An Industrial Engineering Approach to Improve Railway Planning: A case study

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ABSTRACT

Railway planning is a continuous and very complex planning process in which many planners are involved. The process of plan creation can be characterized by long throughput times, strict division of tasks, a high task complexity, and a lack of standardization. The resulting plans need to be robust and satisfy all kinds of safety regulations. Literature has given attention to shunting task planning, but often the proposed solution approaches have not been implemented in planning systems. We investigate reasons for the lack of applicability of such solution approaches. Next, we examine the process of creating plans for shunting operations at stations during the night in a case study. Several planners are involved in this process. Both the efficiency and effectiveness of this process had to be improved. We apply an industrial engineering approach to improve this process. This approach consists of a process analysis, a task analysis, an investigation of improvement possibilities, and finally the development of computerized tools for improving parts of planning tasks. The result is an improved system for supporting the planning process. We will discuss characteristics of this support system and the implemented algorithms.

1. INTRODUCTION

An important task of a shunting planner of The Netherlands Railways is to plan the reconfiguration and relocation of all trains that arrive at a station at the end of the day such that they can depart in the correct configuration at the start of the next day. Moreover, the planner has to schedule the washing and cleaning activities and plan the movement of the trains to and from these facilities during the night. Finally, the planner has to modify already generated plans if additional information is released, for example if the maintenance schedule for the railway system is updated.

There are many planners involved in the process of shunting plan generation. They are supported by information systems that contain information on the railway network, equipment, and all expected and planned events related to both trains and shunting teams over time. Literature on train routing and scheduling problems suggests that there is a high potential for the application of decision support in these information systems. However, a recent survey of 153 papers on train routing and scheduling problems concludes ([1]: 399): "even though most proposed models are tested on realistic data instances, very few are actually implemented and used in railway operations".

Based on empirical research, Buxey [2] and [3] provide insight into the applicability and usage of techniques that have been designed for production planning and scheduling. He concludes that some areas and problems are more receptive than others, especially if the problem size is limited and model conditions can be specified with reasonable certainty. For detailed planning and scheduling, algorithms have been of limited value. The four reasons Buxey ([2]: 29) gives for this lack of value are: (1) inflexible models that are not able to cope with changing environments, (2) higher level priorities that are not correctly taken into account, (3) algorithms that are not able to cope with uncertainty regarding the actual state of the system, and (4) objectives of the algorithms that are only soft constraints and for the system as a whole only of limited value.

These conclusions seem also valid in the related field of transportation planning and railway scheduling. Watson [4] investigated various railway planners in the UK and states that the reasons for not using optimization models in railway scheduling are (1) a lack of integration with software that fits the needs of the users, (2) a lack of co-
operation between software developers and model builders, (3) a lack of extendibility of the models to real-life circumstances, and finally (4) no international applicability of the models.

We suggest that the more fundamental reason for not using these models can be found in the design approach applied. Traditionally, model builders use a problem-oriented approach, focusing on the conceptualization of the planning problem as viewed by the experts and on improvement of decision quality. This approach differs from the industrial engineering approach to design (see e.g. [5]), which provides more insight in the context of the problem and the process of solving it. The industrial engineering approach starts with a process analysis to identify the function of a model in its environment. Next, it gives attention to the interaction between worker and (machine) tools when redesigning the tools and tasks. Additionally, it investigates the possibilities for improvement of the whole process in terms of quality, speed, flexibility and/or costs. Finally, it chooses to improve some parts of the process that will yield the highest improvement/cost ratio.

This paper applies such an industrial engineering approach to the process of shunting plan generation. Section two describes the case study of a planning process at the Netherlands Railways. Section three applies the industrial engineering approach to improve this process. Section four discusses several characteristics of the proposed support system and the implemented algorithms.

2. CASE STUDY OF SHUNTING PLANNING

In the Netherlands, most passenger trains stay at a station during the night. They arrive at the end of the day and depart the next day in a possibly different configuration of coaches and probably from a different track. During the night, they must be stored on one of the shunting tracks; otherwise they would block the tracks that are needed for incoming and outgoing trains. Such ‘storage’ capacity at a station is limited. Additionally, all trains must be cleaned both internally and externally during the night at a track that contains the cleaning equipment. The task of the shunting planner is to plan the movements of the trains and coaches and to decide on what tracks trains stay during the night. To plan the movements, the planner must also assign train drivers, train shunters (employees that amongst other tasks connect and disconnect coaches), and routes of the trains on the station.

