Computers in Industry 64 (2013) 121–127

Contents lists available at SciVerse ScienceDirect

Computers in Industry

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

An innovative freight traffic assignment model for multimodal networks

Luís Couto Maia *, António Fidalgo do Couto

Secção de Vias de Comunicação – DEC, Faculdade de Engenharia da Universidade do Porto, Rua Dr. Roberto Frias, s/n 4200-465 Porto, Portugal

ARTICLE INFO

Article history:
Received 9 February 2012
Received in revised form 12 July 2012
Accepted 18 October 2012
Available online 27 December 2012

Keywords:
Freight transportation
Traffic assignment
Logit

ABSTRACT

Although there is a considerable number of freight traffic assignment models available, they still tend to lag behind their passenger counterparts in terms of maturity of their scientific knowledge. In order to contribute to the improvement of this state of affairs, the authors developed an innovative traffic assignment model, intended to model large networks with a strategic level of planning, which considers both road and rail transport modes and is not very demanding in terms of data. The model applies two different assignment techniques for the two types of cargo considered, with its main innovative feature being the fact that it takes into account both capacity constraints and a variable perception of costs by users, while being much simpler and lighter than a stochastic user equilibrium model. The simultaneous consideration of both of those factors distinguishes it from the traditionally used traffic assignment techniques, namely all or nothing, equilibrium or stochastic (multi-flow) techniques, none of which considers those factors simultaneously.

1. Introduction

Although freight transportation plays a crucial role in the day to day life of any modern society, being critical to a large part of the economy, it is a subject that has received considerably less attention by the academia than its passenger counterpart. This is justified, among other reasons, by the fact that freight is a more complex subject, being considerably harder to model, and also by the difficulty in obtaining the needed data to run the models. Even so, more and more attention has been given to this subject, and several transportation assignment models have been developed considering freight as a separate part of the transportation spectrum, instead of it being modeled together with passenger transportation. This is justified not only by the importance of freight in itself, but also because the reality of freight transportation is different, which means that the assignment models need to be different, as well as the type of data that is considered.

This paper contributes to the advance of freight transportation models by presenting a new and innovative strategic freight traffic assignment model. This model, developed in the scope of the creation of a freight transportation network improvement model [1], is designed to model macro networks with a high aggregation level, namely national or international networks, being a strategic planning model [2]. As such, it will not require very detailed data inputs, and the outcome of its application is the estimation of the movement of freight at a national scale. It is therefore intended to be a useful tool for a variety of planning and policy decisions, which are the kind of tasks for which this type of models are more suited for [3].

The traffic assignment model presented in this paper is intended to simulate land freight transportation, considering both road and rail transportation modes. It considers two different types of cargo (general cargo and intermodal cargo) and uses different assignment techniques for each type, with its main innovative feature being the fact that it takes into account both capacity constraints and a variable perception of costs by users, while being much simpler than stochastic equilibrium model. This is a characteristic that distinguishes it from the commonly used all or nothing, equilibrium or stochastic (multi-flow) models, none of which considers these two factors simultaneously.

The model is applied to a fictitious network and its results are analyzed and compared to those obtained by using a simple all or nothing technique. This application produces satisfactory results, which clearly reflect the fact that the model takes into account both capacity constraints and a variable perception of costs.

This paper is organized as follows. Section 2 presents a brief background study on freight traffic assignment models, with the presented model being described in Section 3. Section 4 reports the application of the model on a fictitious network, and the conclusion of the paper is presented in Section 5.

* Corresponding author. Tel.: +351 220413798; fax: +351 225081902.
E-mail address: luis.maia@fe.up.pt (L.C. Maia).

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http://dx.doi.org/10.1016/j.compind.2012.10.011

2. Background

2.1. Existing traffic assignment models

While there is a considerable number and variety of traffic assignment models present in the literature, the traditional assignment techniques can be divided in just four big groups, as it is shown in Table 1.

As it can be seen in the table, there are two major factors that are used to determine to which of the four traditional techniques does a model belong, namely if there are capacity constraints and if there is a variable perception of costs. Capacity constraint models are those in which the capacity of links is limited, often including time penalties due to congestion when certain limits of traffic are exceeded. As for the variable perception of costs, it reflects whether or not the mode and route choice decisions are made uniquely based on the lowest generalized cost (no variable perception), or if some stochasticity is included, spreading the traffic through different modes and routes. The strategic freight transportation traffic assignment models that exist in the literature usually opt for the all or nothing or equilibrium techniques, with stochastic (multi-flow) models being seldom used. As for stochastic equilibrium models, and according to the authors' best knowledge, their use in this area of study has been limited, probably due to their complexity.

