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The dynamic vehicle allocation problem with application in trucking companies in Brazil

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ABSTRACT

This paper deals with the dynamic vehicle allocation problem (DVAP) in road transportation of full truckloads between terminals. The DVAP involves multi-period resource allocation and consists of defining the "movements" of a fleet of vehicles that transport goods between terminals with a wide geographical distribution. These movements may be of fully laden vehicles, unladen vehicles for repositioning or vehicles held at a terminal to meet future demands. Emphasis is given to the characterization of the problem in real situations, the mathematical modeling of the problem and the use of exact and heuristic methods to solve it, including GRASP and *simulated annealing* metaheuristics. Results based on a case study of a transportation company in Brazil are presented and analyzed, showing that the approach can be effective in supporting practical decisions.

1. Introduction

This paper deals with the dynamic (multi-period) vehicle allocation problem (DVAP) in the road freight transportation sector where a fleet of vehicles should be managed over time responding to known or forecasted demands. The DVAP is presented in a variety of situations where it is necessary to allocate a fleet of vehicles in periods of time, with applications in trucking, both full truckload (FTL) and less-than-truckload (LTL), and in rail and maritime transportation with the repositioning of empty containers.

This study aims to contribute to supporting decisions at the operational level for ground transportation companies that need to manage a heterogeneous fleet of vehicles, particularly the optimization of the use of trucks for transport of cargo shipments between terminals involving vehicles of large capacity. The allocation of empty vehicles due to geographical differences in demand for transport services often accumulates temporarily vehicles in a region where they are not needed, or generates a deficit of vehicles in other regions where there is demand. Thus, the vehicles should move empty or additional freight needs to be found in order to reposition them where they are needed. The movement of empty vehicles does not contribute directly to the company's profit, but it is essential for the continuity of operations and service. Balancing empty vehicles, or rather, the distribution of empty vehicles to balance supply and demand in future periods, is a central component of the operations planning and control of trucking companies, being one of the biggest challenges for fleet management.

Powell et al. [25] was one of the pioneering works that studied the DVAP applied to the trucking industry. They presented a dynamic non-linear mathematical model taking into account the uncertainty in demand forecasts. Following up on this, Powell [18] refined and extended the previous model, incorporating uncertainties related to the number of vehicles kept in stock and also keeping track of both empty and full vehicle movements. In subsequent studies, Powell [19,20] presented alternative mathematical models to be used in operational settings, aiming to help in the management of a fleet of vehicles, anticipating the consequences of the decisions to be taken. They also reviewed the DVAP in the context of full truckload trucking transportation, with special attention to the dispatch and repositioning of vehicles, taking into account forecasted demands and four methodologies: (a) deterministic transportation networks; (b) stochastic non-linear networks; (c) stochastic programming processes, and (d) Markovian decision processes. It was also stated that, besides the fact that deterministic models are more simpler, they are sufficiently useful in practical settings.

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Dejax and Crainic [4] proposed a taxonomy for the empty vehicle repositioning problem in the freight transportation sector, and also presented a comprehensive review about the subject. Frantzeskakis and Powell [7] developed a new heuristic solution method to solve the DVAP with stochastic demands, and Braklow et al. [2] presented an interactive large-scale optimization model, aiming to define the routing of parcels in a transportation network, and also the repositioning of empty vehicles in response to the imbalance of demand. Powell et al. [24] deepened and extended the study of dynamic vehicle allocation and its variants to the rail, trucking and air transportation modes, including the repositioning of empty containers. The authors presented a basic formulation of the problem, expressed by a dynamic network for only one type of vehicle, and also for multiple types of vehicles. In subsequent studies, Powell [21] and Powell and Carvalho [22,23] presented hybrid models combining the best features of the previous models, and included an experimental test with the use of a simulator. The problem was represented in a network named *logistics queueing network* (LQN).

