Problem Transformations for Vehicle Routing and Scheduling in the European Union

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Abstract. In the European Union working hours of truck drivers must comply with regulation (EC) No 561/2006 which entered into force in April 2007. The regulation has a significant impact on travel times including the driving time and the time required for compulsory breaks and rest periods. Recently, several approaches for solving vehicle routing and scheduling problems have been proposed in which European Union legislation must be complied with. All of these approaches restrict the application domain by constraining the maximum amounts of driving time and working time by the "weekly" limits of 56 hours and 60 hours imposed by regulation (EC) No 561/2006. In this paper it is shown that the amounts of driving time and working time a driver may accumulate within a period of six days can be significantly higher due to inconsistent definitions in the regulation. Problem transformation rules are presented which can be embedded in the previously developed approaches to exploit these inconsistencies.

1 Introduction

The vehicle routing problem is the problem of determining a set of vehicle routes to service a set of customers at minimal costs. There are many applications of the vehicle routing problem and a multitude of variants of the classical vehicle routing problem have been proposed considering various problem characteristics found in real-life applications. Many of these variants are discussed in [5]. The scope of this paper is an extension of the vehicle routing problem in which each customer must be visited within a given time window and working hours of truck drivers must comply with applicable legislation. In the European Union regulation (EC) No 561/2006 regulates working hours of truck drivers. The combined vehicle routing and truck driver scheduling problem in the European Union has been introduced by [1] and studied by [3] and [4].

The most prominent rules of regulation (EC) No 561/2006 are that a truck driver may not drive for more than four and a half hours without taking a break period of at least 45 minutes, and that a driver may not drive for more than 9 hours without taking a daily rest period of at least 11 hours. The regulation

J. Pahl, T. Reiners, and S. Voß (Eds.): INOC 2011, LNCS 6701, pp. 379–384, 2011.

defines a *week* as the period of time between 00.00 on Monday and 24.00 on Sunday and a *weekly rest period* as a period of rest of at least 45 hours. Some of the constraints of the regulation are imposed on the time between two weekly rest periods and some on the time during a week. A driver may drive for up to 56 hours and work for up to 60 hours during a week. At most 144 hours (six days) may elapse between the end of a weekly rest period and the start of the next weekly rest period. Twice a week, a driver may drive up to 10 hours without taking a daily rest period. Three times in between two weekly rest periods a driver may take a reduced daily rest period of at least 9 hours. It most be noted that several other constraints are imposed by the regulation. For brevity and w.l.o.g. these other constraints will not be considered in the remainder of this paper. For a comprehensive discussion of the entire set of rules imposed by regulation (EC) No 561/2006 the reader is referred to [2].

If we only consider a planning horizon of six days which does not include the night from Sunday to Monday, the inconsistent definition regarding weeks and the time between two weekly rest periods has no ramification on the feasibility check of a vehicle route. The heuristics for the combined vehicle routing and truck driver scheduling problem presented by [1], [3] and [4] as well as the exact truck driver scheduling method presented by [2] take advantage of this and make such a restriction.

In the general case, however, the planning horizon may begin at any time of the week. Let us for example consider a planning horizon of six days starting at 0.00 on Thursday. The driver may have up to 7 daily driving periods and 6 daily rest periods within the planning horizon. Without making use of the options to extend the daily driving time or reduce the daily rest, the driver can drive up to $7 \cdot 9 = 63$ hours (the total amount of break required is $7 \cdot \frac{3}{4} = 5\frac{1}{4}$ hours and the total amount of rest is $6 \cdot 11 = 66$ hours). As the planning horizon ranges across two weeks, the driver may have four extended daily driving times of 10 hours: two in the first week and two in the second week. Thus, a total of $4 \cdot 10 + 3 \cdot 9 = 67$ hours of driving can be accumulated (the total amount of break required is $4 \cdot (2 \cdot \frac{3}{4}) + 3 \cdot \frac{3}{4} = 8\frac{1}{4}$ hours and the minimum amount of rest required is $3 \cdot 9 + 3 \cdot 11 = 60$ hours). The "weekly" driving limit of 56 hours imposed by the regulation can therefore be exceeded by almost 20 percent. Similarly, the accumulated amount of working time within six days can exceed the "weekly" working limit of 60 hours significantly. In the next section we see how we can check feasibility of a vehicle route with a planning horizon starting at any time of the week.

