



Optimization and simulation for robust railway rolling-stock planning



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ABSTRACT

In this paper, we focus on the problem of robust rolling-stock planning for French passenger trains. First, we characterize robustness and define some indicators for the evaluation of rolling-stock rosters. We take a particular interest in homogenizing turning-times in a roster in order to absorb potential delays. Then, we propose a new approach to solve the problem of robust rolling-stock planning. The SNCF reference tool (PRESTO) calculates a solution to the rolling-stock planning problem. It consists of a multi-step approach to cover demand while minimizing operating costs, and to further add maintenance slots to the roster. We propose an integrated ILP model to add robustness to a roster while maintaining low operating costs compared to PRESTO. We have carried out tests on nine real French regional transport instances, and we use a simulation module to evaluate the results. We observe a significant improvement in robustness indicators while maintaining low operating costs and meeting maintenance requirements.

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1. Introduction

Huisman et al. (2005) describe the three major tasks of railway operations management:

- Timetabling;
- Rolling-stock circulation planning to cover timetable;
- Crew scheduling to operate the rolling-stock.

These tasks are interdependent, but carried out separately by railway operators, usually in cooperation with the infrastructure manager. This paper deals with robustness issue in rolling-stock planning, which takes place from one year to six months before operations. We point out that building a robust transportation plan requires a collective work of all the actors.

Punctuality and reliability are essential elements of passenger transportation systems. But disturbances such as infrastructure failures and rolling-stock breakdowns can occur, and then require an adaptation of the timetable, rolling-stock and

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crew schedules. The aim of this study is to anticipate those potential disturbances by proposing robust rolling-stock rosters. A robust rolling-stock roster should anticipate operational disturbance possibilities in order to limit service quality deterioration and additional costs.

In this work, we take a special interest in the robust rolling-stock planning problem applied to passenger trains in France. The rolling-stock planning problem consists in providing the minimal number of rolling-stock units to cover a set of trains to operate. Several technical constraints have to be respected, such as maintenance requirements. For instance, each unit has to go to a maintenance depot every three days. However, in case of disturbances, optimized rolling-stock rosters usually make delays spread into the traffic network. Then, robust approaches enable roster to absorb delays. We propose an integrated method to build robust rolling-stock rosters while taking into account technical constraints such as maintenance requirements.

We first define robustness. We introduce indicators inspired by planning rules in railways to characterize robustness. In particular, we provide an indicator based on the following statement: homogeneous turning times bring robustness to a rolling-stock plan. Then, we propose a method to take into account this robustness indicator while building rolling-stock rosters. It allows us to compute robust solutions by working on their structure. Furthermore, our approach integrates maintenance requirements. Finally, we present optimization and simulation results, which show the relevance of the indicator and method.

Section 2 reviews robust approaches found in the literature. Then, Section 3 is dedicated to the description of the rolling-stock planning problem, while Section 4 describes an existing solution at SNCF. We focus on robustness indicators in railways. In Section 5, we present a definition of robustness in the studied context. We detail the indicators chosen to build and to evaluate robustness of rolling-stock rosters. Section 6 describes an ILP model of the robust rolling-stock planning problem that we address. Section 7 presents optimization tests and results on real instances. Finally, Section 8 describes a simulation process to show the relevance of the method.

2. Literature review

Railway operations management includes timetabling, rolling-stock planning, and crew scheduling (Huisman et al., 2005). Rolling-stock planning is a crucial part of this transportation planning process and has been frequently studied (Schrijver, 1993). Railway operations management also implies many underlying maintenance problems, such as the rolling-stock maintenance planning problem and the rail inspection scheduling problem (Peng et al., 2013). Maintenance on rolling-stock is often considered as technical constraints to respect in rolling-stock planning models (Cacchiani et al., 2010; Giacco et al., 2014). In this paper, we focus on the rolling-stock planning problem, and we integrate rolling-stock maintenance requirements.

Robustness has to be considered at every step of the planning process. All the resources of the transportation system have an effect on the system's robustness: times, rolling-stock, crew, stations, even signaling system (Hofman and Madsen, 2005; Landex and Jensen, 2013; Goverde et al., 2013). It is also considered during real-time operations, usually as rescheduling problems in case of disturbances (Larsen et al., 2014). Many criteria come under consideration regarding railway operations, such as costs, performance, quality of service, and robustness. These criteria sometimes are antagonistic, then transportation planning is a matter of tradeoff. For instance, Abril et al. (2008) study the tradeoff between capacity (performance) and robustness, Vansteenwegen et al. (2016) look at the tradeoff between quality of service and robustness, and Lidén and Joborn (2016) evaluate the tradeoff between performance and cost.

In this paper, we tackle robustness related to rolling-stock planning in conception, and we take a special interest on the tradeoffs between costs, maintenance, and robustness.

Deterministic optimization approaches do not take into account uncertainty of the data. Under this hypothesis, an optimal solution applied in real conditions might be deteriorated in case of unexpected circumstances, or even become infeasible. Ben-Tal and Nemirovski (2000) came up to this conclusion: "In real-world applications of Linear Programming, one cannot ignore the possibility that a small uncertainty in the data can make the usual optimal solution completely meaningless from a practical viewpoint".

Robust approaches exist to solve optimization problems while taking data uncertainty into account by modeling uncertainty as scenarios or intervals (Kouvelis and Yu, 1997; Soyster, 1973; Bertsimas and Sim, 2004). But classical robust approaches are not always adapted to industrial applications (Le Maitre, 2008).

Smith and Johnson (2006) have studied the robust airline fleet assignment problem. They apply rules related to the context to act directly on the structure of the solution. The rule used is the station purity: the number of fleet types serving a given station should not exceed a specified limit. By using this rule to solve the fleet assignment problem, they obtain robust solutions from an operational viewpoint.

In railways, several robustness indicators have been found to evaluate robustness of a transportation plan, or to build robust solutions.

To evaluate an existing transportation plan, Nielsen et al. (2007) define indicators associated to the delay, e.g. average delay, or cumulative delay. Hofman and Madsen (2005) use two complementary indicators: the regularity is the percentage of on time trains, while the reliability measures the number of actual departures compared to the number of departures planned. At SNCF, Chandesaris (2005) computes the back to normal time, which is the time interval between the appearance of

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