TIMIPLAN: A Tool for Transportation Tasks

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Abstract. Multi-modal transportation is a logistics problem in which a set of goods has to be transported to different places, with the combination of at least two modes of transport, without a change of container for the goods. In such tasks, in many cases, the decisions are inefficiently made by human operators. Human operators receive plenty of information from several and varied sources, and thus they suffer from information overload. To solve efficiently the multi-modal transportation problem, the management cannot rely only on the experience of the human operators. A prospective way to tackle the complexity of the problem for multi-modal transportation is to apply the concept of autonomic behaviour. The goal of this paper is to describe TIMIPLAN, a software tool that solves multi-modal transportation problems developed in cooperation with the Spanish company Acciona Transmediterránea. The tool includes a solver that combines Linear Programming (LP) with Automated Planning (AP) techniques. To facilitate its integration in the company, the application follows a mixed-initiative approach allowing the users to modify the plans provided by the planning module. The system also integrates an execution component that monitors the execution, keeping track of failures and re-planning if necessary. Thus, TIMIPLAN showcases some of the needed autonomic objectives for self-management in future software applied to road transport software system.

1 Introduction

Multi-modal transport is an emerging field [1] that presents many different kinds of challenges for software development. Following the classification of problems in [2], this work focuses on the operational aspects of multi-modal operators, users of the multi-modal infrastructure and services who take care of the route selection for a shipment through the whole multi-modal network. In this work, we deal with multi-modal transportation, that is characterized by the combination of at least two modes of movement of goods, such as road, rail, or sea. The development of multi-modal transportation has been followed by an increase in multi-modal transportation research [2] and tools development. However, there are relatively few applications to solve the multi-modal transportation problem. The logistics research usually focuses on only one mode of movement of goods, whether by road, rail or sea. Multi-modal transportation is more complex than the uni-modal one. There are two observations that make multi-modal transportation problems quite challenging. On one hand, the optimal path is not the shortest path anymore; instead, additional costs have to be taken into account 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 freights from a truck to a ship. Additionally, the transport processes are subjected to a number of noisy inputs, like weather conditions, subjective driver decisions or incidents which cannot be predicted neither controlled.

In most cases, a human operator is in charge of the route selection for each shipment, and manually re-planning when failures occur such as traffic jams or damaged trucks. Thus, the transport management is strongly influenced by the human operator manager, who decides how to manage the services according to his competence about the transport needs. The human operators receive plenty of information from various sets of resources and thus they suffer from information overload. In order to efficiently solve the multi-modal transportation problem, the management cannot rely only on the valuable experience of the human operators. A way to tackle the complexity of the problem for multi-modal transport management is to apply the concept of autonomic behavior. In this paper, we propose a new decision support system (DSS), TIMIPLAN, implementing some autonomic properties for self-management, to solve a real problem assisting the operators in the task of planning the transportation routes for each service in multi-modal transport [3]. Firstly, TIMIPLAN presents the requested services and propose a solution that the users may accept or change using a mixed-initiative approach. Thus, we advocate that a truly autonomic system should also reflect on when it needs the help from humans and interact with them if deemed appropriate. Secondly, TIMIPLAN also allows execution control, as autonomic systems do [4]. Therefore, TIMIPLAN performs a cycle of monitoring the plan execution, analyzing deviation from the original plan (as in the case of traffic jams or damaged trucks), re-planning when unexpected situations are found, and executing the new plans. This cycle requires the system to sense, interpret and deliberate about goals to be achieved, available actions, taking into consideration changes in state, and resource or environmental constraints. TIMIPLAN can plan and act effectively after such deliberation in unexpected situations such as traffic jams, damaged trucks, or new transport requests. In these situations the self-healing objective of TIMIPLAN arises, being the heart on which the tool is built upon. In achieving that objective, TIMIPLAN has the following attributes: self-monitoring of its current state (e.g., truck positions), and self-adjusting and control of itself in unexpected situations (e.g., damaged trucks).

The remainder of this paper is organized as follows. Section 2 gives a brief summary of the multi-modal transportation problem introducing some of the main approaches used to solve it. Section 3 describes the multi-modal transport problem. Section 4 presents the TIMIPLAN decision support tool with a detailed explanation of the application workflow and its modules. Lastly, Section 5 presents the conclusions.

