Int. J. Production Economics 140 (2012) 239–248

Contents lists available at SciVerse ScienceDirect

Int. J. Production Economics

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

Factors for implementing end-of-life computer recycling operations in reverse supply chains

Shams Rahman [a,*], Nachiappan Subramanian [b]

[a] RMIT University, School of Business IT and Logistics, GPO Box 2476, Melbourne 3001, Australia
[b] Thiagarajar College of Engineering, Madurai, India

ARTICLE INFO

Article history:
Received 14 October 2010
Accepted 29 July 2011
Available online 17 August 2011

Keywords:
Australia
Computer
DEMATEL method
Recycling
Reverse supply chain

ABSTRACT

E-waste (discarded computers and electronic goods) has become a major environmental issue. It can be minimized by increasing recovery from the waste stream through reverse supply chains. This paper proposes a framework for end-of-life (EOL) computer recycling operations. It identifies critical factors for implementing EOL computer recycling operations and investigates the causal relationship among the factors influencing computer recycling operations in reverse supply chains using the cognition mapping process DEMATEL. Results indicate availability of resource, coordination and integration of recycling tasks and the volume and quality of recyclable materials, are critical for computer recycling operations. Factors such as government legislation, incentive and customer demand are found to be the major drivers.

1. Introduction

E-waste (discarded computers and electronic goods) has become a major environmental issue that needs national attention. Euromonitor International's (2010) estimate shows that global computer sales are growing. Between 2004 and 2009, portable computers sold in Australia rose from about 2.53 million to 3.88 million units, an increase of about 35% (Table 1). When compared with G8 nations, the percentage growth of computer use in Australia is higher than Japan and Canada and is at par with USA, Italy and the United Kingdom. It is evident from Table 1 that the per capita use of computers in Australia is second highest, when compared with G8 nations. One in five people in Australia has access to a computer, whereas in Italy it is one in 33.

A report by the Australian Bureau of Statistics (ABS) shows e-waste is growing three times faster than regular waste. Australia, a nation of just over 20.6 million people, had discarded or stockpiled a total of 8.7 million computers at the end of 2006 (ABS, 2006). This report predicted that by the end of 2008, 1.6 million computers will be sent to landfill rubbish dumps, while a further 1.8 million would join the 5.3 million old computers already in storage.

One way of minimizing the environmental impact of e-waste is to use reverse supply chains to increase the amount of product materials recovered from the waste stream. Reverse supply chain is a process by which a manufacturer systematically accepts previously shipped products or parts from the point of consumption for possible reuse, remanufacturing, recycling, or disposal. Thus reverse logistics has an important environmental dimensions (Ciliberti et al., 2008; Linton et al., 2007; Zhu et al., 2008; Álvarez-Gil et al., 2007; Wu and Dunn, 1995) as well as dimensions relating to value reclamation (Ilgin and Gupta, 2010; Mutha and Pokharel, 2009; Alshamrani et al., 2007; Pokharel and Mutha, 2009; Kumar and Putnam, 2008; Logozar et al., 2006; Andel, 1997). The effective implementation of reverse logistics does not preclude achieving one goal at the expense of the other. Considering this, many world class companies have realized that reverse logistics practices, combined with source reduction processes, can be used to gain competitive advantage and at the same time can achieve sustainable development (Maslennikova and Foley, 2000; Lee et al., 2010; Hu and Bidanda, 2009; Seuring and Muller, 2008; Neto et al., 2008). The purpose of this study is to use the cognition mapping process to identify the critical factors in designing and implementing end-of-life (EOL) computer recycling operations in reverse logistics and investigate their causal relationships.

The reminder of the paper is organized as follows. A review of the literature relevant to this study is presented in Section 2, followed by a description on the research methodology in Section 3. The results of the analysis are presented in Section 4. Finally, a discussion of various implications and the conclusions drawn from this research are in Section 5.

2. Literature review

2.1. Reverse logistics

In the past decade there has been a renewed interest in reverse logistics. The first contributions to the knowledge on this subject

* Corresponding author. Tel.: +61 3 9925 5530; fax: +61 3 9925 5960.
E-mail address: shams.rahman@rmit.edu.au (S. Rahman).

0925-5273/$ - see front matter Crown Copyright © 2011 Published by Elsevier B.V. All rights reserved.
doi:10.1016/j.ijpe.2011.07.019

Table 1
Statistics of computers sold and population in Australia and G8 economies. (Source: Adapted from Euromonitor International (2010) and World Bank (2010)).

