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Invited Review

Integrating deterioration and lifetime constraints in production and supply chain planning: A survey

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ABSTRACT

Items with short lifetimes that are subject to deterioration are important in the business world. Research has a long tradition in integrating deterioration and value loss effects into mathematical models for inventory planning and control where such effects are understood as a general loss or shrinkage of inventory. However, there has been little work in the modeling of lifetime restrictions of items to prevent wastage and disposals, especially in a dynamic planning context. Globalization and other trends extend the consideration of single companies to whole supply chains, implying increased coordination and information needs. This is important as planning decisions impact lead times and thus the quality of items in the whole supply chain. Products that exceed their useful lifetime can impose high costs due to inventory loss or the need to rework them. This implies increased utilization of (scarce) resources, e.g., machine time, metals, and/or energy, thereby increasing CO_2-levels. We survey the state-of-the-art regarding depreciation effects and the modeling of lifetime constraints as well as a classification of models following business planning functions of the value chain. A critical evaluation of approaches and their limitations is provided, highlighting directions for future research.

1. Introduction

Constraints on the lifetime of items force organizations to carefully plan their production in cooperation with their supply chain partners. Significant waiting times imply increased *work in process* (WIP) inventories that might lead to longer lead times and, thus, increase the likelihood of deterioration (Pahl, Voß, & Woodruff, 2011), imposing additional costs on the supply chain. In the worst case, such items cannot be used for their original purpose and need to be disposed. This is particularly problematic in the food industry where significant losses occur during handling, processing, and distribution (Gustavsson, Cederberg, Sonesson, van Otterdijk, & Meybeck, 2011). A study conducted for the International Congress "Save Food!" states that 1.3 billion tons of food per year are wasted on a global scale: around one-third of all food produced worldwide for human consumption is wasted (Gustavsson et al., 2011). This is particularly relevant in developing countries, where more than 40% of food losses relate to processing problems. In industrialized countries more than 40% of food waste occurs at the retailer and consumer level (Gustavsson et al., 2011). Increased supply chain costs are only one problem; other challenges include loss of valuable resources, increased energy consumption, and related CO_2 emissions.

Deterioration has a great influence on inventory management and also on all other elements of the production process where items are stocked or forced to wait due to uncertain demand, technical matters, variabilities, or disruptions of the production process (Pahl, Voß, & Woodruff, 2007).

In this paper, we provide a comprehensive survey on how deterioration and lifetime constraints are integrated in production and supply chain planning. We explore this integration following different business functions (see Fig. 1) that are closely related but not limited to inventory management. In this sense we also complement reviews that focus on deterioration in inventory management (Karmakar & Choudhuri, 2010; Li, Lan, & Mawhinney, 2010) and extended settings (Karaesmen, Scheller-Wolf, & Deniz, 2011, chap. 15). An earlier review is given in Pahl et al. (2007) and a special industrial focus on agri-food supply chains is treated in Ahumada and Villalobos (2009). Specifically, we discuss how these issues are integrated in mathematical modeling.

The general question that we pursue is how losses due to spillage or degradation of items in the (industrial) process can be prevented. Apart from engineering issues to enhance the production process, related coordinated planning throughout the overall supply chain is a starting point. Despite a long stream of operations

