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REVIEW ON REGIONAL FREIGHT TRANSPORT NETWORK DESIGN

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ABSTRACT

This paper presents a review on regional multimodal freight transport network design aiming to identify the main features of freight transport network that should be captured in network design model from a regional perspective, to present existing methods that are used to model these features. Furthermore, several previous models and challenges are discussed at the end of the paper.

KEYWORDS

Freight transport, Network design, Multimodal, GIS

INTRODUCTION

Network design, formulating effective measures supporting decision making (e.g. cost saving, congestion relieving and social concerns), has been discussed extensively in literature and is recognized as an important method to solve freight transport planning problems (Caris, A., et al. 2008, Crainic, T. G. and G. Laporte 1997). By reviewing the literature, we observed that most of transport planning problems normally arise and are studied at firm level. However, since transport system development is increasingly related to public concerns, such as regional economy, sustainability, and living quality, network design for regional transport planning becomes a new topic of transport planning along with a line of models focusing on large scale network design. These models are expected to deal with large amount of geographic and transport data, to search for optimal solutions among numerous options. Some existing models (Crainic, T. D., et al. 1990, Fernandez, E., et al. 1994, Jourquin, B. and M. Beuthe 1996, Southworth, F. and B. E. Peterson 2000, Tavasszy, L. 1996, Yamada, T., et al. 2009) apply GIS based techniques to visualize the data and to manage the database, and use modern heuristic optimization techniques. However, due to the complicated nature of this type of planning problem and the scale of the network, more effort is needed to better model the complex features of the transport system.

This paper aims to identify the main features of freight transport network that should be captured in regional network design, to present existing methods that are used to model these features. Furthermore, several previous models and challenges are discussed at the end of the paper.

REGIONAL FREIGHT NETWERK DESIGN IS A NEW TYPE OF NETWORK DESIGN PROBLEM

(Crainic, T. G. and G. Laporte 1997) categorized the freight transport planning problems into strategic, tactical, and operational planning according to these three classical decision making levels in a firm. However, the problems arise at regional level, for example infrastructure configuration, tax/fee/subsidy, access permission, and time window, that take system cost, sustainability, and public concerns into account from a systematic prespective is missing (see Figure 1). By reviewing qualified journal papers (SCI) published during the last two decades (1990-2010), we figure out that the objectives and the influencing factors of decition making are such different in transport planning at firm level and at regional level (see Figure 2 and Figure 3), therefore it make sence to recognize the regional freight transport planning' (RFTP) as a new group of transport planning problem.

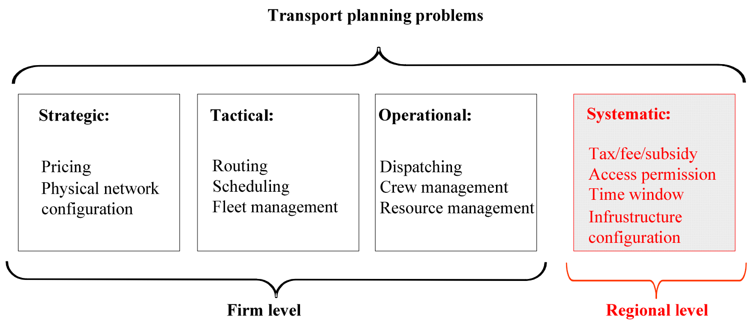

Figure 1: Transport planning problems at firm level and regional level

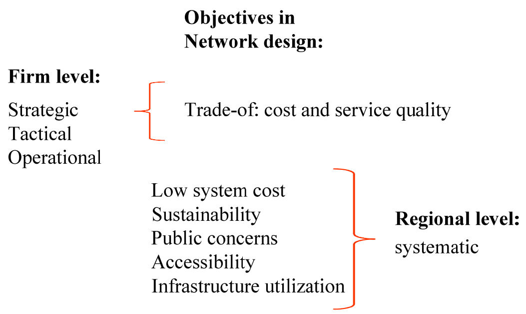

Figure 2: Objectives in network design at firm level and regional level

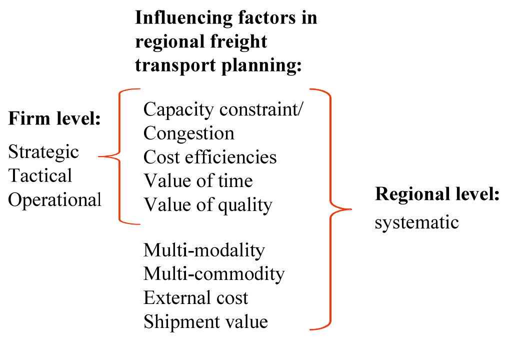

Figure 3: influencing factors in transport planning at firm level and regional level

RFTND METHODS AND RECENT DEVELOPMENTS

The quality of a network design is determined to a great extent by the way of capturing the network features and influencing factors of decision making. Multi-modal and multi-commodity, capacity and congestion effect, cost efficiencies, value of time, external cost, value of quality, and shipment value are recognized as important factors in regional freight transport planning. In this section we discuss the existing methods and challenges of dealing with these factors in network design.

