Available online at www.sciencedirect.com
ScienceDirect
Journal of Operations Management xxx (2007) xxx–xxx
Journal of Operations Management
www.elsevier.com/locate/jom

Sustainable supply chains: An introduction

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Abstract

Consideration is given to the convergence of supply chains and sustainability. In doing so, the focus on environmental management and operations is moved from local optimization of environmental factors to consideration of the entire supply chain during the production, consumption, customer service and post-disposal disposition of products. This is a critical and timely topic that captures increasing concerns over sustainability, whether driven by current legislation, public interest, or competitive opportunity. As such, sustainable development is a rich area for academic research that is still in its infancy and has the potential to affect future government policy, current production operations, and identify new business models. This paper provides a background to better understand current trends in this multidisciplinary field that intersect with operations management, and the research opportunities and challenges it presents.

Keywords: Supply chain; Sustainability; By-products

1. Introduction

The interaction between sustainability and supply chains is the critical next step from recent examinations of operations and the environment (Corbett and Kleindorfer, 2003) and operations and sustainability (Kleindorfer et al., 2005). While important contributions have been made in relation to environmental operations and policy, strategy, finance, product design, supplier relations and post-consumer product management it is critical to move forward to the systemic issues that exist at the intersection of sustainability, environmental management and supply chains.

This paper gives consideration to both sustainability and supply chains. First, the relationship between these two concepts and previous work on environmental management of operations is considered. Second, new questions and research directions prompted by taking a sustainable supply chain perspective are considered. While many of the resulting areas of research relate directly to operations management, a great number of these open issues are fundamentally interdisciplinary in nature. This interdisciplinary nature is evident from the variety of fields in which researchers and practitioners are considering the challenges and implications of sustainability. Finally, the papers in this special issue are positioned within the growing study of sustainable supply chains.

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0272-6963/$ – see front matter
doi:10.1016/j.jom.2007.01.012

2. Sustainability—an overview

Sustainability is increasingly discussed by policy makers (President's Council on Sustainable Development, 1996; American Chamber of Commerce of Europe, 2004), the popular press (Anon., 2001) and journals in various technical fields. To provide a sense of its recent dramatic growth, Fig. 1 summarizes the number of articles in different fields that consider sustainability and sustainable development, thereby demonstrating sustainability's interdisciplinary nature.

While the first consideration of sustainability can be traced back to practices of many ancient cultures, more recent attention toward sustainability and the environment can be found in the works of economists and philosophers (e.g., Harding, 1968; Parsons, 1997). Simultaneously, the concept of sustainability entered the popular culture, such as books – the Lorax (Geisel, 1971) – and films – Soylent Green (Fleischer, 1973). This migrated in the 1990s to the consideration of sustainability in the management literature and has quickly increased since then (Fig. 2).

The transition from a set of the technical concepts into the political and business mainstream is commonly linked to the book *Our Common Future*, also known as the Brundtland Report (WCED, 1987). Sustainability is generally defined as using resources to meet the needs of the present without compromising the ability of future generations to meet their own needs (WCED, 1987; Daly and Cobb, 1994). Not surprisingly, given the vaguarities that surround this definition, hundreds of different interpretations have evolved to operationalize sustainability. As a result, this all encompassing definition of sustainability raised more questions than answers. These questions include:

- What resources will future generations require?
- At what levels can pollutants be released without having a negative effect on future generations?
- To what extent will new sources of depletable resources be identified in the future?
- At what level can renewable resources be exploited while ensuring that these resources remain renewable?
- To what extent can technology address sustainable use of resources with continued increases of material wealth?
- To what extent can market forces drive sustainability?
- Do lifestyles need to change and if so how?
- What sort of policies are required to achieve sustainability?