2 Related Work

There are already some published works in the multi-modal transport task. However, none of these works solves the complete logistic problem, focusing on other problems associated with multi-modal transportation or in subproblems that do not represent all the constraints [2,5]. In [2], the authors discuss the opportunities for Operations Research (OR) in multi-modal freight transport. The paper reviews OR models that are currently used in this emerging transportation research field and defines the modeling problems which need to be addressed. In [6], the authors present a case study applying an interactive vehicle routing and scheduling software to a brewing company in the UK. They explain 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 and human intervention, which enables self-management.

There is very few research in solving the whole problem of planning the multi-modal transportation route for all services. Some works model the problem as a multi-commodity flow network and use heuristics to obtain suboptimal solutions [7,8]. For example, in [7] the problem is modelled as a multi-objective multi-modal multi-commodity flow problem and relaxation and decomposition techniques are used to break the original problem into a set of subproblems. A re-optimization approach helps to produce valid solutions when this relaxation of constraints leads to infeasible ones. In [8] the problem is solved using a linear programming compilation. The constraints considered in those works are similar to the ones considered here, but they are not exactly the same due to differences related to the company organization. For example, in our case the requested services are given with fixed pickup and delivery times instead of time windows. Additionally, the above works do not offer the ability of monitoring the proposed solutions and replanning to unforeseen situations, which is a essential requirement for self-management.

Regarding decision support systems, there are many works dealing with the monitoring of goods. In [9] the authors recall the relevance of monitoring, and review the different technologies and applications that have been used in this aspect. While other systems consider several kinds of sensors, like radio frequency identification (RFID) tags on the containers or goods, TIMIPLAN only assumes that the trucks are provided with a GPS sensor so their location is known. Although there are many works dealing with the monitoring of goods, trucks, or means of transport, very few works use this monitoring information for self-management. The applications are used only to provide information and they delegate all responsibility for decision making in unexpected situations to human operators. Instead, TIMIPLAN self-adjusts in unexpected situations such as damaged trucks or new services, and it requires very little human intervention.

There have been some architectures in the literature which use state-of-the-art plan generation techniques, plan execution, monitoring and recovery in order to address complex tasks in real-world environments [10]. However, they are designed mainly as robotic control architectures. Lastly, there has also been some work using automated planning for enabling autonomic properties in road traffic support systems [11]. In this case, they are only focused on diverting the flow of regular traffic during unplanned circumstances and, hence, they do not solve a real logistic problem.

3 Problem Description

We define a multi-modal logistics problem 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. The nodes in G represent the locations where the goods should be picked up or delivered as well as the intermodal choice locations: ports and train stations. We work in a real problem, where goods can be picked-up and delivered in any location all over peninsular Spain, its islands, and some cities in Europe and Morocco. In order to reduce the number of locations involved in the whole problem, we make an approximation based on the first three numbers of the postal code. The error in the number of kilometers induced by this approximation is small in comparison with the total kilometers of most services. This allows us to bound the number of locations to 600 and cache the number of kilometers and transportation time between each pair of locations in our database, speeding up the problem loading process.

A service $s \in S$ specifies pickup and delivery operations, each one with a location and service time, that indicates the time at which the corresponding location is available for the pick-up or the time at which a delivery service should be performed. To complete a service only a container $c \in C$ is required, but it can be moved by using a combination of vehicles: trucks, trains and/or ships. Each truck $t \in F$ has information relative to the location and time at which it will be available and its corresponding driver's accumulated driving time. If a truck is selected, it should travel to pick the container up, and either visit all locations of the transportation request (pick up and delivery locations), or transport it to the next transportation means (train station or port), where the rest of the plan might involve one or several other transportation vehicles. Trains and ships have a timetable specifying their movements and the load and unload actions can only be executed when they are at a station/port. The resulting plan should satisfy the given service times of the locations involved. For instance, if the truck and container arrive early, they have to wait at the location until the next transportation mean is available. If the truck and container arrive late, there will be a cost penalty (e.g. when transporting perishable goods, as bananas). In multi-modal transportation, several trucks are usually needed.

