Restrictions for the operational transportation planning by regulations on drivers' working hours

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Abstract. In this paper the new EC Regulation No 561/2006 and related regulations on drivers' working hours as well as their influence on vehicle routing will be discussed. Therefore all rules of the regulation affecting vehicle routing are presented and classified according to the different but interconnected time horizons they refer to. Essential consequences of ignoring the regulations during the planning process are discussed and demonstrated using an example. Furthermore general aspects of modelling the restrictions are presented.

Keywords: Road Transportation, Driving Hours, Breaks, Rest Periods

1 Introduction

Since April 2007 the new EC Regulation No 561/2006 concerning driving and working hours of drivers in road transport 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. Especially the restrictions for the accumulated driving times during several days and weeks and the optional extensions of driving times are widely neglected. In literature there exists neither an accurate analysis of the restrictions' impact on transportation planning or vehicle routing and scheduling nor a comprehensive description and classification of the rules from the perspective of vehicle routing and scheduling. Moreover, the regulations themselves are difficult to read and to interpret. Although reading them thoroughly, it is sometimes necessary to check how some details have to be interpreted. Therefore in this paper the restrictions of the EC Regulation No 561/2006 and related restrictions on working times which are relevant for the planning and execution of road transport are presented. Moreover the associated rules are structured in different planning horizons.

In Section 2 related work is presented. Section 3 describes the rules of the EC Regulation No 561/2006 and additional rules on drivers' working hours. Section 4 gives an example of the consequences of neglecting breaks in the vehicle routing and scheduling planning process. Section 5 discusses global aspects of modelling the restrictions. Some conclusions are collected in Section 6.

2 Literature on Vehicle Routing Including Restrictions on Driving Times

[4] investigates a vehicle routing problem with breaks modelled as fictitious customers with time windows according to the breaks that must be taken and with service times which equal to the minimum duration of the breaks. A similar approach is used by [11]. [13] 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 modelled as the transition from one stage of the network to the next stage. [14] 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 consider the limitation of 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. [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 these 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 exceptional rules. [9] present a comparison of the former regulation and the new EC Regulation which is effective now.

In this paper the relevant restrictions of the EC Regulation No 561/2006 and related acts on working hours are presented, structured and critically analysed. Furthermore aspects for modelling the restrictions required by EC Regulation No 561/2006 and future research for including them into vehicle routing models are discussed.

3 The EC Regulation No 561/2006 and Related Rules

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 at least 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 [10]. The relationship between these different horizons is depicted in Figure 1.

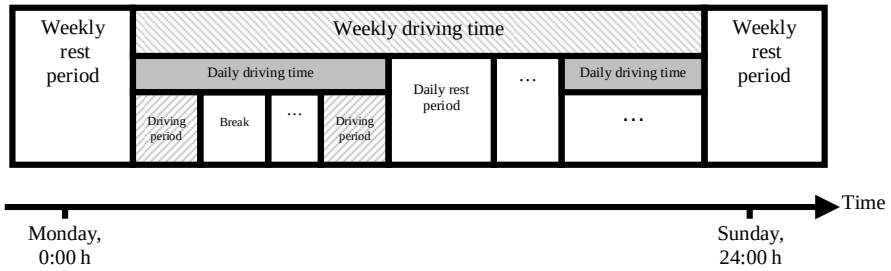

Fig. 1. Relation of the different time horizons.

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 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 beginning 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 maximal 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. 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 [3] and which contains restrictions on weekly working times and breaks. 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 [3]. 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 Example of the Negligence of Breaks and Rest Periods in Vehicle Routing

Solving vehicle routing and scheduling problems without simultaneous consideration of the EC regulation will have severe consequences on the feasibility and quality of the outcoming plans.

In the case of vehicle routing problems with time windows the ex post planning of breaks in vehicle tours will fail, since time windows may be violated by including breaks in existing feasible tours [8]. Additionally the length respectively the required driving time of a tour might exceed the maximal working time of a driver. As a consequence the tour cannot be completed during the scheduled time period and must be continued in the next period. Assigning two drivers to a vehicle executing a long tour may help, but this requires the modelling and solution of a combined vehicle routing and crew management problem.

In the case of vehicle routing problems without time windows [4] suggests the ex post planning of breaks into existing vehicle tours. As there are no customer time windows which can be violated the vehicle plan remains feasible. However, the objective of the vehicle routing model including breaks and rest periods should no longer consist in the minimization of the total driving time but rather in the minimization of the total fulfilment time of the tours. Considering this objective the ex post planning of breaks does no longer yield an optimal solution even for problems without time windows. This is illustrated in the following example.

