Modelling constraints in automatic vehicle rostering - demands and possibilities

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Abstract

The optimisation of vehicle utilisation is an important task for an economic operation. To achieve this goal many constraints have to be considered. These constraints arise either from operation, from organisational structure within the transportation companies or are affected from external conditions. This paper describes some of the constraints and shows an approach to modelling these constraints into an automatic vehicle rostering system. Most of these constraints were collected during a conceptual design phase with the "DB AG, UB P" (German Railways) and afterwards modelled into the vehicle rostering system Dispo. The types of the operational constraints are the type of turnaround and the resulting turnaround time, vehicle substitution, maintenance and structural defaults for the allocation plan. The planning of vehicle allocation is organized as an iterative process, because the planning is heavily dependent on the results of other planning. Once the initial roster plan is created, this plan is distributed to all other involved planning departments. The results of their planning are subsequently included into the roster plan. The above described constraints are modelled in Dispo using network flow algorithms as well as heuristic approaches. The heuristic approach is used for maintenance planning and for vehicle substitution, because these constraints cannot be modelled with graph theory.
Keywords: vehicle allocation, roster planning, resource planning, network flow, meta heuristic, operations research, train operation.

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1 Planning process

There are several planning departments involved in the planning of rolling stock at "DB AG, UB P" (German Railways). The planning process itself is an iterative process, because changes made from the different departments have to be incorporated in the allocation plan. However, the planning process can be abstracted to a planning process valid for every rolling stock type (locomotives, coaches and railcars).

The planning process begins one to one and a half years before the timetable changes. The planning department starts by creating an initial allocation plan. This plan is then handed over to the station planners.

The station planners are responsible for storage of the vehicles and for the tracks from which the trains arrive/depart. The changes from the station planner may result in new turnaround times for trains which affect the initial plan. The planning department includes these changes in the allocation plan.

The above described process is an iterative process, because the different train companies have their timetables finished at different times. Furthermore, at an early stage of the planning process, trans-national trains are planned at a conference. These trains have to be included in the allocation plan as well. Figure 1: shows the flow of work during the iterative planning process.

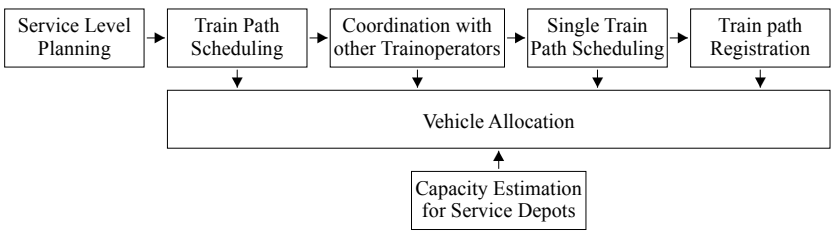

Figure 1: Allocation schedule.

2 Constraints

In this chapter the constraints which arise from operation are investigated further. There are three types of constraints which are described in more detail in this paper. However, there are other constraints that have to be considered for the planning of vehicle allocation.

At first, an allocation plan must be valid. The validity is given when every train run can be served by the assigned vehicle(s) and when every destination station is equal to the following departure station of the train runs. Additionally the allocation plan has to comply with the maintenance intervals.

Additionally the arrival time of the preceding train run most not be greater than the departure time of the following train run.

The goal of the optimisation is to achieve an optimal solution regarding the given cost function. We can identify at least three types of costs:

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- The real costs like fixed costs for vehicles or variable costs for operation.
- Penalty costs if constraints are violated.
- Edge costs in the network model to model constraints (see below)

The other constraints are described in the following sections.

2.1 Turnaround times

Turnaround times define the duration of turnarounds depending on class, station and turnaround type. Additionally the time is dependent on the vehicle type the time of day and local conditions.

The turnaround describes the transition of a vehicle from one train to a following train. Six types of turnarounds can be identified:

- without train composition
- without train composition and with change of direction of travel
- change locomotive
- attaching wagons
- detaching wagons
- changing wagons

If a vehicle changes from one train to another train, a minimum turnaround time has to be considered before the next train can leave the station. The multiple turnaround types can result in different turnaround times.