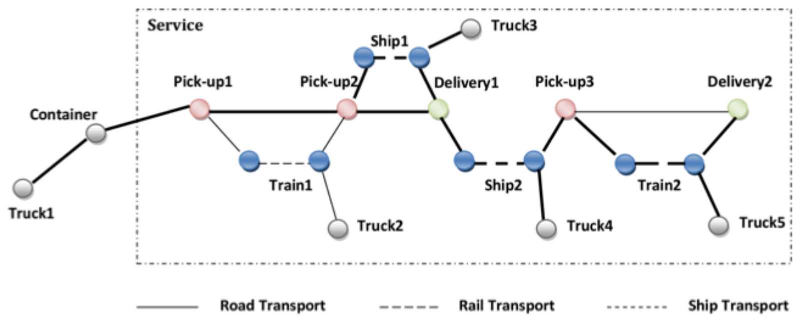

Fig. 1. Example of multi-modal transportation graph. A possible transportation route is highligthed.

Each service may be completed by different routes: either single mode routes, as all road, or multi-modal routes, as combining trucks with ship and/or rail. In the case of the Spanish company, they are mostly based on ships transportation, so most services involve at least one ship segment. The trucks are defined by their average speed, the cost per hour when they are stopped and the cost per kilometer when they are loaded and when they are not (moving an empty truck has different cost than moving it loaded). Moreover, the trucks have temporal and resource constraints imposed by the legal regulations about the number of continuous driving hours. When the drivers have driven during some time, they have to rest. The concrete maximum continous driven time and the minimum rest time varies for each truck.

Several constraints have not been included in the previous description of the problem, due to the difficulty of formalizing them or because they depend on information that is not available in the system. For example, there are soft goals related to the places where the drivers prefer to stop or to the client's preferences about vehicles and/or containers used to transport their goods. Also, human planners have expert knowledge about the probabilities of new services arising at each zone. They use that knowledge to reserve trucks or containers in these zones or to make movements that prepare all resources for future unknown services. Given that it is impossible to predict all potential soft goals to be taken into account when planning, we use a mixed-initiative approach to help the user taking into account those constraints that cannot be easily handled by TIMIPLAN.

The planner is executed every day in the evening for the next day. A daily problem has approximately 600 locations (summing up all pick-up and delivery locations, as well as initial positions of trucks, containers, ships, and trains), 175,000 edges among those locations, 300 trucks, 300 containers, 300 services, 50 train segments and 150 ship segments. The company imposes a time limit of 2 hours for computing the daily plan. More services are requested through the day and must be planned as they come.

Currently, the problem is solved by human experts who assign the resources of each service and the multi-modal route to deliver the goods. The company divides the planning problem between several headquarters, each one responsible of planning the services in one part of Spain. Each of them has its own resources, including trucks and containers. Resources can be shared among several headquarters if one of them requests it through phone calls. Thus, the current approach necessarily leads to suboptimal solutions, due to the local view of all the available resources. The main areas of improvement highlighted by the company are planning all the services at once and reducing the number of kilometers done by trucks without any goods.

4 TIMIPlan

The tool, TIMIPLAN, solves multi-modal transportation problems. It receives as input the positions of the set of all available resources (initial state), a number of services to be performed (goals) and it has to generate a plan with actions including: the load of goods in containers in different places; the unload on others; and the assignment and movement of the available resources (trucks, containers, ships, trains, ...) to achieve all goals. Also, it must take into account several constraints, such as pick-up and delivery times or driving hours, as well as taking into account all related costs. The objective is to minimize the cost of servicing all the daily requests. TIMIPLAN is composed of a set of modules as shown in Figure 2.

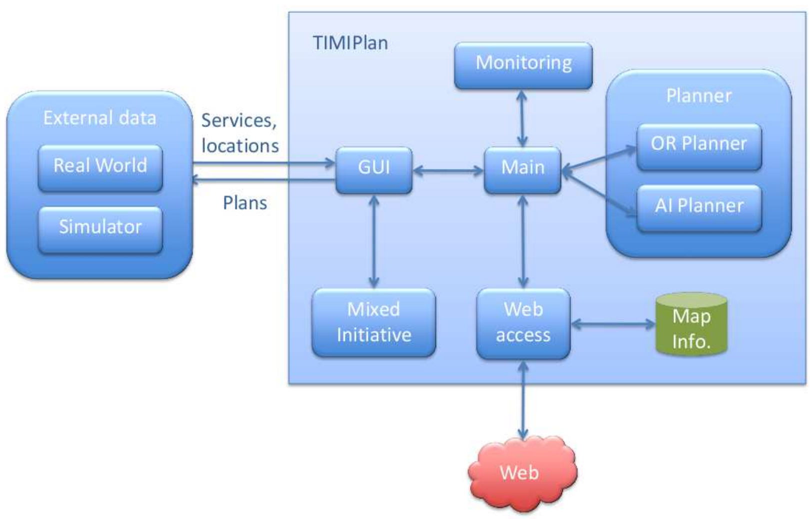

Fig. 2. TIMIPLAN architecture.

