Transportation Research Part E 75 (2015) 164–187

Contents lists available at ScienceDirect

Transportation Research Part E

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

Freight transport network design using particle swarm optimisation in supply chain–transport supernetwork equilibrium

Tadashi Yamada [a,*], Zukhruf Febri [b,1]

[a] Dept. of Urban Management, Graduate School of Engineering, Kyoto University, C-1 Kyotodaigaku Katsura, Nishikyo, Kyoto 615-8540, Japan
[b] Dept. of Civil Engineering, Faculty of Civil and Environmental Engineering, Bandung Institute of Technology, Bandung 40132, Indonesia

ARTICLE INFO

Article history:
Received 5 October 2014
Received in revised form 6 December 2014
Accepted 8 January 2015
Available online 14 February 2015

Keywords:
Discrete network design problem
Multimodal transport network
Supply chain network
Mathematical programmes with equilibrium constraints
Discrete binary particle swarm optimisation

ABSTRACT

This paper presents a discrete network design problem for optimally designing freight transport network in terms of the efficiency of supply chain. Modelling is undertaken within the framework of mathematical programmes with equilibrium constraints, which first incorporates both supply chain and transport networks explicitly. The upper level determines the best set of actions for transport network improvement, while the lower-level decision is based on a supply chain–multimodal transport supernetwork equilibrium. New variants of particle swarm optimisation are developed to approximately solve the upper level. Numerical tests reveal their superior performance and the effective freight transport-related actions.

1. Introduction

The term, "supply chain management" (SCM), was coined by Oliver and Webber (1982), and its basic concept was firmly established by Houlihan (1985), and Jones and Riley (1987). It has recently become a crucial long-term strategy for businesses, as consumer demands have become more diversified and international sales competition has intensified (e.g., Mentzer et al., 2001). The fundamental objective of SCM is to develop effective networks among businesses and/or organisations, that is, to create efficient supply chain networks (SCNs) (e.g., Ellram, 1991; Christopher, 1992; Lee and Billington, 1992; Towill et al., 1992; Cooper and Ellram, 1993; Lee and Ng, 1997; Kopczak, 1997), even though SCM has lately focused also on agility and responsiveness in SCNs for reacting quickly and cost effectively to changing market requirements (e.g., Gunasekaran et al., 2008; Wu and Barnes, 2011; Roh et al., 2014). At present, SCM is positively implemented by businesses as a means of remaining competitive, and consequently, decisions on product distribution and freight transport are made practically by looking over the relevant SCNs as a whole. Thus, the comprehension of what occurs on SCNs, namely, to describe the behaviour of economic entities in SCNs and the resulting flow of products, allows administrators and planners to understand the generation mechanism of product movement and to explore the effects of transport- and logistics-related measures. It also enables businesses to recognise the necessity and effectiveness of such measures.

* Corresponding author. Tel.: +81 75 383 3230; fax: +81 75 950 3800.
E-mail addresses: t.yamada@kiban.kuciv.kyoto-u.ac.jp (T. Yamada), febrizukhruf16@gmail.com (Z. Febri).
[1] Tel.: +62 22 2504393; fax: +62 22 2506445.

http://dx.doi.org/10.1016/j.tre.2015.01.001
1366-5545/

A supply chain network equilibrium (SCNE) model can be used as a tool for describing what happens on multi-tiered SCNs, incorporating decentralised decisions made by multiple agents on the SCNs and their behavioural interaction. The SCNE model, developed first by Nagurney et al. (2002), provides several important outputs, such as the quantity of products produced by manufacturers, transacted and distributed between the entities involved in an oligopolistic three-tiered SCN, and the prices of the products. The equilibrium conditions governing the SCN are derived on the basis of a finite-dimensional variational inequality (VI) formulation, where the behaviour of manufacturers, retailers and consumers is taken into account.

