Scheduling Bus Drivers in Real-Life Multi-Objective Scenarios with Break Constraints

Extended Abstract

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Received: date / Accepted: date

1 Introduction

When there is varying demand for employees at different times of the day, it is important to have efficient schedules for the employees in order to cover the demand with minimal cost. On the other hand, there is a range of legal requirements, collective agreements and company policies that need to be taken into account to create feasible schedules. Further, not every schedule that is feasible will be readily accepted by the employees, purely optimizing cost might result in reduced employee satisfaction and potential conflicts with labour unions.

An area that is especially restricted by various constraints is scheduling for drivers in public transport. As these employees have a great responsibility keeping their passengers safe, legal requirements enforce strict break assignments in order to maintain concentration. In addition to that a spatial component needs to be considered. This makes the goal to create cost-efficient and employee-friendly schedules even more challenging. This paper deals with optimizing schedules for bus drivers in Austria, using the regulations from

The financial support by the Austrian Federal Ministry for Digital and Economic Affairs, the National Foundation for Research, Technology and Development and the Christian Doppler Research Association is gratefully acknowledged.

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the Austrian collective agreement for employees in private omnibus providers serving regional lines.

The contributions of this work are as follows. We extend previous work [12] on the problem with a focus on more complex objectives including various new criteria that are relevant in practice. As in [12], we also apply a Simulated Annealing approach, but we additionally propose new moves that take into account the characteristics of the extended problem. Based on this, we can provide high quality solutions for real-life scenarios.

2 Related Work

Due to its high practical relevance, the topic of employee scheduling has seen tremendous research for many years. Several surveys [8,3] provide a good overview of work in different areas. A survey for the different objectives in operating bus transport systems is provided by [11]. Driver scheduling is located between vehicle scheduling and driver rostering in a six step process. Driver scheduling belongs to the area of crew scheduling problems [8] that is also frequently applied to airline [9] and train crew scheduling.

Research on Bus Driver Scheduling (BDS) Problems has started decades ago [24]. Previous work explored different solution methods. Exact methods mostly use column generation with a set covering or set partitioning master problem and a resource constrained shortest path subproblem [19,7,17,14]. Heuristic methods like greedy [16,6,20] or exhaustive [4] search, tabu search [15,18], genetic algorithms [15,13] or assignment problems [5] are used in different variations. The scheduling of breaks within shifts is considered by several authors [1,2,22].

[12] presents a complex version of the BDS problem based on the Austrian collective agreement for employees in private omnibus providers [23], using the rules for regional lines (up to 50 km per line). New benchmark and real life instances are solved using Simulated Annealing.

3 Problem Description

The Bus Driver Scheduling Problem deals with the assignment of bus drivers to vehicles that already have a predetermined route for one day of operation. The shifts that are generated need to respect a range of constraints regarding length and complex break assignment rules. The specification presented here extends [12]. New extensions are presented in sections 3.3 and 4.

3.1 Problem Input

The bus routes are given as a set of individual bus legs $\mathbf{L}$, each leg $\ell \in \mathbf{L}$ is associated with a tour $tour_\ell$ (corresponding to a particular vehicle), a start time $start_\ell$, an end time end_ℓ, a starting position $startPos_\ell$ and an end position

Table 1 Example bus tour

ℓ	$tour_\ell$	$start_\ell$	end_ℓ	$startPos_\ell$	$endPos_\ell$
1	1	360	395	0	1
2	1	410	455	1	2
3	1	460	502	2	1
4	1	508	540	1	0

$endPos_\ell$. The amount of time within the leg that is actually spent actively driving is specified as $drive_\ell$. This problem uses $drive_\ell = length_\ell = end_\ell - start_\ell$.

Table 1 shows a short example of one particular bus tour. The vehicle starts at time 360 (6:00 as our time units are minutes) at position 0, which could be the bus depot. 35 minutes later it arrives at position 1. Before the next leg of the bus tour there is a 15 minutes waiting time which might qualify as a break for the employee depending on the constraints explained later. After four legs, the bus returns to the depot at time 540. Valid input never has overlapping bus legs for the same tour and consecutive bus legs i, j of the same tour always respect $endPos_i = startPos_j$.

Further input is a distance matrix, which, for each pair of positions i and j, denotes a time $d_{i,j}$ it takes a driver to get from i to j when not actively driving a bus. If no transfer is possible, we set $d_{i,j} = \infty$. $d_{i,j}$ with $i \neq j$ is called passive ride time. $d_{i,i}$ represents the time it takes to switch tour at the same position, but is not considered passive ride time. We define the occurrence of a tour change as when a driver has an assignment of two consecutive bus legs i and j with $tour_i \neq tour_j$.

Finally, for each position i an amount of working time for starting a shift at that position $startWork_i$ and for ending a shift $endWork_i$ are given. At any depot d preparing the bus ($startWork_d = 15$) and finishing the bus ($endWork_d = 10$) are considered, for other positions the value is 0.