The input for the multi-modal task is the list of services to accomplish and the list of available resources (initial locations of each resource, costs, constraints, etc.), both in XML format, that are extracted from the company database. 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,[1] postal codes services or traffic information. The main module fuses all the gathered data to generate the problem description and delegates the work to the planning and monitoring modules. Once TIMIPLAN creates the problem description, it is given to the planner, which combines Operations Research (OR) and Automated Planning (AP) techniques, as described in more detail in [3]. The mixed-initiative module allows the human experts to interact with TIMIPLAN, when TIMIPLAN considers it necessary, as when including additional information in the problem (constraints and goals that cannot be formalized explicitly), or to validate the plans for solving unexpected failures. The Monitoring component allows TIMIPLAN to detect deviations from the original plan, or new services to be planned for, that arise everyday, and triggers replanning when necessary. The system also incorporates a simulator that allows the analysis of potential plan alternatives generated by the user.

TIMIPLAN has to support two modes of operation: offline and online. The offline mode runs everyday to generate the next day's planning. The user interacts with the generated plan modifying it and chooses the definitive plan. In the online mode, the system monitors the position of each resource and the execution of actions and replans when necessary. During this phase, the user is notified of every incidence that affects the predicted execution for the plan.

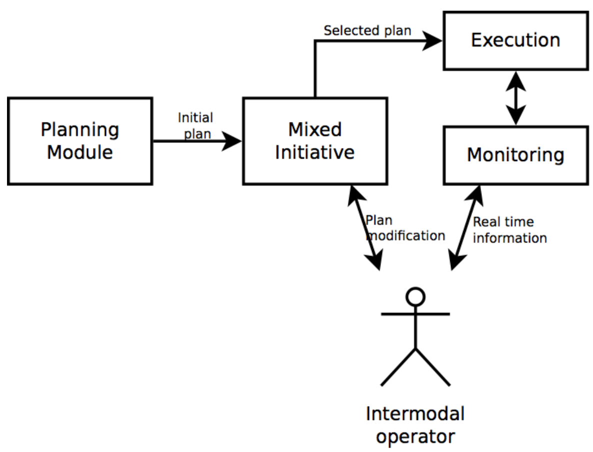

Fig. 3. TIMIPLAN user interaction workflow.

4.1 Planning module

This module can be understood as a core of deliberative reasoning and decision making in the proposed architecture. Most current autonomic computing systems

[1] webpage: http://maps.google.com

tend to rely on reactive rather than deliberative reasoning. However, techniques as automated planning are proliferating into the realization of the properties of autonomic computing [11]. The potential role of automated planning in autonomic computing was originally highlighted in [12]. The use of such type of deliberative reasoning is particularly suitable for self-adjustment, because, in the context of multi-modal transportation, it can reason about unforeseen or unexpected situations in the road network and come up with plans achieving desired transport goals with minimum cost. Building a reactive system can be a complex and time-consuming endeavor because of the need to pre-code all of the behaviors of the system for all foreseeable circumstances. So, our solution consists on making the system autonomic until it figures out that it needs the help from the user.

Our approach tries to exploit the benefits of techniques from automated planning and linear programming, decomposing the problem into two parts: the assignment problem and the planning problem. The assignment problem decides which resources will be used in each service. We use a linear model that estimates the cost of each assignment. The planning problem decides the transportation route, taking into account all the non-linear constraints, but limiting the number of resources to those selected by the assignment problem.