2 Problem Transformation

The approaches for combined vehicle routing and truck driver scheduling presented by [1] and studied by [3] and [4] consist of a heuristic framework to determine potential vehicle routes and a feasibility check determining whether all customers in the route can be visited within the given time windows and without violating the regulation. Let us denote with $n_1, n_2, \ldots, n_\lambda$ the locations of a vehicle route and with $\delta_{\mu,\mu+1}$ the driving time required for moving from a node n_μ to a node $n_{\mu+1}$. At each location n_μ some stationary work of duration w_μ shall be conducted. This work shall begin within a given time window denoted by $[t_\mu^{\min}, t_\mu^{\max}]$. Let s_0 denote the state of the driver at the beginning of the planning horizon of six days. With each period of driving, conducting other work, taking a break or rest, or waiting idle, the state of the driver is changed. The *European Union truck driver scheduling problem (EU-TDSP)* is the problem of determining whether state s_0 can be successively changed into a state s with the following characteristics

1. the driver has visited λ locations
2. at the μth location the driver conducted some stationary work of duration w_μ
3. the stationary work at location n_μ started within time window $[t_\mu^{\min}, t_\mu^{\max}]$
4. the total amount of driving between location n_μ and $n_{\mu+1}$ is $\delta_{\mu,\mu+1}$
5. the driver complies with regulation (EC) No 561/2006

A mathematical formulation of the EU-TDSP including all the constraints of the regulation (EC) No 561/2006 is given by [2] who also presented an exact approach that can be used if

$$\sum_{\mu=1}^{\mu<\lambda} \delta_{\mu,\mu+1} \leq 56 \text{ and } \sum_{\mu=1}^{\mu<\lambda} \delta_{\mu,\mu+1} + \sum_{\mu=1}^{\mu\leq\lambda} w_\mu \leq 60.$$

The same assumption has been made by [1], [3], and [4]. All of these approaches determine a set of labels for each location in the tour representing different driver states. If this assumption can not be made, the approaches may determine labels representing driver states violating the regulation. However, we can transform the problem representation in such a way that these approaches can still be used. For this we have to make sure that the accumulated amount of driving time and the accumulated amount of working time are not exceeded in both weeks that may belong to the planning horizon.

Let λ' be the index for which

$$\sum_{\mu=1}^{\mu<\lambda'} \delta_{\mu,\mu+1} \leq 56 \text{ and } \sum_{\mu=1}^{\mu<\lambda'+1} \delta_{\mu,\mu+1} > 56.$$

Then, the accumulated amount of driving time exceeds 56 hours on the trip from location $n_{\lambda'}$ to location $n_{\lambda'+1}$. We have to make sure that the accumulated amount of driving time in the first week of the planning horizon does not exceed 56 hours. This can be achieved by inserting a virtual location n' between locations $n_{\lambda'}$ and $n_{\lambda'+1}$. The time window of this location begins at the beginning of the second week and ends at the end of the planning horizon. The working time at location n' is set to zero, the driving time from $n_{\lambda'}$ to n' is set to $56 - \sum_{\mu=1}^{\mu<\lambda'} \delta_{\mu,\mu+1}$, and the driving time from n' to $n_{\lambda'+1}$ is set to $\sum_{\mu=1}^{\mu<\lambda'+1} \delta_{\mu,\mu+1} - 56$. By this, we ensure that the accumulated amount of driving in the first week cannot exceed 56 hours if all time window restrictions are satisfied.

