

# TIMIPLAN: An Application to Solve Multimodal Transportation Problems

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## Abstract

Intermodal transportation is a very challenging task for AI planning. It is a logistics problem in which a set of goods have to be transported to different places, with the combination of at least two modes of transport in a single transport chain, without a change of container for the goods. The main goal of this paper is to introduce TIMIPLAN, a new application to solve multimodal transportation problems. TIMIPLAN has been developed in the context of a research project involving one of the biggest Spanish companies in intermodal transportation, Acciona Transmediterránea Cargo. The main challenge of this project is the size of the planning problems: more than 300 containers, trucks, locations and services have to be dealt with everyday. Thus, internally, TIMIPLAN combines Operational Research (OR) techniques with Artificial Intelligence (AI) planning in order to obtain good quality plans, by exploiting the benefits of both kinds of techniques. These plans can be also graphically visualized.

## Introduction

Nowadays, multimodal transportation plays a key role in international logistics. Multimodal transport is commonly known as referring to the combination of two or more modes of movement of goods, such as road, rail, or sea (Muller 1999). The development of multimodal transportation has been followed by an increase in multimodal transportation research (Bontekoning and Kreutzberger 1999; Macharis and Bontekoning 2004; Jourquin, Beuthe, and Koul a Njang Ha 1999). Thus, it provides a real and challenging domain for researchers working on AI planning and scheduling. However, there are relatively few applications to solve the multimodal transportation problem. The logistics research usually focus only on one mode of movement of goods, whether by road (Eibl, Mackenzie, and Kidner 1994; Ropke and Pisinger 2006), rail (Tormos et al. 2008; Salido and Barber 2009), or sea (Imai, Shintani, and Papadimitriou 2009). However, the multimodal transportation is more complex than the unimodal one. First, the number

of ways to complete a transportation route grows exponentially as the number of vehicles raises due to the possibility of changing the transportation mode in the middle of the route. In addition, multimodal transportation increases dramatically the search space of the problem, because it introduces several alternatives to attend each transportation route, and it forces us to take into account many more constraints in order to connect one type of transportation to the others.

In this paper, we deal with a real-world problem and in particular we focus on intermodal freight transport. Our contribution attempts to provide a new application, TIMIPLAN, to solve problems of this kind. The planner 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 transportation route are selected. In this phase, an assignment model is constructed as a linear programming problem. In phase two, a planning module is used to select the best plan from a first pick-up point to the last delivery point over the transportation route, where best means that the plan fulfills a given set of constraints, including the sequence of the used transportation modes with the minimum cost. The proposed approach tries to balance between the total cost obtained and the time required to compute the plan. This paper focuses on the main aspects of TIMIPLAN.

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 usually substantially different. The possibility of using OR techniques combined with AI planning has not received much attention. However, it seems natural that recent research in AI planning and OR has focused on combining different techniques that are used in these areas trying to exploit the benefits of both kinds of techniques (Bylander 1997; Kautz and Walser 1999; Bockmayr and Dimopoulos 1998).

The remainder of this paper is organized as follows. Section *Problem Description* describes the multimodal transport problem in detail. Section *TIMIPLAN* presents the TIMIPLAN application. Section *Example Problems* shows some examples problems and the plans proposed to solve them. Section *Related Work* gives a brief summary of the trans-

portation problem in its unimodal and multimodal versions, introducing some of the main approaches used to solve it. Lastly, Section *Conclusions* presents the conclusions and further research.

## Problem Description

In our problem, there is an initial set of transportation requests, and for each request (or service) a route must be generated. Each transportation request specifies the locations where the goods need to be picked up and locations where they are to be delivered. A service time is associated with every pickup and delivery location, that indicates the time at which the corresponding location is available for the pick-up or delivery service. In addition, there are trucks and containers. To complete a transportation route only a container is required, but it can be moved by using combinations of trucks, trains and/or ships. If a truck is used, it should travel to pick the container up, and either visit all locations of the transportation request (picks up and delivery locations), or transport it to the next transportation means (train station or port). The resulting plan should satisfy the given service times of the locations. For instance, if the truck and container arrive early, they have to wait at the location until it is available. If the truck and container arrive late, there will be a cost penalty.