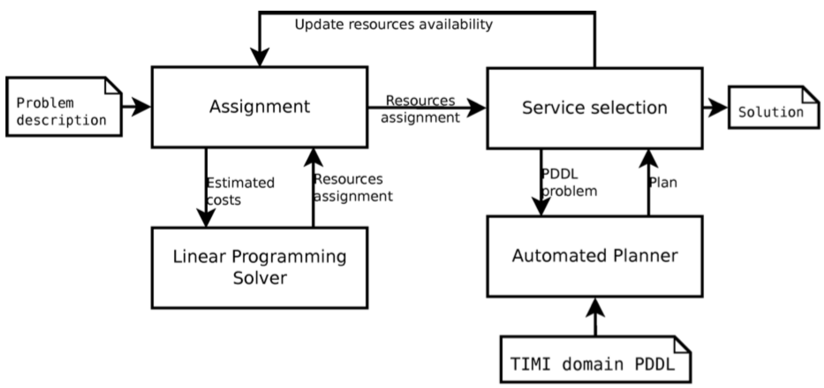

Fig. 4. Workflow of the TIMIPLAN top level algorithm.

Figure 4 shows the TIMIPLAN top level algorithm workflow. First, we compute the assignment of trucks and containers to services using a LP approach that selects the resource assignment for each service that minimizes the estimated total cost. Then, our approach sequentially solves the problem. For each service, the algorithm follows three steps. The first step consists of selecting the truck and containers that had been selected in the solution of the assignment problem as the ones that minimize the total plan cost. Then, the planning module is used to select a path from a first pick-up point to the last delivery point over the transportation route of each one of the selected services. This path includes all the actions that fulfill the given set of constraints, including the sequence of the transportation modes used (where several trains and/or ships can be used) with the minimum cost. Finally, to allow the use of the selected trucks and containers in other services, their position and availability time after attending the planned services is updated in the assignment problem. The problem of the assignment of trucks and containers to services is refined using the LP algorithm and the new resources assignment will be used in the next iteration. This approach balances the total cost obtained and the time required to compute the plan. More details can be found in [3].

4.2 Plan visualization

When developing a real application, usability is a key issue. Figure 5 shows TIMIPLAN's graphical user interface (GUI). Users can access all the information from this single view, avoiding the use of several windows and simplifying the problem comprehension. The window is divided in six frames:

1. Graphical map with the transportation routes of the selected services. It uses the Google Maps service.
2. Plan hierarchy for the mixed-initiative process.
3. List of services with their cost and information about the goods delivered and customer. The user can select a service to show more detailed information in frames 3 and 4 and has the option of showing its transportation route in frame 1.
4. Information about the pick-up and delivery operations of the selected service.
5. Actions needed to complete the selected service with their time and resources involved. A color code identifies whether each action is being executed (purple), has been correctly executed (blue), has failed (red), or will be executed in the future (uncoloured).
6. State of the trucks. Only available in the online mode in which the system monitors the position of each resource.

4.3 Mixed-Initiative

TIMIPLAN implements a full planning process that allows the user to automatically obtain a complete plan from the services and the available resources description. That plan takes into account most of the constraints, but not all because some cannot be efficiently represented and handled by the system. For example, drivers prefer services near home, or prefer to work only on week days, or prefer to be located where their football team play, or simply they do not want some of their preferences to be made explicit or to be recorded by any means. In addition, several failures or changes may occur once the services are planned (e.g., misunderstandings between the client and the transportation company about the conditions of the services, timetables, number of pick-ups and deliveries of a service, etc.), which are fixed by humans in real time through phone calls. Finally, human experts are usually suspicious of tools that provide solutions which cannot be changed, regardless of how sophisticated, intelligent or autonomic the tool is.

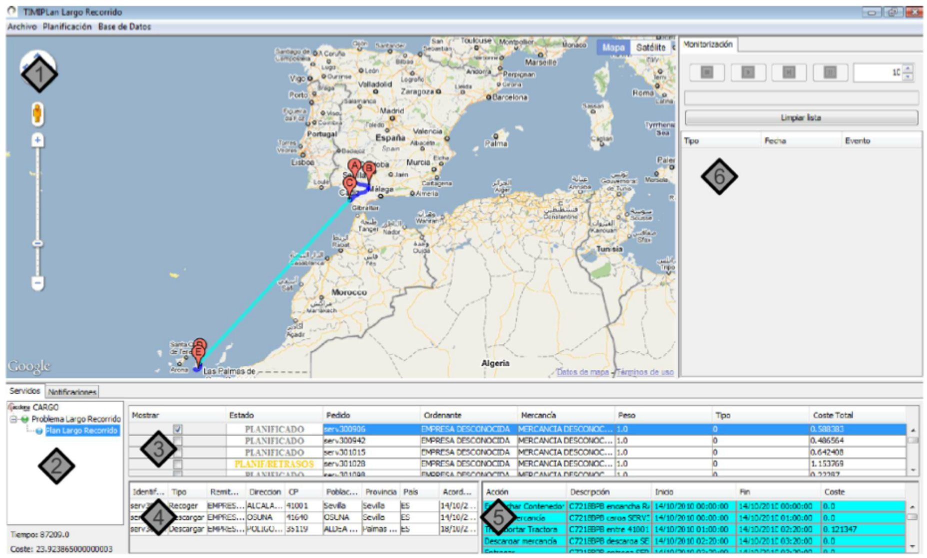

Fig. 5. Plan visualization interface.