Multi-modal and multi-commodity are presented firstly by structuring multi-layer network (Sheffi 1985) (Southworth, F. and B. E. Peterson 2000). In order to enable transfer among all modalities during the flow assignment process, super network is developed (Jourquin, B. and M. Beuthe 1996) (Tavasszy, L. 1996). Representation of terminal plays also an important role in realizing multi-modal and multi-commodity network (Middendorf, D. 1998) (Tavasszy, L. 1996) (Yamada, T., et al. 2009).

Capacitated model and 'link performance function' method (Sheffi 1985) are widely used to model congestion effect, whereas may not suitable for RFTP. Because (1) it is difficult to determine the capacity of a link dedicated to freight transport; (2) it is difficult to estimate peak-hour and non-peak hour flow distribution; (3) freight transport carriers can schedule the distribution according to the regional time-window and their experience to avoid the urban congestions.

Cost efficiencies attract much attention in RFTP for its importance in intermodal freight transport. Linear and concave link cost functions (Ernst, A. T. and M. Krishnamoorthy 1998, Morton O'Kelly, et al. 1995, Skorin-Kapov, D., et al. 1996) (O'Kelly, M. E. and D. L. Bryan 1998, Racunica, I. and L. Wynter 2005) (Kim, B. J. and W. Kim 2006) are the most used methods. However, this concave cost function leads to new challenge in RFND for its mirror opposite relation to the convex capacity-cost related function. The equilibrium based traffic assignment methods are theoretically not applicable to incorporate both of them into network design.

The literature is limit on VOT of freight transport, and even more limit in the context of RFTP although it is as important as other cost elements in freight transport. One reason is the difficulty in valuation (Beuthe, M., et al. 2005, Cardebring, P. W., et al. 2000). (Beuthe, M., et al. 2002) (Commission, E. 2002) (Yamada, T., et al. 2009) estimate VOT in different ways. An extensive review of the VOT in European freight transport system can be found in (Kreutzberger, E. D. 2008).

The research about external cost focused on how to measure and monetarize these cost, integrate them into total cost, and to be calculated in network design models. (Ian Black, et al. 2003) measured the air pollution cost in terms of emission. (Forkenbrock, D. J. 2001) specifies the safety cost of truck and rail transport, and (Janic, M. 2008) provides definition and formulation of safety cost for intermodal rail-road transport. Noise is less included in transport models as these costs are most difficult to estimate in the external costs.

Value of quality and shipment value are also important factors in regional freight network design for their importance in decision making of shippers and regional economic concerns, whereas, we hardly find literature other than conceptual descriptions.

PREVIOUS MODELS

(Southworth, F. and B. E. Peterson 2000) develops a large and detailed GIS based multimodal network (CFS model) with invoking network technique in the scope of US. It is able to simulate the routing of origin to destination intermodal freight movement which were reported in the 1997 United States Commodity Flow Survey. The features of a network such as congestion effect, cost efficiencies, value of time, are indicated conceptually by link resistant and relative modal resistance factor, but not modeled in details.

Trans-Europeannetwork (Geerts, J.-F. and B. Jourquin 2001, Jourquin, B. and M. Beuthe 1996, Limbourg, S. and B. Jourquin 2009) is a GIS based optimization model which conducts mode choice and route choice in purpose of minimizing the system cost of a given origin-destination matrix. It is able to assign ten groups of commodity to the network with nine sub-modes. Congestion effect and economies of scale are captured by giving calibrated speed to each link and setting a discount to the hub-hub links in the form of a percentage of the total link cost correspondingly. This leads to a limit of this model. The link cost is not dependent on its flow. Thus the flow assigned to a link has no impact on its pre-defined congestion level or the economies of scale level.

(Yamada, T., et al. 2009) introduces another multi-modal freight transport network design model in a geographic scope of southeastern Asia, which realizes the optimization function by bi-level programming where the lower level describes the multi-modal multiuser equilibrium flow on the transport network, and the upper level determines the best combination of investment actions by using GA (Genetic Algorithm)-based procedures. Comparing to the network representation in the previous networks, it represents the terminals in more details. The model deals with both freight and passengers by defining them as multiclass users. Generalized cost is defined for each mode and each user-class. The congestion effect is reflected by flow dependent cost function, but the model is not able to capture the economies of scale.

DISCUSSION AND CONCLUSION

Regional freight transport network design problems have being studied since two decades ago. Many models were developed and applied in transport planning. With reviewing large body of the relevant literature, it concludes that (1) the notable characteristics of freight transport, capacity constraints, congestion, economies of scale, are studied in different purpose, but we lack a model taking all of these factors into account; (2) the activities involved in freight transport are much more complicated than that are considered in the existing models, even some important activities e.g. storage and consolidation are omitted in order to avoid over complex computation; (3) intermodal traffic assignment has been realized in previous models, but the cost difference between pre/end haulage and uni-modal trucking transport need to be further clarified; (4) the relationship between cost and flow in the existing models are over simplified and lose its power of interpreting the reality, new mathematical models are needed to deal with the complexity of the traffic assignment; (5) GIS based model are increasingly favored by researchers for freight transport network design whereas the computation capability becomes a significant limit in solving the complicated network design problems, which requires more efficient and reliable optimization algorithms.

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