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An integrated rolling stock planning model for the Copenhagen suburban passenger railway

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ABSTRACT

A central issue for operators of passenger railways is providing sufficient number of seats for passengers while at the same time minimising operating costs. This is the task of rolling stock planning. Due to the large number of practical, railway specific requirements that a rolling stock plan has to take into account, rolling stock plans are often constructed in a step-by-step manner, taking some requirements into consideration in each step. This may make it difficult in the final step to produce a plan that is feasible with regard to all of the requirements and at the same time economically attractive.

This paper proposes an integrated rolling stock planning model that simultaneously takes into account all practical requirements for rolling stock planning at DSB S-tog, the suburban passenger train operator of the City of Copenhagen. The model is then used to improve existing rolling stock plans using a hill climbing heuristic.

Experiments show that the heuristic used in the integrated rolling stock planning model is able to produce feasible solutions within minutes of computation time starting from infeasible rolling stock plans. Furthermore, the heuristic is able to improve the economic attractiveness of typical rolling stock plans with an average of 2%.

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1. Introduction

1.1. Background and terminology

Rolling stock planning is the process a passenger railway operator performs in order to plan how to use the rolling stock for the conveyance of passengers. The goal of the rolling stock planning process is to provide sufficient seats for passengers while at the same time keeping operating costs as low as possible. This goal is of course a highly important matter for operators of passenger railways since it is the core question of their very existence: *Can the passenger railway convey its passengers at an acceptable price?*

A passenger railway operates a *timetable* of *train services* for the conveyance of passengers for *revenue*. Rolling stock planning is performed by assigning individual *train units* to the train services from the timetable.

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When producing rolling stock plans for a passenger railway, a large number of practical, railway specific requirements need to be taken into account. These requirements relate to the railway infrastructure, the timetable, the rolling stock itself, the passenger demand, maintenance scheduling and a large number of other aspects of the railway operation.

Due to the large number of practical, railway oriented requirements and their complexity, rolling stock planning is often performed in a step-by-step manner, taking only some of the many requirements into consideration in each step. This is also the case in the rolling stock planning system currently used at DSB S-tog, the suburban passenger train operator of the City of Copenhagen. DSB S-tog is considered as case study for this paper.

In the rolling stock planning system of DSB S-tog, as it is typical for the industry, the first step is to decide how much seating capacity should be allocated to each train service. This step is called *composition planning*. Based on this, in the next step, individual train units are assigned to train services in a process called *rotation planning*. Finally, in the last step it is decided where the train units are to be parked in the *depots* when not in use. This step is called *depot planning*. Needless to say, the step wise approach may produce plans that are neither optimal nor feasible.

For DSB S-tog this is especially the case due to the very limited space in the depots where train units are parked when not in use. For this reason, the most constraining requirement for the rolling stock planning at DSB S-tog is that of being able to move the train units in and out of the depots. Planning this as the **last** step may prove highly problematic, since decisions taken in the earlier steps may limit the degrees of freedom for the depot planning steps to an extent that no feasible solution can be found. Such infeasible plans will have to be corrected manually, most often incurring extra cost.

Other suburban passenger train operators may have similar, challenging conditions that make sequential planning equally problematic. For this reason, an integration of **all** the different rolling stock planning processes is essential if an automated model is to produce plans that are usable in practice. This is achieved by the integrated rolling stock planning model proposed in this paper.

The combined process of composition planning, rotation planning and depot planning is called *circulation planning*. The circulation planning phase of rolling stock planning has a tactical scope and is conducted months before the plan is set into motion. The process of setting a circulation plan into motion is called *train unit dispatching*. This is the operational, short-term or real-time phase of rolling stock planning where last minute changes are made based on which physical train units are available, whether delays or disruptions have occurred, etc.

1.2. Literature review

Until recently, operations research (OR) techniques have been applied to a wide range of specific problems in the railway industry, which are summarised in various surveys (Cordeau et al., 1998; Ahuja and Cunha, 2005; Huisman et al., nov 2005; Caprara et al., 2007; Kroon et al., feb 2009). The challenge for the adaptation of OR techniques to the railway industry now no longer seems to lie in finding solutions to each specific problem, but much more in integrating the individual solutions to the (often highly interconnected) specific problems into holistic, integrated models. By integrating the specific models with each other, sub-optimal solutions can be avoided. The tendencies for the integration of models are currently also seen in the airline industry (Saddoune et al., feb 2012).

Table 1 shows an overview of characteristics of selected and reviewed, recent literature for rolling stock planning. The characteristics are grouped as follows: The overall topic of article; The railway planning processes it addresses; The type of the model proposed; The properties of the model graph (all reviewed models feature a graph); The railway specific requirements the model integrates; The objective of the model; And finally, the solution method applied.

As may be seen from Table 1, a large portion of the reviewed methods use an *arc based multi-commodity flow* or similar modelling scheme. In such a scheme the flow of train units or locomotives is modelled in a flow graph, with flow conservation constraints on each vertex of the graph making sure the flow into the vertex equals the flow out of it. Arc based flow models are typically relatively low in complexity, a presumed reason for their widespread use. In arc based flow models, however, it adds to complexity to model sub-path constraints such as recurring maintenance at regular distance intervals.

In *path based multi-commodity flow models* on the other hand, each potential sequence of movements of the individual train unit or locomotive is modelled (e. g. by enumeration), making it easier to also take recurring distance related constraints such as maintenance into account.

In Table 1, the literature reviewed is also categorised according to the properties of the graphs involved in the models. As may be seen, most models use a *space-time graph* type (also called time-expanded graph type), where each vertex in the graph is an event in space and time, e. g. the arrival of a train at a given time at a given station (in space). Correspondingly, arcs in a space-time graph may e. g. represent train services. Such a graph is also an *event-activity graph*, referring to the vertices as events and the arcs as activities. This type of graph is also well known in the airline industry (Ryan, 1992; Barnhart et al., 2003; Rasmussen et al., 2011; Saddoune et al., feb 2012).

Some authors use the *edge-to-vertex dual* or *line graph* (Harary, 1969) graph type, conjugated from the space-time graph mentioned before. In the line graph type, vertices represent train services whereas arcs may e. g. represent the possibilities of a train unit to perform train services in sequence.

Similar “line graph” style graph types are used to model train composition changes at stations, the approach direction in depot planning and maintenance constraints. In two papers a hypergraph is used (Borndörfer et al., 2011, 2012).

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