Increasing the Capacity of Shunting Yards within the Current Infrastructure: A Computational Perspective

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Abstract. With a dense infrastructure and limited space, the opportunities for increasing the capacity of the railway network in the Netherlands are limited. One of the bottlenecks is optimally using the available space around stations and in shunting yards. Many details must be considered, increasing the complexity of the problem. Human planners can benefit from computational support to ensure efficient use of the infrastructure. We introduce a framework for positioning previous research in terms of abstractions and highlight a promising future direction: the development of a new approach that combines different methods and uses the relations between the abstractions to create more efficient solutions.

Keywords: railway hub, train shunting, train servicing, abstractions, hybrid model, human-AI collaboration, neuro-symbolic AI

1 Introduction

The dense infrastructure of the Dutch railway system serves almost one million people daily but is restricted in handling more passengers due to a lack of space and limited personnel. To address this, intelligent solutions are being sought, like automating trains to reduce the demand for personnel and decrease the distance between trains. In this paper, we look at a different opportunity for improvement, namely in creating more efficient plans for railway hubs.

To reach a higher capacity, the demand for more train carriages increases and the need for efficient servicing arises. The parking and servicing of trains take place in shunting yards located within major cities in the Netherlands, hence they have limited expansion opportunities. Shunting yard operations include the parking and routing of trains to ensure they leave the yard at their scheduled time to return to their route in the timetable. If a train leaves the yard later than expected, this results in other delays across the timetable. Moreover, to depart correctly, train compositions might require splitting and recombining. Finally,

Fig. 1: Schematic layout of the railway hub at Amsterdam Central station.

service actions must be scheduled to clean and maintain trains. All these operations are included in the Train Unit Shunting Problem with Service Scheduling [5]. As the free space on tracks is reduced due to an expansion of the rolling stock, reallocation must often be used to route trains from their initial parking track to another one. Since this is a costly operation, the goal is often to minimize these reallocation moves. Although solution methods to this problem can already solve some real-world scenarios, the problem becomes increasingly more difficult with more added details, and due to complex operations like reallocation.

Shunting yards are part of railway hubs: regions in the railway network operated as one unit and often located around a major station. Fig. 1 shows an example of the Amsterdam Central station hub with two yards (*Dijksgracht* and *Watergraafsmeer*) and two smaller stations (*Amsterdam Science Park* and *Amsterdam Muiderpoort*). In practice, most operations in a railway hub are focused on trains outside their scheduled route in the timetable, when they must be parked and serviced. However, the scheduled routes of other trains through a station must also be considered, as these can conflict with trains being shunted.

In this paper, we highlight the importance of finding a good plan for the railway hub operations, including the parking and servicing of trains within shunting yards as well as the movements between stations and shunting yards. Previous studies use many models with various levels of abstraction, in other words, they each consider a different subset of problem components. Including all the details leads to very long computation times, so an abstraction is often used to get meaningful results within a certain amount of time. We introduce a framework to differentiate between these abstractions, illustrate the relations between them, and position previous work within this framework. Finally, we propose a new direction of research towards solving the complete problem.

2 Abstraction Framework

When planning train shunting operations in practice, many relevant details must be considered, from the splitting and combining of trains into different configurations, to the scheduling of personnel to operate them. However, it is often

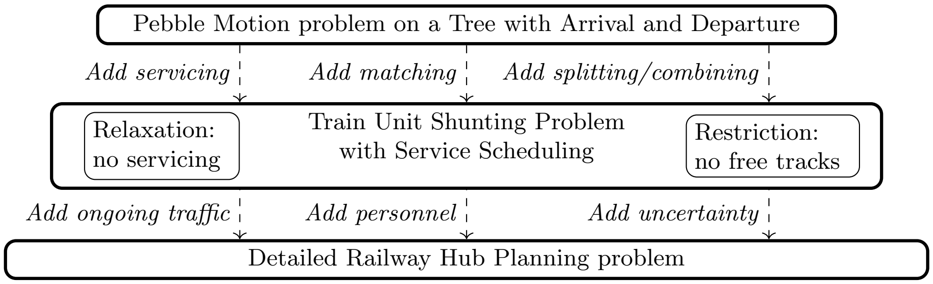

Fig. 2: Examples of different abstractions.

impractical or even impossible to include all these details, as this would lead to long and unrealistic computation times. Moreover, having up-to-date and real-time information on all problem components is a challenging task, and human planners would not be able to oversee the details effectively. Therefore, researchers often use an abstracted model, though there are many variations of abstractions to consider.

We propose a framework that shows the relations between different models with varying levels of abstraction, by identifying when one model A is a *relaxation* of another, usually more detailed, model B. This is the case if every solution to model B can be translated to a solution in model A, and we say B is a *restriction* of A. Consequently, proof that no solution in model A exists also proves that no solution for B exists. Often, a more abstract (relaxed) problem is easier to solve, and we can use such relations to combine different models into an approach to find a plan for shunting operations. Besides, these relations can be used to communicate results to human planners and show why a decision was made. In this paper, we highlight three different models, explain their relations, and show how to relate them to other ones. After introducing our examples, we explain how to use this framework to address the complexity of creating a shunting plan.

The first work we discuss is a high-level representation of the practical problem called the Pebble Motion problem on a Tree with Arrival and Departure, which was introduced by Hanou et al. (2023) [9]. The second model, called the Train Unit Shunting Problem with Service Scheduling, was created by Van den Broek et al. (2021) [5], which includes more practical details. As we will show, a lot of previous research is related to this problem, while we point out the need for a more detailed model, which will be our third example. This low-level structure does not have a name yet in the literature, and we refer to it as the Detailed Railway Hub Planning Problem. In the next subsections, we highlight several restrictions and relaxations that are often used, and show the underlying relations between the three examples in Fig. 2.