While debate does occur regarding the implications of sustainability and the types of lifestyle or philoso-

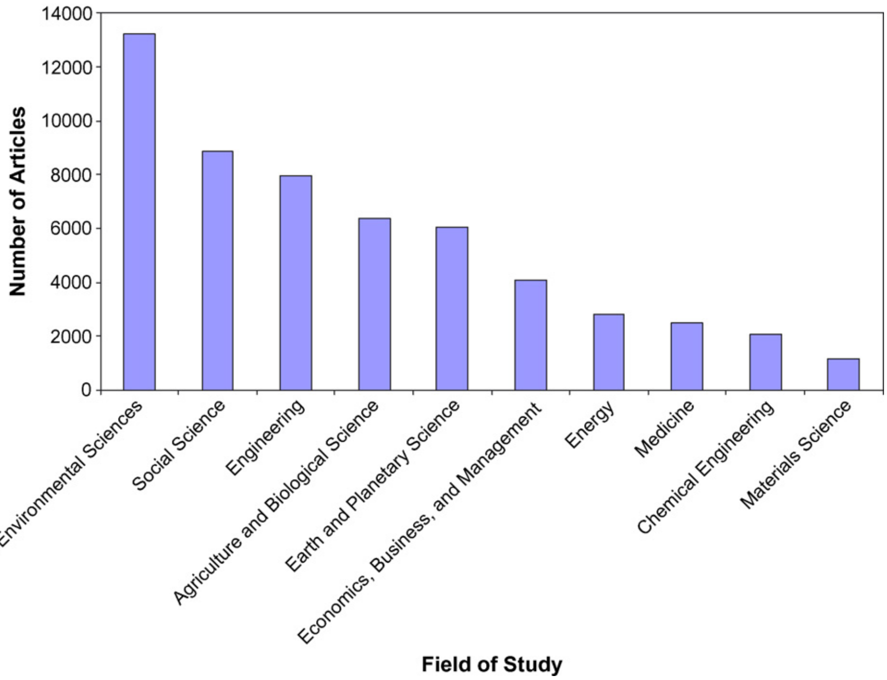

Fig. 1. The number of articles in different fields that consider sustainability (articles identified by a search of 'sustainability' or 'sustainable development' performed on Scopus on 6 August 2006).

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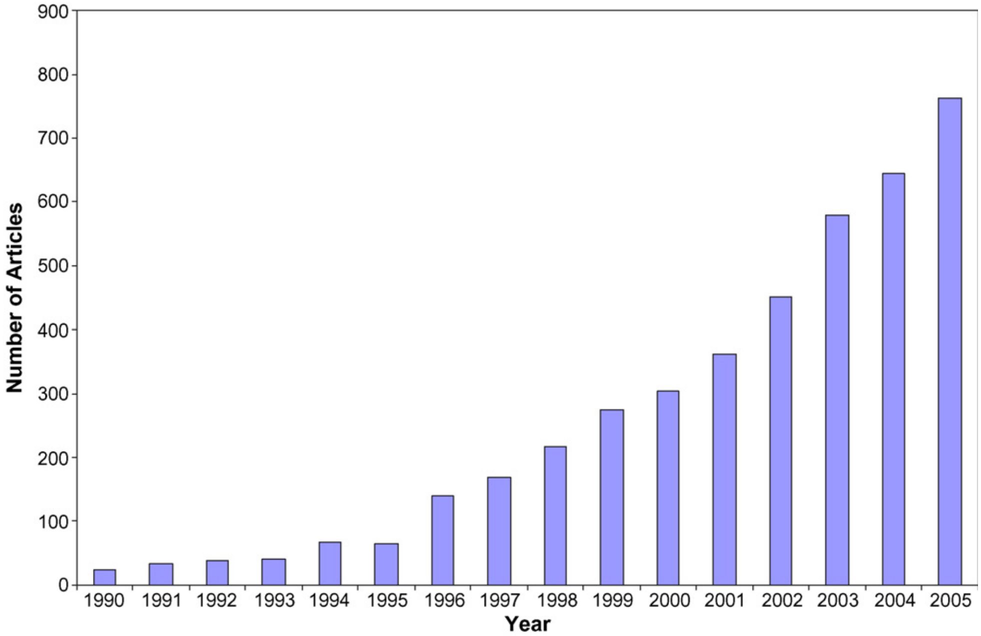

Fig. 2. Consideration to the concept of sustainability is increasingly found in the management literature (economics, business and management articles identified by a search of 'sustainability' or 'sustainable development' performed on Scopus on 6 August 2006). An increase in publishing frequency of about 3/1000 to 15/1000 articles, over the period under consideration.

