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A review of mathematical inventory models for reverse logistics and the future of its modeling: An environmental perspective

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ABSTRACT

The responsible management of product return flows in production and inventory environments is a rapidly increasing requirement for companies. This can be attributed to economic, environmental and/or regulatory motivations. Mathematical modeling of such systems has assisted decision-making processes and provided a better understanding of the behavior of such production and inventory environments. Therefore, this paper reviews the literature on the modeling of reverse logistics inventory systems that are based on the economic order/production quantity (EOQ/EPQ) and the joint economic lot size (JELS) settings, so as to systematically analyze the mathematics involved in capturing the main characteristics of related processes. The literature is surveyed and classified according to the specific issues faced and modeling assumptions. Special attention is given to environmental issues. In addition, there are indications of the need for the mathematics of reverse logistics models to follow current trends in 'greening' inventory and supply-chain models. Finally, the modeling of waste disposal, greenhouse-gas emissions and energy consumption during production is considered as the most pressing priority for the future of reverse logistics models. An illustrative example for modeling reverse logistics inventory models with environmental implications is presented.

1. Introduction

The concept of reverse logistics is not new. The reuse of products, components, and materials has been previously applied, mainly for the economic benefits of reusing the product or material instead of its disposal (Fleischmann et al., [1]). In addition to economic motivations, environmental concerns have directed the increase in the development of reverse logistics activities. Moreover, government pressure and legislation have contributed to the increasing motivation for global environmental awareness and sustainability influencing green supply chain management principles and practices (Sheu and Chen, [2]). One such approach is the Extended Product Responsibility (EPR) legislation, which concentrates on the life-cycle and environmental performance of products (Subramanian et al., [3]) and fundamentally holds producers physically and financially responsible for the environmental impact of their products after their life has reached an end (Atasu and van Wassenhove, [4]). Concerns regarding declining landfill sites, depletion of resources and damage to the ozone layer, along with environmental legislation have led to the developments required for prolonging product life, recycling, and reducing greenhouse-gas (GHG) emissions (Bei and Linyan, [5]; Gülsün et al., [6]; Bonney and Jaber, [7]). A traditional forward supply chain involves the acquizition of raw material, production, and distribution of materials and products to end consumers. By contrast, reverse logistics is the opposite. It involves the

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collection, inspection, disassembly, reprocessing, redistribution and reuse of used products, and the disposal of associated wastes (Bei and Linyan, [5]). A closed-loop supply chain integrates and coordinates the forward and reverse supply chain activities (Bei and Linyan, [5]; Guide et al., [8]). As a result, an increase in environmental issues and green supply chains have emerged (both forward and closed-loop supply chains). The underlying difference between green supply chains and reverse logistics and/or closed-loop supply chains is that green supply chains account for environmental issues while reverse logistics and closed-loop supply chains focus on the economic benefits of product recovery options (Bei and Linyan, [5]; de Brito and Dekker, [9]).

As the concern for managing product return flow increases due to both economic and/or environmental motivations, many authors have proposed quantitative models to study and analyze reverse logistics. Most of the mathematical modeling studies of reverse logistics have been focused on deterministic methods with limited research considering stochastic demand for repaired or recovered products (Pokharel and Mutha, [10]). This paper, therefore, focuses on and studies the literature pertaining to the mathematical modeling of reverse logistics inventory models, based on the economic order quantity (EOQ) and the joint economic lot size (JELS) settings, to review and analyze the mathematics involved in capturing the associated processes. The literature is surveyed and classified according to content related issues and modeling assumptions. The paper is organized in the following order: first, a literature review is presented, followed by a review of mathematical models and finally a discussion summarizing what has been achieved and what needs to be done with emphasis on environmental concerns. The paper concludes with some findings and outlines future research directions.

2. Literature review

Quantitative inventory models and closed-loop supply chains can be classified under three main categories: distribution planning, inventory control, and production planning (Fleischmann et al., [1]). The focus of this paper is on the mathematical modeling of inventory with return flows that were developed in EOQ and JELS settings. The general objective of the inventory management models is to control product orders, inventory levels, and recovery processes to guarantee a specific service level and minimize total costs. This paper provides a review of the studies that provided mathematical models that cite and extend the work of Schrady [11], which is believed to be the first to trigger this line of research (Fleischmann et al., [1]). The research papers are classified based on content related issues and modeling assumptions.

Inventory models are classified as either (a) single or multi-echelon, (b) deterministic or stochastic, and (c) one-for-one or batch repair and replenishment (Guide and Srivastava, [12]). There are different solution tools and techniques (single and multi-objective linear, integer, non-linear and mixed-integer programming, etc.) that can be used to solve the various content related issues, including inventory models, reverse distribution and product recovery activities (Sasikumar and Kannan, [13]). Reverse logistics networks can be classified as: directly reusable, remanufacturing, repair service, and recycling networks (Bostel et al., [14]). This classification basically depends on the type of the product considered. Recovery activities include product, components/parts, material, and energy recovery (De Brito and Dekker, [9]). The demand and return processes presented in the literature could be dependent, independent of each other, or dependent on price and quality, and are assumed as a continuous constant rate, a continuous dynamic rate, an arbitrary function of time, or not explicitly modeled (De Brito and Dekker, [9]; Singh and Saxena, [15]). Further, the demand and return rates could be assumed deterministic where all model parameters are known throughout the planning horizon, or stochastic, which accounts for uncertainty. Another important characteristic of 'return flow' inventory systems is the number of stock points and the type of stock inventory (Akçalı and Cetinkaya, [16]). These stock points can be classified as manufactured items, remanufactured items, combined manufactured and remanufactured items, new material items, and used item inventory (Akçalı and Cetinkaya, [16]). From this classification it is clear that the quality of the remanufactured items is either assumed as-good-as-new or less than the newly produced items. The management of quality for different items has also been investigated in the literature (El Saadany and Jaber, [17]). In general, a typical remanufacturing environment can be distinguished by the motivation behind the product recovery, the type of item to be recovered, the form of recovery, the activities required for recovery, the agents performing the recovery process, and finally the location of the recovery activities (Akçalı and Cetinkaya, [16]). Repair shops can either be in-house or independent, and if spare parts are considered, they can be ordered from the original equipment manufacturer (OEM) or they can be repaired (Kleber et al., [18]).

Using the various classification and categorization from the aforementioned literature, the research papers regarding the modeling of inventory management of reverse logistics can be identified under the following categories and sub-categories:

- Type of model
  - EOQ, optimal, optimal quadratic, simulation, linear programming, integer programming, mixed integer programming
  - Single objective, multi-objective
  - Deterministic, stochastic
  - Number of decision variables
  - Decision variable (batch quantity, production rate, number of batches, etc.)
- Inventory stock
  - Number of stock points (single-stock, two-stock, three-stock, and multi-stock points)
  - Types of stock points (new/raw material, manufactured item, used item, remanufactured item, manufactured and remanufactured item inventories)
- Recovery process
  - Recovery activities (collection, inspection, separation, and disassembly)
  - Form of recovery