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Reliable flow in forward and after-sales supply chains considering propagated uncertainty

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ABSTRACT

An integrated mathematical framework for production planning is presented for companies providing product-warranty packages through both their forward and after-sales supply chains. This model integrates manufacturers and merchandisers of the pre- and after-sales operations and incorporates the interactions between forward and after-sales chains. The demands and qualified output of facilities are stochastic. We demonstrate that service levels depend on the local reliability of facilities and that there are critical prices at which the order of profitability of the warranty options changes. This order becomes more fragile in price-sensitive markets and more stable in warranty-sensitive markets.

1. Introduction

After-sales service is a marketing strategy used by manufacturers to assure customers of product quality. Hyundai Motor Company changed customer perception about its products by providing an extensive warranty, thus signaling to customers that the quality of its cars had improved (Business Week, 2004). Khajavi et al. (2014) and Baines et al. (2007) believe that in today's markets, the focus of competition has shifted from quality and price to the delivery of value. They believe that customers now value an assurance that the product will work.

Recently, companies have become more aware of the profitability of after-sales service and have started to invest in it further. In high-tech product markets, Lenovo provides after-sales maintenance services for its PC customers (Li et al., 2014). Dell sells its laptops under a default hardware warranty that states "1 Yr Ltd Warranty, 1 Yr Mail-In Service, and 1 Yr Technical Support." However, customers are offered a 3-year warranty plan for an additional price (dell.com, 2010). In the automobile industry, Nissan offers a 10-year/unlimited mileage warranty for its cars (Nissan, 2011).

According to Gallagher et al. (2005), providing after-sales service by supplying spare parts for household appliances, automobiles, copy machines, heating and air conditioning is a business worth more than $200 billion. In 2009, based on data from the United States Logistics and Material Readiness Office, the US military spent $194 billion on their spare parts supply chain (SC) and logistics, with $104, $70, and $20 billion related to supply, repair, and transportation, respectively. At the end of that year, the value of the spare parts inventory was $94 billion. In the automobile industry, retailers of General Motor, Volkswagen and Toyota provide 4S (sale, spare parts, service and survey) services for their customers (Li et al., 2014). Fiat uses TNT Post to handle its distribution of spare parts in Europe and South America. TNT has 2000 employees and 3 million square feet

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of warehouse space, handles 120,000 tons of shipments, and processes 34.6 million order lines a year on Fiat's behalf. These numbers illustrate that even a small improvement in the product and its spare parts SCs can lead to a significant gain in profitability.

The after-sales business is an important part of the economy and is nearly twice as profitable as the original product business (Kim et al., 2007). Based on the work of Dennis and Kambil (2003), GM's after-sales revenue of $9 billion generated a profit of $2 billion. This profit is considerably greater than GM's profit from the $150 billion in revenue from its car sales. On average, after-sales services contribute 25% of the total revenue but generate more than 40–50% of the total profit.

For these reasons, providing after-sales service is an important part of daily operations in successful companies. These companies have a forward SC and an after-sales SC. Whereas the forward SC involves producing and supplying the original products to the target pre-market, the after-sales SC provides the required spare parts to fulfill the after-sales commitments. Production planning in companies with both forward and after-sales SCs is extremely complex. In addition to having to address two SCs, these chains are not independent. The events occurring in one SC affect the performance of the other chain. Appropriate concurrent flow planning throughout the forward and after-sales SCs is critical to providing good service in the pre- and after-sales markets. Although a company's pre-market service level is typically defined as the product's demand fulfillment rate to avoid lost sales, the after-sales service is a function of: (i) warranty length and (ii) just-in-time fulfillment of the required spare parts inside the warranty period. In the remainder of this paper, the spare parts' demand fulfillment rate is called the after-sales service level. Improving the after-sales service imposes more costs on the after-sales SC but also improves the attractiveness of the product for the customers in the pre-market and stimulates product demand. This is an important interaction between the two SCs. Higher product sales volumes in the pre-market augment the spare part or repair requests in the after-sales market. This means that the after-sales demand is a function of the total sales realized in the forward SC. This is another important interaction between the two SCs. These interactions justify the rationality of their concurrent flow planning.

Boone et al. (2008) conducted a Delphi study in 18 industries in which senior service part managers were asked about the challenges in their industries. The main challenge mentioned was "*lack of holistic perspective and system integration among SC partners.*" This result illustrates the strong need to improve integration in after-sales operations. In the academic literature, there is a lack of research with an integrated perspective in the after-sales domain (Bacchetti and Saccani, 2012). According to Boone et al. (2008), McAvoy (2008), Cohen and Agrawal (2006), and Wagner and Lindemann (2008), the main challenges in the after-sales domain are the lack of (i) systematic approaches for spare parts management; (ii) consideration of SC relationships; (iii) accurate models for predicting the demand for spare parts; and (iv) practical models for determining appropriate inventory levels. In this paper, we fill the first and second voids by integrating all after-sales operations as an after-sales SC to consider their relationships. Consideration of the interactions between the forward and after-sales SCs significantly improves the after-sales demand prediction, the third deficiency. We also determine the inventory levels of the product and its spare parts to preserve the best pre- and after-sales service levels for the SCs, i.e., the fourth deficiency.

1.1. Literature on after-sales services

In this section, we review some of the work performed in the after-sales literature to highlight the gaps. Detailed information is provided in Table 1.

For capital goods (Column 2 in Table 1), such as computer networks, and complex technical systems, such as medical or defense systems, the most frequent after-sales services offered by manufacturers are: (i) material contracts; (ii) performance-based warranties; and (iii) end-of-life (EOL) warranties. In these systems, operational disruptions can lead to considerable losses, and the loss becomes greater as the duration of the disruption increases. In material contracts, customers pay the manufacturer for parts, other resources, and labor (Kim et al., 2007). In performance-based warranties (Column 11 in Table 1), there is an agreement with respect to the availability of the system in the field (Chakravarthy and Gómez-Corral, 2009; Chen and Chien, 2007; Chien, 2005; de Smidt-Destombes et al., 2006, 2007, 2009; Finkelstein, 2009; Jhang, 2005; Jung and Park, 2003; Kuo and Wan, 2007; Li and Li, 2012; Lieckens et al., 2013; Marseguerra et al., 2005; Nourelfath and Ait-Kadi, 2007; Öner et al., 2010; Sahba and Balcıoğlu, 2011; Wang et al., 2009; Yeh et al., 2005). EOL warranties (Column 10 in Table 1) ensure after-sales service without a time limit. The company provides the required service as long as the products are in use, even if their production has been discontinued (Kim and Park, 2008).

For durable consumer goods (Column 3 in Table 1), which are considered in this paper, rebate warranties and failure-free warranties are the most common after-sales policies. Rebate warranties (Column 8 in Table 1) are typically used for non-repairable goods, and manufacturers commit to refund customers some portion of the sale price if the product fails during the warranty period. Goods such as automobile batteries and tires are typically sold with this type of warranty. Failure-free warranties (Column 9 in Table 1) are commonly used for household appliances and electronic devices, and with these warranties, manufacturers commit to repair products free of charge during the warranty period. As highlighted by Cohen and Agrawal (2006), Niemi et al. (2009), and Wagner and Lindemann (2008), little work has been completed on warranty service and spare parts management for failure-free warranties. See Bacchetti and Saccani (2012) for a review of the literature of spare parts classifications and demand prediction for stock control. According to Kleber et al. (2011), the focus of the majority of the work performed in spare parts management has been only on inventory management (Columns 18–27 and 30 in Table 1). For example, Chien and Chen (2008) have developed a model for optimal spare parts ordering for a non-repairable