phies that may be required to achieve sustainability (Hart, 1997; Myers, 1997; Vincent and Panayotou, 1997; Kemp, 1994), the discussion is still in its early stages. One may argue that it is premature and/or just an academic curiosity to consider the operationalization of sustainability. In the past there have been many examples of environmental and public health concerns that were over-hyped and eventually either discounted or seen as a reduced threat by many after additional evidence and insights were obtained (Wildavsky, 1995). However, recent reactions to growing environmental concerns of product- and process-derived pollution have included rapid substantive changes. For example, legislation was adopted worldwide over a relatively short timeframe to phase out chemicals with Ozone Depleting Potential (Cook, 1996; UNEP, 1994). More recently a steady increase can be seen in both public and private sector recognition of global warming as a societal issue (Ball, 2004; Corey, 2004, 2005; Bodansky et al., 2004). Sustainability, as an integrative concept, is starting to follow a similar trajectory, with new initiatives being proposed or adopted by both the public and private sectors.

Recently, the European Union (EU) has become a highly influential proponent of sustainability. The European Parliament views this concept as so critical to the future of the EU that current and future legislation must integrate sustainability into implementation orders (American Chamber of Commerce of Europe, 2004). One recent outcome has been the European Directives on Waste and Electronic Equipment (EU, 2003a,b; Perchards, 2005). If the EUs earlier influence in the area of quality management and the global adoption of ISO 9001 certification is an indication, the EUs emphasis on sustainability is likely to be a strong harbinger of actions to by others. Many other countries and jurisdictions are introducing legislation that addresses similar issues (Maine, 2005; State of California, 2003; State of Minnesota, 2003; DEP, 2002; Shih, 2001; DEP, 1998; Micklitz, 1992).

Clearly there is sufficient activity and ongoing development in the area of sustainability, that it is worthwhile for operations management researchers and practitioners to consider the implications and impacts of sustainability on traditional assumptions and practices in the field of operations management. While some of the relevant questions have been considered by work in topics such as greener product design (Lennox et al., 2000; Dambach and Allenby, 1995; Sarkis, 1995), cleaner process technology (Clelland et al., 2000; Hasek, 1997; Porter and van der Linde, 1995; Huisingh and Martin, 1986), product life extension (Linton and Jayaraman, 2005), and environmental management systems (Sroufe, 2004; Melnyk et al., 2003; Kitazawa and Sarkis, 2000), these subjects are not considered from the unifying perspective of sustainability. Also worth noting is research in industrial ecology, a field that considers industrial processes from the perspective of a biological ecosystem (Allenby, 2000; Esty and Porter, 1998; Ayres, 1989). Industrial ecology offers useful insights to researchers on the use productive use of by-products (wastes) generated along a supply chain. References on industrial ecology include: Frosch (1994), Frosch and Gallopoulos (1989), Journal of Industrial Ecology and Progress in Industrial Ecology. Having offered an overview of sustainability, sustainability's increasing importance in policy, and the limitations of current research to the many questions sustainability poses, the interaction between sustainability and supply chains are briefly considered next.

3. The interaction between sustainability and supply chains

During the last two decades, the focus on optimizing operations has moved from a specific facility or organization to the entire supply chain. By optimizing along the entire sequence of steps that are involved in the production of a product whether it is a good or service, the greatest value can be produced at the lowest possible cost (Handfield and Nichols, 1999). In many cases, this approach requires organizations to operate sub-optimally from a cost perspective to create the greatest possible value along the entire supply chain (Leenders and Blenkhorn, 1988).

A focus on supply chains is a step towards the broader adoption and development of sustainability, since the supply chain considers the product from initial processing of raw materials to delivery to the customer. However, sustainability also must integrate issues and flows that extend beyond the core of supply chain management: product design, manufacturing by-products, by-products produced during product use, product life extension, product end-of-life, and recovery processes at end-of-life.

3.1. Product design

Techniques such as life cycle assessment (Rebitzer et al., 2004; Pennington et al., 2004) are used to assist in the determination of how to design a product to minimize its environmental impact over its useable life and afterwards (Karna and Heiskanen, 1998). This field at the interface of engineering, product design and engineering considers resource depletion as well as environmental impacts.

