Development and analysis of mathematical and simulation models of decision-making tools for remanufacturing

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This article presents decision-making tools for remanufacturing. The first decision-making tool was used to address inventory lot-sizing problems in a hybrid remanufacturing–manufacturing system with varying remanufacturing fraction. In this article, the new inventory lot-sizing model with variable remanufacturing lot sizes has been shown to exhibit better performance than the benchmark model with fixed remanufacturing lot sizes. The new inventory lot-sizing model is anticipated to become a valuable decision-making tool in companies that are planning to adopt remanufacturing. The second decision-making tool was applied to address a production and inventory planning problem in a remanufacturing system considering different remanufacturing policies for a given remanufacturing strategy. For a remanufacture-to-stock system with two quality remanufacturables groups four alternative policies were examined, a policy which specifies simultaneous processing utilising dedicated resources was shown to be the best policy to achieve a shorter remanufacturing cycle time. For a remanufacture-to-order system with two quality remanufacturables groups, the three relevant policies of the four alternative policies were examined, a policy which specifies sequential processing and switching between various quality remanufacturables groups was shown to be the best policy to achieve a shorter remanufacturing cycle time. The production and inventory planning simulation models in a remanufacturing system are expected to become significant decision-making tools in remanufacturing operations.

Keywords: remanufacturing; inventory; production planning and control; hybrid

1. Introduction

Recently, the remanufacture of used products (remanufacturing) has become an important part of normal production activity in many companies (Guide *et al.* 1999a, b, Guide 2000, Aras *et al.* 2004, Ferrer and Swaminathan 2006). This trend has been motivated by three emerging factors; strict environmental regulations (Directive 2000/53/EC, Directive 2002/96/EC), increasing customers' awareness of green environment (Gungor and Gupta 1999, Ferrer and Whybark 2000, McGovern and Gupta 2004) and economical benefits (Rogers and Tibben-Lembke 1998, Dowlatshahi 2000, Maslennikova and Foley 2000, Giuntini and Gaudette 2003). The automotive sector, particularly, has a strong history of remanufacturing (Seitz 2007), where numerous auto parts have been remanufactured and resold as spare parts (Steinhilpher 1998). Several pioneering companies like Fuji Xerox Australia (2007) and Xerox Europe and Kodak (Guide *et al.* 2003a) have also expanded their core business operations to include remanufacturing. Remanufacturing is also gaining scientific significance in industries that include single use-devices for hospitals, such as wheelchairs and hearing aids (Rudi *et al.* 2000, Srivastava 2004), cellular phones (Guide *et al.*, 2003b) and truck tyres (Lebreton and Tuma 2006). Remanufacturing aims to transform used units or some of their components into a like-new condition (Lund 1984a, Van der Laan 1997). This typically involves processes that include inspection/grading, disassembly, component reprocessing/replacement and reassembly/testing (Figure 1) (Lund 1984b).

There are several unique characteristics that predominantly and naturally occur in the remanufacturing environment that further complicates production planning and control activities (Fleischmann *et al.* 1997, Guide and Srivastava 1997, Guide *et al.* 1997a, b, 1998, 1999a, b, Ferrer 2003). First, used products exhibit highly uncertain quality conditions due to their different degree of usage. Used products that originate