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Reliable product-service supply chains for repairable products

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ABSTRACT

A mathematical model is developed for integrated flow planning in forward and after-sales supply chains of a company supplying repairable product-warranty packages to markets. Ignoring their interactions, these two supply chains are usually planned separately in literature. We consider demand- and supply-side variations in pre- and after-sales demands and qualified outflow of the SCs' facilities. We show that to neutralize the impact of variations, orders should be amplified by moving from the downstream to the upstream of chains. Results of an example from the gear industry show what interdependencies exist between the company's retail price, service levels, and warranty strategies.

1. Frame of reference

In highly competitive markets, products manufactured by rivals become almost homogeneous from quality and price perspectives. In such markets to differentiate from rivals and to leverage competition capabilities, increasing number of companies try to provide better pre and after-sales services for their customers. This marketing strategy is called "servitization" in the literature (Vandermerwe and Rada, 1988). Product-service system (PSS) is introduced by Baines et al. (2007) as a special case of servitization. Servitization works as a motivational lever and signals the high quality of a product and attracts customers. Warranty and other after-sales services as types of servitization protect customers against defects in materials or workmanship, unexpected failures, and unsatisfactory performance. Also a warranty provides an opportunity for companies to build and maintain a longer relationship with the customers. For example, Hyundai changed customers' perception about the quality of its products by providing an extensive warranty. This long warranty signals the customer that the quality of its cars has improved to match the best in the market (Business Week, 2004). In the same industry, Nissan has been offering 10 years/unlimited mileage warranty for its cars (Nissan Warranty Information Booklet, 2011).

Servitization not only improves a company's competitive capability in pre-markets, but also opens a new and profitable income resource in the after-sales markets. Based on the estimate of Gaiardelli et al. (2007), after-sales services in the consumer electronic devices, power tools, vacuum cleaners and personal computer industries yearly generate around $6–8 billion income in the United States. In European car markets, 40–50% of the total revenue is related to after-sales services provided by the companies. The gross profit of this income is much greater than that resulting from new cars' sales (Bohmann et al., 2003). According to Bundschuh and Dezvane (2003), the profitability of the after-sales markets is four or

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five times larger than the pre-markets'. The importance of the after-sales services is much greater in capital intensive industries such as aerospace, defense and industrial equipment. For example, in the defense industry only 28% of the system's total cost is related to its development and procurement and the rest (more than 72%) is due to its operation and maintenance (GAO Report, 2003). The United States Department of Defense has a budget of about $70B (in 2007) to operate and maintain its systems. Thus, there is a severe competition among supporting industries to offer better after-sales services.

In addition, there are governmental regulations require companies provide warranties for their customers. The United States Congress passed the Magnusson Moss Act and the European Union passed legislation requiring two-year warranties for all products.

All of these economic and non-economic reasons make it necessary to consider and service after-sales markets. However, considering after-sales markets made supply networks of companies much more complicated. These companies not only include a forward supply chain (SC) producing and transshipping products to pre-markets, but also include an after-sales SC dealing with replacing and repairing defective products which have been returned inside the warranty period. The considerable interactions between these SCs highlight the importance of concurrent design and flow planning. For example, the total product supplied by a forward SC to a pre-market constitutes the potential demand for the after-sales SC that can be realized as repair requests. Also providing a high service level in the after-sales SC improves the product's attractiveness in the pre-market and increases the forward SC's sales. Due to these interactions, a huge synergy can be achieved by concurrent flow planning through these SCs. In this paper, we deal with concurrent flow planning in the forward and after-sales SCs of a company servicing both pre- and after-sales markets. This company supplies a durable product to the pre-market with a failure free warranty. While the product is produced and transported by the forward SC, the after-sales SC is responsible for repairing defective products returned inside the warranty period.

After-sales and warranty services have an extensive literature. Reviews by Murthy and Djamaludin (2002) and Wang et al. (2015) provide more details. Some of the main streams of research in this field are:

(I) *Marketing aspect of the warranty*: In these papers, warranty is treated as a competitive factor and the authors offer methods for selecting the best warranty strategies by analyzing the tradeoff among the cost and income along with other marketing factors such as price and service level (Zhou et al., 2009; Chu and Chintagunta, 2009; Majid et al., 2012; Su and Shen, 2012; Chen et al., 2012; Jiang and Zhang, 2011; Li et al., 2012; Aggrawal et al., 2014; Esmaeili et al., 2014; Wei et al., 2015; Huang et al., 2015). For example, Zhou et al. (2009) propose a mathematical model to determine price and warranty policy dynamically for a repairable product with a fixed life cycle. First, they study the purchase pattern of customers with a fixed warranty length and a linearly decreasing price function. Then, they use this pattern to determine optimal price and warranty strategies. Wei et al. (2015) develop five models to formulate competition between two manufacturers producing complementary products and a common retailer selling their products to end customers. These models determine the optimal strategies on price and warranty period for the products in different cooperation/noncooperation strategies and bargain powers. Esmaeili et al. (2014) present a three-level warranty among a manufacturer, an agent and a customer by using the game theory approach. The customer faces several warranty options with the sales volume being sensitive to the price of each option. Their model determines optimal sales price, warranty price, and warranty period for the manufacturer, and the best repair cost for the agent. Aggrawal et al. (2014) use two dimensional innovation diffusion model to demonstrate product sales cycle and develop an approach to determine optimal price and warranty length for a product. Huang et al. (2015) perform cost analysis to determine an appropriate two-dimensional warranty policy, considering both time and usage, for a repairable product. They consider two customer groups: (1) a customer group whose warranty is ended because the warranty time has reached its limit; and (2) a customer group whose warranty is ended because the warranty usage has reached its limit.

The papers of this research stream consider warranty as a marketing variable in their model that should be optimized by analyzing cost and income tradeoff in retail outlets in monopoly cases or be equalized in the competition of sellers and buyers in duopoly cases. These papers only focus on downstream marketing activities in after-sales SCs and ignore upstream manufacturing activities should be done to fulfill customers' claims inside the warranty period. In this paper, we develop an integrated model considering both upstream manufacturing operations and downstream marketing operations in after-sales SCs.

(II) *Marketing and engineering aspects of the warranty*: By considering that engineering factors such as product reliability and quality have an important role in the warranty service cost, the authors of these papers simultaneously analyze the marketing and engineering aspects of the warranty (Murthy, 1990; Balachandran and Radhakrishnan, 2005; Kamrad et al., 2005; Lin and Shue, 2005; Huang et al., 2007; Oner et al., 2010). For examples, Murthy (1990) proposes a model to jointly determine price, warranty length, and reliability for a new product to maximize the total profit. Oner et al. (2010) consider a company producing and selling a system to its customers with a service contract. To fulfill the after-sales commitment of the company, they develop a model that determines spare parts inventory levels and best reliability for the system's critical components. Huang et al. (2007) concurrently determine product reliability, retail price, and warranty for a repairable product. They assume that the product demand is a positively correlated function of the warranty length and a negatively correlated function of the retail price. They consider free replacement and repair warranty for the product.

The papers of this group focus on the product design decisions and analyze their impacts on the after-sales costs in companies. They ignore that to realize these design and marketing decisions, two highly convoluted forward and after-sales SCs are working in the companies. To provide an integrated framework, integrating manufacturing operations in SCs with design and marketing operations is necessary. This paper fills this gap by incorporating forward and after-sales SCs.