements of the company Acciona Transmediterránea Cargo. Formally, our intermodal transportation problem can be defined as the tuple $\langle G, F, C, R, B, S \rangle$ where $G$ is the network graph, $F$, $C$, $R$ and $B$ are the sets of trucks, containers, trains and ships respectively and $S$ the services that should be fulfilled. Let $G = (P, E)$ be a directed graph, where $P$ and $E$ are, respectively the set of nodes and set of edges representing a direction in which the corresponding arc can be traversed. In intermodal transportation there are different kinds of nodes: all nodes in $P$ represent nodes that can be reached by trucks and containers, and $M \subseteq P$, represents intermodal nodes where one has to select between continuing with the current mode or changing it (as ports or train stations). Also, there are different kinds of edges representing roads, rails or ship routes.

Let $F$ be a set of trucks, with $|F| = n_f$, and let $C$ be a set of containers, with $|C| = n_c$. Each truck $f \in F$ and container $c \in C$ is characterized by a series of parameters as shown in Table 1. The existing temporal restrictions in the problem (each pick-up and delivery is scheduled according to the service time of each place) imply that an explicit management of the current time is needed. If a truck arrived early to a pick-up or delivery point, it must wait, and when it arrives late a penalty cost is applied. In addition, a container must wait at the station or port for the next departure of the train or ship. So, associated to each truck and container, there is a time counter, $t_f$ and $t_c$. The truck and container movements conveniently increase the value of these time counters. Let also $R$ be a set of trains, and let $B$ denote a set of container ships. Each train $r \in R$ and $b \in B$ are characterized as shown in Table 2.

Let $S$ be a set of services, with $|S| = n_s$. For each service $s \in S$ a predefined route is given by the ordered sequence of points $U_s = (u_1, u_2, \ldots, u_j)$, where $u_1$ is a pick-up point, $u_j$ is a delivery point, and $u_k$, $1 < k < j$, is a delivery or pick-up point. The pick-up and delivery order is set by the Acciona's client requesting the service.