3.2. Manufacturing by-products

Consideration of the extended supply chain includes the reduction and elimination of by-products through cleaner process technologies (Kemp, 1994; Johansson, 1992) and quality and lean production techniques (Zink, 2005; Zhu and Sarkis, 2004; King and Lennox, 2001). From the industrial ecology literature and increasingly considered by manufacturers is the use of by-products of manufacturing such as the use of waste heat for conditioning space or the use of food waste for producing new food products (Frosch and Gallopoulos, 1989). This is a function of both process design and continuous improvement activities.

3.3. By-products produced during product use

The management of product sustainability is not only a function of design, but also product management. The potential for great opportunities and profit have been recognized by many who have called for extended producer involvement and responsibility. This involvement has appeared in calls for the provision of a product as a service (Michaelis and Coates, 1994) or for manufacturers to provide a series of services to support and supplement sale of the original product (Wise and Baumgartner, 1999).

3.4. Product life extension

There are a variety of techniques that are used to extend the life of products (Linton and Jayaraman, 2005). Through the extension of product life, the depletion of resources through the production of new product is avoided. This approach works against the design for obsolescence typical in a consumption-oriented society. However, it increases the value created by an individual product. The challenge for the provider of the product is to develop offerings that allow for them to capture more of the product value. Such approaches are discussed by the authors of work relating to by-products produced during product use above. While some manufacturers have capitalized on opportunities created by product life extension (examples include: Woellert, 2006; Guide et al., 2003; Linton and Johnston, 2000), the failure of Original Equipment Manufacturers to capitalize on opportunities has led to vibrant highly profitable businesses in such areas as remanufacturing (Arndt, 2005; Lund, 1982, 1984).

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3.5. Product end-of-life

The disposition of the product at the end of its life relies to a great extent on actions taken at earlier stages. The initial product design has great influence on the degree to which a product can be reused, remanufactured, recycled, incinerated or disposed of. For example, the high lead content in cathode ray tube and electronics products results in complications for disposal due to the toxicity of lead. In the case of electronics, phase-out of lead use in solders in process (see for example Liew et al., 2006) complicated disposal decisions. While in the case of cathode ray tubes, some jurisdictions have introduced special regulations to divert these products from municipal landfills with the intent of integrating the lead into new products (Linton and Yeomans, 2004). Policies that have been developed with the intent of producing more environmentally favorable modes of product end-of-life disposal have to-date resulted in more storage of product and less redeployment of parts and materials into new products than intended (Shih, 2001; Micklitz, 1992). Desired outcomes not only require changes in the process associated with the development of environmental policies, regulations, incentives and disincentives; but also the related operational aspects: forecasting, logistics, processing and other operations related functions. To date substantial research has focused on the capture of value remaining in products at the end of a products life through remanufacturing (Guide and van Wassenhove, 2003; Guide et al., 2000; Guide, 2000; Gungor and Gupta, 1999; Fleischmann et al., 1997).

3.6. Recovery processes at end-of-life

The recovery of used products has become a field of rapidly growing importance. A number of papers have been published on design considerations for product recovery networks (Thierry et al., 1995; Bloemhof-Ruwaard et al., 1999; Fleischmann et al., 2000; Jayaraman et al., 2003; Dekker et al., 2004; Flapper et al., 2005). These papers include product types such as carpeting (Louwers et al., 1999), copiers (Krikke et al., 1999), steel by-products (Spengler et al., 1997), reusable packaging (Kroon and Vrijens, 1995) and sand (Barros et al., 1998).

A number of studies have found that an increased emphasis on sustainability in the supply chain is related to lower costs and a neutral or positive effect on value (e.g., Rao and Holt, 2005; Florida, 1996). However, others have identified trade-offs between what is economically rational for supply chain members and what is of greatest value to the entire system or population (Walley and Whitehead, 1994).

