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Tabu search with path relinking for an integrated production–distribution problem

V.A. Armentano [a,*], A.L. Shiguemoto [b], A. Løkketangen [c]

[a] Faculdade de Engenharia Elétrica e de Computação, Universidade Estadual de Campinas, Dpt. de Engenharia de Sistemas, Campinas, São Paulo 13081-852, Brazil
[b] Departamento de Estatística e Matemática Aplicada, Universidade Federal do Ceará, Campus do Pici, Bloco 910, Fortaleza, Ceará 60455-760, Brazil
[c] Molde University College, Specialized University in Logistics, Britveien 2, 6411, Molde, Norway

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ABSTRACT

This paper deals with the problem of integrating production and distribution planning over periods of a finite horizon. We consider a capacity-constrained plant that produces a number of items distributed by a fleet of homogenous vehicles to customers with known demand for each item in each period. The production planning defines the amount of each item produced in every period, while the distribution planning defines when customers should be visited, the amount of each item that should be delivered to customers, and the vehicle routes. The objective is to minimize production and inventory costs at the plant, inventory costs at the customers and distribution costs. We propose two tabu search variants for this problem, one that involves construction and a short-term memory, and one that incorporates a longer term memory used to integrate a path relinking procedure to the first variant. The proposed tabu search variants are tested on generated instances with up to ten items and on instances from the literature involving a single item.

1. Introduction

The characteristics of high competition in the global market, such as the introduction of items with short life cycles, increased service level, higher efficiency and lower costs, have led companies to focus attention on the management of their supply chains. The definition of a supply chain provided by Simchi-Levi et al. [1] emphasizes the importance of integrating decisions of different functions such as outsourcing, procurement, production planning, inventory and distribution management so as to obtain an optimal strategy that minimizes total costs for the entire company. However, due to the complexity of the supply chain, it is usually not viable to build a model that encompasses the decisions of all functions. For this reason, there has been increased interest on optimization models that integrate smaller sections of the supply chain.

This paper addresses the following integrated production–distribution problem over periods of a finite horizon [2]. A plant with capacity constraints produces several items, and a homogeneous fleet with an unrestricted or restricted number of vehicles is available for the distribution of the items in order to meet the customers' demands. In each period, the production problem involves determining the amount produced for each item, while the distribution problem consists of defining the quantities of each item to deliver to each customer and the vehicle routes. A production fixed cost and a transportation fixed cost are incurred every period that an item is produced, and every period that a vehicle is used, respectively. If the customer is visited in a given period, we consider that the customer is served by a single vehicle. The objective is to minimize fixed and variable production costs, inventory costs at the plant and customers and transportation costs. The first review on optimization models for tactical and strategic coordinated decisions for supply chain management problems was conducted by Thomas and Griffin [3]. At the tactical level, the authors point out that the three fundamental stages of the supply chain, namely, procurement, production and distribution have been managed independently, buffered by large inventories. The tactical models are then organized in three categories of operational coordination: buyer–vendor, production–distribution and inventory–distribution. The strategic planning models include decisions such as opening or closing a facility, assigning equipment to facilities and selecting locations for manufacturing a new item. Vidal and Goetschalckx [4] present an extensive literature review on domestic and international strategic production-distribution models.

Sarmiento and Nagi [5] present a review on integrated production–distribution systems and stress the importance of simultaneously optimizing decision variables of different functions or stages of the supply chain, as opposed to the traditional decoupled

* Corresponding author. Tel.: +55 19 3788 3705; fax: +55 19 3289 1395.
E-mail addresses: vinicius@densis.fee.unicamp.br (V.A. Armentano), shiguemoto@ufc.br (A.L. Shiguemoto), Arne.Lokketangen@hiMolde.no (A. Løkketangen).

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optimization, in which the optimized output of one stage becomes the input to another stage, such as setting production plans and then planning the distribution. The review focuses on models that consider the transportation system explicitly in order to evaluate the way it is integrated and the resulting competitive advantage. Erengüç et al. [6] identify relevant decisions in the supplier, plant and distribution stages that need to be considered in the integrated planning of a supply chain, but do not emphasize models that achieve such an integration.

Chen [7] states that production and distribution are the most important operational functions in a supply chain and provides a comprehensive review of models that explicitly integrate such functions. At the tactical level, the problems involve joint lot sizing and finished product delivery models with infinite horizon or a finite horizon with discrete time periods. Such models are concerned with decisions such as, how much and when to produce, how much and when ship to customers, how much of inventory to keep at the plant and at the customers. The models are classified into five classes according to the following factors: (i) tactical or operational level; (ii) integration structure involving inbound transportation, production and outbound transportation; (iii) length of planning horizon and constant rate or dynamic demand. A number of real world problems belong to one of these classes, and the only reported application that requires vehicle routing is production and distribution of newspapers ([8,9]; see also [10]).

According to the above classification, the integrated production–distribution problem addressed in this paper is at the tactical level, characterized by a joint capacitated lot sizing production and vehicle routing distribution planning.

