DRIVERS' AUTONOMY FOR PLANNING BREAKS AND REST PERIODS IN VEHICLE ROUTING

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Abstract: This paper analyses the planning problem of including breaks and rest periods in vehicle routes and schedules from a conceptual point of view. The relevant legal restrictions for drivers' driving and working hours are presented and their impact on vehicle routing is shown. Consequently the overall planning problem is decomposed into three subproblems: clustering of customer requests, scheduling of vehicles and the rest periods planning. These subproblems can be solved either simultaneously or in sequence with the possibility of solving two of the three tasks simultaneously. Moreover in sequential approaches the planning tasks are usually divided between two decision making units, namely the scheduler and the driver. Therefore the decision situation in the sequential approaches is characterized by hierarchies in distributed decision making. These decision situations are analysed from a conceptual perspective.

1. INTRODUCTION

Since April 2007 the new EC Regulation No 561/2006 concerning driving and working hours of drivers in road transportation is effective. This regulation affects the planning of vehicle tours by restricting the maximum driving times. Although compulsory for all member countries of the EC and therefore of high practical importance this regulation has attracted little interest in models for vehicle routing and scheduling so far.
The task of planning breaks and rest periods in vehicle tours, denoted here as combined vehicle routing and scheduling and rest period planning problem (short: combined problem), is accomplished by the interaction between the drivers and the schedulers. The planning problem decomposes into three partial tasks, namely the clustering of customers, the routing of the vehicles and the planning of breaks and rest periods in the routes. These tasks can either be solved simultaneously or in sequence. Solving the problem sequentially and assigning the partial tasks to the involved decision making units (DMUs) results in a hierarchical planning problem in distributed decision making. Therefore the framework presented in [13] and [14] will be used to describe this situation. The aim of this paper is to analyse the different planning situations arising in the combined problem from a conceptual perspective.
The paper is organized as follows. In Section 2 related literature on vehicle routing including rest period planning is presented. Section 3 describes the legal rules for

driving times and rest periods laid down in the EC Regulation No 561/2006 and related rules on drivers’ working hours. In Section 4 different planning approaches for the combined problem and its partition over different decision making units are analyzed. Some conclusions are collected in Section 5.

2. LITERATURE ON VEHICLE ROUTING AND SCHEDULING INCLUDING BREAK TIMES

In the literature only few contributions for including general breaks and rest periods into vehicle routing and scheduling methods can be found. All have in common that they apply a simultaneous planning approach performed by a top-level decision unit like a scheduler.

[4] investigates a vehicle routing problem with breaks modeled as fictitious customers with time windows according to the breaks that must be taken and with service times which equal the minimum duration of the breaks. A similar approach is used by [11]. [15] includes some driving time restrictions specified by the former EC regulation. [12] include breaks and daily rest periods into a Pickup and Delivery Problem. [2] suggest the use of a multi-stage network for the inclusion of breaks in a vehicle routing problem. In this approach breaks can be modeled as the transition from one stage of the network to the next stage. [16] present a Pickup and Delivery Problem which includes some restrictions on driving times specified by the US Department of Transportation. [1] modify an insertion heuristic in such a way that it considers maximum shift times for drivers. [5] introduce a Large Neighbourhood Search algorithm for a vehicle routing problem which considers maximum driving times according to the former EC regulation. Two recent works partially considering the current EC Regulation No 561/2006 are [6] and [7]. They focus on the limitation of single driving periods to 4:30 hours and maximum daily and weekly driving times of nine hours and 56 hours respectively. However, the relevant rules are much more complex. For example a weekly driving time of 56 hours is only allowed if the driving time of the weeks before and after the week in consideration remains below 34 hours. Another paper including some of the restrictions of EC Regulation No 561/2006 is [17]. In this work a mixed-integer model for a combined vehicle routing and crew scheduling problem is presented which allows for the integration of breaks after 4:30 hours of driving time and for daily rest periods after 9 hours of driving time. To solve the model a Tabu Search approach and a Genetic Algorithm are proposed. [8] give a full description of the EC regulation's restrictions affecting vehicle routing and scheduling and structure them according to the different time horizons they comprise. Moreover a mathematical formulation of essential restrictions is presented. However there is no publication which gives a full model for vehicle routing and scheduling considering all the restrictions of the EC Regulation No 561/2006 affecting several days, several weeks and all excep-