The complex and busy station of Zwolle, a city in the northeastern part of The Netherlands, is used to illustrate the planning problem. This station has also been studied in [6] and [7].

Figure 15 shows an example of a part of a shunting plan for station Zwolle. The horizontal axis denotes the time. The vertical axis contains the tracks. The bars are trains that occupy a track during a certain amount of time. For example, the train ZN1 is located on track 3B from 05:52 until 07:02. At that time, it is moved to track 4B, where it stays until 08:14.

In Figure 15, the movement from track 3B to 4B seems instantaneous. In practice, however, the movement takes a few minutes. Figure 16 shows a route from track 3B to track 4B. A more efficient route via track 3A is possible, but there are trains blocking that track. Sometimes it is impossible to find a feasible route between two tracks.
We studied the planning task of planners that are responsible for making short-term adjustments (one week ahead) to already created plans. Some of their activities are (unordered):

1. If one of the tracks on the station needs maintenance, all trains that are on that track during the time of the maintenance must be rescheduled to other tracks.
2. If a train will not arrive at the station due to maintenance, the plan has to be modified such that an extra train that is sent to replace the other one and arrives at another time will take the place of the original train.
3. If the time of departure of a train changes, the planner must find out the consequences and fix the plan where appropriate.
4. If a train has to be moved, the planner must find a train driver that can move the train.
5. If a train has to be moved to another track, the planner must find a feasible route.
6. If the planner detects errors in the plan, he has to correct them.
7. If the planner decides that the robustness of the plan is insufficient, he has to improve the plan.

Some of the constraints and goals that the planner takes into account are:

1. Changing the departure track of a train should be avoided as much as possible, as passengers have to be notified of such changes.
2. At least two routes should be kept free for traffic going through the station.
3. Within a three-minute time window (headway), only one movement may take place on a track.
4. Aim at efficient schedules for both drivers and shunters, resulting in minimal walking and waiting times.
5. Trains ought to be cleaned internally every day. If this is not possible at the special cleaning track, try to clean it along a non-cleaning track.
6. Externally cleaning can be skipped one day but not for two subsequent days.
7. Check the train length with the available storage capacity at a track when allocating trains to tracks.

The planning tasks are performed manually. Some computer programs are used to collect information, but the plan itself is made on paper before it is put in the computer. From the total group of 130 planners, about 60 are involved in planning these short-term adjustments. The short-term planners are geographically specialized, such that each planner performs these tasks for a limited number of stations.

3. INDUSTRIAL ENGINEERING APPROACH TO SHUNTING PLAN IMPROVEMENT

We have extensively analyzed the first task in the list of section two: some tracks need maintenance for a couple of hours during the night, and all trains that are on those tracks within that time window must be repositioned. In some aspects, this task is an easy one. The configuration of trains stays the same, so the planner only has to move trains. However, the number of shunting tracks is limited already, and when there are even less to use, it becomes a difficult puzzle. If more than two trains are put on one track, the trains in the middle can get blocked. Furthermore, less tracks available means also that it becomes more difficult to find free routes.

We analyzed the strategy of a planner that has a long experience in solving this task. The planner was requested to solve actual problems and to think aloud during his work. The thinking-aloud protocols were analyzed, after which we held sessions with the planner in which we actively asked for and discussed explanations of decisions.