In multimodal transportation several trucks are usually needed. For example, Figure 1 shows how, in order to complete the transportation route, there are available three trucks, one container, one train or two ships. The first truck with the container picks the shipment up from P1 and transports it in the container to either P2 (to continue by road) or S1 (to continue by train). Also, two different ships could be used to transport the container with the goods to the islands.

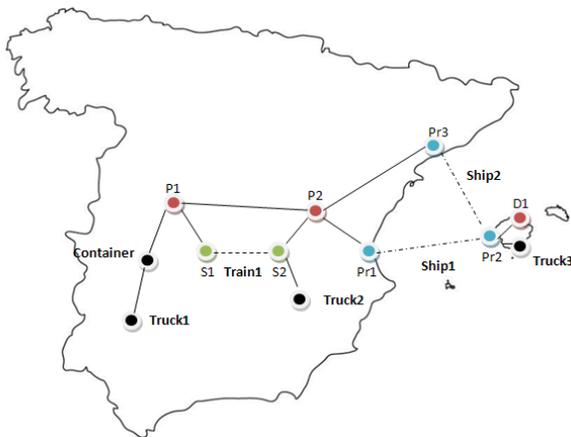


Figure 1: Example of a multimodal transportation route.

Thus, there are several kinds of resources, each one with different kinds of costs (e.g., moving the truck empty is dif-

ferent from moving it loaded), different routes (either single mode routes, as all road, or multi-modal routes, as combining trucks with badge and/or rail), and with temporal and resource constraints (drivers have constraints on number of hours driving, for instance). In addition, Acciona Transmediterránea imposes a time limit to solve a daily graph with about 600 nodes (summing up all pick-up and delivery nodes, as well as initial positions of trucks, containers, ships, and trains), 179,700 edges, 300 trucks, 300 containers, 300 transportation routes, 42 train segments and 148 ship segments. The time limit is fixed to only 2 hours.

## TIMIPLAN

TIMIPLAN solves logistic multimodal problems. In our context, this implies to receive a number of requests as input, understanding a request as the load of goods in different places and the unload on other ones, and the assignment of the available resources (trucks, containers, ships, trains, drivers, ...) to complete this request. Also, it must take into account several constraints, such as pick-up and delivery times. The objective is to obtain a plan that minimizes the cost of servicing all the daily requests. Actions are similar to any standard logistics planning task: assign a driver and truck to a request; move transportation means to a location; load goods on truck/train/ship; or unload goods from truck/train/ship.

## Architecture

TIMIPLAN is composed of a set of modules as shown in Figure 2. The input is the list of services to accomplish and the list of available resources (initial locations of each resource, costs, constraints, ...), both in XML format. The output is a plan for each service. This plan can be graphically inspected on a map which includes points where the actions are performed and the routes followed by the vehicles. The Web access component performs different queries to Web portals like Google Maps or traffic information. Once TIMIPLAN creates the problem description, it is passed to the planner (combination of OR and AI). The Monitoring component allows TIMIPlan to detect deviations from the original plan or new services to be planned for, that arise everyday.

## Solving the problem by Linear Programming and Planning

The first approach that we tried was giving the complete problem to an automated planner. Unfortunately, given the size of the problem, no domain-independent planner can go beyond the instantiation phase. For instance, the load-truck action has three parameters (truck, container, location). Thus, there are about  $300 \times 300 \times 600 = 54$  million potential instantiations of that action only. Given its complexity, to tackle the multimodal transportation problem, we