tional rules. [9] present a comparison of the former regulation and the new EC regulation which is effective now.
As mentioned above all approaches neglect the problem that in practice the combined problem comprises two decision units resulting in a hierarchical structure. In this paper the decision situation arising in this context will be analysed. To better understand the complexity of the problem the relevant restrictions of the EC Regulation No 561/2006 and their imputation on working hours are introduced, structured and critically analysed.

3. THE EC REGULATION NO 561/2006 AND IMPUTATIONS ON DRIVERS' WORKING HOURS

The EC Regulation No 561/2006 is compulsory for all drivers in road transportation of goods and passengers in the EC or between the EC, Switzerland and the countries party to the Agreement on the European Economic Area. It applies to drivers of vehicles with a total mass of more than 3.5 tonnes or vehicles constructed to carry more than nine persons respectively [10].
The EC Regulation No 561/2006 concerns three different time horizons: single driving periods, daily, and weekly driving times. The relationship between these different time horizons is depicted in Figure 1.

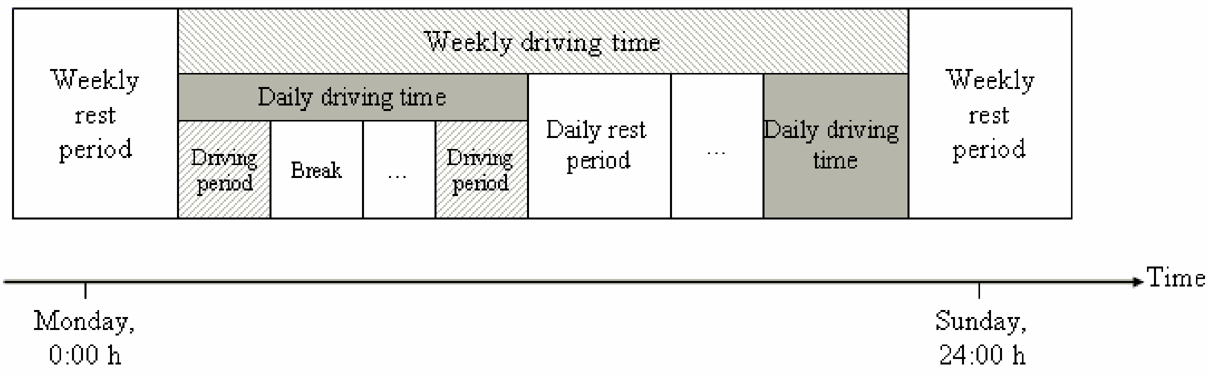

Fig. 1. Relation of the different time horizons [8]

The regulation restricts single driving periods to a maximum duration of four and a half hours. Drivers are obliged to take a break of at least 45 minutes after each driving period. Such a break can be divided into two parts. The first part must at least last 15 minutes and the second part at least 30 minutes. A driving period ends, when a break of sufficient length has been taken. Therefore a driving period consists of the complete time interval between two valid breaks and the total driving time of that period comprehends all particular driving times between these two breaks. However breaks not satisfying the described structure do not lead to the be-