Thus, a mixed-initiative component has been implemented to allow the human planners to modify the plans provided by TIMIPLAN, according to their suggestions made during the project, and also to fulfill the goal of letting the autonomic system decide when the help of users is needed.

We believe this is a key component of any self-management system, that enables the solution of problems related to controllability, or responsibility of computer decisions. TIMIPLAN collaborates with the users, updating the whole plan when the user proposes a change and allowing the comparison among different plans. In order to make changes on the operations or resources involved in a service, a new window is displayed, as shown in Figure 6. It contains detailed information about the resources and operations involved in the selected service as well as a list of alternative resources. The information is displayed over five frames:

1. Information about the actions planned for the service. For each action, the resources involved in it are shown, highlighting with an image the type of resource. The user may select an action to change the truck that currently performs it.
2. A map comparing the position of the previous selected truck with the new one for the action selected in frame 1. The proposed truck should be selected in frame 4 and appears in the map as a black truck. The truck in the current plan is shown in red.
3. Information about the truck that currently performs the action.
4. List of trucks that can be used in the action and information about the selected one. The user has the option to show all trucks or only the currently free ones.

Fig. 6. Mixed-initiative interface.

5. A displayable window for checking if there are any problems with the changes proposed by the user. In the example, the proposed change does not incur in any constraint violation. When TIMIPLAN has to execute a plan where some constraints are violated, the user should be told, since it would go against the good "health" of the full system.

Currently, TIMIPLAN allows users to perform two kinds of modifications over the services. On one hand, it is possible to change means of transport, such as trucks, containers or ships. The user selects the resource to change and a list of equivalent resources is displayed, with information about its location shown on the map. When a new resource is selected TIMIPLAN replans the service, using the planning module to obtain the new plan, propagating the availability time of each resource involved, and verifying the impact on the cost. On the other hand, users can change the order of the pick-up and delivery operations for a particular service. Even if the operations order is included in the service description, the users may want to modify it due to changes in the customer preferences or to react to unforeseen problems in the availability of the goods. Before applying the changes, the user may check if they result in a penalty for violating a constraint, such as an operation delay. The system shows a comparison of the violated constraints in the plan with the new changes against those of the previous plan, including the cost difference between both options. The user may decide to apply the changes even if the cost is increased. TIMIPLAN propagates the effects of the changes: whether the plan is still valid (does not violate any constraint) as well as its new cost.

After trying some changes over the plan the user may want to undo some of them or even compare two different plans. As the user changes the plan, she can store previous versions of the plan in a plan hierarchy. The root is the original plan proposed by TIMIPLAN and any plan on this hierarchy can be duplicated, adding a new node in the hierarchy to be modified. Thus, the user can compare different plans with their cost and keep track of the changes made.

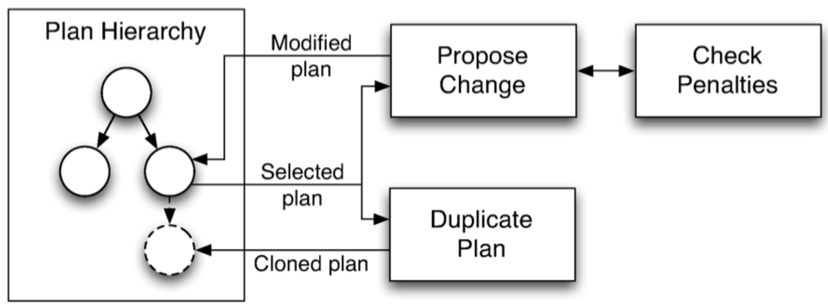

Fig. 7. Mixed-initiative workflow.