Analogously, let λ'' be the index for which

$$\sum_{\mu=\lambda''}^{\mu<\lambda} \delta_{\mu,\mu+1} > 56 \text{ and } \sum_{\mu=\lambda''+1}^{\mu<\lambda} \delta_{\mu,\mu+1} \leq 56.$$

Then, the accumulated amount of driving time (when counting backwards) exceeds 56 hours on the trip from location $n_{\lambda'}$ to location $n_{\lambda'+1}$. We have to make sure that the accumulated amount of driving time in the second week of the planning horizon does not exceed 56 hours. This can be achieved by inserting a virtual location n'' between locations $n_{\lambda''}$ and $n_{\lambda''+1}$. The time window of this location starts at the beginning of the planning horizon and ends at the end of the first week. The working time at location n'' is set to zero, the driving time from $n_{\lambda''}$ to n'' is set to $\sum_{\mu=\lambda''}^{\mu<\lambda} \delta_{\mu,\mu+1} - 56$, and the driving time from n'' to $n_{\lambda''+1}$ is set to $56 - \sum_{\mu=\lambda''+1}^{\mu<\lambda'} \delta_{\mu,\mu+1}$.

By inserting the virtual locations n' and n'' in the route of a vehicle we make sure that the accumulated amount of driving time does not exceed the limit imposed for either week of the planning horizon. Similarly we can make sure that accumulated amount of working time does not exceed the limit imposed for either week of the planning horizon.

Let λ''' be the index for which

$$\sum_{\mu=1}^{\mu<\lambda'''} \delta_{\mu,\mu+1} + \sum_{\mu=1}^{\mu\leq\lambda'''} w_\mu \leq 60 \text{ and } \sum_{\mu=1}^{\mu<\lambda'''+1} \delta_{\mu,\mu+1} + \sum_{\mu=1}^{\mu\leq\lambda'''+1} w_\mu > 60.$$

If $\sum_{\mu=1}^{\mu<\lambda'''} \delta_{\mu,\mu+1} + \sum_{\mu=1}^{\mu\leq\lambda'''} w_\mu + \delta_{\lambda''',\lambda'''+1} > 60$ then the accumulated amount of working time exceeds 60 hours on the trip from location $n_{\lambda'''}$ to $n_{\lambda'''+1}$ and we insert a virtual location n''' between these locations. The time window of this location begins at the beginning of the second week and ends at the end of the planning horizon. The working time at location n''' is set to zero, the driving time from $n_{\lambda'''}$ to n''' is set to $60 - (\sum_{\mu=1}^{\mu<\lambda'''} \delta_{\mu,\mu+1} + \sum_{\mu=1}^{\mu\leq\lambda'''} w_\mu)$, and the driving time from n' to $n_{\lambda'+1}$ is set to $\sum_{\mu=1}^{\mu<\lambda'''} \delta_{\mu,\mu+1} + \sum_{\mu=1}^{\mu\leq\lambda'''} w_\mu + \delta_{\lambda''',\lambda'''+1} - 60$. If $\sum_{\mu=1}^{\mu<\lambda'''} \delta_{\mu,\mu+1} + \sum_{\mu=1}^{\mu\leq\lambda'''} w_\mu + \delta_{\lambda''',\lambda'''+1} \leq 60$ then the limit of 60 hours is reached during the stationary work conducted at location $n_{\lambda'''+1}$. Instead of inserting a virtual location n''' between locations $n_{\lambda'''}$ and $n_{\lambda'''+1}$, we increase (if necessary) the beginning of the time window of location $n_{\lambda'''+1}$ to the beginning of the second week reduced by $60 - (\sum_{\mu=1}^{\mu<\lambda'''} \delta_{\mu,\mu+1} + \sum_{\mu=1}^{\mu\leq\lambda'''} w_\mu + \delta_{\lambda''',\lambda'''+1})$.

