
A Closed-loop supply chain with remanufacturing of EOL products and environmental considerations

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Résumé

In a traditional supply chain, production, inventory, and distribution operations are treated separately due to the complexity of jointly planning these operations and the lack of information shared among stakeholders. Today, in order to face the fierce competition in the global market, companies are forced to jointly plan these activities in order to benefit from the economic and environmental benefits generated by this integration. In fact, many companies are now realizing that greater added value can be provided to their customers by effectively integrating logistics management and product availability to improve the speed and consistency of delivery. To achieve an integration level that will produce new benefits, production and distribution decisions must be made on a daily basis to balance the associated costs within an optimal framework. Dealing with these components in a single framework provides a holistic view of the logistics network and provides a good starting point for full supply chain integration. On the other hand, too often these decisions are processed independently. However, in many cases, these problems are closely linked, and it is necessary to solve them simultaneously, especially since their integration can have a significant impact on the overall performance of the system. In addition, in order to reduce costs, production is increasingly carried out in batches and it is therefore necessary to determine the size of these batches in relation to the transport ones. This is because in a typical supply chain that consists of sequential production, inventory and distribution activities, each individual process is often planned and optimized using predetermined decisions from its previous activities. For example, a production planner decides the size of the batches to be produced in order to minimize production and inventory costs at the production site. The planned batch decisions are then used as inputs in the subsequent stages of distribution planning. Since decisions are limited by the old process plan, the benefits of coordination in the planning process are overlooked. Thus, the integrated planning of production, inventory management and distribution operations is now seen by many decision-makers as a competitive advantage. The rapid development of advanced information and communication technologies has enabled companies to set up integrated planning systems for the management of their supply chains, through which production, inventory and distribution activities are jointly optimized. Early work in the literature reported various experiences in which considerable cost savings result from integrated planning (Chandra, 1993; Fumero et al., 1999; Thomas et al., 1996). This is

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because activities are optimized with a monolithic model, as opposed to sequential optimization of parts of the overall problem. Logically, the impressive results obtained by monolithic models have helped to increase interest in integrated planning processes. However, the huge jargon of decisions and factors to consider often creates difficult problems to solve (Stadtler et al., 2008).

Among the optimization problems existing in the literature, the integrated production-inventory-routing problem (IPIRP) which jointly optimizes production, inventory management, distribution, and vehicle routes decisions, has recently received considerable attention, despite its *NP-hardness*. Indeed, its benefits in terms of synchronization between processes, cost reduction and improved service level can be significant. The classical IPIRP aims to optimize the supply chain overall cost and improve service level to customers. It can be defined as a logistics network made up of one or more production plants that produce and distribute one or more types of product to a set of customers in order to fulfill their dynamic demand. One solution to the IPIRP is to decide for each period: 1) the amount to be produced at the plant; 2) how much to deliver to each customer; 3) the amount of products to be held in the plant and with each customer; and 4) how to organize vehicle routes for each scheduled delivery. These decisions typically need to be made within a finite planning horizon consisting of multiple time periods.

On the other hand, the rapid development of manufacturing industries has caused serious environmental consequences in terms of depletion of natural resources and degradation of climate quality. This has led governments to hold manufacturers responsible for collecting their products after use by their customers. In this sense, many manufacturers have turned to green manufacturing. One of the measures taken by manufacturing companies for greener manufacturing is to collect their End-of-Life Products (EOLs) from customers for reuse by refurbishing them through remanufacturing operations or properly disposing of them. This has led many researchers and practitioners to study the process of collecting EOL products through the investigation of the reverse logistics paradigm. Moreover, managing returned EOL flows within closed-loop supply chains is seen as a business opportunity by many decision-makers. Many companies have chosen to integrate the concept of reverse logistics into their production, inventory and distribution decision-making systems, for several reasons such as growing concern for the environment, applicable government regulations and laws on recycled products and waste elimination, increased energy consumption and strong competition between companies. The integration of these three decisions in the context of closed-loop supply chains thus offers enormous possibilities for reducing costs for companies. Consequently, studying the IPIRP in the context of closed-loop supply chains with End-of-Life Product (EOL) management could lead to the development of increasingly sustainable supply chains. Furthermore, growing concerns about environmental issues linked to industrial activities have led to the emergence of policies to control carbon emissions. Taking these regulations into account can have a positive impact on the company's environmental responsibility.

Although the classic IPIRP has been extensively studied for the past decades, several aspects of the problem have not been investigated in recent literature. For example, IPIRP in the context of closed-loop supply chains with the remanufacturing option has not received enough attention. In addition, the few models that exist in the literature dealing with IPIRP in the context of closed-loop supply chains, focus on optimizing a purely economic criterion and neglect the negative effects caused by production, inventory, and distribution operations such as excessive greenhouse gas emissions in particular carbon dioxide ones (). This reality involves incorporating carbon emissions into the decisions of operations induced by IPIRP in a reverse logistics context and controlling their levels through carbon emission regulation policies.

To meet these challenges, the objective of **our** study is to design models and develop optimization approaches to solve an integrated planning problem of production, remanufacturing, inventory, and direct-reverse distribution operations. We considered a closed-loop supply chain consisting of a production line for new products, a remanufacturing line for

returned EOL products, two types of inventories for serviceable products and EOL ones to be remanufactured, as well as customers with dynamic demands for delivery and pickups. The **aim** is to determine the optimal amounts to produce, remanufacture and store, as well as the order of visiting customers in order to meet their requests simultaneously for delivery and pickup, while minimizing the total cost due to the involved operations.

First, a linear integer model is proposed to optimize the supply chain system by considering one or more vehicles with limited capacity. Then, a decomposition metaheuristic procedure is proposed to solve the multivehicle integrated model. Finally, an environmental aware version of the integrated multivehicle model is studied by incorporating carbon emissions into production, remanufacturing, inventory, and distribution decisions while controlling their levels under carbon cap-and-trade policy. Several numerical experiments are provided to demonstrate the applicability and the limits of our approaches.

Keywords: Closed-Loop Supply Chain; Reverse Logistics; Integrated Production-Inventory-Routing Problem; Lot-Sizing Problem with Remanufacturing; Vehicle Routing Problem with Simultaneous Pickup and Delivery; Decomposition Metaheuristic; Carbon Cap-and-Trade Policy; Decision Support System.

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