Shunting of Passenger Train Units in a Railway Station

One of the problems occurring in passenger railway planning is the problem of shunting train units in a railway station. Shunting occurs whenever train units are temporarily not necessary to operate a given timetable. We discuss several aspects of this problem and sketch a solution approach.

Since this research has been carried out together with NS Reizigers (part of the Dutch railways, which is responsible for passenger transport), the main focus is on their situation. However, similar situations occur in other countries as well.

Introduction

Shunting focuses on train units that are not necessary to operate a timetable. Here, one can think of the period between the morning and the evening peak, where trains are shorter than in these peaks and no peak trains are operated. However, the night is even more important for the shunt plan, since only a very limited number of train units is required to operate night trains of NS Reizigers. In order to use the available infrastructure as efficiently as possible, it is necessary to park units at shunt yards. For this problem, we look at one station at a time. The planning period is typically a 24 hour period starting around the morning peak.

The creation of shunt plans plays an important role at the strategic, tactical and operational level of planning. At the strategic level, we are interested in e.g. the layout of the station infrastructure, while the tactical level concentrates on a global check on the capacity of a station. At the operational level, detailed plans are created, describing which unit should be parked where and when, and who should park it there. Of course, during operations, disturbances occur and changes in the operational plan need to be handled.

Here, we will describe the operational level of planning. The aim of this level is to choose the configurations and locations of the trains on the shunt tracks in such a way that the railway process can start up as smoothly as possible in the next morning. Typically, train units arrive one by one during the afternoon and evening but the next morning starts almost immediately with the sharpest peak in demand for passenger rail transportation for that day. During this morning peak, practically all train units of NS Reizigers are either in service or in maintenance.

The operational planning of shunting train units is a complex task, because train units are restricted in their movements by the railway infrastructure, and the fact that this infrastructure is also used by e.g. through trains and freight trains. Other aspects that complicate this process are:

- Trains are configured by combining train units of the same family. Within one family of train units, there are types based on the number of carriages in a train unit, e.g. a double-decker with 3 or 4 carriages.
- The timetable gives the arrival and departure times and platforms of all trains. Furthermore, it exactly prescribes the configuration of all trains.
- The routes of train units that need parking, are not allowed to conflict with each other nor with the routes of through trains and freight trains.
- At certain stations, train units should undergo related processes, such as maintenance, washing and internal cleaning. Typically, these processes take place at dedicated tracks and extra routing is required. This also results in increased flexibility since these processes allow for changes in the order of the train units on the shunt tracks.
- All local activities, resulting from the operational shunt plan have to be carried out by local shunt personnel. For this personnel, a set of duties that covers the activities, needs to be constructed.

As all travellers by train can tell, disturbances occur during operations. Robustness of the shunt plan is therefore an important characteristic of shunt plans, especially since the creation of these plans is the last stage of the planning process at NS Reizigers.

All these aspects are taken into account in the Rintel (Dutch abbreviation for “Rangeren Intelligent”) project. In this project researchers and students from Erasmus University Rotterdam and Rijksuniversiteit Groningen corporate with NS Reizigers. However, we will focus in this article only on a subset of these processes, which results in the Train Unit Shunting Problem (TUSP). The TUSP will be formally described in the next section.

Problem description TUSP

Given

- a railway station,
- a shunt yard, usually geographically dispersed from
the station, a timetable, with for each train the arrival and / or departure time and platform at the involved station, and its composition,
- estimates of the routing cost from each platform track to each shunt track and vice versa, as well as several other cost estimates,

the TUSP consists of (i) matching the arriving and departing shunt units, and (ii) parking these shunt units on the shunt tracks, such that the total shunting costs are minimal. These costs consist of routing costs, train unit dependent penalties for certain shunt tracks, and penalties for not parking some shunt units at all.

The main characteristics of the shunting problem are the following:

- Arrivals and departures of train units may be mixed in time. This implies that, within the planning horizon, the first departure may take place before the last arrival has taken place.
- Shunt units may belong to different families and types (and thus lengths). The family of a unit may restrict the set of shunt tracks where the unit can be parked. For example, electrical train units can only be parked on a track with catenary.
- Shunt tracks may have different types and lengths. The type of a track determines how a unit can approach the track. Some tracks can be approached from one side only. These tracks will be called \( \text{Last In First Out (LIFO)} \) tracks. Other tracks can be approached from both sides. These tracks will be called \( \text{free tracks} \).
- Trains have fixed arrival and departure times, but flexible arrival times at and departure times from the shunt tracks. For example, the departure time of an arriving shunt unit from a platform to a shunt track is flexible within a time interval starting at the arrival time of the unit at the platform and ending some time before the next arrival of another train at the same platform.

