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A long-haul freight transportation problem: Synchronizing resources to deliver requests passing through multiple transshipment locations

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ABSTRACT

This research aims at tackling a real-world long-haul freight transportation problem where tractors are allowed to exchange semi-trailers through several transshipment points until a request reaches its destiny. The unique characteristics of the considered logistics network allow for providing long-haul services by means of short-haul jobs, drastically reducing empty truck journeys. A greater flexibility is achieved with faster responses. Furthermore, the planning goals as well as the nature of the considered trips led to the definition of a new problem, the long-haul freight transportation problem with multiple transshipment locations. A novel mathematical formulation is developed to ensure resource synchronization while including realistic features, which are commonly found separately in the literature. Considering the complexity and dimension of this routing and scheduling problem, a mathematical programming heuristic (matheuristic) is developed with the objective of obtaining good quality solutions in a reasonable amount of time, considering the logistics business context. We provide a comparison between the results obtained for 79 real-world instances. The developed solution method is now the basis of a decision support system of a Portuguese logistics operator (LO).

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1. Introduction

Setting an efficient and flexible logistics network and defining its planning and operational processes is one of the most complex challenges one can find in the transportation sector. In the last two decades, we have witnessed a considerable effort towards the creation of a new generation of transportation systems (Crainic, Gendreau, & Potvin, 2009) which have to fit the value proposals of each company, focusing on distinct strengths such as quality, speed, reliability or cost.

Recently, cost pressures fostered a modification in the logistics paradigm and transshipment points are being deployed for long-haul freight transportation, introducing more flexibility into logistics networks. Usually, LO find different solutions for the challenges imposed by long distance trips, such as using more than one driver per vehicle. However, adopting a transshipment-based distribution process may be truly advantageous.

From a global point of view, the transportation network becomes much more flexible as it provides additional possibilities to perform the transportation of freight. Since the tasks assigned to each resource are much shorter, points in time when a resource becomes available can be rationally spread along the entire area occupied by the customers and will happen more frequently. In what concerns real-world cases, knowing that the variance of the planning variables may drastically affect timings, this is an advantage to ensure the execution of a transportation plan. In fact, this flexibility will be reflected in an increment of the service level as the network offers more solutions per unit of time. Furthermore, this flexibility not only accounts for the aforesaid facts, but also may yield solutions with less and shorter empty truck paths, which are a major concern among LO.

Logically, these advantages come at a cost. On one hand, the complexity of a planning problem considering transshipment points is much larger. On the other hand, the operational complexity at each facility is also likely to increase due to the difficulties imposed by the need to synchronize resources. This also means that it is extremely difficult to obtain a feasible solution manually.

In this research we develop a systematic approach on top of a real transportation network that has both the intermediate facilities and the human expertise to perform transshipment operations. Since in Mitrovic-Minic and Laporte (2006) the authors state that transshipment points have shown to be very useful in clustered instances (typical found in long-haul transportation) and that the advantages of using those nodes increases with problem size (real-world instances are large), we consider that our challenge is a valuable research topic.