Analogously, let λ'''' be the index for which

$$\sum_{\mu=\lambda''''}^{\mu<\lambda} \delta_{\mu,\mu+1} + \sum_{\mu=\lambda''''}^{\mu\leq\lambda} w_\mu > 60 \text{ and } \sum_{\mu=\lambda''''+1}^{\mu<\lambda} \delta_{\mu,\mu+1} + \sum_{\mu=\lambda''''+1}^{\mu\leq\lambda} w_\mu \leq 60.$$

If $\sum_{\mu=\lambda''''+1}^{\mu<\lambda} \delta_{\mu,\mu+1} + \sum_{\mu=\lambda''''+1}^{\mu\leq\lambda} w_\mu + \delta_{\lambda'''',\lambda''''+1} > 60$ then we insert a virtual location n'''' between locations $n_{\lambda''''}$ and $n_{\lambda''''+1}$. The time window of this location starts at the beginning of the planning horizon and ends at the end of the first week. The working time at location n'''' is set to zero, the driving time from $n_{\lambda''''}$ to n'''' is set to $\sum_{\mu=\lambda''''+1}^{\mu<\lambda} \delta_{\mu,\mu+1} + \sum_{\mu=\lambda''''+1}^{\mu\leq\lambda} w_\mu + \delta_{\lambda'''',\lambda''''+1} - 60$, and the driving time from n'''' to $n_{\lambda''''+1}$ is set to $60 - (\sum_{\mu=\lambda''''+1}^{\mu<\lambda} \delta_{\mu,\mu+1} + \sum_{\mu=\lambda''''+1}^{\mu\leq\lambda} w_\mu)$. If $\sum_{\mu=\lambda''''+1}^{\mu<\lambda} \delta_{\mu,\mu+1} + \sum_{\mu=\lambda''''+1}^{\mu\leq\lambda} w_\mu + \delta_{\lambda'''',\lambda''''+1} \leq 60$ then the limit of 60 hours is reached (when counting backwards) during the stationary work conducted at location $n_{\lambda''''}$. Instead of inserting a virtual location n'''' between locations $n_{\lambda''''}$ and $n_{\lambda''''+1}$, we decrease (if necessary) the end of the time window of location $n_{\lambda''''}$ to the end of the first week reduced by $w_{\lambda''''} - (60 - (\sum_{\mu=\lambda''''+1}^{\mu<\lambda} \delta_{\mu,\mu+1} + \sum_{\mu=\lambda''''+1}^{\mu\leq\lambda} w_\mu + \delta_{\lambda'''',\lambda''''+1}))$.

By making these modifications to the problem representation before invoking the feasibility check presented by [1], [2], [3], or [4] we can make sure that the accumulated amounts of driving time and working time do not exceed the limit imposed for either week of the planning horizon even if conditions (1) and (2) are not satisfied. By this the inconsistencies in the time frames used by the regulation can be exploited without the need to modify the existing methods for checking feasibility of a vehicle route. [3] and [4] also presented variants of their methods which make use of the provision of the regulation that a driver may drive up to 10 hours twice a week without a daily rest period. If the planning horizon ranges across two weeks the driver may drive up to 10 hours four times within the planning horizon. To fully consider this provision of the regulation, the number of extended daily driving times can be increased to four and the approaches need to verify that only two extended daily driving times are are used in each week. If necessary, the "weekly" limits can be adjusted to consider previous activities conducted by the driver and the resulting impact on the maximum amount of driving and working time within the planning horizon.

3 Conclusions

In the European Union a truck driver may only accumulate 56 hours of driving time and 60 hours of working time within a week. This paper shows that, due to inconsistent definitions of the regulation, the amount of driving and working time within a period of six days can be significantly higher if the planning horizon ranges across two weeks. Although driving on weekends is restricted in some member states, there are various exemptions from weekend driving bans. The significant increase in accumulated driving and working time may promote driving on weekends.

Recently, several approaches for combined vehicle routing and truck driver scheduling in the European Union have been proposed. These approaches only consider a planning horizon starting on Monday or later and ending on Sunday of the same week or earlier. This paper shows that the feasibility check of these approaches can also be used for a planning horizon starting on any day of the week. This only requires relatively simple modifications of the problem representation.

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