In the matching of arriving and departing train units it is required that the matched units have the same type. This is a hard restriction in the Dutch rolling stock deployment. Furthermore, if several units of different types of one arriving train are matched to one departing train, then the types of the units in both trains have to be in the same order. Finally, a crossing occurs whenever a train unit \( i \) obstructs a train unit \( j \) during the departure or arrival of train unit \( j \). Such crossings are not allowed.

**An example**

Table 1 describes a shunt plan for 5 shunt units on a free shunt track. Each row indicates the matching of one or more arriving shunt units to some departing shunt units. In this example, the train with ID 3628 arrives at 11:09 on Monday at platform 5A. One unit of type MAT64_4 is parked on the shunt track and this unit leaves the station in train 3629 at 07:49 on Tuesday from platform 5A. Furthermore, the third row describes two units of type MAT64_2, arriving in train 3678, that also depart in train 3629 on Tuesday. These units are coupled with each other on the shunt track.

Figure 1 represents the situation on the track on Tuesday morning at 6 o'clock. The arriving units of trains 561 and 3678 cannot arrive via the same side of the track. Indeed, suppose that the units of these trains would do so. Then the train units of train 520 that have to leave at 07:18 on Tuesday are blocked from both sides of the track and this results in a crossing. Furthermore, in that case the units of train 3629 would not be parked next to each other, which would lead to additional shunting effort in the early morning. Note that, if the track would have been a LIFO track, a crossing can only be avoided by parking some of the units at another track.

<table>
<thead>
<tr>
<th>Arriving Train</th>
<th>Departing Train</th>
<th>Types of train units</th>
</tr>
</thead>
<tbody>
<tr>
<td>Train ID</td>
<td>Platform</td>
<td>Time</td>
</tr>
<tr>
<td>3628</td>
<td>5A</td>
<td>Mo 11:09</td>
</tr>
<tr>
<td>561</td>
<td>3B</td>
<td>Mo 21:02</td>
</tr>
<tr>
<td>3678</td>
<td>5B</td>
<td>Mo 23:43</td>
</tr>
</tbody>
</table>

Table 1: An example of a shunt plan with 5 train units.

\[
\text{Arrival Train} \\
\begin{array}{|c|c|c|} \hline 
\text{Train ID} & \text{Platform} & \text{Time} \\ \hline 
3628 & 5A & Mo 11:09 \\ 561 & 3B & Mo 21:02 \\ 3678 & 5B & Mo 23:43 \\ \hline 
\end{array} \\
\text{Departing Train} \\
\begin{array}{|c|c|c|} \hline 
\text{Train ID} & \text{Platform} & \text{Time} \\ \hline 
3629 & 5A & Tu 07:49 \\ 520 & 1A & Tu 07:18 \\ 3629 & 5A & Tu 07:49 \\ \hline 
\end{array} \\
\text{Types of train units} \\
\begin{array}{|c|} \hline 
\text{MAT64}_4 \\ \text{ICM}_5 \\ \text{MAT64}_2 \text{MAT64}_2 \\ \hline 
\end{array}
\]

Figure 1: The situation at the track on Tuesday, 6 o'clock.
The solution approach

We developed a two step solution approach, since solving the problem in one step is too complicated. The first step is related to the matching arriving to departing shunt units, and the second one deals with assigning shunt units to tracks on the shunt yard.

Step 1

In the first step, we match train units that need to be parked, to trains units that need to be supplied from the shunt yard. As already mentioned, the order of the train units as well as the desired types are very important. This results in a set of so called blocks of train units. The train units in one block remain together during the entire period of planning. The main objective in this step is to create a minimum number of blocks since this implies a minimum number of shunt activities.

Step 2

Step 2 is modelled as a Set Partitioning Problem (SPP). Since most of the computation time is spent in Step 2, we will discuss this step in a little more detail.

A track assignment, or shortly an assignment, is defined as a feasible assignment of a subset of blocks to a particular shunt track during the planning period. Here, an assignment is feasible if the following conditions hold:

- the assignment does not contain crossings,
- the total length of the blocks never exceeds the track length, and
- all blocks in the assignment are allowed to park on the track.

Table 1 and Figure 1 contain an example of a feasible assignment of blocks to a shunt track, given that these units are allowed to park on the track and that the shunt track is long enough.