There is a possibility of the SCN entities and traffic conditions on a transport network (TN) influencing each other's behaviour, since products are moved through the TN. Thus, the construction/renovation of TN links (i.e., TN design) has significant effect on the movement of the products and on the efficiency of the SCN. Having further developed the SCNE model by integrating SCNs with a TN, Yamada et al. (2011) propose a supply chain–transport supernetwork equilibrium (SC–T-SNE) model. In this model, the behaviour of six entities within a supernetwork – manufacturers, wholesalers, retailers, freight carriers, demand markets, and TN users – is interpreted as shown in Fig. 1. With the behaviour of TN users including freight vehicles being incorporated, the model allows for endogenously determining transport costs based on freight carriers' decision-making, as well as for investigating mutual effects between behavioural changes in SCNs and the TN. Notably, the effects of traffic conditions in the road network on the behaviour of the entities on each SCN and vice versa are explored. To enhance the applicability of the model, the behaviour of wholesalers and the facility costs for manufacturers, wholesalers, retailers and freight carriers are also embedded within the model, which are not taken into consideration in the existing SCNE models. Furthermore, the SC–T-SNE model has the capacity of elucidating the relationship between traffic flow and product movement throughout the entire SCNs. In that sense, the SC–T-SNE model is more applicable to SCNs than currently existing TN models (Friesz et al., 1983; Harker and Friesz, 1986; Crainic et al., 1990; Guelat et al., 1990; Fernandez et al., 2003; Yamada et al., 2009).

In this study, on the assumption of SCN–TN interaction, a discrete optimisation model for TN is developed within the framework of mathematical programmes with equilibrium constraints (MPEC) (e.g., Luo et al., 1996; Outrata et al., 1998). Some SCNE studies optimise the objectives of decision makers under the constraints that describes what occurs on a SCN using their SCNE models (Chiou, 2007; Meng et al., 2009; Yang et al., 2010). These commonly adopt the MPEC-based modelling framework, where the upper level decision controls combinatorial optimisation, and the lower level describes the state of the SCNE. The upper level is solved using approximate solution approaches, such as genetic algorithms (GAs), since this type of MPEC is a discrete optimisation problem with the time-complexity of NP-complete due to the parameterised VI constraints. These studies have not explicitly focused on transport measures or considered traffic conditions in TNs. As such, there have been no MPEC studies incorporating SC–T-SNE within their constraints, and this paper is the first one to embed SC–T-SNE within MPEC-based models.

The upper level of the model proposed in this paper can also be considered as a combinatorial optimisation problem, which determines the best combination of TN links. The lower level is integrated with the supply chain–multimodal transport supernetwork equilibrium (SC–MT-SNE) for a multimodal TN, which can include road, rail, air, and water modes. SC–MT-SNE is a modified version of SC–T-SNE that deals only with road networks. Therefore, the SC–T-SNE model is first extended to a multimodal environment in this paper.

Unlike the SC–T-SNE model, the SC–MT-SNE model does take into consideration transhipment and transfer between different transport modes. For example, a set of TN links ($A = A_{road} \cup A_{rail} \cup A_{sea} \cup A_{transfer}$) consists of road ($A_{road}$), railway ($A_{rail}$), sea route ($A_{sea}$), and transhipment/transfer ($A_{transfer}$) at traffic nodes (i.e., terminals). The SC–T-SNE model only considers road traffic where the movement of passengers is measured by the number of passenger cars. In the SC–MT-SNE model, transfer between different transport systems must be explained, and therefore, the movement of passengers is expressed with the number of persons. Products are traded by weight in the same manner as in the SC–T-SNE model. In the SC–T-SNE model, the amount of products transacted by any SCN entity is distinguished according to the TN paths. However, because the TN paths are most likely to be chosen by freight carriers, the amount of products is distinguished according to the TN paths only when it is transported by freight carriers (see Objective function (18), and Constraints (19)–(21)).

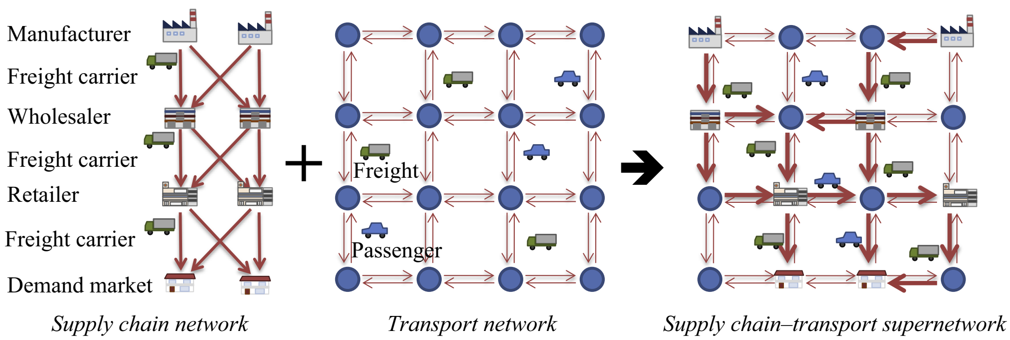

Fig. 1. Supply chain–transport supernetwork.