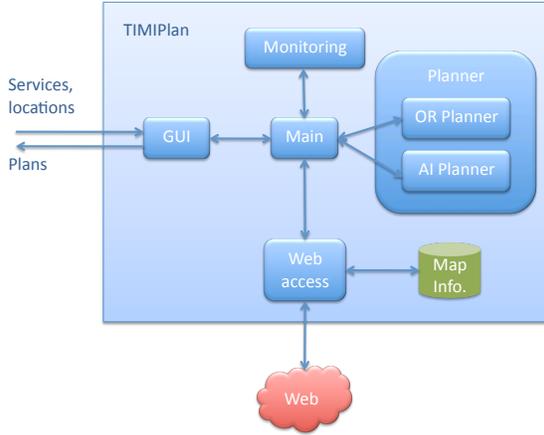


Figure 2: TIMIPLAN architecture.

decompose it into two subproblems. The first subproblem is an assignment problem, in which for each transportation route the truck/s and container with minimum estimated cost to complete it are selected. The second subproblem is a logistics planning problem, in which the best transportation modes to achieve each individual service are selected trying to minimize its cost, using the truck/s and container selected in the previous phase. The high level algorithm is depicted in Table 1.

```

TIMIPLAN(G, F, C, R, B, TR)
:: Inputs: the network graph (G), and the set of trucks (F), containers (C), trains (R), ships (B)
:: and transportation routes (TR)
For each  $tr \in TR$ 
  :: Select the truck/s and container to complete the transportation route
  selectedTrucks,selectedContainer=solveAssignmentProblem(G, F, C, R, B, TR, tr)
  :: Plan the transportation route with the truck/s and container selected. Select the
  best transportation modes
  plan=solvePlanningProblem(selectedTrucks, selectedContainer, R, B, tr)
End
Return plan

```

Table 1: Top level algorithm of *TIMIPLAN*.

The transportation routes are solved sequentially. In each iteration, the algorithm takes into account the final positions and times of trucks and containers computed in previous iterations. In the next section, we explain first the algorithm used in this paper to solve the assignment problem based on linear programming. Later, we explain the planning problem in more detail.

**Assignment Problem** Again, this problem is quite complex: assigning an initial truck and container to each transportation request, such that the total cost of all assignments is minimal. Linear programming problems experience combinatorial explosion in that the number of solutions grows extremely fast as the number of the different elements in the problem increases, because of the many possible ways of combining the elements. Thus, we decompose it into three assignment subproblems: assignment of containers to trucks, assignment of truck and container to transportation routes, and assignment of trucks to multimodal nodes. In the first one we solve the assignment of containers to trucks. In the second one, we solve the assignment of trucks with containers to transportation routes, using the assignments computed in the previous phase. These operations involve the provision of an empty truck and container to the transportation route. The truck and container are used in the subsequent transportation until they arrive to the last delivery point in the transportation route or until they arrive to a multimodal node in the transportation route.

In multimodal transportation, additional trucks are needed in order to complete a transportation route. These trucks pick-up the containers from the destination station/port and transport it to complete the transportation route, or until they arrive to the next multimodal node. So in the third assignment subproblem, the method selects the best truck to pick-up the container from the destination station/port to continue the transportation route, taking into account again the previous assignments.

**Planning Problem** Once the truck/s and container are selected for each transportation route, a planning problem is built in order to find the best transportation modes to complete it. In our work, the planning system is built on a forward state-space planner, SAYPHI (La Rosa, García Olaya, and Borrajo 2007), that uses different kinds of heuristic search techniques. SAYPHI re-implements and augments the Metric-FF planner (Hoffmann 2001). The heuristic used by the planner is the relaxed planning graph heuristic and the search technique is  $A^*$ .

This module receives as input the truck/s and container selected in the previous phase to complete the transportation route. First, it selects the trains and ships that can potentially be used to complete the transportation route. Then, the planning problem is constructed taking into account the trains, ships and the truck/s and container selected to complete the transportation route. The problem is modeled using the PDDL language (Fox and Long 2003). Lastly the SAYPHI planner decides the best transportation modes in order to complete the transportation route. It also takes into account the time and resource constraints, through the extensive use of PDDL functions and metric computation.