Define $S$ as the set of shunt tracks. Furthermore, let $K'$ be the set of potential assignments on track $s \in S$, and let $K'_s$ be the set of potential assignments on track $s \in S$ containing block $b \in B$. We define the following binary decision variables:

\[
    x^*_k = \begin{cases} 
    1 & \text{if assignment } k \in K' \text{ is used on shunt track } s \in S \\
    0 & \text{otherwise}
    \end{cases}
\]

\[
    y_b = \begin{cases} 
    1 & \text{if block } b \in B \text{ is not parked on any shunt track} \\
    0 & \text{otherwise}
    \end{cases}
\]

The parameters $c^*_k$ model the costs of assignment $k$ on track $s$, which equals the sum of the route costs of the different blocks in the assignment. In addition, the parameter $d$ models a penalty if a block is not assigned to any track. The problem is then formulated as follows:

\[
    \text{minimize} \sum_{s \in S} \sum_{k \in K'} c^*_k x^*_k + d \sum_{b \in B} y_b \tag{1}
\]

subject to \( \sum_{k \in K'_s} x^*_k + y_b = 1 \quad \forall b \in B \tag{2} \)

\( \sum_{k \in K'_s} x^*_k \leq 1 \quad \forall s \in S \tag{3} \)

\( x^*_k \in \{0,1\} \quad \forall s \in S, \forall k \in K' \tag{4} \)

\( y_b \in [0,1] \quad \forall b \in B \tag{5} \)

We aim at minimizing the total costs of a shunt plan, such that as many blocks as possible are assigned to the shunt tracks. Constraints (2) state that each block is covered by exactly one assignment on one shunt track or it is not parked at all. Constraints (3) describe that each shunt track can have at most one assignment.

A major advantage of the proposed formulation is that difficult constraints with respect to the feasibility of an assignment are taken into account implicitly. A major disadvantage is the fact that the number of potential track assignments is exponential in the number of blocks. In order to handle the exponential number of potential assignments, we propose a column generation approach, where columns are generated dynamically in the root node of the branch and bound tree. Notice that in the root node the LP relaxation is solved.

In our setting, the master problem consists of selecting a set of track assignments according to the model (1) - (5). In the pricing problem, assignments for individual shunt tracks are generated implicitly and independently. Here, new columns are generated based on dual information obtained from the master problem. This information guides a dynamic programming algorithm with multiple resources in a particular network towards columns to be added. That is, several aspects of a (partial) path are of interest, e.g. reduced costs and the length of the units on the shunt track. The fact that shunt tracks can be approached from both sides greatly complicates this dynamic programming algorithm.

Applying the algorithms in practice

Our solution approach has been tested in station Zwolle. Here, the creation of a shunt plan is very complex, since there are a lot of related processes that also need to be planned, such as maintenance, interior cleaning, and washing.

In addition, there are a lot of different types of train units, which greatly increases the complexity. Finally, the shunting capacity in terms of the total length of the shunt tracks is scarce.

Daily, between 550 and 600 trains, consisting of 800 to 1000 train units, arrive at and depart from Zwolle. The train units range in length from 44 to 124 meters, while the 19 shunt tracks vary in length from 114 to 390 meters. In addition, 15 of the 19 shunt tracks can be approached from both sides.

In Figure 2 we see the layout of station Zwolle. The black areas in the middle of the figure represent the platforms, while the 19 shunt tracks are located around the platform tracks.
Figure 2: The layout of station Zwolle

In all cases, the required computation time for the Step 1 is negligible. For a typical Tuesday (Saturday), the computation time for Step 2 is 30 to 55 minutes (1 to 3 minutes). The resulting number of blocks on a Tuesday (Saturday) is around 68 (48). In addition, planners evaluate the results as a good basis for the development of the actual, final shunt plans.

Further research

In future research, we will focus (i) on a reduction of the computation times, and (ii) on an extension of the scope of the models. The models will be extended in order to support planners also in several related planning processes, such as crew planning and the planning of cleaning and short term maintenance of rolling stock. These extensions will lead to additional steps in our solution approach, but they will not change the general structure of the two presented steps. Another extension of the models will involve the modification of existing shunting plans in addition to the generation of shunting plans from scratch.

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References


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Notes

[1] This article is a summary of Freling et al. (2002), which has been awarded with the first prize in the 2002 Management Science in Railroad Applications Student Competition, organized by the Rail Applications Special Interest Group of INFORMS and Railway Age.