A freight forwarder located at Bremen has planned his vehicle tours without consideration of breaks. He does not have to take into account time windows in his vehicle tours. Multi-manning is not possible since the forwarder cannot spend two drivers on a vehicle. The optimal vehicle plan includes a tour from Bremen to Hannover where the truck picks up a full truck load (+1) which has to be carried to Magdeburg (-1). On his way back the truck goes from Magdeburg to Hamburg to pick up another full load (+2) and deliver it at Bremen (-2). The vehicle tour and the partial driving times are depicted in Figure 2. Additionally, service times (time for loading or unloading respectively) of 30 minutes at each node are assumed.

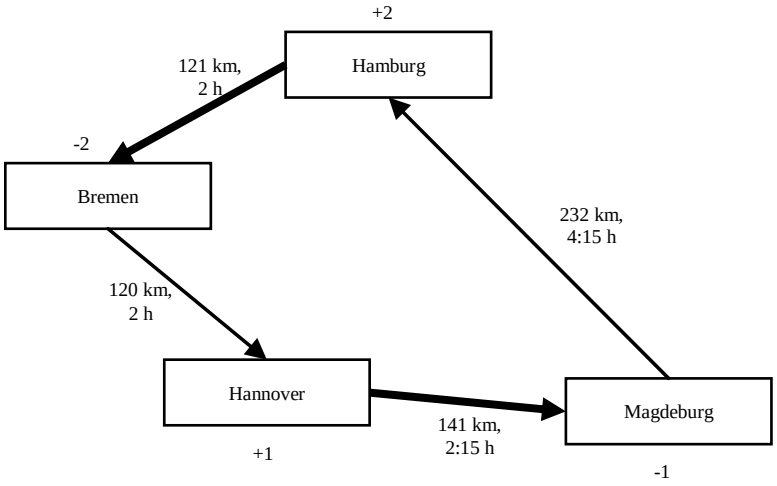

Fig. 2. Vehicle tour without breaks.

The total driving time of this tour amounts to 10:30 hours and the total working time (sum of driving times and service times) amounts to 12:30 hours.

Therefore breaks and also a daily rest period have to be taken in order to meet the driving and working time restrictions. After a maximum driving time of 4:30 hours a break of at least 45 minutes has to be taken. Thus the driver has to take this break the latest on his way from Magdeburg to Hamburg. This break of 45 minutes also meets the working time regulations. As the total driving time of the tour lies above 10 hours, it is clear that a daily rest period has to be taken. This necessity cannot be prevented by adding another break and extending the daily driving time to 10 hours. Therefore a reduced daily rest period of 9 hours has to be planned after 9 hours of driving time.

After this rest period the driver may continue his way back to Bremen without further breaks. The total fulfilment time of the tour amounts to 10:30 hours of driving time plus 2 hours of service time plus a break of 0:45 hours plus 9 hours for the reduced daily rest period, i.e. 22:15 hours in total.

The vehicle plan with the breaks planned ex post is depicted in Figure 3. Partial routes containing breaks or rest periods are depicted in dashed lines.

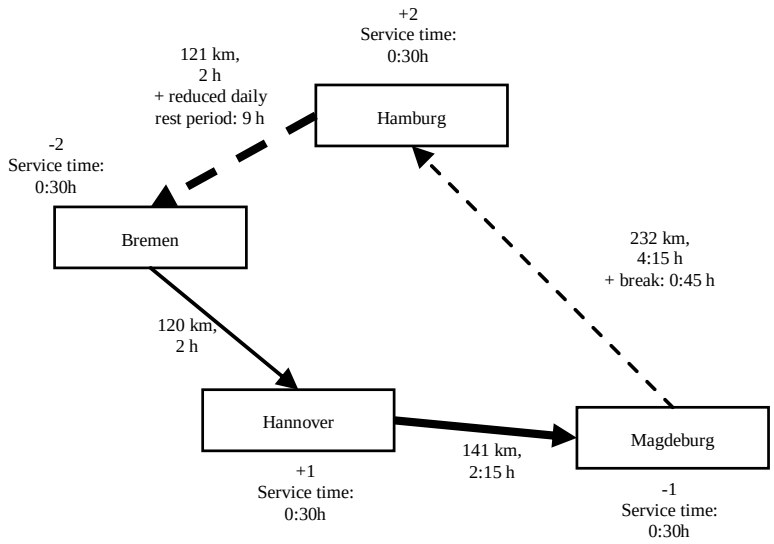

Fig. 3. Ex post planning of breaks.