ginning of a new driving period. Yet if a driver takes a break of 45 minutes before driving 4:30 hours he enters a new driving period.
The daily driving time is restricted to nine hours. However twice a week, i.e. twice between Monday 0:00 am and Sunday 24:00 pm, the daily driving time can be extended to ten hours. Daily driving times are defined as the accumulated driving time between two daily or between a daily and a weekly rest period respectively. A daily driving time ends when a daily rest period is taken or a weekly rest period starts. Within 24 hours after the end of a daily or weekly rest period the next daily rest period has to be started. A regular daily rest period is defined as a period of eleven hours or more in which a driver may freely dispose of his time. A reduced daily rest period is a rest period of at least nine hours. The regulation allows drivers to take up to three reduced daily rest periods between two weekly rest periods.
The weekly driving time amounts to 45 hours on average and is limited to a maximum of 56 hours. Additionally the maximum driving time of any two consecutive weeks must not exceed 90 hours such that the average driving time of 45 hours per week is maintained. In contrast with driving periods and daily driving times the boundaries of the interval for the weekly driving time are not determined by weekly rest periods but the weekly driving time is defined as the accumulated driving time during a week, i.e. between Monday, 0:00 am and Sunday, 24:00 pm. A weekly rest period is a recreation period between two weekly driving times. During this recreation period a driver may freely decide how to spend his time. The regular length of a weekly rest period is at least 45 hours; the reduced duration is at least 24, but less than 45 hours. A driver is allowed to take one reduced weekly rest period in any two consecutive weeks. A reduction has to be compensated by an equal extension of another rest period of at least nine hours before the end of the third week following the week considered. A weekly rest period has to be taken after at most 144 hours after the end of the previous weekly rest period.
The EC Regulation No 561/2006 contains modified restrictions in case of multi-manning. Multi-manning means that in the time interval between two daily or between a daily and a weekly rest period a vehicle is manned by at least two drivers. In this case one driver can take a break while the other is driving. However daily and weekly rest periods may not be taken while the vehicle is en route. Nevertheless, in case of multi-manning the maximum time between two daily rest periods is extended from 24 hours to 30 hours to exploit the additional possible driving time of the different drivers.
The EC Regulation No 561/2006 only comprises restrictions on driving times. As driving times are considered as working times they are also affected by the Directive 2002/15/EC which is effective for persons performing mobile transport activities and which contains restrictions on weekly working times and breaks [3]. Therefore the Directive 2002/15/EC supplements the EC Regulation No 561/2006 in the following respects. In the directive the working time is defined as the time devoted

to all road transport activities, i.e. driving time, time for loading and unloading, for assisting passengers while boarding and disembarking from the vehicle, time spent for cleaning and technical maintenance, and the time a driver has to wait at the workstation when the end of the waiting time is not foreseeable. The directive postulates that after a working time of no more than six hours workers have to take a break. The total duration of breaks during working periods of six to nine hours must at least equal 30 minutes. If the daily working time exceeds nine hours the total break time has to amount to 45 minutes or more. These break times can be divided into parts of at least 15 minutes. Consequently a break which meets the requirements of the EC Regulation No 561/2006 also satisfies the Directive 2002/15/EC.
Furthermore the directive restricts the weekly working time to a maximum of 60 hours. Moreover an average working time of 48 hours per week over a period of four months must not be exceeded. Therefore in vehicle routing it has to be assured that both driving time restrictions and working time restrictions for drivers are satisfied.

4. CONCEPTUAL ANALYSIS OF THE PLANNING PROBLEM

The planning problem of combined vehicle routing and scheduling and rest period planning consists of three interconnected partial planning problems to be solved, namely the clustering of customer requests, the routing of vehicles and the planning of breaks and rest periods for the drivers on the routes. These problems can be solved simultaneously or in sequence. In the case of sequential planning the possibility of solving two of the three planning problems simultaneously remains.
Apart from the three interconnected planning problems there is another factor in this planning process that adds to its complexity. This is the fact that usually the planning process is partitioned over two DMUs, namely the scheduler and the driver. Therefore the overall problem is characterized by hierarchical structures in distributed decision making. These hierarchies can be found both in the relationship between schedulers and drivers and in the structure of the planning problems to be solved.
First the possible division of the planning tasks between the scheduler and the driver will be analysed according to the degree of the driver's autonomy. The first possible decision structure is constituted by a totally centralized structure giving all decision rights to the scheduler and resulting in a zero degree of autonomy for the driver as assumed in most of the related literature presented in Section 2. This means that the scheduler performs all three planning tasks and the drivers have to follow his instructions. If the scheduler's planning method is a simultaneous optimizing method the results of this centralized planning would constitute the overall

