

Refuel decisions and driver time management in long-haul freight transportation

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1 Problem description

We study a problem motivated by the truckload shipping services offered by a medium-sized company operating in Europe. Typically, the dispatcher is responsible for planning vehicle routes and instructing the drivers with respect to the sequence in which customer locations should be visited. Each request for transportation consists of a pickup and a corresponding delivery location. As these locations are often far apart, only a few customers can be serviced in the same week. A feature usually observed in long-haul freight transportation is that customer orders are placed with several alternative time windows. Hence, the construction of routes also involves the choice of time windows.

The outcome of this manual planning phase is a rough schedule which takes into account the duration of travel between locations, service times at customers, and a large time buffer for daily rest periods, breaks and refueling stops. Decisions concerning driving, resting and refueling are taken by the driver as time unfolds. The latter aspect has not received much attention in the vehicle routing literature although fuel prices are a critical factor as they represent on average 20 to 30% of the operating costs of a road haulage company, [1]. Long-haul trips involve driving through different countries and since fuel prices differ considerably across Europe, there is a significant potential for cutting fuel expenditures. In practice, a driver may even take detours to purchase cheaper fuel. However, such detours can be costly in terms of time and, in the worst case, jeopardize the compliance with customer time windows.

These problems have been dealt with separately in the literature. Different heuristic approaches for the vehicle routing problem with European regulations for driving and resting were considered for example in [3], [6] and [7]. In [2], a combined vehicle routing and break scheduling model is proposed to service orders within short travel distances.

Additionally, in [4] a heuristic is introduced to find a schedule complying with the EC regulations for a given sequence of locations. The literature dedicated to vehicle refueling is rather scarce and many factors relevant to real-life problems (e.g. time windows, driving hours and rest periods of drivers) are neglected by the existing models (see e.g. [5], [8]).

Obviously, driving, resting, and refueling decisions are interconnected and therefore, a sub-optimal solution is obtained when they are planned sequentially. To overcome this drawback, we propose a new formulation for the single vehicle case that integrates these decisions into one model. Our approach can also be used in the context of online replanning, i.e. for adjustments of the original schedule to respond dynamically to unforeseen events. To the best of our knowledge, the model to be outlined in the next section is the first attempt at integrating scheduling and refueling decisions into a single model.

2 A new model for driver scheduling and refueling

The input of the new model includes a sequence of stops to be visited, each having one or multiple alternative time windows. In some particular cases, it may not be possible to meet any of the available time windows at a given location. As the dispatcher often has the possibility to negotiate the arrival time of the vehicle with the customer, we consider soft time windows that can be violated at a penalty. The time management of the driver prior to his departure from the first node in the route is considered, as this influences his future activities. In addition, information regarding the location of fuel stations and fuel prices as well as various parameters for refueling are assumed to be known beforehand. We first focus on scheduling the driver's activities, which comprise driving, resting and working hours. The integration of refueling decisions is described at the end of the section.

Modeling EC rules on driving and rest periods

Regulation (EC) No. 561/2006 provides a set of rules for maximum daily and weekly driving times as well as daily and weekly minimum rest periods for drivers of companies operating in the EC. A break of at least 45 minutes must be taken after at most 4.5 hours of driving. The break may be split into 15 minutes followed by 30 minutes. A daily rest period must last at least 11 hours and may be split into (at least) 3 hours rest followed by (at least) a 9 hour rest. Several alternative provisions to these basic rules are also allowed. For instance, a daily driving period can be extended twice a week from 9 to 10 hours. The legislation is rather complex as many different ways of constructing driver schedules are possible, most of which are not currently explored by freight carriers.

In our case, as the distances traveled between locations are considerable, the model developed in [2] is not applicable. Moreover, it may not suffice to determine the required number of rest periods and breaks between two locations as in [2]. The exact specification of driving and rest periods is also desirable in order to comply with the EC regulations in such a way that all customers are visited within one of their time windows.

We developed a comprehensive mixed integer linear programming (MILP) model to determine a detailed schedule of all activities to be performed by a driver and to select customer time windows. By considering a planning horizon of one week, specific activities are modeled in each node and arc in the route as shown in Fig. 1.

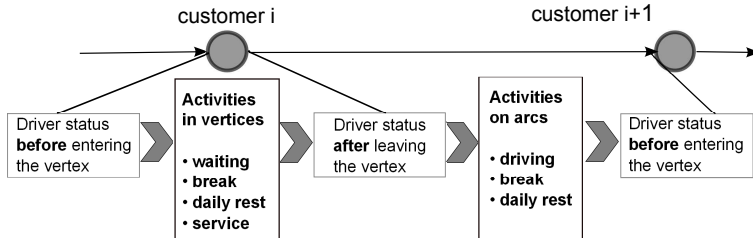


Figure 1: Modeling driver time management activities on arcs and in vertices

In each node, the driver may wait, take a break or a daily rest before servicing the customer. Possible activities on an arc comprise driving and taking breaks and daily rests. A break as well as a daily rest period may have a regular or a reduced length. In addition, several sets of so-called *status variables* are defined. They capture the amount of time left for different activities without taking a break or daily rest. Other status variables keep track of driving time extensions and shorter daily rest periods that were previously scheduled. Moreover, if a break or a daily rest period is split into two parts as described above, this information is managed by these variables. The model also explores the possibility of taking a break or a daily rest earlier than the time limit set by the EC legislation. This is beneficial when it leads to saving a break or even a rest period in a subsequent node or arc. In turn, this may reduce the waiting time at a customer or even prevent a time window from being violated.

Planning refueling stops

We assume that potentially attractive fuel stations for a refueling stop (e.g. within a given distance of the main route) as well as the corresponding fuel prices are known beforehand. Moreover, the vehicle starts with an initial fuel quantity and it must arrive at the last location in the route with at least a pre-specified fuel quantity. Fuel is consumed at a constant rate per distance unit and for safety reasons, a minimum quantity is to be maintained at all times in the tank. As drivers are not willing to stop too often for refueling, a pre-specified minimum quantity of fuel has to be purchased at a stop.

In the model presented in [8], fuel stations are selected between an origin and a destination and the quantities of fuel to be purchased are determined. A straightforward application of this model to our case is not possible as a vehicle route usually contains more than two nodes. Hence, we extended the basic model by constructing a specific

graph. All fuel stations for a potential stop between two consecutive customer locations i and $i + 1$ are mapped on the arc connecting i with $i + 1$. Furthermore, the mapping also considers the distance associated with a detour, both to reach a fuel station and to return to the main path. For each fuel station, a binary decision variable indicates whether or not the vehicle stops for refueling. In addition, continuous variables indicate the quantity of fuel purchased at each stop. The relevant travel distances are determined during the mapping phase by using real geographic data.

By integrating the features just described with those for constructing a driver's schedule, a challenging MILP model is obtained. For example, a small instance with six stops and 20 fuel stations leads to a model with 4391 constraints, 435 integer and 931 binary variables. The objective function to be minimized is a weighted sum of three terms that reflect a trade-off between punctuality, fuel costs and route duration. The impact of violating time windows is assumed to be significantly larger than fuel costs and the completion time at the last node.

3 Solution methodology

Instances based on real-life data were solved with Cplex 12.1. Our model is embedded in the software platform of a medium-sized transportation company and makes use of modern telecommunication and information systems. In particular, it involves the use of real-time information on vehicle positions, travel times, and fuel quantities in the tank. This information is provided by a geographical information system integrated with telematics.

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