Transportation Research Part E 82 (2015) 162–198

Contents lists available at ScienceDirect

Transportation Research Part E

journal homepage: www.elsevier.com/locate/tre

A stochastic model predictive control to heterogeneous rail freight car fleet sizing problem

Miloš S. Milenković [a,*], Nebojša J. Bojović [a], Libor Švadlenka [b], Vlastimil Melichar [b]

[a] *Division for Management in Railway, Rolling Stock and Traction, The Faculty of Transport and Traffic Engineering, University of Belgrade, Vojvode Stepe 305, 11000 Belgrade, Serbia*

[b] *Department of Transport Management, Marketing and Logistics, Jan Perner Transport Faculty, University of Pardubice, Studentska 95, 53210 Pardubice, Czech Republic*

ARTICLE INFO

Article history:
Received 11 January 2015
Received in revised form 18 June 2015
Accepted 22 July 2015
Available online 27 August 2015

Keywords:
Railway
Freight cars
Fleet size
Allocation
Stochastic model predictive control
ARIMA-Kalman
EOQ
Random newsboy

ABSTRACT

In this paper a rolling horizon approach is applied for simultaneous optimization of the rail freight car fleet size and allocation problem. Developed dynamic model of loaded and empty rail freight car flows explicitly treats state, control and station capacity constraints in presence of various freight car types under the partial substitutability among them. Demands and traveling times are considered as random variables. Proposed approach is applied to a set of test cases and it shown to be successful, ultimately providing a new managerial tool for more effective and efficient planning and analyzing rail freight car fleets.

1. Introduction

Freight transportation constitutes one of the most important economic activities in today's world. Railways perform a significant portion of the associated operations and are known for their ability to offer cost effective long-haul transportation services. Yet, railways have the relatively small share of the overall transport market. The reason for this lies in inefficiencies in the service provided, particularly in terms of transportation times and reliability of on-time delivery. Rail transport frequently contains fleets of rail cars which circulate on networks, carrying people or goods (Sayarshad and Ghoseiri, 2009). The capacity of rail transport is directly related to the number of available cars. Owners and operators of rail transport invest in rail cars in order to provide the capacity needed to meet demands. Determining the optimal number of cars for a particular system requires a tradeoff between the cost of owning rail cars and the potential costs or penalties associated with not meeting some demands as a result of not using enough cars. Serving demands results in the relocation of rail cars. The consequent movement of rail cars between various locations is often imbalanced, and this implies the need for optimal allocation of empty cars over the network. Thus, the fleet size of rail cars which are available for service at any given time (and their locations) depends upon the rail car allocation strategy. The demand for a transportation service in a current period is certain and

* Corresponding author.
E-mail addresses: m.milenkovic@sf.bg.ac.rs (M.S. Milenković), nb.bojovic@sf.bg.ac.rs (N.J. Bojović), Libor.Svadlenka@upce.cz (L. Švadlenka), Vlastimil.Melichar@upce.cz (V. Melichar).

http://dx.doi.org/10.1016/j.tre.2015.07.009
1366-5545/

is recorded and monitored in a centralized information system. Unfortunately, the demand in future periods is subject to uncertainty whose degree increases with time. Investigations performed on the railroads have shown that the demand for freight cars is most often very variable and varies by 50% above or below an average weekly value. Moreover, the travel times of freight cars are also followed by a great uncertainty. In real-life situations it is often the case that the exact travel time of freight cars between a pair of origin/destination nodes cannot be known in advance.

Model Predictive Control (MPC), often referred to as moving horizon control or receding horizon control and represents one of the most successful and most popular advanced control methods. It is based on the repeated solution of a finite-horizon optimal control problem subject to a performance specification, constraints on states and inputs, and a system model.

In this paper, a model predictive control approach is presented to find an optimal policy for optimizing the rail freight car fleet sizing and allocation problem. Rail freight car demands and traveling times were assumed to be stochastic variables. Developed approach assumes a heterogeneous fleet of cars with interchangeability among them.