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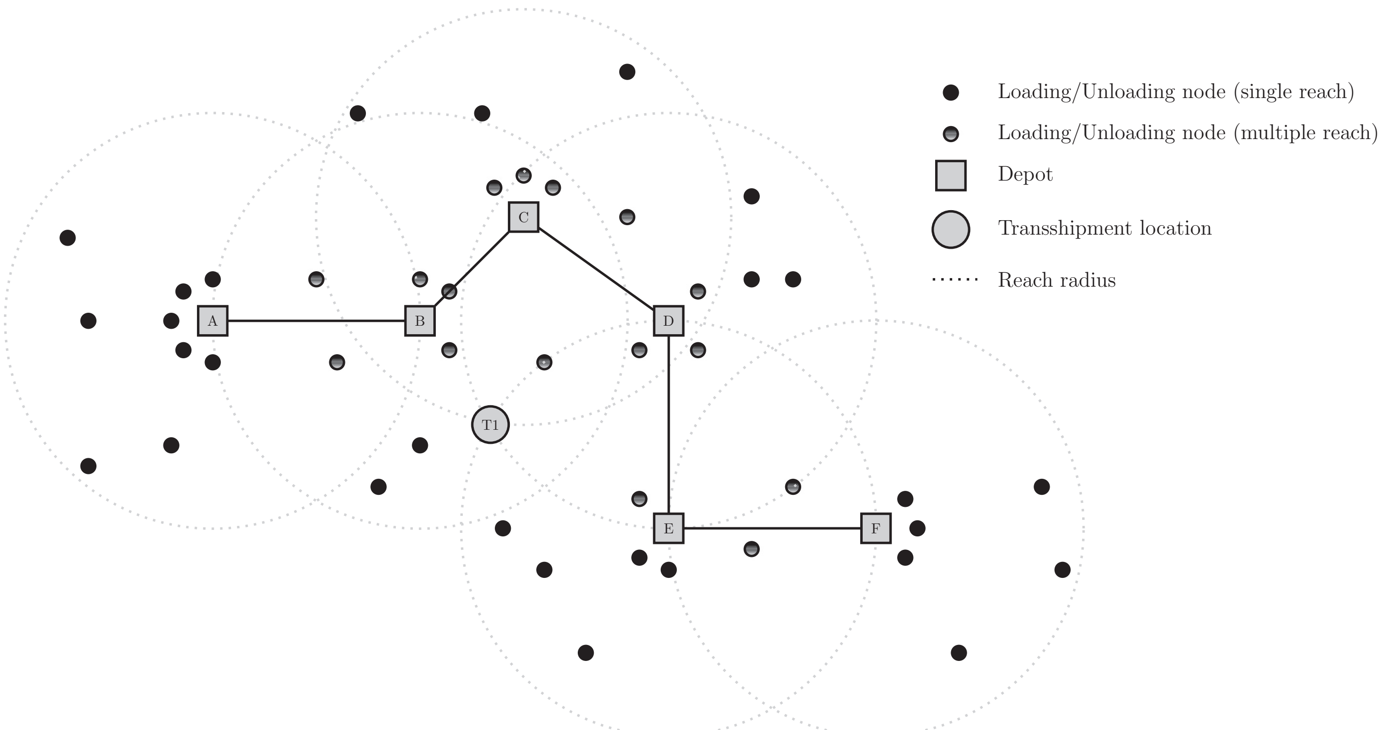

Fig. 1. Long-haul transportation network.

(a) Tractor used to pull semi-trailers **(b)** Semi-trailer to be pulled by tractor

Fig. 2. Resources that compose a vehicle.

In order to provide an example of the aforementioned networks and context, Fig. 1 is shown. In this novel problem, a set of tractors (Fig. 2a) is located in each depot and the objective is to pickup requests from a certain location and deliver them to other locations. A request consists in the transportation of an entire semi-trailer (Fig. 2b) and thus, considering that each tractor can only pull one semi-trailer at a time, we are in the presence of a full truckload case. Whenever a customer submits a request, both a pickup and a deliver time-window have to be defined, meaning that loading and unloading operations have to occur during those intervals. It is also possible to request each operation to be made in different days and for that reason, semi-trailers can be temporarily stored in a transshipment location (note that every depot also has a transshipment location). Additionally, a service to be provided by a tractor can only occur during the period in which its base depot is opened. Tractors can only travel inside their reach radius which is defined by the maximum number of hours that drivers are allowed to work.

This real-world challenge includes a combination of conditions that are rare in the literature.

Firstly, in consideration of the company's desire to maintain a certain level of comfort among its drivers, the maximum working time (including driving and other activities) is assumed to be 9 hours. Note that tractors are obliged to return to their base depot in the end of a workday. Therefore, drivers have a limited reach radius of approximately 4.5 hours which clusters the customers around each depot. In sum, we may assume that policies found in short-haul transportation activities are preferred.

Secondly, since drivers are confined to a limited region around their base depot, the necessity of executing multiple transshipments with the same request may be imposed in some services. Thus, in order to provide long-haul services by means of short-haul jobs, the company allows for the possibility of performing transshipments at certain locations. In fact, different regions may only communicate in these locations where two vehicles are able to exchange freight. This is strictly necessary, otherwise it would not be possible to send requests between every combination of sender/receiver, while ensuring compliance with the law and with the policies of the company. It is now clear that if a request is to be picked in the zone of a certain depot and to be delivered in the zone of another depot, it is mandatory that at least one transshipment is going to happen. Additionally, a transfer is only possible if the compatibility between tractors and semi-trailers is assured (the terms "transfer" and "transshipment" are used interchangeably in this paper).

Thirdly, tractors are only able to leave a certain depot if they are to return pulling a semi-trailer, meaning that the delivery of a request must always be paired with the pickup of another request in the same trip (throughout the paper we use the term *path* to describe the movement of a vehicle from one location to another and the term *trip* to refer to a set of paths performed by a vehicle). Specifically, a tractor is not allowed both to leave or to arrive at its base depot

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