3.2 Solution

A solution to the problem is an assignment of exactly one driver to each bus leg. A feasible solution must satisfy the following criteria:

- No overlapping bus legs are assigned to the same driver.
- Whenever tour or position changes for a driver between assigned bus legs i and j, then $start_j \geq end_i + d_{i,j}$.
- Each shift respects all hard constraints regarding work regulations as specified in the next section.

Within the set of feasible solutions, different criteria might be optimized as explained later.

3.3 Work and Break Regulations

Valid shifts for drivers are constrained by work regulations and require frequent breaks. There are many constraints related to different measures of the schedule.

– Driving time: The time actually spend driving the vehicle is constrained by a maximum value of 9 hours and the requirement for breaks after at most 4 hours of driving that might be split into smaller parts.
– Total time: The time between the start and end of the shift is limited to 14 hours.
– Working time: The working time does not include certain unpaid breaks or shift splits, there are complex rules which breaks are unpaid according to their length and location within the shift. The working time should be within 6.5 and 10 hours except for part time employees whose working time may last only three hours.

This work extends the problem by looking at different vehicle types as well as training of employees. First, this leads to the notion of the level of a duty, based on the different vehicles and the different lines that a duty contains. More different vehicles and lines require an employee to be trained for all of them, therefore the level of the duty is higher. Second, when optimizing duties for both bus and tram lines, some tram lines have different driving break requirements compared to the bus lines. Therefore, the driving break requirements become dependent on the current line of a duty.

4 Objectives

There are several optimization criteria, setting a different and often conflicting focus on the resulting schedules. These include both cost objectives and objectives to obtain schedules that are actually workable in practice considering the needs of the employees. The following minimization objectives are considered in our real-life application:

– Number of employees (cost objective)
– Sum of working times (cost objective)
– Sum of missing working time (shifts below 6.5 hours need to be paid 6.5 hours anyway, in combination with the previous objective this enforces shifts to be well distributed)
– Sum of long unpaid break time (time above a limit of 1.5 hours)
– Sum of passive ride times (drivers are riding as a passenger or walking to a different location)
– Number of major location changes (drivers change to a different location that is very far away, including a hard maximum of one such change per duty)
– Number of duties where the second part is longer than the first part (to achieve a favourable location of the main break)

– Number of duties with more than two stretches (a stretch is defined as a consecutive assignment of bus legs on the same tour, i.e., this objective minimizes vehicle changes, also including a hard maximum of three parts per duty)
– Sum of missing break safety time (driving breaks should be several minutes above the minimum length in order to have a buffer for minor operational delays, this objective sums missing buffer time)
– Sum of missing stretch time (a stretch should be at least 1.5 hours, this objective sums the difference in case a stretch is shorter)
– Sum of the squared duty levels (reduce especially high levels)

5 Solution Method and Results

The solution method is based on a construction heuristic and Simulated Annealing. The objectives are combined using a linear objective function. The weights are set based on the goals of the bus operator. Compared to previous schedules, the importance of the different goals are set (should be improved, should not get worse, might get worse in a certain range) and the weights are repeatedly tuned and carefully evaluated to match those goals.

The construction heuristic uses a greedy approach trying to assign consecutive bus legs of the same tour to the same duty. Simulated Annealing uses different moves that are applied to duties with high objective values with higher probability.

Different moves are used for the problem:

– Moving a bus leg to a different duty
– Swapping bus legs between different duties
– Swapping a range of bus legs between different duties
– Swapping stretches between different duties

Regarding the selection of the duties for the application of a move, with higher probability we select duties such that consecutive elements of the same tour are placed next to each other. As duties with many stretches are unwanted, this selection of moves combined with their application helps to reduce the number of tour changes in the solution.

The method has been deployed in practice just recently. We have applied it to a real-world scenario where solutions calculated with different weight distributions allow to compare different options. Compared to existing solutions the initial results can provide solutions that greatly improve important characteristics of the duties like the long break times while moderately raising less important characteristics in a controlled way. Table 2 shows a comparison of the results for the focus on improving long breaks and passive ride time. The total paid working time can be slightly improved, unpopular break over-length can be reduced by more than half, passive ride time by more than a third, and major location changes by two thirds, while increased short breaks and duty levels are still acceptable.

Table 2 Objective improvements

Objective	Goal	Previous	New
Employees	keep	133	134
Working time (inc. missing)	not worse	64904	64722
Long break time	better	2905	1261
Passive ride time	better	810	525
Major location changes	better	15	5
Second > first	not worse	49	46
3 stretches	better	14	13
Short break time	worse	29	47
Missing stretch time	not worse	95	98
Duty levels	worse	374	767

As future work we will provide more detailed experimental results. It would also be interesting to explore computing a Pareto front for the problem. However, due to the large number of objectives this will be difficult and will require methods from the area of many-objective optimization [21,10].

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