optimum of the total planning problem and could be seen as a benchmark for the decentral approaches.
The other extreme might be seen in the case where the drivers may freely plan the tours, their routes and their rest periods. In this case the scheduler's task is reduced to the negotiations with the customers and the administration of the customer requests. This situation gives all planning autonomy to the drivers and could be realized in coalitions of free drivers pooling their resources and sharing and exchanging the requests.
The aforementioned decision structures both are characterized by one party having full decision autonomy. In between these two extremes there are other decision structures resulting in hierarchal structures in distributed decision making.
In practice the scheduler negotiates conditions for the customer requests and typically carries out the clustering of the customer request. The routing is usually also performed by the scheduler and is performed either in a simultaneous planning approach with the clustering, or in a sequential approach. However there are certain application areas where the scheduler only builds clusters of customer requests and passes those requests to the drivers who have the competence to determine the sequence of carrying out the requests in the clusters by themselves. This is especially found in the application area of city logistics where customer locations are very close to each other. The planning of breaks and rest periods is usually carried out by the drivers. This is due to the facts that first the driving times are not deterministic and therefore a fixed schedule for the required breaks is hardly possible. Second to date there are no planning algorithms that can account for all the legal rules in the routing of vehicles and guarantee a feasible vehicle schedule. Beware that the planning for routing and scheduling performed by the schedulers must ensure that there is an admissible solution for the planning of breaks and rest periods performed by the driver.
In the described situations with partial autonomy and shared decision competences there are two different DMUs. Using the framework presented by [13] and [14] the situation can be described as a structure of organizational hierarchies. The scheduler might be considered the top-level as he instructs the driver, who constitutes the base-level. According to the instructions from the top-level the driver visits the customers assigned to his tour and potentially follows the route planned by the scheduler. In this context a team situation can be assumed, i.e. the decision criteria of both decision units are not conflicting.
On the other hand in these instances there can also be seen a case of constructional hierarchies between the decision problems encountered by the two DMUs. These constructional hierarchies will first be analysed for the most common case of the scheduler performing the clustering and routing and the driver executing the rest period planning. Subsequently the case in which the scheduler only performs the

clustering and the driver carries out the routing and rest period planning will be discussed.
In the first case the top-level faces the planning problem of clustering customers and building routes. These problems can be solved either simultaneously or sequentially. In sequential approaches there is still the possibility of interchanging the sequence of the clustering and the routing procedure. Consequently there is no predetermined problem structure between these two partial problems.
The plans derived by solving the clustering and the routing problem are given to the base-level as instructions. They constitute a frame for the base-level's planning task of including breaks and rest periods into the routes. While generating customer clusters and vehicle routes the top-level has to anticipate the base-level's planning problem. This means that the planning procedure of the top-level has to take into account that the base-level has to plan breaks and rest periods in the vehicle tours it is instructed to carry out. The anticipation function has to be generated with respect to the legal rules on driving and working times described in Section 3. In the case that there are customer time windows to be kept tight schedules which fulfil the top-level's planning task optimally may result in infeasible plans at the base-level as shown by [8]. Therefore the base-level may react to the instructions of the top-level by communicating the feasibility of the planning task. If the plan turns out to be feasible it can be implemented to the object system, i.e. the physical transportation is performed. If it is infeasible the top-level's plan has to be revised and its anticipation function has to be updated. The resulting hierarchical planning process is depicted in Figure 2.
In the case that the scheduler only performs the clustering of customer requests the situation turns out to be similar. In this case the customer clusters generated by the top-level are sent to the base-level as instructions. The clustering has to be performed anticipating the routing to estimate the total time required to fulfil the customer requests. After estimating the fulfilment time of each tour a lower bound for the total time required for breaks and rest periods can also be obtained by including as little breaks as possible that are needed for this fulfilment time. For example if the total driving time of a tour is estimated to 9:30 hours at least two breaks of at least 45 minutes duration each are required. Therefore the total break time's lower bound is 1:30 hours. However it might turn out that the exact time required for breaks and rest periods is much higher, e.g. if the total driving time exceeds 10 hours since in this case a daily rest period of at least 9 hours has to be included. It is obvious that in this case the anticipation of the base-level's planning is far from trivial.