Each pick-up and delivery is scheduled according to the time service of each place. This implies that we need an explicit management of the current time. If a truck arrived early to

a pick-up or delivery point, it must wait, and when it arrives later a penalty cost is applied. In addition, the container must wait at a station or port for the next departure of the train or ship, scheduled by functions (*departure-time-train ?t - train ?station1 - location ?station2 - location*) and (*departure-time-ship ?s - ship ?port1 - location ?port2 - location*). So, associated to each truck and container, we have a time counter, (*time-truck ?truck*) and (*time-container ?container*). The actions conveniently increase the value of these time counters. An alternative would have been to use a temporal planner, but there are very few currently that can also support functions, and metrics, as need in this project.

Figure 3 shows the description of action *load-train*. In this case, the time counter *time-container ?c* takes the value from the next departure of the train in which it is loaded. We can also see how actions are declaratively defined, so it is relatively easy for end users to understand what they perform or even modify those when problem constraints change.

```
(:action load-train
:parameters (?t - train ?c - container
             ?station1 ?station2 - localization)
:precondition (and (in-town ?c ?station1)
                  (in-town ?t ?station1)
                  (<= (+ (time-container ?c)
                        (time-load-train ?t ?station1))
                     (departure-time-train ?t ?station1 ?station2)))
:effect (and (not (in-town ?c ?station1))
             (in-train ?c ?t)
             (assign (time-container ?c)
                     (departure-time-train ?t ?station1 ?station2))))
```

Figure 3: Action *load-train*.

In our case, the initial state can be expressed as in Figure 4. As we can see, there is a cost per kilometer associated to each truck, when a *?truck* travels without a container or the container is empty as expressed by predicate (*cost-per-kilometer-empty ?truck - vehicle*). Also, we define a cost per kilometer when a *?truck* travels with a container and it is loaded (*(cost-per-kilometer-loaded ?truck - vehicle)*). Other functions represent the mean speed, expressed by (*mean-speed ?truck - vehicle*), and the cost applied when the truck is stopped in a location (*(cost-stopped ?truck - vehicle)*).

Associated to each pick-up or delivery service we define the time at which the corresponding location *?town* is available for the pick-up or delivery service (*(pickup-time ?freight - freight ?town - location)*), (*delivery ?freight - freight ?town - location*) and the penalty cost per hour applied when the pick-up or delivery is delayed (*(penalization-pickup-delayed ?freight - freight ?town - location)*), (*penalization-delivery-delayed ?freight - freight ?town - location*). Finally, associated to each ship or train there are different departure times and trip durations.

The goals in the problem are to reach the state where both pick-up and delivery points have been served. This goal can be defined as shown in Figure 5.

```
(:init
;; Trucks
(in-town truck1 11)
(= (cost-per-kilometer-empty truck1) 0.5)
(= (cost-per-kilometer-loaded truck1) 0.3)
(= (mean-speed truck1) 50.0)
(= (cost-stopped truck1) 0.6)
...
;; Roads
(road 15 12)
(= (distance 15 12) 347.0)
(road 14 11)
(= (distance 14 11) 200.0)
...
;; Containers
(in-town container1 11)
(empty container1)
(disengaged container1)
...
;; Freights
(in-town freight1 15)
(= (pickup-time freight1 15) 100)
(= (penalization-pickup-delayed freight1 15) 0.1)
...
;; Ships
(in-town ship1 10)
(ship-trip 10 13)
(= (departure-time-ship ship1 10 13) 200)
(= (departure-time-ship ship1 10 13) 400)
(= (trip-duration-ship ship1 10 13) 60.0)
...)
```

Figure 4: Example of an initial state of a problem.

```
(:goal (and
       (picked freight1 15)
       (picked freight1 11)
       (delivered freight1 16)))
```

Figure 5: Goals to be achieved.