2.1 Pebble Motion problem on a Tree with Arrival and Departure

At the highest level, we consider the most abstract representation based on a well-studied problem in graph theory called pebble motion. In the current variant [9], we consider the shunting yard as a graph, with vertices to define the locations where a train can be parked and an additional track for the arrival and departure of trains. By using an original graph representation, we can also apply graph theoretical results to the railway scenario. These theoretical results can provide new insights to solve the problem and use the results in a more detailed model. The problem is focused mainly on the parking configuration, which is still shown to be a difficult challenge [9]. This abstract representation is a relaxation of the practical scenario, so if there is no solution here, there is no solution in practice. Thus, we can spare unnecessary computation time by quickly determining infeasibility in some scenarios. For example, when there is less space in a shunting yard than minimally required [9][e.g., Fig. 3, p. 5] or when the angles between tracks in the infrastructure are too sharp for a train to make a turn [1]. However, solutions to this model do not always translate to solutions in practice due to missing details, which we consider in the next subsection.

2.2 Train Unit Shunting Problem with Service Scheduling

The second model is probably the most complete representation of a railway hub in the literature. The Train Unit Shunting Problem with Service Scheduling [5] includes the allocation of parking tracks to incoming train units, the routing from the point of arrival in the shunting yard to their allocated tracks, the splitting and combining of train compositions, the matching of train units between arriving and departing compositions, and the scheduling of the service actions to be performed. This problem description is already a lot more detailed than the previous one, and the translation may not always be straightforward.

Many other models can be related to this problem, and we give a few examples of such relaxations. Like, a study focusing on rolling stock scheduling relaxed the problem such that no service actions needed to be scheduled [8]. A different work on human decision support systems initially restricted their approach to handle only last-in-first-out tracks, though they also added a generalization to include free tracks [7]. An overview of several studies related to our second model was previously written [12], though the review does not give the relaxation and restrictions as we described here.

A final direction of relevant abstractions considers studies that have simplified their model to regard either the train station or the shunting yard as a single point. Then, their research focuses on the other component and minimizes the collaboration between the different parts. For example, many studies on shunting yards assume there is a certain point where trains arrive and depart for shunting, which is a simplified version of the track between the station and the yard. This is also the case in the Train Unit Shunting Problem with Service Scheduling. Such a relaxation results in the disregard of the ongoing traffic on the tracks that cross the path between the station and the yard. In railway networks that are not as dense as the Dutch network, the tracks between the station and the shunting yard may be less busy, so the ongoing traffic is unlikely to be a limiting factor.

2.3 Detailed Railway Hub Planning Problem

Finally, our newly suggested model includes the most practical details. We consider the complete hub of a railway station, which should be detailed in the same way as in practice, including track sections, switches, etc. The model considers all the components from the previous problem (parking, matching, routing, splitting, matching, and servicing) and adds three others that have so far only been studied individually.

First, we should consider the movements between the station and shunting yards, as the routing problem must now ensure no conflicts occur between the ongoing trains passing through the general network and the trains that are shunted [10]. The second component regards the scheduling of rolling stock and personnel, their details (e.g., train length or job type), and the constraints posed by them [4]. The latter could include the personal preferences of conductors or the fact that there is often only one driver to operate trains in a shunting yard. Finally, the most important characteristic of this model is the notion of uncertainty since in practice we deal with many uncertainties, like the delayed arrival of a train or a prolonged time to clean a train. These should be included in the model to create solutions robust to small delays [3].

3 Discussion

Artificial Intelligence (AI) can provide promising new approaches to solving practical problems by finding abstractions or combining different models and their outcomes. For example, consider neural networks, which could be used to help the search procedure find good solutions. Neural networks are often bad at satisfying all the problem constraints, while they are very good at generalizing from a lot of data. So, they could very well be used to help the search, though not necessarily taking over. This combination of learning and more traditional methods is called neuro-symbolic AI and is also a very interesting direction of research in general, providing many benefits [11].

Quite some research has already been done considering a more abstract model. Nonetheless, these solutions are not applicable to the practical problem straightaway. Therefore, we suggest a focus on the relations between different abstractions. With the help of simulators, solutions can be tested and propagated through our framework. However, the more advanced railway hub simulators only exist as proprietary software to railway companies [6]. And since most scientific simulators focus on disruption management instead [2], there is still a need for a scientific simulator for railway hub operations.

Combining approaches from different models could also be an exciting focus. Machine learning methods can provide new insights and aid the decision of which approach to use, which is another form of neuro-symbolic AI. Joining several solutions could be more beneficial than striving for more advanced models, as the inclusion of extra details tends to make them more challenging. So, we suggest a model that uses these insights.

Moreover, we highlight the importance of creating methods that work together with human operators. Human-AI collaboration is important to ensure that research is useful and applicable in practice. Then, even in scenarios where AI methods fail, they can provide insights to human operators to solve the last details. Therefore, we propose hybrid methods that not only combine solutions but also have a human-in-the-loop perspective, to assure planners of the benefits.

With this overview, we have provided a framework to position previous research. We have given three examples of different models, shown the relations between them, and positioned them in our framework. Finally, we have pointed out the most promising directions for future research. Given the limited space within a heavily used infrastructure in the Netherlands, we believe that solutions that work for Dutch scenarios will also be useful in other countries, especially when dealing with capacity issues.

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