European Journal of Operational Research 238 (2014) 143–154

Contents lists available at ScienceDirect

European Journal of Operational Research

journal homepage: www.elsevier.com/locate/ejor

Production, Manufacturing and Logistics

Optimisation of integrated reverse logistics networks with different product recovery routes

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ARTICLE INFO

Article history:
Received 19 July 2013
Accepted 21 March 2014
Available online 1 April 2014

Keywords:
Supply chain management
Reverse logistics
Quality of returned products
Uncertainty modelling
Inventory control
Fuzzy optimisation

ABSTRACT

The awareness of importance of product recovery has grown swiftly in the past few decades. This paper focuses on a problem of inventory control and production planning optimisation of a generic type of an integrated Reverse Logistics (RL) network which consists of a traditional forward production route, two alternative recovery routes, including repair and remanufacturing and a disposal route. It is assumed that demand and return quantities are uncertain. A quality level is assigned to each of the returned products. Due to uncertainty in the return quantity, quantity of returned products of a certain quality level is uncertain too. The uncertainties are modelled using fuzzy trapezoidal numbers. Quality thresholds are used to segregate the returned products into repair, remanufacturing or disposal routes. A two phase fuzzy mixed integer optimisation algorithm is developed to provide a solution to the inventory control and production planning problem. In Phase 1, uncertainties in quantity of product returns and quality of returns are considered to calculate the quantities to be sent to different recovery routes. These outputs are inputs into Phase 2 which generates decisions on component procurement, production, repair and disassembly. Finally, numerical experiments and sensitivity analysis are carried out to better understand the effects of quality of returns and RL network parameters on the network performance. These parameters include quantity of returned products, unit repair costs, unit production cost, setup costs and unit disposal cost.

1. Introduction

Within the past few decades, environmental concerns have led to a significant increase in product recovery activities and interest in sustainability of supply chains and logistics networks. Consumer's inclination toward 'green logistics', legal pressure and possible economic benefit are among the main reasons which led manufacturers to integrate recovery activities into their processes (Ilgin & Gupta, 2010). RL concerns handling of the flow of material and production from the point of consumption to the point of origin (Fleischmann et al., 1997). It covers product recovery activities which are crucial to sustainability, such as repair, remanufacturing and recycling. While recycling typically refers only to the reuse of materials used for a product without preserving its structure, repair usually involves activities necessary to restore a damaged product into the working order, while preserving its integrity. In contrast, remanufacturing comprises disassembly, replacement of components where necessary and assembly of a product to bring it back into as-good-as-new condition.

One of the most important features of the reverse flow is the presence of uncertainty in both quantity and quality of returned products which needs to be considered when developing quantitative models of reverse flows (Inderfurth, 2005; Fleischmann et al., 1997). Quality of returned products has been discussed in the literature from various point of view such as inventory control, buy-back price, and different markets for new and repaired products (Dobos & Richter, 2006; Zikopoulos & Tagaras, 2007; Aras, Boyaci, & Verter, 2004; Mitra, 2007).

The focus of this paper is on RL networks with two alternative recovery routes, including repair and remanufacturing, which are integrated with a traditional forward production route and a disposal option. Return products are inspected to determine their quality. They are separated into repair, remanufacturing and disposal routes based on repair and remanufacturing quality thresholds. The effects of different repair and remanufacturing thresholds on the RL network performance are examined.

In this paper, fuzzy sets are used to describe uncertainty in both demand and quantity of returned products of a specific quality level. One of the main advantages that fuzzy sets provide is the possibility of describing parameters as linguistic variables (Zadeh, 1975). In this approach, in the absence of statistical data, the expert can give linguistic descriptions of the quantity values which are

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http://dx.doi.org/10.1016/j.ejor.2014.03.034
0377-2217/

modelled using fuzzy numbers, for example, returned quantity is ‘considerably more than *x*’, ‘about *x*’, ‘more than *x* but less than *y*’, etc. (Petrovic, Xie, Burnham, & Petrovic, 2008).

This paper is arranged as follows. Section 2 will briefly introduce the relevant literature. In Section 3, the problem statement is presented by describing RL networks under consideration and the main assumptions made. In Section 4, a fuzzy mixed integer optimisation model of the RL network is presented. Using the model described in Section 4, a set of numerical experiments are conducted and the results are reported in Section 5. Finally, in Section 6 the paper is concluded by discussing the outcomes and possible future directions.