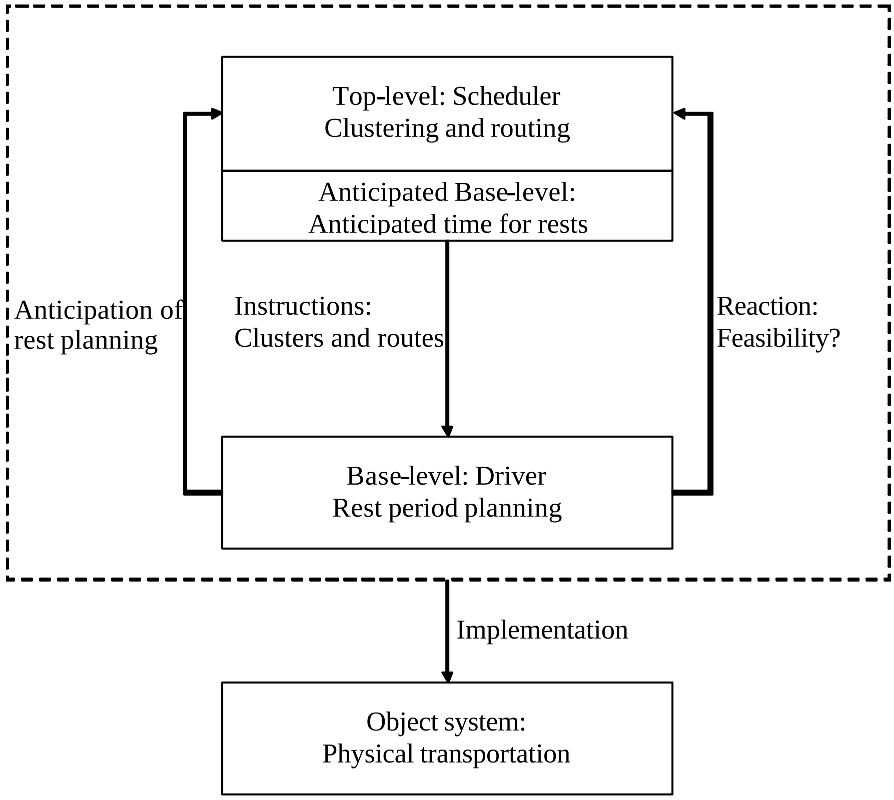

Fig. 2. Hierarchical structure in vehicle routing and rest planning

In the frame of predefined customer clusters the drivers have to carry out the routing and rest period planning. This division of tasks leaves more autonomy to the driver than in the aforementioned case. In between the tasks of routing and rest period planning the possible solution sequences are restricted as opposed to the clustering and routing. The rest period planning can sensibly only be carried out simultaneously with the routing or after the routes have been established. Changing the sequence is not reasonable since the schedule of the breaks and rest periods depends on the routes and is determined by them.

5. CONCLUSIONS

In this paper the decision situation arising in the combined vehicle routing and scheduling and rest period planning is analyzed from a conceptual perspective. The problem can be decomposed into the three interconnected partial problems of clustering, routing and rest period planning. Moreover the solution of these problems affects two kinds of interacting DMUs. Therefore the combined problem can be considered as a typical example of a hierarchical planning problem in distributed decision making. It is obvious that the centralized simultaneous exact solution of all three tasks results in the global optimum as it includes the solution spaces of the decentralized planning approaches. However the complexity of the simultaneous problem is very high compared to the decentralized planning problems. Decentralized planning has the advantage of being more flexible by adjustments performed by the driver as a response to sudden plan variations. Therefore in this context the impact of the different degrees of the drivers' planning autonomy on the resulting vehicle schedules has to be assessed by establishing and solving a mathematical model for the simultaneous planning problem as a benchmark for the decentralized approaches.

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