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Integrated strategic and tactical planning in a supply chain network design with a heuristic solution method

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ABSTRACT

In the current competitive business world, viable companies are those that have flexible strategies and long-term plans, by which they can appropriately respond to a dynamic environment. These strategies are used to find the optimum allocation of company income to the main sources of development, for the expansion of company activities and for service expansions.

This paper presents a new mathematical model for multiple echelon, multiple commodity Supply Chain Network Design (SCND) and considers different time resolutions for tactical and strategic decisions. Expansions of the supply chain in the proposed model are planned according to cumulative net profits and fund supplied by external sources. Furthermore, some features, such as the minimum and maximum utilisation rates of facilities, public warehouses and potential sites for the establishment of private warehouses, are considered. To solve the model, an approach based on a Lagrangian Relaxation (LR) method has been developed, and some numerical analyses have been conducted to evaluate the performance of the designed approach.

1. Introduction

A supply chain is defined as the chain that links each entity of a manufacturing and supply process, from the raw materials to the end user. A supply chain comprises many systems, including various procurement, manufacturing, storage, transportation and retail systems [1].

The terminology Supply Chain Network Design (SCND) is sometimes employed as a synonym for strategic supply chain planning (see [2–5]). In the current competitive world, a supply chain network is expected to be viable for a considerable time, during which many parameters can change. It may be important to consider the possibility of making future adjustments in the network configuration to allow gradual changes in the supply chain structure and/or in the capacities of the facilities. In this case, a planning horizon that is divided into several time periods is typically considered, and strategic decisions are to be planned for each period. Such a situation occurs, for example, when large facility investments are limited by the budget that is available during each period [6].

In Supply Chain Management (SCM), three planning levels are usually distinguished, depending on the time horizons: strategic, tactical and operational [7,8]. The strategic level addresses decisions that have a long-lasting effect on the firm, such as decisions about the number, location and capacities of warehouses and manufacturing plants or the flow of material through the logistics network [5].

In strategic decisions that involve large investments, facilities that are currently in operation are expected to operate for a long-term horizon. Moreover, changes of various types during the facility's lifetime could make a location that is good today become a bad location in the future [6].

There are several models that have been developed to help managers when designing and planning their supply chain. Arntzen et al. [9] developed a mixed integer linear programming model for production and distribution planning with multiple products and a network of sellers. Amiri [10] proposed a mixed integer linear model to select the optimum numbers, locations and capacities of plants and warehouses to open so that all of the customer demands are satisfied at a minimum total cost for the distribution network in three echelons for a single period and a single product. In this paper, an efficient heuristic solution procedure for this supply chain system problem is provided.

Wouda et al. [11] developed a mixed integer linear programming model for the optimisation of the supply network of Nutricia Hungary. Their model focused on consolidation and

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product specialisation of plants, and the objective was to find the optimal number of plants, their locations and the allocation of the product portfolio of these plants, while minimising the sum of the production and transportation costs.

Noorul Haq and Kannan [1] developed an integrated supplier selection and multi-echelon distribution inventory model in a built-to-order supply chain that involved a single selected supplier, multiple plants, multiple distributors, wholesalers, and retailers. Dias et al. [12] worked on the re-engineering of a two-echelon network (facilities and customers). The authors assumed that facilities could be opened, closed, and reopened more than once during the planning horizon. They studied these conditions within three scenarios: with maximum capacity restrictions, with both maximum and minimum capacity restrictions, and with a maximum capacity that decreases. All of these problems are solved by primal-dual heuristics. In this paper, three linear formulations correspond to the three previous scenarios, and their linear dual formulations are presented.

Melo et al. [13] aimed at relocating a network with expansion/reduction capacity scenarios. The capacity can be exchanged between an existing facility and a new facility, or between two existing facilities under certain conditions. Each change of capacity is penalised by a cost. In this model, closed facilities cannot be reopened, and new facilities will remain active until the end of the planning horizon. Thanh et al. [14] propose a dynamic mixed integer linear programming model for a four echelon supply chain that includes suppliers, manufacturing firms, distribution centres, and customers. The bill of materials and multiple products have been taken into consideration. This paper aims to help strategic and tactical decisions, which include the following: opening, closing or enlargement of facilities, supplier selection, and flows along the supply chain. They make a distinction between a private warehouse (owned by the company) and a public warehouse (hired by the company). The status of a public warehouse can change more than once during the planning horizon. Park et al. [15] proposed a mathematical model for single-sourcing a network design problem with a three-level supply chain that consists of multiple suppliers, distribution centres and retailers. The proposed integer nonlinear programming model is solved using a two-phase heuristic solution algorithm based on the Lagrangian relaxation approach.