Regarding the existing models, although there are many different models present in the literature, with many being built for just one specific work, there are at least two major freight traffic assignment models that are worth mentioning, due to their importance and extensive use. Those are STAN, which was developed in 1990 in Canada [5,6], making use of an equilibrium assignment technique, and the NODUS software, which was developed in Belgium a few years later [4,7–9] and that has been employed using all the three most common assignment techniques: all or nothing, stochastic (multi flow) and equilibrium. While the most commonly used assignment procedure is the equilibrium, the fact that various techniques were used with the NODUS software shows that each one has its own advantages, which should be considered when choosing which type of technique to use. An all or nothing technique is the most straightforward technique, which works by simply minimizing the total generalized costs in each O/D pair trip (least cost path) thus minimizing it for the whole network. It is best suited for cases where other assignment techniques are considered too complex, or simply not fit for the proposed approach [7,8]. Also, if a modeler chooses not to consider a variable perception of costs, all or nothing can be preferred to an equilibrium approach when, due to the nature of the network being analyzed, it does not make sense to consider congestion. Regarding the use of the equilibrium assignment technique, it is suited for networks with capacity limits, where congestion effects are taken into account by admitting cost penalties when traffic is close to the capacity [5,6,9]. Its solution is based on the Wardrop equilibrium [10], in which all vehicles choose their optimal route, so that no vehicle can improve its travel time by unilaterally changing routes. To solve this problem, the most commonly used algorithms are the incremental assignment, the method of successive averages and the algorithm of Frank-Wolfe [9]. As for the stochastic (multi-flow) approach, it differs from an all or nothing assignment in the fact that not all the traffic used the least cost path, being distributed by the different alternatives. While this technique does not consider capacity constraints, it also distributes the traffic by different routes, which makes it useful for models where congestion is not important, as it is the case in most intercity freight assignment models [4].

Table 1
Assignment techniques [4] – adapted.

Capacity constraint	Variable perception of costs	
	No	Yes
No	All or nothing (AoN)	Stochastic (multi-flow)
Yes	Equilibrium	Stochastic equilibrium

Contrarily to all or nothing or equilibrium techniques, the use of stochastic assignment techniques ensures that the path with the least generalized costs never receives the totality of the traffic, meaning that other paths are also used. This is a valuable feature when dealing with strategic aggregated models, where the generalized transportation costs are just an estimation of the average costs, in that it does not consider the mere minimization of the generalized costs as an undisputable deciding factor. This is additionally justified by the fact that there are many factors that are almost impossible to incorporate in the generalized costs of a strategic model, but have a decisive influence on the modal or route choice, such as the shipment size [11,12], the frequency of service [13], the service quality [14,15] and the existence of an integrated door to door logistic chain [16]. As for the method used to perform the distribution of traffic, the Logit formulation has consistently been chosen to address this problem, due to its versatility and convenience [17,18,4,19]. The multinomial Logit model is a function that calculates the percentage of trips (P_{ij}) realized from an origin i to a destination j through route k, with a generalized cost of C_{ij}, chosen out of a sum of n alternative options, as follows [19]:

$$P_{ij}^{k} = \frac{\exp(-\mu \cdot C_{ij}^{k})}{\sum_{k=1}^{n} \exp(-\mu \cdot C_{ij}^{k})}, \tag{1}$$

where μ is a parameter that can be calibrated by the user, which determines the impact that the cost differentials have on the percentage of trips assigned to each alternative. The percentage of traffic that uses the least costly route increases for higher values of this parameter. The Logit function is practical and appealing for its analytical convenience [20], and it can be used in any traffic assignment model to estimate the share of traffic that uses each one of the n alternative route options.

2.2. Innovative aspects of the presented model

As for the model presented in this paper, and as it will be described in Section 3, it is innovative in the fact that it uses two different assignment techniques for the two types of cargo considered (general cargo and intermodal cargo), and that it considers both capacity constraints and a variable perception of costs. Due to this mix of techniques and to the fact that the capacity limits are imposed using a gradual introduction of the traffic in the network instead of a congestion effect, the model cannot be classified under any of the four traditional assignment techniques seen in Table 1. Therefore this model considers both capacity constraints and a variable perception of costs, while being much simpler and faster to run than a stochastic equilibrium model. This is particularly important due to the fact that this simplicity makes the model relatively light and fast to run, which is very important in the context of a network optimization model (where the assignment model has to be run multiple times), which is where this model is intended to be used in the future.

3. Description of the model

3.1. Model's general attributes and computation of the shortest paths

The presented model is a strategic freight traffic assignment model, made for the simulation of freight transportation on land.