Transportation Research Part C 33 (2013) 107–133

Contents lists available at SciVerse ScienceDirect

Transportation Research Part C

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

A fuzzy random model for rail freight car fleet sizing problem

Miloš Milenković *, Nebojša Bojović [1]

Division for Management in Railway, Rolling Stock and Traction, The Faculty of Traffic and Transport Engineering, University of Belgrade, 11000 Belgrade, Serbia

ARTICLE INFO

Article history:
Received 11 May 2012
Received in revised form 5 May 2013
Accepted 5 May 2013

Keywords:
Rail freight cars
Empty car allocation
Fleet size
Optimal control
Fuzzy randomness

ABSTRACT

In the area of freight transport, the railroads of almost all countries face with strong competition and a prominent trend of market reduction. It has become imperative for rail systems to develop better planned instruments for more rational and efficient utilization of freight cars that represent a great amount of total investments. In this paper a new formulation and a solution procedure is proposed for optimizing the fleet size and freight car allocation in the presence of uncertainty. The uncertainty of the rail freight car demand is often tackled from the traditional probability theory. However, various types of uncertainties and fuzziness are inherent in real rail freight transport operating environment. In this paper, the issue of rail freight car fleet sizing and allocation problem will be addressed under such circumstances. Specifically, an approach based on optimal control theory by considering the fuzziness and randomness for rail freight car demand is developed here. The problem is formulated as the problem of finding an optimal fuzzy regulator for a fuzzy linear system with fuzzy quadratic performance index and fuzzy random initial conditions. Numerical example is given to illustrate the model and solution methodology.

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.

The capacity of rail transport system is directly related to the number of available freight cars. Owners and operators of rail transport invest in freight cars in order to provide the capacity to meet the demands. Determining the optimal number of rail cars requires a tradeoff between the cost of owning and the potential costs or penalties associated with not meeting some demands due to insufficient freight car fleet. Serving demands results in the relocation of freight cars. The consequent movement of freight cars between various locations is often imbalanced, and this implies the need for optimal allocation of empty rail cars over the network. Thus, the fleet size of rail cars which are available for service at any given time and location depends upon the rail car allocation strategy.

The demand for a transportation service in a current period is certain and 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

* Corresponding author. Address: Division for Management in Railway, Rolling Stock and Traction, The Faculty of Traffic and Transport Engineering, University of Belgrade, Vojvode Stepe 305, 11000 Belgrade, Serbia. Tel.: +381 64 13 13 794.

E-mail addresses: m.milenkovic@sf.bg.ac.rs (M. Milenković), nb.bojovic@sf.bg.ac.rs (N. Bojović).

[1] Tel.: +381 11 3091 308.

0968-090X/$ - see front matter
http://dx.doi.org/10.1016/j.trc.2013.05.003

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.

Many models for vehicle fleet management have been proposed and they treat inputs on deterministic or stochastic manner. Deterministic approaches assume that input parameters (like transport demand, supply and travelling 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 very 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) address 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 it is 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 a 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 Pareto optimal set is depicted and used for a trade-off analysis. Javadian et al. (2011) develop an optimization formulation and a solution procedure for the determination of the capacity of rail yard stations with respect to the optimal number of shunting and reclassification operations at the nodes of the rail network. The model has been analyzed with respect to one type of rail cars. A simulated annealing (SA) algorithm is proposed to solve the model. Zak et al. (2011) studied a fleet sizing problem (FSP) in a road freight transportation company with heterogeneous fleet and its own technical back-up facilities. The mathematical model of the decision problem is formulated in terms of multiple objective mathematical programming based on queuing theory. The solution procedure is composed of two steps. In the first one, a sample of Pareto-optimal solutions is generated by an original program called MEGROS. In the second step, this set is reviewed and evaluated, according to the Decision Maker's (DM's) model of preferences. The evaluation of solutions is carried out with an application of an interactive multiple criteria analysis method, called Light Beam Search (LBS). Finally, the DM selects the most desirable, compromise solution. Sherali and Lunday (2011) addressed a problem of equitable allocation of homogeneous rail freight car fleet among participants in a pooling agreement. Authors demonstrated potential inequities in the current railcar allocation practices, and have proposed four alternative shipper allocation methods and one alternative carrier allocation technique. Cheon et al. (2012) analyzed a heterogeneous rail freight car fleet sizing optimization problem in the chemical industry. Because of the long economic life of railcars, problem is formulated as a long-term capacity expansion problem considering various economic factors. Authors included inventory in the determination of the optimal fleet size. A mixed-integer programming approach to modeling and solving this problem is proposed. Yaghini and Khandaghabadi (2012) presented a dynamic and multi-periodic model for rail freight car fleet sizing. Fleet composition in the transportation system is homogeneous. Proposed solution method is a generalization of genetic algorithms and simulated annealing algorithms.

As mentioned, in real rail freight transport operation, there is a great uncertainty. In the literature, besides the other methods like scenario planning, sensitivity analysis and robust optimization, stochastic approach based on probability the-