4.4 Monitoring and Re-planning

After the interaction with TIMIPLAN, the user selects the final plan and starts its execution. The self-management in automatic control requires that the behavior of the systems elements are monitored and analyzed, and the performance is used to plan and execute suitable actions to take or keep the system in desirable states [13]. In a similar way, TIMIPLAN monitors the plan execution retrieving information of the current state based on information from road sensors and trucks positions, noticing the deviations from the expected plan execution and re-planning if needed. Given that we are dealing with a real-time system, with a large number of resources involved and that changing transportation routes already in execution may disturb the drivers, it is not possible to replan from scratch. In the monitoring mode, some of the resources assigned to one service cannot be changed: the trucks that have been already assigned to a service must be preserved. So, our replanning component consists on adapting the existing plan to the current state, aiming to perturb the original plan as little as possible (also known as *plan repair*), only modifying the services affected directly by the incidence. We consider three kinds of failures (incidences) that may occur during the monitoring process and for each one TIMIPLAN is able to self-adapt with little or no human intervention: damaged trucks, new services, and traffic jams.

- **Damaged trucks:** Sometimes trucks may break down, being impossible for them to finish the services they are assigned to. In this case, only the services associated with the damaged truck are replanned (i.e. only a part of the original plan is modified). The replanning process is composed of two different steps: *assignment* of a new truck to replace the damaged truck, and *planning* of the new transportation modes to complete the service. The assignment process selects the truck to replace the damaged truck following a greedy strategy: select the truck with the least estimated cost, taking into account whether it is associated with a previous service or not, its current location, and whether it is engaged with a container or not. The new selected truck drives to the damaged truck location, picks the container up and continues the transportation route. If the damaged truck was associated

with more services, a new truck is selected to replace it on each of them. The new times and action costs are propagated throughout the plan.
- **New services:** New services may arrive at any moment throughout the day. These services must be attended as they come, so TIMIPLAN proceeds in a similar way as previously; first, an *assignment* of truck/s to complete the service, and then *planning* the best transportation modes to complete it. The truck/s are again selected following a greedy strategy, and only these trucks are considered for the planning problem. The actions planned to solve the new service are added to the original plan, with its corresponding action times and costs.
- **Traffic jams:** Traffic jams increase the duration of actions related to trucks movements. These situations may occur at any moment during the monitoring process. TIMIPLAN monitors the positions of trucks and compares them to the expected positions in order to detect delays. If a truck is delayed due to a traffic jam, TIMIPLAN propagates the delay to all the actions that depend on that truck (in the same service or others using that truck), computing the new time and plan cost. If the delays create a constraint violation TIMIPLAN alerts the user who decides if replanning is necessary.

Although it could be possible to use a different strategy of the greedy approach [14], Flórez et al. [15] demonstrate that the replanning process using this strategy is able to deal successfully with the daily damaged trucks and new services of the company (even in extreme situations). If some other unexpected situation arises during the monitoring process, this module delegates to the mixed-initiative component, allowing the human experts to solve it. The strength of the combined effort of system autonomic behavior and the user through the mixed-initiative component makes this tool an example on how to integrate man-machine in hard combinatorial control problems, as the ones arising in road transportation tasks. Figure 8 shows TIMIPLAN interface when the monitoring mode is enabled. As in the planning mode, the users can select the services they want to monitor and the transportation route is shown on the map. Also, the trucks associated with the service are shown too. Other resources such as ships are always shown. In the bottom part, the actions planned for each service are coloured to highlight the current action and those which are finished. The cost of the plan is constantly being updated, allowing the users to monitor it.

Finally, an extensive experimentation has been conducted in order to test the planning, monitoring and replanning capabilities of TIMIPLAN. Due to space limitations we have not included it in this chapter, so we refer the reader to [16,15,3] for details.

5 Conclusions

In this paper, we have introduced TIMIPLAN, a tool that successfully solves large multi-modal transportation tasks. We provide a formal model for the multi-modal transport problem and a good way to solve it that could be reused by

