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Long haul freight network design using shipper–carrier freight flow prediction: A California network improvement case study

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ABSTRACT

Transportation network design is a method for analyzing the interactive benefits of transportation projects applied to a network. In this paper, a network design model is developed for long haul freight movements which are represented by relationships between shippers and carriers. Additionally, an explicit capacity constraint is used to divert traffic volume from congested links. A case study based on the California transportation network is implemented to examine the effectiveness of this model when applied to a large network. A geographic information system is used to facilitate data management and analysis of the results.

1. Introduction

Freight transportation has long been recognized as an important foundation of economic strength. Demands for long haul freight movements continue to grow due to increasing international trade. This increase drives the need for major infrastructure improvements at the local, state and federal level. Many states have undertaken recent freight planning studies (NJDOT and PBQD, 2004; USDOT and FHWA, 2005). They have identified the need to develop transportation networks that coordinate freight movements and reduce bottlenecks.

In contrast to cost–benefit analysis which studies investments on an individual or sequential basis, the network design model examines all projects simultaneously. As part of a network, one project can compete with or complement the others. Cost–benefit analysis can create scenarios consisting of many projects to study these interactions. However, the complexity of transportation networks can produce a large number of promising scenarios which cannot effectively be examined on a case by case basis. Therefore, a network design model to manage the combinatorial problem and identify changing traffic flows corresponding to the selected projects should be developed.

This paper expands the long haul freight network design model developed by Apivatanagul and Regan (2008) by conducting a case study on the California transportation network. The primary objective is to apply our network design model to a real transportation network and actual freight demand. The case study is a validation step that can demonstrate that useful problems can be solved within reasonable computational times.

Although the model concepts and the solution algorithm introduced are quite general, some details are modified to fit the case study. The freight model developed by Apivatanagul and Regan (2008) is explained first. The problem setting and the data base development is then described, followed by the solution algorithm. The result is the comparison of project selections made using the network design model and using case by case evaluation. Section 7 presents our conclusions and future research.

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2. Literature review

The network design problem is a general term for an approach to automatically search for an optimal network based on a set of objectives and constraints. Our network design model has public investment as its focus and it is classified as a bi-level network design model. The upper level is a budget allocation model with an objective to minimize total social costs. It is represented by the transportation agency decisions. The lower level represents the user route choice behaviors. The bi-level nature results from the different objectives of the transportation agency and the transportation users. This is hard to consolidate into one level because the user behavior is represented by a multiple commodity nonlinear optimization problem.

The pioneering research on bi-level network design had urban highway networks and passenger movements as their focus. Boyce et al. (1973) and Leblanc (1975) present the classic road network design problems formulated as bi-level models. The typical objective is to minimize the total delay while the road users optimize their own benefits, causing the traffic conditions to converge to user equilibrium conditions. The cost functions are usually assumed to be strictly increasing convex functions.

The models use discrete variables to represent candidate projects. The optimization techniques for these problems include Bender's decomposition Hoang (1982) or branch and bound algorithms (Boyce et al., 1973; Leblanc and Boyce, 1986) or meta-heuristics (Friesz et al., 1992, 1993).

Developments related to network design for freight movements have been limited. The main challenge is to combine the models with freight behavior, which is in many ways more complicated and also less well understood than that related to passenger movements. One of differences between freight and passenger transportation is that freight route choices are cooperative decisions made by multiple agents. The two primary agents in the decisions are the shipper and the carrier. The shipper is a transportation customer who needs to move commodities from one point to another. The carrier provides transportation services for these demands.

Harker (1987) defines three general approaches used to predict freight flows. These include the econometric model, the spatial price equilibrium model, and the freight network equilibrium model. This last model type is the focus of our work since it uses the physical transportation network along with travel demands to predict freight flows and thus gives specific information for each link. This information is used to select the links that should receive improvements. The freight network equilibrium model is similar to the passenger traffic assignment model except that multiple agents are considered. Two distinctive earliest models discussed in Harker (1987) or Roberts (1966) which focuses on the shipper with constant unit costs and Peterson and Fullerton (1975) which focuses on the carrier and nonlinear unit costs with a user equilibrium assumption.

The first model considering multiple agents is Friesz et al. (1981). That paper is explained later in Friesz et al. (1986). The model considers both shippers and carriers explicitly. The shippers have travel demand and must decide how to load it to the transportation service network which represents services provided by the carriers. The service demand, an output from the shipper decision model, is then sequentially routed on the physical transportation network (i.e. transportation infrastructure) in order to estimate traffic conditions of highway and railway networks. The model's further improvements include the simultaneous shipper–carrier loading by Friesz et al. (1985) and the addition of a spatial price equilibrium model by Harker and Friesz (1986a,b).

The concept to develop this freight network design model is introduced in Apivatanagul and Regan (2007). That paper considers issues related to the development of freight network design models and emphasizes the importance of developing models which can integrate multiple local networks. An example is shown to stress the need to designing a network for larger broader social benefits rather than focusing on local network improvements.

Apivatanagul and Regan (2008) develop a freight network design model focusing on the modification of the lower level model which represents the freight route choice behavior. The shipper–carrier freight prediction model of Friesz et al. (1986) is applied to the network design problem. Additionally, the model assumes that links which are overused are unreliable and will be avoided by the users. Therefore, capacity constraints are considered when the traffic volumes are assigned to the network. These constraints make the network design more sensitive to the improvement projects. A branch and bound algorithm is applied to an example which shows that the proposed network design model can identify the bottleneck problem and give a better solution compared to considering projects individually or sequentially.

3. The long haul freight network design model

The main contribution of Apivatanagul and Regan (2008) is the application of the shipper–carrier freight flow prediction model to reflect freight route choice behavior and ultimately to design the optimal integrated network which combines multiple dense local network areas together. A small transportation network is used as an example for the paper. In this paper, a case study involving a larger transportation network integrated with real freight demand data is performed to measure the models computational time and validate that the approach is applicable for use with available data by transportation planning agencies.

The concept of binding the multiple network areas takes place in the shipper or service network. The links in the shipper network are available transportation services linking strategic transportation points including large cities, rail stations, and ports together. Intermodal transportation is achieved through the transfer links created to connect different modes. The input to the shipper network is the freight demand between large cities. The output is the freight demand classified by modes