Country	Population (millions, 2009)	No. of computers sold (million units, 2009)	% growth over last five years (Base year 2004)	No. of person having access to single computer in 2009
Australia	20.60	3.88	34.70	5
Japan	127.07	13.72	14.78	9
Germany	81.88	6.42	49.32	13
Russia	141.37	5.78	75.23	25
France	65.07	10.03	64.23	7
Italy	60.11	2.01	42.55	33
UK	61.39	7.21	40.26	8
Canada	34.00	7.45	26.87	5
US	305.00	93.10	36.41	3

began in the 1960s and 1970s (Seitz and Wells, 2006). One of the comprehensive studies in the field of reverse logistics was conducted by Kopicki et al. (1993). They observed that in implementing an environmentally conscious program, companies typically reflect three phases: reactive, proactive and value seeking. Newly introduced environmental standard regulations usually force organizations to a reactive response to them. These organizations may examine environmental issues from time to time, but they do not actively pursue competitive advantage through environmental practices. Unlike reactive companies, proactive companies often implement reverse logistics programs, such as reuse and recycling, and attempt to develop a competitive advantage by designing effective environmental programs. They tend to produce products that generally satisfy customers' environmental concerns. Value seeking companies, on the other hand, integrate environmental programs into their business strategy. Most companies in this phase have advanced environmental programs with extremely efficient reverse logistics systems.

Research on reverse supply chain has ranged from quantitative modeling to qualitative case studies. One of the valuable sources for qualitative case studies is Flapper et al. (2005). They assembled a number of case studies from a variety of industries, including pharmaceutical, automotive and cell phone manufacturing and a mail order company. A useful summary of case studies, which employed quantitative modeling can be found in Rahman (2003). By categorizing studies into the three recovery processes of reuse, remanufacturing and recycling, Rahman (2003) discussed the modeling and solution techniques employed in these studies. Jayaraman et al. (2003) developed a mathematical model for a reverse distribution of product return flows and suggested a heuristic solution methodology for this problem. Salema et al. (2007) proposed a more generalized model for designing a capacitated multi-product reverse supply chain network with uncertainty. More recently, Aras et al. (2008) focused on the collection and reuse aspects of reverse supply chains, whereas, Teunter et al. (2008) dealt with the question of when companies should use shared resources for production and remanufacturing and when they should use specialized resources. In their study, Zuidwijk and Krikke (2008) considered two strategic questions in the context of closed-loop supply chains to establish how much a company should invest in product design and how much in the production processes to process their returned products. They formulated the problem as both an integer linear programming and a rules of thumb-based problem. A summary of these cases is presented in Table 2, which shows not only the sources of the studies, but also the types of reverse logistics networks used.

A reverse logistics network may occur in one of two contexts: either as a closed-loop or open-loop system. In a closed-loop

Table 2
Reverse supply chain network type (Source: Updated from Rahman (2003)).

Reverse network	Source	Network type	
		Open-loop	Closed-loop
Reuse	Kroon and Vrijens (1995)		X
	Jayaraman et al. (2003)		X
	French and LaForge (2006)		X
	Tan and Kumar (2008)		X
	Aras et al. (2008)		X
Recycle	Barros et al. (1998)	X	
	Louwers et al. (1999)	X	
	Realff, et al. (2000)	X	
	Spengler et al. (1997)	X	
Remanufacture	Jayaraman et al. (1999)		X
	Krikke et al. (1999)		X
	Listes and Dekke (2005)		X
	Inderfurth (2005)		X
	Teunter et al. (2008)		X
	Zuidwijk and Krikke (2008)		X

system, sources (origin) and sinks (destination) coincide so that flows cycle in the system. On the other hand, in an open-loop system, flows enter at one point of the logistics system and leave at another (Rahman, 2003). Table 2 shows that generally, recycling operations in reverse logistics operate in open-loop systems whereas, remanufacturing and reuse operations operate in closed-loop reverse logistics systems.

Using a sample of 141 manufacturing facilities in a wide variety of process industries, French and LaForge (2006) investigated the sources of returned product and materials and the subsequent reuse decisions made by these companies. Within a remanufacturing environment, Inderfurth (2005) examined to what extent the profit orientation in product recovery management stimulates an environmentally conscious behavior. Rahman (2006) investigated the relationship between world class logistics (WCL) competencies and environmentally focused logistics (EFL) practices. Using data from the Australian top 500 companies, the study established that there exists a significant relationship between the WCL competencies and EFL practices. Skinner et al. (2008) examined the impact of different disposition strategies such as recycle, refurbish, remanufacture and repackage on strategic performance in the reverse supply chain process. Analyzing responses from 118 auto part companies they found that in instances of active resource commitment to reverse supply chain programs, supply chain managers may expect superior economic and operational performances by choosing recycling and remanufacturing recovery processes. Srivastava (2007) and Pokharel and Mutha (2009) provided a useful review of reverse logistics research.

2.2. Reverse supply chain in the computer industry

Over the last decade several reverse supply chain studies have been conducted in the context of computer firms. For example, Ferguson (2000) reported how Dell exploits reverse supply chain to streamline the process for customers to refurbish existing computers or buy new components. IBM's asset recovery services have integrated reverse supply chain practices to enhance environmental performance (Roy and Whelan, 1992; Thierry et al., 1995; Grenchus et al., 2001). Taking a qualitative approach, Knemeyer et al. (2002) studied the factors that affect reverse supply chain systems for end-of-life computers. Boon et al. (2002) on the other hand, investigated the critical factors influencing the profitability of end-of-life processing of computers and suggested appropriate policies, which would ensure viable infrastructure for