Some scholars in the field of supply chain modelling have considered the location problem in their networks [16–20]. Thanh et al. [14] presented four echelons for a multiple period supply chain with dynamic demands in which they suggest adding budget constraints to their model.

In many papers, the expansion of facilities is restricted to a predetermined fund or a fixed number of maximum facilities allowed to be established in each period. In real situations, a company's expansion budget is supplied mostly by their net profit after tax and stakeholders' share deduction.

In this paper, a supply chain network design problem with multiple commodities is considered in which the main objective is to make strategic and tactical decisions. This model is a mixed integer linear programming (MILP) model for network design and expansion planning of a four echelon multiple commodity supply chain. This approach also considers different time resolutions for strategic and tactical decisions. Furthermore, this model makes decisions about supplier selection, production facility and warehouse location as well as production, distribution, and expansion planning in a long-term horizon. Expansion of the supply chain in the proposed model is restricted to cumulative net profit and funds supplied from external sources.

This model can be applied in firms with the capability of producing a family of products. For example, firms in the food industry design their market strategies to promote their brand by producing a variety of products. In such markets, customers' demands are affected mainly by population changes and, consequently, can be predicted for a strategic time horizon with a negligible deviation.

The remainder of this paper is organised as follows: in Section 2, the MILP model for the SCND problem will be presented. To evaluate this model, some numerical analyses are conducted using the CPLEX solver and are presented in Section 3. In Section 4, a solution procedure based on the Lagrangian relaxation method will be presented. To evaluate the performance of the proposed approach, some computational experiments will be performed and described in Section 5, and finally, conclusions are drawn in Section 6.

2. MILP model for the SCND problem

In this section, a MILP model for the supply chain network design, expansion planning and production–distribution planning is presented based on the model proposed by Bashiri et al [51]. This model helps managers to make their strategic and tactical decisions. Because in a real-world situation many parameters are dynamic, it is essential to take this dynamic nature into consideration when using multiple period models. In contrast, one of the most important features of strategic decisions is that they should be maintained the same for a long time. The facility location problem is a type of strategic problem, but there are some papers in the literature in which the locations are determined in a single period and with static parameters. There are a few papers in the literature that consider a facility location and the production–distribution problem in a dynamic model [14].

The proposed model in this paper makes some strategic decisions, such as facility locations and capacity expansions. From the tactical viewpoint, this model determines the production and distribution planning during the decision horizon. Strategic decisions are those in which a long-term horizon is considered during the decision making, but many papers make strategic decisions in a midterm horizon in addition to tactical decisions. In the proposed model, the strategic and tactical decisions are made in different periods and time resolutions, which are high resolution for tactical decisions and low resolution for strategic decisions. Furthermore, the interest rate is considered to take time into consideration in monetary calculations.

Thanh et al. [14] suggest that budget constraints be added for the establishment of new facilities in each period. Melo et al. [13] consider a predetermined budget for investment in each period. In many firms, an expansion budget is supplied by the cumulative net profit after tax and stakeholder share reductions. Because costs, incomes and, thus, net profit are unknown parameters before the supply chain is designed, managers are not able to determine the expansion budget to use in a budget constraint. In the proposed model it is supposed that the main financial resource for expansion is the net profit of the chain. Therefore, the proposed model in this paper uses cumulative net profits and a budget limited to a predetermined maximum amount which could be supplied from external sources. Obviously, the difference between maximum (potential) external budget and the amount actually supplied for each period has not been assigned and therefore, cannot be transferred to the next periods. In [13] it is assumed that the predetermined budget has been assigned completely, and unused amount of this budget is transferred to the next periods. A similar approach in both models is that in Melo et al. [13] budget not invested in each period is accumulated for the next periods and in our proposed model remaining net profits are an accumulating capital.