Minimizing the Total Cost in an Integrated Vendor–Managed Inventory System

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Extended abstract

The integration of production, distribution and inventory management is one of the challenges of today's competitive environment. The basic idea is to simultaneously optimize decisions that traditionally have been optimized separately and to take into account the relations existing between internal management and external world. In the last decade the importance of these relations has been widely recognized, and the expression "supply chain management", which emphasizes the view of the company as part of the supply chain, has become of common use. Sometimes the expression "coordinated supply chain management" is used to emphasize the coordination among the different components of the supply chain. The availability of data and information tools which derive from the advances in technology and communication systems has created the conditions for the coordination inside the supply chain. From the modeling side, three different categories on the integration of decisions of different functions have been proposed: supply and production planning; production and distribution planning; inventory and distribution planning. We refer to Thomas and Griffin (1996) for a review on the coordination of these three areas at an

operational level when deterministic models are used, to Sarmiento and Nagi (1999) and to Erengüç et al (1999) for reviews that focus on the integration between production and transportation and to Hall and Potts (2003) for an interesting introduction to the problem of minimizing the scheduling and delivering costs. Different approaches and levels of analysis have been proposed for the problem of integrating production, distribution and inventory. Cohen and Lee (1988) propose a strategic stochastic model for a complete supply chain, in which four different functions are considered (material control, production control, finished good stockpile and distribution network control). A hierarchical decomposition approach is proposed to solve the problem. Blumenfeld et al (1985) analyze the trade-offs between transportation, inventory and production set-up costs over an infinite time horizon. Different shipping policies (direct shipping, shipping through a consolidation terminal and a combination of them) are studied on the basis of several simplifying assumptions. Chandra and Fisher (1994) propose a computational study to evaluate the value of coordination between production and distribution planning over a finite time horizon. Different scenarios, obtained by varying the time horizon, the number of items, the number of retailers and the costs, are analyzed. The integrated approach is compared with the sequential optimization of the problem.

The availability of new information technologies has also led in the last years to the development of new forms of relationships in the supply chain. One of these is the so called Vendor–Managed Inventory (VMI), in which the supplier monitors the inventory of each retailer and decides the replenishment policy of each retailer. The supplier is responsible of the inventory level of each retailer and acts as a central decision–maker; therefore, she/he has to solve an integrated inventory–routing or production–inventory–routing problem. The advantage of the application of a VMI policy with respect to the traditional retailer–managed inventory policies relies in a more efficient utilization of the resources: The supplier can reduce its level of inventories maintaining the same level of service or can increase the level of service and can reduce the transportation cost by a more uniform utilization of the transportation capacity. On the other hand, the retailers can devote fewer resources to monitor their inventories and to place orders, having thus the guarantee that no stock-out will occur. The VMI policy gives the supplier the opportunity to determine a globally optimal policy, that is a policy which minimizes the total production, transportation and inventory costs with advantages for the whole facility-retailers system in terms of costs, profit and competitiveness. We refer, for instance, to Kleywegt, Nori and Savelsbergh (2002) for applications of the VMI policy to systems with stochastic demand.

We study an integrated model in which several items are produced at a production facility and shipped to several retailers over a finite time horizon by applying a VMI policy. Shipments from the production facility to the retailers are performed by a fleet of vehicles. Each vehicle has a given transportation capacity. The total transportation cost is given by the sum of a fixed cost and the routing cost. The fixed transportation cost is charged for each vehicle used at least once during the time horizon. The rationale is to formulate a planning model that allows us to determine the optimal dimension of the fleet. When the fixed transportation cost is set to 0, this model can also handle the case of outsourced transportation service. Each item is absorbed by the retailers in a deterministic and time-varying way. By deterministic we mean that the quantity of the item that is absorbed by the retailers in each discrete time instant is known. By time–varying we mean that the quantity of the item absorbed by the retailers in each time instant can be different from the one absorbed in a different time instant. A starting level of the inventory of each item is given for the production facility and for each retailer. Since the level of the inventory at the retailers at the end of the time horizon can be different from the starting one, the problem is not periodic. Each retailer determines a maximum and a minimum level of the inventory of the items and can be visited several times during the time horizon. Every time a retailer is visited, the quantity delivered is such that the maximum level of inventory is reached. This inventory policy is inspired, in a deterministic setting, by the classical order-up-to level policy, widely studied in inventory theory. We refer to Axsäter and Rosling (1994) for an overview of inventory policies in multi–level systems and to Bertazzi, Paletta and Speranza (2002) for an application of the deterministic order-up-to level policy to an inventory-routing problem. This policy implicitly assumes that the production facility monitors the inventory of each retailers and is responsible to maintain the right level of the inventory at each retailer, i.e. a VMI policy is applied. The problem is to determine the production policy and the shipping policy that minimize the total cost, given by the sum of fixed and variable production cost, fixed transportation cost, routing cost and inventory cost both at the production facility and at the retailers. The production policy consists in determining for each discrete time instant the quantity of each item to produce, while the shipping policy consists in determining for each delivery time instant the set of retailers to visit, the quantity of each item to ship to each visited retailer and the route that each vehicle has to travel. The constraints of the problem guarantee that the level of the inventory both at the production facility and at each retailer is always not lower than the minimum level and that feasible routes are determined for each delivery time instant.

Since the problem is very complex and the exact solution would be impractical, we propose heuristic algorithms to solve it. In particular, we decompose the problem into two subproblems, one concerning the production and one concerning the distribution, on the basis of two different criteria and then we hierarchically solve them on the basis of the two possible different rankings. This approach gives rise to four different solution methods. In each of these methods, the subproblem concerning the production is optimally solved by the procedure proposed by Wagner and Whitin (1958), while the subproblem concerning the distribution is solved by applying a constructive heuristic algorithm in which at each iteration a retailer is inserted in the solution. For each retailer, the heuristic builds a network in order to represent the incremental cost due to the insertion of the retailer in the solution. A shortest path in the network identifies a "min cost" way for adding the retailer to the solution. The solution obtained by hierarchically solving the two subproblems is improved by applying two procedures which try to coordinate production and distribution. We will analyse the impact of the different decompositions and of the different rankings on the solution.

We will also use the proposed solution procedures to compare the application of the VMI policy with respect to a conventional inventory management policy. In a traditional management system, the information on the retailers inventory is available at the retailers only, each retailer defines its own replenishment, typically an order-up-to level, policy and the facility defines the transportation and the production policies, given the retailers requests for service (times of service and quantities to be delivered). Each retailer minimizes its own inventory and requires to be served just before the stock-out, while the facility, given the retailers requests, minimizes the production and inventory costs at the facility and the transportation costs. We call this policy the retailer-managed inventory (RMI) policy. To find the RMI policy, we used an optimal algorithm to determine the production and inventory costs at the supplier and a heuristic to determine the transportation policy. It turns out that the VMI policy, although not optimal but heuristically found, can dramatically reduce the costs. The computational results show that the RMI policy has a cost which increases from 17% to up to 94% the cost of the VMI policy, depending on the data of the problem instance. While the retailers inventory costs are slightly lower in the RMI policy, the transportation costs are much greater and involve a much larger number of vehicles than in the VMI policy. Our conclusion is that the coordination costs necessary to implement a VMI policy are likely to be more than compensated by the cost reduction obtained by the opportunity to optimally manage an integrated system.

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