Extending the supply chain to include issues such as remanufacturing, recycling and refurbishing adds an additional level of complexity to existing supply chain design in addition to a new set of potential strategic and operational issues, which in turn can increase costs, at least in the short term. Two basic problems gives rise to these issues: (a) the uncertainty associated with the recovery process with regards to quality, quantity, and timing of returned products, containers, pallets and packaging and (b) the collection and transportation of these products, containers, pallets and packaging. Increased costs can reflect the transfer of external costs from society to supply chain partners. If viewed broadly, sustainability opens a larger set of opportunities for improvement that may require short-term investment (Corbett and Klassen, 2006).

4. Linking sustainability and supply chains—the big picture

Changes in policy, such as that for electrical and electronic equipment in Europe (EU, 2003a), force both manufacturers and researchers to explore options to improve the sustainability of operations across the supply chain. However, change can also flow in the opposite direction. Research and practice in supply chain management can affect policy, science or social science by presenting alternative scenarios for the development of sustainable supply chains. Sustainability stretches the concept of supply chain management to look at optimizing operations from a broader perspective—the entire production system and post-production stewardship as opposed to just the production of a specific product. Matos and Hall (in press) question the notion of optimization as they explore how the complexity associated with defining, coordinating and interacting with stakeholders increases substantially, in their work on integrating sustainability into the supply chain.

In addition sustainability introduces less quantifiable considerations relating to the natural environment and in some cases social issues—what the business ethicists and the accounting fields refers to as the triple bottom line (Elkington, 1998). For example, consideration of the interaction between economic consideration with social and environmental issues – such as noise pollution, congestion, and carbon dioxide emissions – in logistics has been considered by Quak and de Koster (in press) in their work on exploring retailers' sensitivity to sustainability policies.

The previously mentioned trend towards integration of sustainability concepts into legislation changes the environment that firms operate in and the nature of competition as considered by researchers such as Webster and Mitra (in press) in their study of competitive strategy in remanufacturing and the impact of take-back laws. These changes require management to not only address new issues, such as the reverse supply chain, but to tightly change existing practices and create new production and management systems. Kocabasoglu et al. (in press) consider some of these issues in their research on linking forward and reverse supply chain investments: the role of business uncertainty. Having illustrated the broad effects that the integration of sustainability considerations have into the supply chain on policy, competitive environment and strategy, it is also critical to consider that many critical tactical and operational issues must be considered. For example Ackali et al. (in press) consider decentralized collection and processing of end-of-life products and Mazhar et al. (in press) consider how to obtain better use from used products through remaining life estimation of used components in consumer products: life cycle data analysis by Weibull and artificial neural networks. It is also evident upon reflection of this and other research that due to the closed-system nature of sustainability, opportunities to modify operations or changes in tactics can have substantial effects on policy, firm strategy and the competitive environment.

While sustainability provides an overarching framework for much of the past and ongoing environmental research in operations, sustainability moves beyond current common practice. Supply chains must be explicitly extended to include by-products of the supply chain, to consider the entire lifecycle of the product, and to optimize the product not only from a current cost standpoint but also a total cost standpoint. Total cost must include the effects of resource depletion and the generation of by-products that are neither captured nor used (pollutants and waste). Research into the operational implications of various policies and how business can integrate sustainability is critical, since current legal trends will force many of these changes whether or not academe and practice is prepared. Such research requires not only that many questions be answered, but a wide variety of approaches including: case studies analysis (Matos and Hall, in press), statistical testing of hypotheses (Kocabasoglu et al., in press), multiple case modeling (Quak and de Koster, in press), model development (Webster and Mitra, in press; Ackali et al., in press) and machine learning (Mazhar et al., in press).

References

Ackali, E., Karakayali, I., Emir-Farinas, H., in press. An analysis of decentralized collection and processing of end-of-life products. Journal of Operations Management, doi:10.1016/j.jom.2007.01.017.

Allenby, B.R., 2000. Implementing industrial ecology: the AT&T matrix system. Interfaces 30 (3), 42–54.

American Chamber of Commerce of Europe, 2004. European Union Environmental Guide 2004. American Chamber of Commerce of Europe, Brussels, Belgium.

Anon., 2001. Europe's steelmakers get lean and green. BusinessWeek 3720 (February 19), 92.

Arndt, M., 2005. Cat sink its claws into services. BusinessWeek 3692 (December 5), 56–59.