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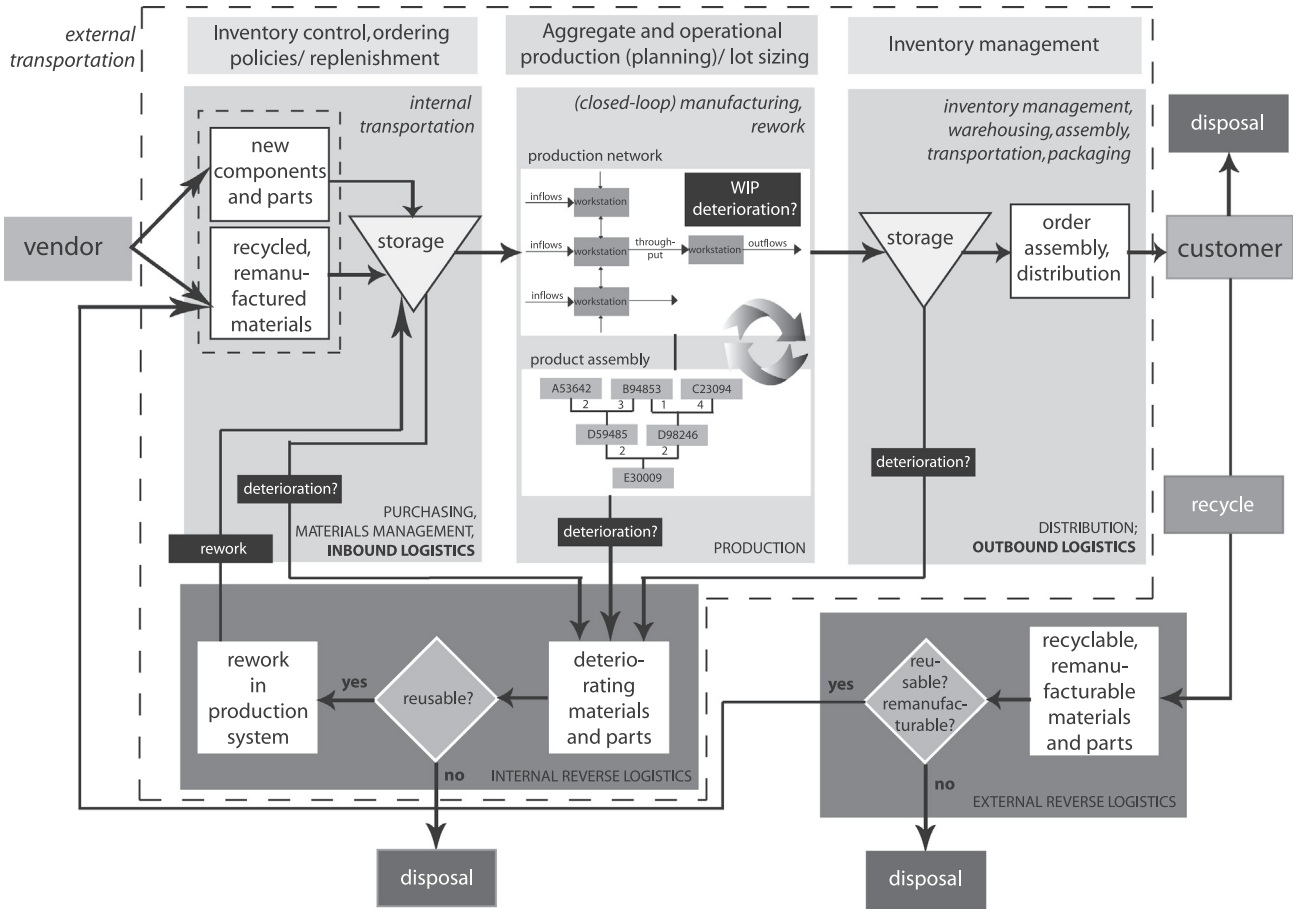

Fig. 1. Material flow along the internal and external supply network; (Pahl et al., 2007).

research literature attempting to integrate deterioration effects in models for planning beginning in 1960 (see, e.g., Barankin & Denny, 1963; Ghare & Schrader, 1963) with a significant increase until today (Pahl & Voß, 2013), there are only a few models that integrate lifetime constraints of products, e.g., (Ahuja, Huang, Romeijn, & Romero-Morales, 2007; Amorim, Antunes, & Almada-Lobo, 2011; Caserta & Voß, 2013; Förster, Haase, & Tönnies, 2006; Pahl & Voß, 2010).

The paper is organized as follows: In Section 2 we provide general thoughts on the classification of models including depreciation effects and lifetime constraints. We present mathematical formulations and discuss the role of demand. Section 3 reviews the literature regarding important business planning functions and identifies research gaps. The structure of the paper follows the business functions given in Fig. 1.

Specifically, Section 3.1 reviews inventory control and procurement/replenishment models including marketing issues whereas Section 3.2 is devoted to aggregate and operational production-inventory and lot sizing. Section 3.3 presents available research concerning final goods inventory and their delivery (outbound logistics). Extensions like multiple warehouses and rework options are discussed in Sections 3.4 and 3.5, respectively. Section 3.6 broadens the perspective by integrating the models over the supply chain.

2. Classification

The operations research community began studying the deterioration of items by modeling inventory management in blood banks (see Dumas & Rabinowitz, 1977; Jennings, 1973; Naddor, 1966; Prastacos, 1984) and the distribution of blood from transfusion centers to hospitals (Brodheim & Prastacos, 1979; Hemmelmayr, Doerner, Hartl, & Savelsbergh, 2009; Katasaliaki & Brailsford, 2007; Sapountzis, 1989); see Belien and Forcé (2012) for a literature review of blood products in *supply chain management* (SCM). Other products have also been examined; e.g., radioactive elements, chemicals, food, fashion clothes, technical components, and newspapers (Dave, 1986; Emmons, 1968a, 1968b; Shah & Jaiswal, 1977).

2.1. Depreciation

Most products deteriorate within a certain interval of time. If the observed time horizon is sufficiently short relative to the deterioration rate, there is little need to consider this product characteristic. The time horizon for aggregate planning is sufficiently long so that deterioration starts to play an important role. Deterioration and lifetime restrictions render the planning process complex due to restrictions on inventory holding (Pahl, 2011). Inventory holding refers to producing ahead of demand and sales realizations to hedge against uncertainties (e.g., employing overproduction), exploit volume discounts, or harness in-house set-up-sequence advantages (Nahmias, 2009; Pahl & Voß, 2010).

Deterioration of goods is the process of decay, damage or spoilage of items in such a way that they can no longer be used for their original purpose; i.e., they undergo changes while stored (Dave, 1986) and continuously lose their utility (Darlington & Rahimifard, 2006; Ferguson & Koenigsberg, 2007; Shah, Shah, & Shah, 2005; Wee, 1993; Zhao, 2007). Perishable goods are considered as items