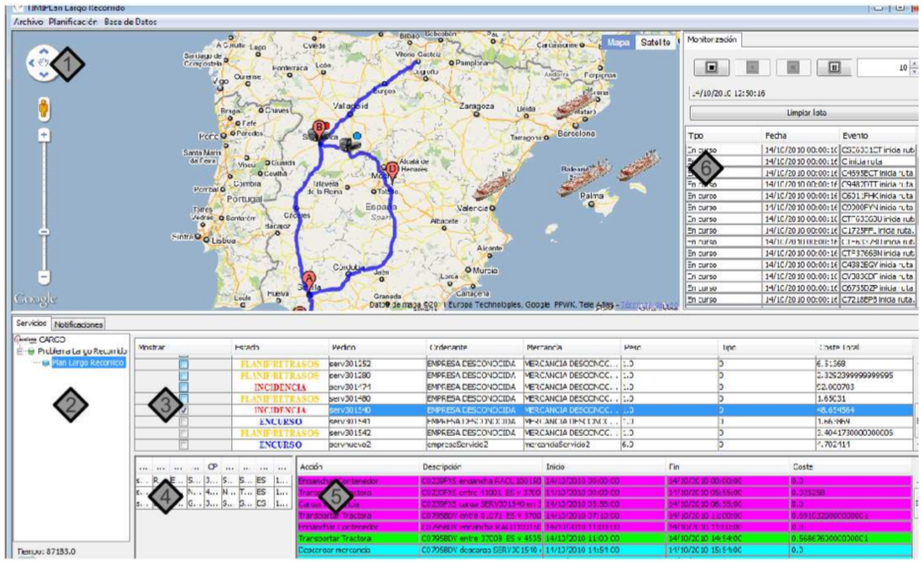

Fig. 8. Monitoring interface.

researchers in the ARTS community for other tasks. Multi-modal transport usually involves the combination of a large number of resources, together with temporal constraints, resource consumption, cost functions, etc., which makes the decision making process relying only on the experience of human operators not advisable. So, TIMIPLAN architecture incorporates some autonomic properties for self-management. One of the features which make TIMIPLAN self-managed is the use of a planning algorithm which combines linear programming and automated planning techniques. Automated planning enables control systems to automatically reason with knowledge of their environment and their actions, in order to generate plans and schedules to manage themselves. These properties make the automated planning particularly suitable for self-management, and, in general, for automatic computing [12]. Additionally, automated planning uses a standard language, PDDL [17], for the definition of domain models and problems, making the modeling of any road transportation problem easier and, hence, making TIMIPlan easily generalizable to other ARTS scenarios.

In our case, the proposed planning algorithm is integrated within an application which offers a plan visualization interface with a mixed-initiative module. Hence, the users can access all the information and modify the plans accordingly. We believe that a pure full autonomic system in some domains, as the multi-modal transportation problem of the Spanish company Acciona Transmediterránea, is not adequate for three main reasons. Firstly, although the self-* components take into account most constraints, some others cannot be efficiently represented and handled by the system (e.g., drivers prefer services near home, or prefer to work only on week days, or prefer to be located where their football team play, or simply they do not want some of their preferences to be made explicit or to be recorded by any means). Additionally, modeling all the knowledge (preferences, constraints, etc) managed by experienced human operators for a multinational company like Acciona could be very time consuming and not always possible. We believe that our current solution is a viable solution that has also minimized the modelling time (programming effort) providing a good solution to the task. As a side effect, we have also separated the modelling difficulties, so that we deal with the best solution in terms of the multiple criteria problem of <modelling time, quality of solution, time to solve>. Secondly, some failures or changes may occur once the services are planned, which must be fixed by humans in real time through phone calls, according to company business rules. Lastly, and most importantly, human operators are reluctant to delegate their entire control of the planning processes to computer applications.

Regarding the latter, this does not mean that we can not build real autonomic systems for those applications, but they then will most probably not be used by companies for some few more years (until the needed speed for decision making makes even for humans operators the idea of being in the loop impossible). However, the application of real autonomic systems in such domains poses other challenges like the modeling of all the knowledge managed by very experienced human operators. So, TIMIPLAN collaborates with the users through a mixed-initiative component when needed in order to balance self-* properties with human control and responsability.

Also, TIMIPLAN includes a monitoring mode to control the execution of all services, alerting the users when an incidence is detected. In other words, TIMIPLAN has the attributes of self-monitoring its existing current state (e.g., truck's positions, damaged trucks, traffic jams), and self-adjusting and control of itself (e.g., solving unexpected situations such as damaged trucks or new services). It is important to note that some of these attributes overlap; that is, the existence of one requires the existence of the others. For instance, the self-adjusting property is not possible if the system is not self-monitoring. All the above properties confer on TIMIPLAN the ability of self-management with human intervention when deemed appropriate.

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