The literature related to this problem is rather scarce. Chandra and Fisher [11] propose two heuristics for solving the problem. The first heuristic is based on the decoupled approach, in which the production planning problem is optimally solved by the mixed integer optimization (MINTO) software and then the distribution planning problem is solved by means of constructive heuristics followed by 3-opt local search. The second heuristic follows an integrated approach in which the amount of each item delivered to each customer in a given period is anticipated to previous periods in which the item is produced. An optimal production plan is recomputed for the ten vehicle capacity feasible moves that yield the greatest reduction in distribution cost. This process is repeated until no improving move takes place. The decoupled and the integrated heuristics are applied to a set of 132 instances with up to 10 items, 50 customers, 10 periods and the cost savings obtained by the integrated approach ranges between 3% and 20%.

Fumero and Vercellis [12] propose a mathematical model for the problem and develop a Lagrangian heuristic that is applied to 20 instances involving up to 10 items, 12 customers and 8 periods. A cost reduction from 8% to 10% is obtained by the integrated approach relative to the decoupled approach.

Boudia et al. [13] consider a production–distribution problem with a single item and capacity constraints, and suggest a reactive GRASP procedure for solving the problem. A path relinking procedure is also proposed in order to link any two solutions from a pool of elite solutions, as a post-optimization phase, or to link a GRASP local optimum with a solution from the pool. Boudia and Prins [14] develop a memetic algorithm with population diversification management for the same problem. Diversification is achieved by including a new solution in the population only if its distance to the population is greater than or equal to a threshold. This approach outperformed the GRASP procedure on all instances generated by Boudia et al. [13]. For the same problem, Bard and Nananukul [15] propose a reactive tabu search and a path relinking procedure to connect solutions from a pool of elite solutions while being feasible at all times, and compare their results with those of Boudia et al. [13]. Lei et al. [16] deal with a complex real-life integrated, inventory and distribution routing problem involving the production at several plants, demands of distribution centers and heterogeneous fleet. The problem is solved in two phases. In phase I, the routing is ignored and considered as direct shipments from the plants to distribution centers and phase II deals with consolidation of loads and vehicle routing.

Tabu search has been applied with a high degree of success to a variety of hard combinatorial problems, as for example in vehicle routing problems, [17], but its application to solving production–distribution and inventory-routing problems is scant. Two variants of the tabu search approach are proposed here. The first variant has a short-term memory and the search is guided by the objective function aided by the violation of production capacity and vehicle capacity. Therefore, the search has feasible and infeasible trajectories. The second variant has a longer term memory that is used to integrate a path relinking procedure with the first tabu search variant, such that selected solutions from the trajectories are linked with a solution from the pool of elite solutions. The performance of our methods are assessed by a set of instances with up to 10 items generated by the authors, and a set of single item instances generated by Boudia et al. [13].

The remainder of the paper is organized as follows. Section 2 introduces the problem description. Section 3 describes the construction of an initial solution and the tabu search procedure. The path relinking procedure is presented in Section 4. Computational results and analyzes are reported in Section 5 and conclusions and suggestions are outlined in Section 6.

2. Problem description

The integrated production–distribution problem (IPDP) is defined on a complete graph $G=(W, E)$, where $W=\{0, 1, \ldots, N\}$ is the set of nodes and $E=\{(k,l): k,l \in W, k \neq l\}$ is the set of edges. Node $k=0$ represents the plant that produces a set of items $j \in \{1, \ldots, J\}$ shipped to a set of customers corresponding to nodes $k \in \{1, \ldots, N\}$ by a set of homogeneous vehicles $v \in \{1, \ldots, V\}$ with capacity C in periods of time $t \in \{1, \ldots, T\}$. The number of vehicles can be restricted or unrestricted. In each period, each vehicle can perform at most one route of length limited to L, and each customer can be visited by a single vehicle. The capacity of the plant in time units is B and the time required to produce one unit of item j is b_j. The unit inventory cost of item j at the plant is h_{j0}, the unit production cost of item j is c_j^p and if item j is produced in period t, a setup cost f_j^p is incurred. The demand of item j of customer k in period t is d_{jkt} and the unit inventory cost at the customer is h_{jk}. To each item j and each customer k a minimum inventory lower bound L_{jk} and a maximum inventory upper bound U_{jk} are associated. Transportation costs include a fixed cost f^v if a vehicle v is used in period t and a cost c_{kl}^v for traveling from node k to node l. Let M denote a large number, as for example, $\sum_{j=1}^{J} \sum_{t=1}^{T} \sum_{k=1}^{N} d_{jkt}$.

Consider the following variables:

p_{jt}=quantity of item j produced in period t;
I_{jkt}=inventory of item j of customer k at the end of period t;

$$y_{jt} = \begin{cases} 1 & \text{if product } j \text{ is produced in period } t \\ 0 & \text{otherwise;} \end{cases}$$

q_{jkt}^v=quantity of item j delivered to customer k by vehicle v in period t;
x_{jklt}^v=quantity of item j transported on edge (k, l) by vehicle v in period t;

$$z_{klt}^v = \begin{cases} 1 & \text{if vehicle } v \text{ travels along edge } (k,l) \text{ in period } t \\ 0 & \text{otherwise;} \end{cases}$$