The process of shunting planning is as follows. The planner receives a message from the system that a specific set of tracks has to be freed during a given time interval in order to allow for maintenance of these tracks. He generates a list of trains that occupy the tracks that need maintenance. This list is ordered on arrival time at the track. He empties this list by relocating and rerouting the trains to other tracks. The resulting modifications are put into the system and available for other planners and/or the shunting operators. The system controls whether other planners have to modify their partial plans in order to make the total plan feasible.
The task the shunting planner performs is as follows. The planner starts with the first train on his list, searches for a solution, and then takes the next one, etc., until a solution has been found for all trains. For each train, he first tries to find a track that is free for the interval that is needed. If he cannot find such an interval, there are three options. First, he can try to free another track. In that case, he must recursively follow the same procedure for each train that he moves: search for a solution that falls within the constraints or be satisfied with a constraint violation. Second, he can try a more complicated solution, for example changing the time of moving the train or finding a solution in which the train is moved multiple times during the interval. Again, this might include moving other trains as well. Third, he can violate a constraint, for example skip external cleaning. The first and second options are of course preferable, but as the planner uses pencil, fixer, and paper only, backtracking is difficult and time consuming. The depth of searching is therefore limited. The analysis shows that if a planner cannot find a solution in a few steps, he reverts to a constraint violation.

![Figure 17 Flowchart of task structure](image-url)

The flow chart in Figure 17 gives a short description of the sequence of subtasks a planner uses when making adjustments to the plan in case of maintenance of one or more tracks during a specific time window. Subtask 1 identifies trains that have to be re-planned. Subtasks 2 – 4 aim at finding a feasible solution to this problem.
Subtasks 5 - 7 relax a constraint in order to find a solution for the selected train. In subtasks 8 and 9 a check is being performed whether there are a driver and shunter available and whether there is a feasible route to move the train. In subtask 10, the planner will try to find a solution for the constraint violation he caused in one of the subtask 5-9. He tries to solve that violation by changing the shunting time or track of another train.

The task analysis reveals that a planner uses a large assortment of subtasks when solving a specific planning problem. The choices he makes in his solution process (i.e. the depth of search) are not necessarily identical for similar problems, as it also depends on the time available for finding a solution, the history of recent constraint violations, and the required quality of the solution.

In order to find possibilities for improvements, we first investigated performance gaps with respect to quality, speed, flexibility and costs. The management of the Netherlands Railways stressed the importance of responsibility in the process of plan creation. Planners should feel responsible for the quality of the plans they generate. Next, management would like to see an improvement in the quality of the plans, i.e. no constraint conflicts and accurately configured plans. Planners stressed the importance of robustness of the plan, which can be seen as a flexibility measure. They complained about the speed or responsiveness of the information system, which delayed the process of plan generation and made it less efficient.

We found several possibilities for improvement; both in the process of planning and in the way the planner performs the tasks. The process involves activities of several planners that all contribute to the final plan, without knowing the consequences of proposed measures for other partial plans. The main reason is the high complexity and high level of detail of the final plan. These factors can be changed, but it will take a long time before results may be expected. Therefore, we decided to focus on improvements in the way the planner performs his tasks.

The planner aims at achieving robust and high quality solutions within the available time. Management wants to improve the quality while leaving responsibility at the planners. We therefore decided to identify subtasks that cost a lot of effort to the planner without being very important for the acceptability of the solution. Decision aids should both be able to perform these subtasks in a shorter time than manually, and include intelligence on the larger problem, resulting in a higher quality of the final solution achieved, as more time is available to improve the solution.

Identification of subtasks that are candidate for algorithmic support depends on the efforts associated with a specific subtask. From an industrial engineering perspective, the more frequently the subtask is repeated, the more time can be saved by automating or supporting the decision. However, repetition is not the only factor. Subtasks that require many well-described but time-consuming administrative tasks, such as storing and retrieving information, and performing calculations, are also candidate for inclusion in decision aids.

The subtasks that we identified for improved support are:

<table>
<thead>
<tr>
<th>Type of subtask</th>
<th>Example</th>
<th>Frequency per process cycle</th>
<th>Duration of subtask</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>low</td>
<td>high</td>
</tr>
<tr>
<td>Information retrieval</td>
<td>e.g. train numbers</td>
<td>*</td>
<td></td>
</tr>
<tr>
<td>Searching</td>
<td>e.g. finding a free track</td>
<td></td>
<td>*</td>
</tr>
<tr>
<td>Sorting</td>
<td>e.g. on departure time</td>
<td></td>
<td>*</td>
</tr>
<tr>
<td>Routing</td>
<td>e.g. to cleaning track</td>
<td></td>
<td>*</td>
</tr>
<tr>
<td>Backtracking</td>
<td>e.g. problem solving</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Information retrieval tasks result in the largest loss of productive time for the planners. They are gathering data from different systems (data tables, standard times, train schedules, workforce schedules) in order to prepare their own planning task. Although the frequency of this activity per process cycle is low, duration is very high, so it is identified as a candidate for improved support. Searching activities are the most frequent part of the task of a planner. He continuously searches for alternatives, e.g. free tracks for a relocation decision, free intervals on a cleaning track, etcetera. Sorting activities are frequently performed in order to rearrange the input data such that a preferred solution strategy can be applied. Manually sorting is time consuming, so a planner sometimes decides to choose for another strategy that may result in a lower quality plan. Routing decisions are frequently taken while generating a plan and take in some cases much time. Backtracking solutions occur not very frequently, as it
requires a lot of administration time for the planner during the generation of a plan. However, solution quality may improve drastically whenever backtracking is easily made available.

Supporting the identified subtasks will lead to a reduction of the duration of the activity, which makes it possible for the planner to either increase the frequency of performing this task and hence increasing the quality of the solution, or invest more time in finding better solutions. Providing algorithmic support on the level of subtasks does not automate the total planning task, so planners still feel responsible for the solution they provide.

4. Prototype Shunt Scheduling Support System

The prototype shunt scheduling support system that we developed includes elaborate functionality for manual planning and a number of algorithms. Examples of these algorithms are finding a free track and a suitable train routing. The prototype is developed in the Delphi programming environment, which results in quick response times and a graphical user interface that resembles the current desktop of the planners. The schedule shows the location of train and coaches on the tracks over time. The path of individual coaches resembles detailed information for the planner. The list of attributes, constraints and violations uses hyperlinks to enable the planner to search for relevant information and to make modifications. Finally, the blackboard enables backtracking. The planner can easily modify the layout of the screen and open additional windows, such as the one shown in Figure 2 that is used for supporting the routing decision. Figure 18 shows a screenshot of the system.

![Figure 18 Screenshot of prototype planning system](image)

We applied a bottom-up approach for supporting the tasks of the planner by designing algorithms for these subtasks. This bottom-up design approach has several advantages. First, the algorithms are smaller and more robust, as they solve only a part of the whole task. Second, the same algorithms can be reused in different tasks, as identical subtasks will arise in different tasks. Third, the planner better understands the outcome of the algorithms, as the
problem it solves is less complex. Finally, maintenance of the algorithms becomes easier because of the modular
design approach applied. If circumstances change, only a small number of algorithms have to be modified.

The hierarchical view on the planning task and generation algorithms that we apply in this paper provides
stability and robustness for the design of planning support systems. For example, no matter what kind of strategy
the planner uses, he will always need to perform small low level tasks such as finding routes, selecting train drivers,
matching incoming trains to departing trains, etc.

5. CONCLUSIONS AND FUTURE RESEARCH

This paper sets out an industrial engineering approach for designing a support system that helps the planner to
perform the task of train shunting planning. Our approach differs from the traditional problem-oriented design
method in considering the planner explicitly as an object of study when deciding on the tasks that should be
supported. We characterize our approach as a bottom-up task-oriented industrial engineering approach. First, we
analyze the process in which the planner is involved. Next, we analyze the way a human planner makes a plan. We
distinguish activities and describe the order in which they are performed. Next, we determine the performance gaps
that need to be improved by using a support system with algorithms that support selected subtasks. We identify
subtasks using a frequency measure and a duration measure and design algorithms to support these subtasks. The
algorithms are included in a support system with a graphical user interface and a data infrastructure. The screen
layout resembles the usual environment for planners to make a plan, and enables them to use the algorithms in a
coincident problem space.

We developed the prototype for planning the railway network of Zwolle, a station in the northeastern part of The
Netherlands. The prototype of the support system is being developed in Delphi. Planners have been involved in the
design process, both during the task analysis phase and the algorithmic design phase. The study has shown that an
industrial engineering approach can be used to design algorithms for a decision support system. This approach
differs from the approach usually applied when building OR-models. The planner is explicitly considered, both as
object of study and as user of the algorithms. By including the planner in such a way during the design process, we
achieve a higher acceptability of the outcomes of the algorithms.

REFERENCES