Hall [10] developed metrics and dimensions for the spatial and temporal imbalance in the freight flows and studied an application of these metrics for a trucking transportation network. Hall and Zhong [11] researched the decentralized methods of control and management of a fleet of vehicles in LTL trucking transportation. The performance was measured taking into account: (i) the costs involved in the movement of empty vehicles; (ii) the cost of ownership of the equipment; and (iii) delayed orders caused by the lack of equipment. The authors proposed two main steps: to solve a linear programming problem to define where to get empty vehicles, and re-schedule the orders to determine when to move empty equipment. Other discussions about the DVAP are also presented in Ghiani et al. [8], and in Vasco [27].

This brief review about the DVAP shows that some studies were developed mainly for trucking transportation, and the majority of the authors included in the mathematical models the uncertainty in the demand for transportation. The problem to be solved is characterized mainly at the operational level of planning and only a few papers presented results of practical application in transportation companies (see, e.g., Powell [20]). In this paper the DVAP is studied with the focus on full truckload trucking transportation between terminals. The movement of the vehicles can be: loaded, empty for repositioning, or kept in a terminal from one period to the next as a provisioning to meet future demands. Emphasis is given to the characterization of the problem in real world situations faced by transportation companies in Brazil.

The main contributions of this study are twofold. The presentation of a mathematical model for the DVAP appropriately represents this problem in practical situations, where different kinds (or groups) of vehicles are available and there are constraints limiting the vehicle groups that can be allocated to some routes. This integer linear programming model aimed to better represent the reality of road transportation companies (particularly Brazilian carriers), in which the vehicle fleet cannot be treated as homogeneous, even if all vehicles are of the same size. This is because additional considerations should be taken into account when allocating a vehicle to a route as, for example, if the vehicle is a company-owned truck or if it belongs to an independent contractor or a third-party carrier, among others. Due to the difficulty to optimally solve large instances of the DVAP, another contribution of this study is to present fast and efficient solution methods based on heuristics and metaheuristics which can be effectively applied to solve the DVAP in practical settings, as shown by the computational experiments carried out based on real data.

The remainder of this paper is organized as follows. In Section 2, we present the integer linear programming model to represent the DVAP. In Section 3 we describe a greedy constructive heuristic, an improvement procedure using local search, and also an application of the GRASP (greedy randomized adaptative search procedure) [5,6] and the simulated annealing (SA) [14,3] metaheuristics to solve the DVAP. In Section 4 we present the results obtained with the computational experiments to solve a set of problems with size and complexity similar to the practice in the context of trucking transportation in Brazil. Finally the conclusions are presented in Section 5.

2. Mathematical formulation

Considering the mathematical models presented in the literature, we used the linear programming model presented in Ghiani et al. [8] as a starting point to model the problem studied in this paper, which is an adaptation of the model originally presented in Powell et al. [25] and Powell [18]. We included important aspects of the practical problem faced by road transportation companies in Brazil like, for example, the situation where the fleet is heterogeneous and a group of vehicles cannot travel in certain routes.

Similar to Ghiani et al. [8] and other studies found in the literature, we opted to use a deterministic mathematical model to represent the DVAP due to the following reasons: (i) deterministic models are easier to understand, develop, implement and represent satisfactorily some practical situations; (ii) these models are computationally easier to solve than stochastic models [1]; (iii) they do not need too much historic data, like, for example, in stochastic models where is necessary to determine probabilistic distributions of the random variables involved; and (iv) these models are flexible enough to evaluate “what-if” scenarios and perform sensitivity analysis.

In the following we describe the sets, parameters and variables used to model the DVAP, focusing on solving the practical problem faced by trucking companies in Brazil.

2.1. Model sets

- Set N of terminals: comprised by all terminals of the transportation network. We define a transportation terminal as a point in the network which is the origin or destination of freight. These terminals can also serve as consolidation or switching points.
- Set E of group of vehicles: comprised by the separation of the entire fleet into groups, and in this work we differentiate the vehicles in terms of payment method, routes operated, or even to consider the vehicles individually, having in this case $|E|$ as the same quantity of vehicles in the fleet. It is worth mentioning that in this paper the fleet is considered “homogeneous” only in terms of load capacity, performance and average speed on the same route.