It is possible to derive a vehicle plan which has a longer total driving time but does not need a daily rest period. This can be achieved by assigning the two pick-up-and-delivery requests to two different tours. The first tour goes from Bremen to Hannover and then via Magdeburg back to Bremen. The driving time from Magdeburg to Bremen amounts to 4:15 hours, such that the total driving time for this tour is 8:30 hours. This tour can be accomplished with only one break of 45 minutes on the way from Magdeburg to Bremen. The second tour goes from Bremen to Hamburg and then back to Bremen. The total driving time of this tour amounts to 4 hours such that the tour can be completed without any break. The two tours can be carried out either in parallel or consecutively. If they are carried out in parallel, a second driver is needed. In contrast with multi-manning the second driver does not have to be paid for idle time on the vehicle. The total driving time of this vehicle plan is 12:30 hours which lies above the driving time of 10:30 hours of the former tour. However as no daily rest period is required by the driving time regulation the total fulfilment time amounts to 12:30 hours driving time plus 2 hours of service time plus a break of 0:45 hours, in total 15:15 hours which is clearly below 22:15 hours of the former tour. The resulting vehicle routes are shown in Figure 4.

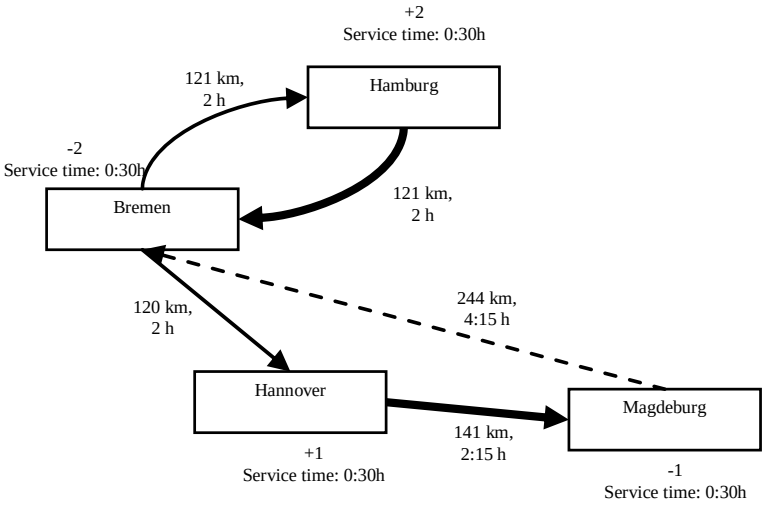

Fig. 4. Vehicle plan including breaks.

This example shows that the ex post planning of breaks into vehicle tours without time windows results in tours with minimum driving times. However the task of finding tours with minimum fulfilment times cannot be met with this approach.

5 Aspects of Modelling the EC Regulation No 561/2006

As shown in the example above the restrictions of the EC Regulation No 561/2006 affect the planning of vehicle tours. Consequently they should be integrated in the solution process since the ex post adaption to the rules deteriorates the solution quality. Yet the interconnection of the different planning time horizons makes it a difficult task to consider all the restrictions. It is obvious that the fixing of the boundaries of the weekly driving time to Monday 0:00 am and Sunday 24:00 pm gives a frame for the planning of vehicle tours. Especially for problems with time windows this frame is very helpful. Customer requests must be served during a specified week and thus can in a first step be assigned to the week their delivery time is set for. Within the time frame of a week the planning problems on lower time levels, i.e. the predetermination of the daily and weekly driving times, can be planned independently from fixed points in time. However, the relationships between consecutive weeks must be observed.

The assignment of customer requests to weeks can be performed as follows: If a customer time window is known in relation to a specified point in time, as assumed in usual vehicle scheduling models, this relationship can be converted into weekly time windows. For example if the start of the planning horizon is Monday 0:00 am, then the start of the time window a_i and the end of the time window b_i given in relation to Monday 0:00 am can be converted to weekly time windows defined by a_i^w and b_i^w. w is an index for the corresponding week of the assigned request and it is calculated according to equation (1):

$$w = \left\lfloor \frac{a_i}{168} \right\rfloor + 1 \tag{1}$$

The denominator is set to 168 since a week consists of 168 hours. It can be assumed that the start and the end of the time window are in the same week since deliveries are usually not made on Sunday nights. However if the time window crosses the weekly border it can be split into two distinct time windows the first ending at Sunday 24:00 pm and the second starting at Monday 0:00 am. The relative beginning and the end of the weekly time windows can be calculated as $a_i^w = a_i \ mod\ 168$ and $b_i^w = b_i \ mod\ 168$ where w is set as described before.