2. Literature review

In the past few decades, various mathematical models for RL network design, distribution, inventory control and production planning have been proposed in the literature (Ilgin & Gupta, 2010; Faccio, Persona, Sgarbossa, & Zanin, 2014). Here, we focus on the literature on RL which consider the quality of returned products only. Various approaches have been proposed to deal with the quality of returned products and inherent uncertainty. One of the common approaches is to model the quality by a probabilistic yield rate which specifies the probability of a single product being successfully recovered. In this approach, only two outcomes are considered: either a returned product is recoverable or it is not. Using yield rates, Dobos and Richter (2006) analysed the case of lot-sizing in a production and recovery environment with two options: either to buyback all returned items from the supplier and use the ones which are recoverable or to buyback the recoverable products only. Inderfurth (2005) developed an optimisation model for an integrated RL system with stationary demand, equal lead times and stochastic uncertainty in both return quantity and quality. Zikopoulos and Tagaras (2007) considered a case of two alternative collection points with different, but probabilistically correlated yield rates considering a single time period. Furthermore, Mukhopadhyay and Ma (2009) investigated yield rate of returned products in relation with production/recovery activities. Different scenarios were investigated with respect to when and how much information about yield rate was available. Similarly, Yoo, Kim, and Park (2012) considered a value of information in lot sizing decisions for a single period production/recovery network when two recovery options were available and the inspection process was imperfect, but could be improved at a cost. In addition, Nenes, Panagiotidou, and Dekker (2010) compared several alternative policies for production planning in the presence of returned products with either as-good-as-new or remanufacturable quality levels. Moreover, El Saadany and Jaber (2010) extended the model by Dobos and Richter (2006) including the return rate as a function of purchasing price and acceptance quality level.

Another approach proposed to handle quality of returned products has been to assume a set of predefined quality levels that have different acquisition costs, remanufacturing costs and lead times. Depending on these parameters, a particular quality level is specified to be desirable for certain recovery activities. Aras et al. (2004) used a Markov chain based model to show the advantage of prioritizing returned products for recovery based on their quality. Behret and Korugan (2009) analysed an integrated manufacturing/remanufacturing system in which returned products are inspected and then classified into three quality levels, namely bad, average and good, where each level can be recovered using its own recovery facility with the corresponding recovery cost and time, or disposed.

Jayaraman (2006) proposed a linear programming model for production planning in a closed-loop RL network with predefined quality levels and zero lead times. Additionally, Das and Chowdhury (2012) utilised an MIP model for RL production planning with product design decisions and quality considerations. Mahapatra, Pal, and Narasimhan (2012) also examined the effect of heterogeneous quality of return and non-uniform quantity of return in integrated RL networks using an MILP model. In the similar line of research, Nenes and Nikolaidis (2012) proposed an MILP based multi period model with deterministic demand and return quantities. They assumed that 3rd party collection sites had batches of returned products available which the recovery facility might choose to acquire or ignore. Furthermore, it had the option of using a certain part of acquired batches. In this model, the quantity of products which belong to a certain quality level for each particular batch was known. Additionally, Das and Dutta (2013) used system dynamics in an integrated reverse network with three recovery options: repair, remanufacturing and recycling. Quality of return was modelled as fixed percentages of products which could go to each recovery route. However, simulation of network behaviour using a custom policy without setup costs was the focus of this work. Furthermore, Guo, Aydin, and Souza (2014) proposed a network with two recovery routes: disassembly and repair where each route satisfied a separate demand. Uncertainty was taken into account by using stochastic parameters but quality of return, variations in demand and return, setup costs and lead times were not considered.

Alternatively, Galbreth and Blackburn (2006) explored the possibility of using a threshold quality level to determine products which were acceptable for the recovery activity. Remanufacturing costs was assumed to be a continuous function of quality and both the acceptable quality threshold and the total return rate were determined in such a way as to minimise procurement and remanufacturing costs in a single period setting.

Most of the RL models, which include quality of return, consider a single recovery route only (for example, Nenes & Nikolaidis (2012) and Das & Chowdhury (2012)). Additionally, some authors included alternative recovery options such as different facilities for the same type of recovery (Souza, Ketzenberg, & Guide, 2002; Behret & Korugan, 2009). However, different types of recovery such as repair and remanufacturing have fundamental differences which lead to considerably different network structures. For example, Jayaraman (2006) considered an optimisation model for a RL network with reuse and remanufacturing options. The author assumed a zero lead time with deterministic demand and return. Guide, Muyldermans, and Van Wassenhove (2005) considered a recovery network with repair and refurbishing options, deterministic demand and a simple yield rate based quality model. Similarly, Mitra (2007) analysed a single period recovery network with remanufacturing and refurbishing, without uncertainty and zero lead time.

We propose a novel multi period, multi quality level, multi recovery route optimisation model with different lead times along a RL network and uncertainty in demand, return quantities and return qualities. Quality thresholds, which determine the recovery route that returned products should follow, are handled in the model. Numerical experiments and sensitivity analysis carried out contribute to better understanding of the impact of relevant RL network parameters on the optimal quality thresholds and on the network performance. The focus is placed on the following network parameters: quantity of returned products, unit repair costs, unit production cost, setup costs and unit disposal cost. Their impact on the network performance is quantitatively analysed.

3. Problem statement

A RL network with two possible recovery routes, including repair and remanufacturing, disposal route, as well as a main production/forward logistics route is considered. Remanufacturing route