## Example Problems

To evaluate TIMIPLAN, we need a set of representative problems, based on the real data gathered by Acciona Transmediterránea Cargo. We developed a random problem generator that uses these data. The problems were generated using ship routes and pick-up and delivery points gathered from real problems. These points are expressed using zip codes and are generated randomly, but according to the statistical frequency of each in the data provided by Acciona. In Figure 6, we show solutions to two different problems. The first one has 8 transportation routes, 10 trucks and 16 containers while the second one has 20 transportation routes, 37 trucks and 62 containers. Both problems contain locations on islands, so it is necessary to use ship transport. In the figure, the ship movements are represented as red lines, while the blue lines represent truck movements. TIMIPLAN solves the first problem in about 10 seconds and the second one in 30 seconds.



Figure 6: Plan examples.

In order to compare the results obtained, two different versions of the TIMIPLAN algorithm are applied to solve problems of different sizes. The first one was explained in Section *Solving the problem by Linear Programming and Planning* (TIMIPLAN (LP)). The second one is a greedy approach that selects at each step the container and truck/s with the least estimated cost for the planning phase (TIMIPLAN (GREEDY)). In this case, no cost matrix is built, taking only the truck and container with least estimated cost.

For each problem size, 10 different problems are solved in order to obtain representative mean values and standard deviations. All problems contain locations on islands, so it is necessary to use ship transport. Figure 7 shows the comparison of times to solve problems of different sizes using the two different versions of the TIMIPLAN algorithm. In Figure 7, x-axis represents the size of the problems solved (number of transportation routes) and the y-axis represents the mean time spent by the planner to solve the problems.

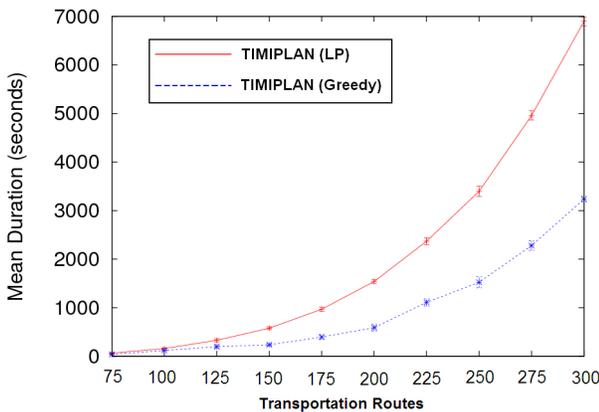


Figure 7: Mean solving time and standard deviations (in seconds) of solving problems of different sizes.

In the case of TIMIPLAN (LP), the mean time grows from 65.15 seconds (the mean time TIMIPLAN takes to solve the simplest problems) to 6896.09 seconds (mean time it takes to solve the most complex problems). Given that it performs a more complex assignment of trucks and containers to routes, this version of the TIMIPLAN algorithm needs more time to solve the problems than the greedy approach.

In the case of the greedy approach, the mean time goes from 38.05 seconds to 3236.94 seconds.

Figure 8 shows the comparison of quality (cost) of solutions of the same problems solved previously.

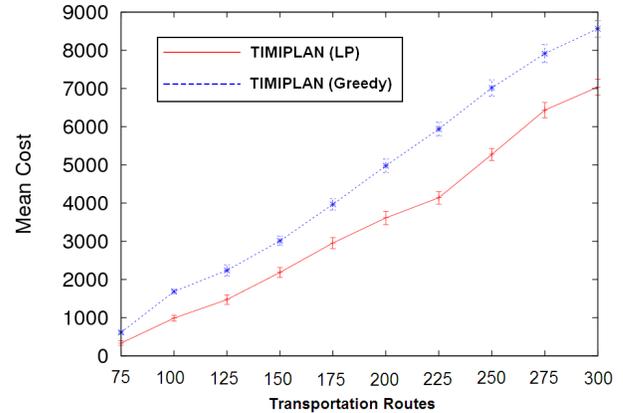


Figure 8: Mean costs and standard deviations of solutions to problems of different sizes.

