



Chapter XIV

A Time-Dependent Supply Chain Network Equilibrium Problem

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Abstract

This chapter deals with a time-dependent supply chain network equilibrium (TD-SCNE) problem, which allows product flows to be distributed over a network, not only between two successive sectors in the same time period (a transaction), but also between two successive periods for the same agency (an inventory). Since product price and flow interactions are inherently embedded within it, the TD-SCNE problem is formulated as a variational inequality (VI) model. A three-loop-nested diagonalization method, along with a specially designed supernetwork representation, then is proposed and demonstrated with a numerical example. In equilibrium, for each time-dependent retailer agency or demand market, the product prices of transactions are the same and minimum, no matter when or where the product comes from, which is a realization of the Wardropian first principle. The proposed framework can be extended with minor modifications to other TD-SCNE-related equilibrium problems.

Introduction

Supply chain management is a major subject in economics (Hopp et al., 2000). A bundle of research topics in this area has been identified and elaborately explored, consisting of optimum buffer sizes, stock levels, and the dynamics and stability of supply chains, among other topics. This book covers a large variety of skills and techniques for analyzing and designing global integrated supply chain systems. Setting it apart from the other chapters, this chapter focuses on a highly technical, yet equally intriguing, topic—the time-dependent supply chain network equilibrium (TD-SCNE) problem. Since development of related models and algorithms is still in an embryonic stage, there is only a handful of relevant publications on the TD-SCNE problem.

The TD-SCNE problem is based largely on its time-independent counterpart, the supply chain network equilibrium (SCNE) problem. The SCNE describes how product flows distribute over a network and finally end up with product prices, which, in turn, affect the amount of product demands. The convective phenomenon between the product prices and demands will resonate. This problem first was formulated using the variational inequality (VI) approach and analytically solved with the modified projection method (Nagurney et al., 2002). Under the assumption that a vector function F enters the VI and is strictly monotone and *Lipschitz* continuous (and that a solution exists for it), the modified projection algorithm for the SCNE model is guaranteed to converge. This equilibrium model captures both the independent behavior of the various decision makers as well as the effect of their interactions, which, indeed, are essential components for closely representing a perfect competitive market. However, this model formulation (in the class of spatial price equilibrium problems) and its modified projection algorithm (consisting of two main algorithmic steps: computation and adaptation) have not really intrigued the transportation community, perhaps because the familiar concept of transportation networks and relevant solution algorithms has not been employed.

Generally speaking, transportation networks are characterized by link/path flow variables, and the corresponding link/path cost information is computed by cost functions based on the known flows. Compared with spatial price models such as the SCNE, transportation network models have been widely taught and applied. Yet, transforming the SCNE model into a corresponding transportation network model is not an easy task. The difficulty arises from the fact that the former is characterized essentially by the demand function in terms of price decision variables (called a price model formulation) and the latter by the quantity function (or the inverse of the demand function) with respect to quantity decision variables (called a quantity model formulation). Unless the inverse of the price model formulation exists and can be derived, the transformation of the SCNE problem into its corresponding transportation network model cannot be made. In fact, the inverse of a function can be derived only when that function is defined under a one-to-one mapping condition. To this end, the premise of the conversion between two types of model formulations relies on the understanding of and, moreover, on resolving the (asymmetric) link interactions embedded in the price model formulation.

Without knowing how to transform the price model formulation into the corresponding quantity model formulation, and by persisting with the quantity model, Chen, et al. (2004a) proposed a brute-force method or, more specifically, a trial-and-error solution

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