2.2 Vehicles

Vehicles are grouped by classes. Within a class, vehicles may have different attributes such as safety equipment, air conditioning, number of seats etc. On the other hand the train runs are defining the demands for those attributes. The planner's work is now to build vehicle groups that fulfil the demands of the train runs.

2.3 Vehicle substitution

If more than one vehicle group fulfils the demands of a train run, all these vehicle groups can be allocated to the train run. These demands can be equipment demands like safety equipment or electrification. It can also be a capacity or comfort attribute like number of first class seats or air condition.

The substitution rules lead to a set of vehicle groups which are valid for a train run. Some of the vehicle groups can additionally be substituted in general by other vehicle groups.

2.4 Maintenance

Two maintenance interval categories have to be considered. The first is the running kilometre interval, the second is the time dependent maintenance

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interval. There are maintenance intervals, where a rule exists for the kilometre interval and for the time interval. In this case the first applying interval has to be taken into account.

The maintenance intervals are depending on the vehicle group. The stations (depots), where the specific maintenance can be performed have to be defined. Finally the durations of the maintenances and the opening hours of the depots have to be specified.

3 Modelling the constraints

The above described constraints are modelled in the program system Dispo in both a network flow and a heuristic approach. The basics of the network flow approach are described in [1]. However, there are some enhancements made to this approach which are described in the next section.

3.1 Network flow

In the network flow model, an allocation plan which is optimal in terms of the given constraints is computed. The following constraints can be covered using the network flow approach:

- The allocation plan is optimal regarding the costs
- The allocation plan is valid
- The turnaround times between train runs are valid

One of the enhancements made in the original algorithm from [1] is the more exact modelling of the turnaround type. Figure 2: shows the representation of three train runs, where every train is made up by two vehicle groups. Additionally there is no change of direction of travel.

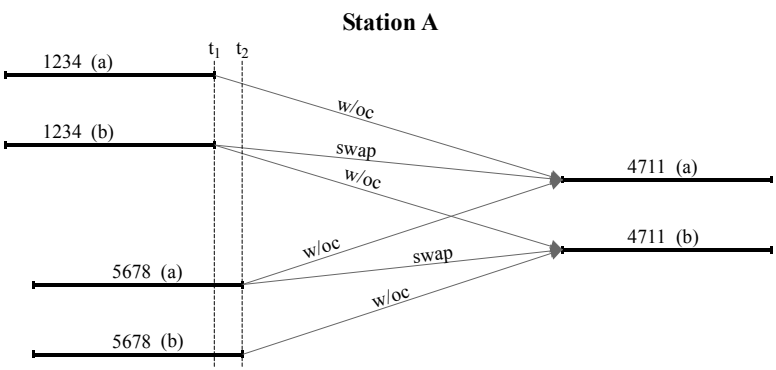

Figure 2: Network representation.

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A cost value is assigned to every transition edge. This cost value is calculated from the time gap between the arrival and departure time from the train runs. We now add the penalty costs for the different coupling types.

Assigning the costs to the transition edges in the above described way leads to the expected result (the vehicles of train run 5678 are transitioning to train run 4711).

3.2 Meta heuristics

The heuristic approach is used to cover the vehicle substitution and the maintenance planning. Several meta heuristics are known including Simulated Annealing, Threshold Accepting and Great Deluge [4].

All these heuristics are implemented in the TopC library [5]. We have chosen the Threshold Accepting algorithm, henceforth abbreviated with TA, to solve the above described problems. The TA compares two solutions of a given problem. Depending on the difference between the solutions one is selected to be the base solution from which a new solution is generated. For the TA the pseudo code is given below:

```
START
Create start solution
Set start temperature T > 0
REPEAT
    REPEAT: create a new solution which is a small change in the start
    solution;
        Calculate delta of quality: DE := Q(new) – Q(old) ;
        IF DE < T
        THEN start solution := new solution
    UNTIL no change in quality for a long time
reduce T;
UNTIL no change of quality at all
END
```

We show how the algorithm works for the vehicle substitution.

