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A Rolling Stock Circulation Model for Railway Rapid Transit Systems

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Abstract

Rolling stock is one of the key operational issues for a railway transportation company. In fact, rolling stock and infrastructure maintenance suppose about 75% of total cost for a typical railway network. Rolling stock circulation consists of defining individual train paths over the network accomplishing pre-defined passenger's services and fulfilling certain design criteria such as minimizing train costs. The maintenance of the train is an important aspect to be considered in the planning of rolling stock circulation. Typically, railway operators follow maintenance policies in which rolling stock must be revised every certain number of kilometers.

In this paper we propose, in the context of railway Rapid Transit Systems (RTS), a mixed integer programming model to develop rolling stock circulation plans considering a rotating maintenance scheme. The model can be applied to any medium size RTS considering a variable number of parking facilities. Train circulation is obtained by following a weekly pattern to include weekend train schedules. This approach minimizes train empty movements whereas equilibrates the weekly number of kilometers covered by every train unit. The rotating schema ensures a long-term maintenance policy that minimizes the train units reserve and balances the workload of the maintenance operation. Finally, as illustration, the modeling approach is applied to the Seville commuter railway network in order to design a rotating rolling stock plan.

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Keywords: Rolling stock circulation; Rapid Transit Systems; Optimization

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1. Introduction

Rolling stock is one of the most difficult phases in the railway planning process and also plays a key role in a cost-efficient operation. The rolling stock represents a huge capital investment for service operators that cannot be changed frequently, which means that rolling stock becomes a strategic decision with a future impact of several decades. The rolling stock circulation plan includes a set of interrelated sub-problems such as train composition determination (locomotives and carriages coupling and decoupling), vehicle and carriage rest location (avoiding empty movements), vehicle circulation problem and maintenance policies.

The rolling stock circulation problem can be viewed as a special multicommodity capacitated minimum cost flow problem where a set of different commodities (trains with different characteristics or rolling stock components depending on the problem) must be routed every day through a network from certain stations (rest places) in order to ensure a set of services and to guarantee minimum operation cost. The problem becomes more complex when train maintenance decisions are also incorporated. In case of considering carriage coupling and decoupling, the capacity of links refers to the maximum number of carriages that can be moved on each service. Other capacity aspects such as track capacity, are usually analysed before in an early phase, commonly when designing train schedules.

Several models have been proposed for railway rolling stock problems. Schrijver (1993) minimizes the number of train units needed to satisfy a given demand. This model computes the minimum number of train units needed for each daily schedule. Related with this paper, (Brucker, Hurink, & Rolfes, 2003) study the problem of routing single carriages through a network, considering empty carriage movements. Their solution approach is based on local search techniques. Cordeau, Soumis, & Desrosiers (2000) present a Benders decomposition approach for determining a set of minimum cost equipment cycles such that every trip is covered using appropriate equipment. (Cordeau, Soumis, & Desrosiers, 2001) extend their model incorporating maintenance issues. Lingaya, Cordeau, Desaulniers, Desrosiers, & Soumis (2002) describe a model and a solution approach for a car assignment problem that arises when individual car routings must be determined considering maintenance constraints and minimum connection depending on the positions of cars. The solution approach is based on a Dantzig-Wolfe (Dantzig & Wolfe (1960)) reformulation solved by column generation. Abbink, Berg, Kroon, & Salomon (2004) present an integer programming model with the objective of minimizing seat shortage during morning rush hours. It is possible to obtain the required fleet size for each of the lines since they are treated separately. Alfieri, Groot, Kroon, & Schrijver (2006) propose an integer programming model in order to obtain the circulation of rolling stock considering order in trains composition. The model is devoted to a single line and for only one day of operation. Fioole, Kroon, Maróti, & Schrijver (2006) presented an extension to an at that time non-officially published model of Peeters and Kroon, which was finally published as Peeters & Kroon (2008). In this model, the authors use a transition graph to represent the possible changes in train's composition at each station ((Alfieri et al., 2006). In order to solve the problem, the model decomposed based on trains using a Dantzig-Wolfe decomposition approach (Dantzig & Wolfe (1960)) instead of the classical flow decomposition used in other multicommodity network flow problems, Barnhart, Hane, & Vance (2000), or Holmberg & Yuan (2003).

Rolling maintenance aspects have also been treated in some rolling stock models. Ziarati, Soumis, Desrosiers, Gélinas, & Saintonge (1997) set up a large scale integer programming model for locomotive assignment considering that locomotives requiring inspection must be sent to appropriate shops within a given time limit. Cordeau et al. (2001) propose a multicommodity network flow-based model for assigning locomotives and cars to trains in the context of passenger transportation. The model structure allows the introduction of maintenance constraints, car switching penalties, and substitution possibilities. The work of Lingaya et al. (2002) supports operational aspects concerning locomotive-hauled railway cars. The authors consider maintenance constraints inside a model with the objective of maximizing the expected profit. Maroti & Kroon (2005) propose a multicommodity flow-type model for routing units that require maintenance in the forthcoming one to three days. The authors study the complexity of the problem and determine that feasibility problem for a single urgent train unit is polynomially solvable but that the optimization version is NP-hard. Giacco, D'Ariano, & Pacciarelli (2014) present an integer programming formulation for integrating maintenance planning tasks in the rolling stock circulation problem, considering assigment of rolling stock units, scheduling of maintenance tasks and minimizing the number of empty runs.