The remainder of this paper is organized as follows. After a brief introduction, in Section 2, a comprehensive review of related literature is given. Discrete time MPC framework for rail freight car fleet sizing and allocation problem is presented in Section 3. Proposed MPC controller for the problem of rail freight car fleet sizing and allocation is given in Section 4. In Section 5, a numerical example is provided to illustrate the results. This section also contains the results of other experiments performed in order to test the computational efficiency of the approach. Concluding remarks and directions for future research are given Section 6.

2. Literature review

Rail freight cars are expensive capital items, and fleet sizing is an important issue for both researchers and rail freight transport service providers. Many models for vehicle fleet management have been proposed and they treat rail freight car fleet as homogenous or heterogeneous. Main input parameters in these models, like demand and traveling time, are considered as deterministic, stochastic, fuzzy or fuzzy stochastic.

Deterministic approaches assume that input parameters (like transport demand, supply and traveling time) are exact values. These optimization models were used to optimally distribute empty vehicles according to specified allocation rules and goals. A number of such models have been developed and implemented (Feeney, 1957; Leddo and Warthall, 1968; White and Bomberault, 1969; Mendiratta, 1981; Mendiratta and Turnquist, 1982; Ratclife et al., 1984). Kwon et al. (1998) presented a dynamic freight car routing and scheduling model for heterogeneous freight car traffic on rail networks. A time–space network representation technique was used to represent car moves on possible sequences of car-to-block and block-to-train assignments on a general-merchandise rail service network. The problem was formulated as a linear multicommodity flow problem and the column generation technique was used as a solution approach. Fukasawa et al. (2002) proposed a method to determine an optimal flow of loaded and empty cars in order to maximize profits, revenue or tonnage transported, given the schedule of the trains together with their traction capacities. Heterogeneous rail freight car fleet is considered. They proposed an integer multicommodity flow model for the problem whose linear relaxation leads to good upper bounds. To make a practical tool, they applied a preprocessing phase that may reduce its size and be solved by standard integer program packages. Fu and Ishkhanov (2004) addressed the fleet size and mix problems related to paratransit services whilst presenting a practical heuristic procedure for determining the optimal fleet mix and a real-life example. Lawley et al. (2008) presented a time–space network flow model for scheduling recurring bulk rail deliveries from suppliers to customers. Car assignment and scheduling is for a single commodity only, so the freight car fleet is treated as homogeneous. The model uses a variety of information including customer demand, rail network characteristics, loading and unloading hours, and track and station capacities. The objective is to maximize demand satisfied while minimizing waiting times for loading and unloading the bulk commodity. Narisetty et al. (2008) presented an optimization model for the problem of assigning heterogeneous fleet of empty freight cars defined as the best possible matches between available freight cars and customer demand. The model seeks to reduce transportation cost, and improve delivery time and customer satisfaction. The model is implemented on Union Pacific Railroad and helped company to achieve significant reductions in its transportation costs. Sayarshad and Ghoseiri (2009) proposed an approach for optimizing the rail fleet size and freight car allocation where car demands and travel times are assumed to be deterministic and unmet demands are backordered. The properties of the proposed model have been analyzed with respect to one type of cars. The solution procedure is based on a Simulated Annealing algorithm. Sayarshad and Marler (2010) presented a multi-objective optimization formulation, solution method and analysis for multi periodic fleet sizing problem. The formulation incorporates the following capabilities into one analysis tool: the ability to optimize simultaneously the homogeneous fleet size and the allocation of rail cars, the ability to optimize both profit and quality, and the ability to consider rail cars with the associated rail-yard restrictions. Profit and quality (minimal unmet demands) represent conflicting objectives and are maximized simultaneously. The Pareto optimal set is depicted and is used for trade-off analysis. The solution involves the optimal fleet size as well as the optimal rail car allocation strategy. Sayarshad et al. (2010) propose a three-objective mathematical model and a solution procedure for optimizing the homogeneous fleet planning for rail-cars in railway industry. These objectives are to: (1) minimize the sum of the cost related to service quality, (2) maximize profit calculated as the difference between revenues generated by serving customer demand and the combined costs of rail-car ownership and rail-car movement, and (3) minimize the sum of the rail car fleet sizing, simultaneously. The