The start solution is based on the initial allocation of one vehicle group for each train run. After the allocation process is finished for each vehicle group, the algorithm chooses one ore more train runs allocated to a specific vehicle group and reassigns new vehicle groups to these train runs. Because these alterations affect only two vehicle groups, for each following step only two vehicle groups have to be recalculated.

To ensure that every calculation is reproducible for the same set of parameters, we use reproducible random numbers to choose the trains runs that are reassigned.

For the maintenance planning the TA is used to change an allocation plan for a single vehicle group. The new solution is produced by swapping train runs from different roster days [3].

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3.3 Hybrid model

In the hybrid model, the above described methods are combined to one single algorithm which works as shown in figure 1. The algorithm can calculate all the vehicle groups, but only those that can substitute each other should be calculated at the same time.

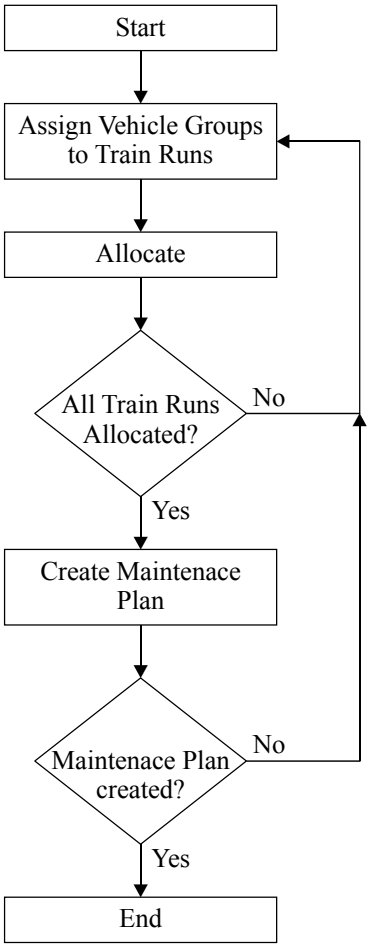

Figure 3: Hybrid model.

The model is controlled by an overall meta heuristic algorithm. This algorithm changes the vehicle groups assigned to the train runs. In the two inner steps of the algorithm first the allocation using the network flow model is performed. If all train runs were allocated during this process, the maintenance plan is calculated afterwards. If one of the inner steps fails, the complete inner loop fails and a new solution is created immediately. If both steps succeed, the delta of the quality is calculated (see section 3.2).

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3.4 Evaluation

To evaluate the model we have chosen an example allocation plan from "DB Reise & Touristik AG" (German Railways). The table below shows the effect on a one day circulation plan. As you can see in the table there is a significant increase in calculation time. On one hand, this occurs because the overall algorithm is more complex. On the other hand the described model is in a proof of concept state, where we haven't paid much attention on performance.

The table shows the results of an allocation plan calculation for the vehicle types BR401. There are different vehicles regarding the equipment in this group. For example there are a few units which are allowed to go to Austria. The original version of Dispo can only handle substitution in both directions. This means, if vehicle group A can substitute vehicle group B then vehicle group B can substitute vehicle group A. In the proof of concept version, this limitation does not apply anymore. This is why we introduced the table row "Number of wrong allocations". This row indicates that for the given example an unfeasible solution was created.

Table 1: Comparison of results.

	Dispo V1.0	Proof of Concept
Number of train runs	139	
Running time [mm:ss]	00:04	02:33
Number of wrong allocations	1	0
Total costs [€]	1.534.000	1.528.412

4 Summary

Although the network flow approach produces good (optimal) results in terms of the related costs, the modelling of all constraints is the fundamental task to solve the problem. Because some constraints (e.g. the vehicle substitution) can only be modelled with restrictions in the network flow model we decided to model these constraints in a heuristic approach. This combination of the two models leads to better solutions for the given problem because more constraints can be modelled. However, a solution can only be as good as the underlying data. The algorithm works even if some data or parameters are missing. In this case, standard values are set. But we have to keep in mind that this may lead to invalid solutions. Therefore the main task for the planner besides the planning will be to keep the database up to date.

The main target in the future is to improve the performance of the overall system by introducing new programming techniques and helper classes for the algorithm.

Additionally we are planning to develop interfaces to use Dispo together with timetable planning and simulation tools [6].

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