Having thereby obtained an assignment of customer requests to weeks for any vehicle it has to be assured that the weekly driving time does not exceed 56 hours. Using wdt_k^w as the weekly driving time of vehicle k in week w this can be achieved by the following restrictions (2):

$$wdt_k^w = \sum_{(i,j)\in A} x_{ijk}^w * t_{ij} \leq 56 \quad \forall \ vehicles \ \ k, weeks \ \ w \tag{2}$$

where x^w_{ijk} is a binary variable which equals 1 if vehicle k travels from customer i to customer j in week w, t_{ij} is the driving time from customer i to customer j and A is the arc set of all arcs between any two nodes i and j.

Moreover it has to be assured that the weekly driving times of any two consecutive weeks w, $w+1$ remain below 90 hours. This can now easily be achieved using the following restrictions (3):

$$wdt_k^w + wdt_k^{w+1} \leq 90 \quad \forall \ vehicles\ k, weeks\ w \in \{0,\ldots,W\text{ - }1\} \tag{3}$$

where wdt_k^0 is the driving time of the last week before the planning horizon which is given exogenously.

Additionally a customer request may only be fulfilled in one week, namely the week it is assigned to, as stated by the equations (4):

$$\sum_{k\in K} \sum_{j\in I} \sum_{w\in W} x_{ijk}^w = 1 \quad \forall\ nodes\ i \tag{4}$$

These restrictions assure that each node i is assigned to exactly one vehicle route in one week. Different customer requests with the same location must be considered as different nodes. Within these weekly frames breaks and daily rest periods must be planned on lower time levels.

To take into account the restrictions on the different time horizons Hierarchical Planning as a means for decomposing a complex problem into interconnected sub problems might be applicable. However, a top-down approach is not promising as the planning of vehicle tours has to start on lower time levels considering the sequence and time windows of requests on small time intervals. For example the insertion of a request into a tour usually leads to a postponement of the delivery of all succeeding requests of this tour. Therefore in a first step the driving periods are concerned. The

daily driving time is also affected by the insertion of the request. This suggests using a bottom-up planning approach. Yet restrictions on higher levels have to be met which influence decisions on lower levels. If for instance the insertion of a request into a driving period seems possible as the increased driving time remains below 4:30 hours the insertion might still violate the restriction of the daily or weekly driving time. Moreover the planning algorithms for the tours of one day must keep in mind the workload of the previous day, the previous week, the actual week, and the planned workload of the next week. The workload of a complete week must also be planned in advance, since the extension of the weekly driving time to 56 hours in the next week will only be possible if the driving times of the actual week go below a limit of 34 hours. Consequently the simultaneous planning of vehicle tours on all levels is inevitable.

The fact that the boundaries of daily driving times are defined by daily rest periods allows drivers to take several daily driving times a day. At maximum 3 daily driving times a day can be taken each of a duration of two hours separated by two reduced daily rest periods. Moreover it is possible to take many driving periods a day. Theoretically up to 32 driving periods a day are possible each of them of a duration of one minute. This might be of importance for drivers in local traffic or parcel service which take many stops of different length during a day and thus have a great leeway for positioning the breaks.

6 Conclusions

As shown above the inclusion of breaks and rest periods into vehicle routing models is of high practical importance in order to generate feasible vehicle tours. Therefore the modelling of the restrictions set by the EC Regulation No 561/2006 and related restrictions on working hours is of crucial importance. Neither in practice nor in literature there exist algorithms for vehicle routing and scheduling which are able to guarantee the completion of all restrictions of the EC regulations. The main challenge for developing suitable algorithms consists in the planning of mandatory breaks for driving intervals while the boundaries of the intervals themselves are recursively constituted by the length and position of the involved breaks. The breaks can be modelled as flexible time windows which can be shifted but must obey to a set of complicated restrictions. The second severe difficulty consists in the simultaneous treatment of different time horizons on different levels.

The overview of the regulations on road transport presented in this paper summarises the relevant rules for vehicle routing and scheduling and provides a structuring of the rules according to different planning horizons. The presentation of the rules and the discussion of the relations of the rules of different horizons are a basis and a starting point for future research on methods and algorithms which meet the EC regulations on road transport.

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