In all cases, the mean cost obtained by TIMIPLAN (LP) is less than the cost obtained by the greedy approach. The planner TIMIPLAN returns valid plans and completes all the transportation routes before the time limit fixed by Acciona Transmediterránea Cargo. Given that the main driver of Acciona is the reduction in cost, once the rest of constraints are fulfilled, the combined approach of OR and AI techniques is the best current option.

## Related Work

There have been already many approaches that deal with the uni-modal transport problem. An overview of methods that approach the pickup and delivery problem and vehicle routing problem can be found in (Desaulniers et al. 2000; Nanry and Wesley Barnes 2000). In the multi-modal transport problem, there has also been some work done. In (Macharis and Bontekoning 2004), the authors discuss the opportunities for OR in intermodal freight transport. The paper reviews OR models that are currently used in this emerging transportation research field and define the modeling problems which need to be addressed. Most papers deal with the complementary nature and the competitiveness of different modes of transportation (Jourquin, Beuthe, and Koul a Njang Ha 1999), the choice of routes (McGinnis 1989; Lozano and Storchi 2001), economic returns vs. congestion (Van Schijndel and Dinwoodie 2000), taking into account either logistical aspects of multimodal terminals (Bostel and Dejax 1998; Kozan 2000), or the environmental impacts of the different transport modes (Campisi and Gastaldi 1996).

In (Eibl, Mackenzie, and Kidner 1994), the authors present

a case of study applying an interactive vehicle routing and scheduling software to a brewing company in the UK. It explains how a commercial tool was applied to schedule the day-by-day (operational) vehicle routing and scheduling to distribute the goods. This tool was specific for the brewing problem, and the operator that manages the tool needs a previous training process to manage all variables involved. In our case, the solution is quite domain-independent, with less user knowledge requirements. In (Catalani 2003), a statistical study is presented to improve the intermodal freight transport through Italy, by using the road-ship and road-train transports. In this study, only the main points of origin or destination are taken into account, so the study does not deal with the complete network complexity problem, as we do. In (Qu and Chen 2008), the authors pose the multimodal transport problem as a Multicriteria Decision Making Process (MCDM). They propose a hybrid MCDM by combining a Feed-forward Artificial Neuronal Network (FANN) with a Fuzzy Analytic Hierarchy Process (AHP). The case of study is a network in which the nodes represent terminals and edges represent different transportation modes (road, ship and train). The model can deal with several cost functions and constraints, but they only define six nodes.

## Conclusions

In this paper, the TIMIPLAN application has been introduced to successfully solve the multimodal transportation problem. Classical planning is able to handle a limited number of symbolic elements, without taking into account the numerical or temporal aspects of many real-world problems. Multimodal transportation usually involve the combination of a big number of resources, together with temporal constraints, resource consumption, cost functions, etc. Given the size of the instantiated problems, existing domain-independent planners can not solve those in a reasonable time. To deal with this problem we combine OR techniques with AI planning in order to obtain good quality plans in the given time limit. Currently, we have a first prototype with all components, except for the Monitoring and replanning component.

TIMIPLAN provides several improvements to the actual way to solve the problem by Acciona. Currently, both the assignment of resources and the route specification are generated manually by human experts who work in different places. The main problem is that each human expert has a particular point of view of the overall problem, and they manage their own resources. The whole planning interaction is performed through phone calls. They assume that this approach produces a significant overhead in terms of resources management, so a system to deal with the entire problem together with a unified user interface which provides mixed initiative services could be very useful to Acciona.

As future work, we attempt to provide a mixed-initiative approach for modifying plans, as well as finishing the implementation. At first, we have defined a set of services to im-

plement, which are divided in domain independent services and domain dependent services. The domain independent services include loading, evaluating, and solving problems, as well as visualizing and handling solutions. The domain dependent services include defining transportation resources or evaluating specific logistics operations.

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