Ayres, R.U., 1989. Industrial metabolism. In: Ausubel, J., Sladovich, H. (Eds.), Technology and Environment. National Academy Press, Washington, DC.

Ball, J., 2004. As Kyoto protocol comes alive, so do pollution permit markets. Wall Street Journal A2.

Barros, A.I., Dekker, R., Scholten, V., 1998. A two-level network for recycling sand: a case study. European Journal of Operational Research 110, 199–214.

Bloemhof-Ruwaard, J.M., Fleischmann, M., van Nunen, J.A.E.E., 1999. Reviewing distribution issues in reverse logistics. In: Speranza, M.G., Stahly, P. (Eds.), New Trends in Distribution Logistics. Springer-Verlag, Berlin, pp. 23–44.

Bodansky, D., Chou, S., Jorge-Trejolini, C., 2004. International Climate Efforts Beyond 2012: A Survey of Approaches. Pew Center on Climate Change, Arlington, Virginia.

Clelland, I.J., Dean, T.J., Douglas, T.J., 2000. Stepping towards sustainable business: an evaluation of waste minimization practices in US manufacturing. Interfaces 30 (3), 107–124.

Cook, E. (Ed.), 1996. Ozone Protection in the United States. World Resources Institute, Washington, DC.

Corbett, C.J., Klassen, R.D., 2006. Extending the horizons: environmental excellence as key to improving operations. Manufacturing and Service Operations Management 8 (1), 5–22.

Corbett, C.J., Kleindorfer, P.R., 2003. Environmental management and operations management: introduction to the third special issue. Production and Operations Management 12 (3), 287–289.

Corey, J., 2004. Global warming. BusinessWeek (August 16), 60–69.

Corey, J., 2005. Global warming: suddenly the climate in Washington is changing. BusinessWeek (June 27), 91–92.

Daly, H.E., Cobb, J., 1994. For the Common Good. Beacon Press, Boston.

Dambach, B.F., Allenby, B.R., 1995. Implementing design for environment at AT&T. Total Quality Environmental Management 4 (3), 51–62.

Dekker, R., Fleischman, M., Inderfurth, K., van Wassenhove, L.N. (Eds.), 2004. Reverse Logistics: Quantitative Models for Closed-loop Supply Chains. Springer, Berlin.

Department of Environmental Protection, 1998. Hazardous and Solid Waste Regulations for Massachusetts: 310 CMR 30.000 and 310 CMR 19.00, Public Hearing Draft Regulations for the Management of Discarded Cathode Ray Tubes. Department of Environmental Protection, Boston, MA.

Department of Environmental Protection (DEP), 2002. Focus on Televisions and Computer Monitors: Lead. Department of Environmental Protection, Florida. , In: http://www.dep.state.fl.us/waste/categories/electronics/pages/lead.htm.

Elkington, J., 1998. Cannibals with Forks: The Triple Bottom Line of 21st Century. New Society Publishers, Gabriola Island, BC.

Esty, D.C., Porter, M.E., 1998. Industrial ecology and competitiveness. Journal of Industrial Ecology 2 (1), 35–43.

European Union (EU), 2003a. Directive 2002/96/EC of the European Parliament and of the Council of 27 January 2003 on waste electrical and electronic equipment (WEEE). Official Journal L 037, 13/02/2003. Brussels, European Union, pp. 24–39.

European Union (EU), 2003b. Directive 2002/95/EC of the European Parliament and of the Council of 27 January 2003 on the restriction of the use of certain hazardous substances in electrical and electronic equipment. Official Journal L 037, 13/02/2003. Brussels, European Union, pp. 19–23.

Flapper, S.D., van Nunen, J.A.E.E., van Wassenhove, L.N. (Eds.), 2005. Managing Closed-loop Supply Chains. Springer, Berlin.

Fleischer, R., 1973. Soylent Green. Metro-Goldwyn-Mayer, Los Angeles, California.

Fleischmann, M., Bloemhof-Ruwaard, J.M., Dekker, R., van der Laan, E., van Nunen, J.A.E.E., 1997. Quantitative models for reverse logistics: a review. European Journal of Operational Research 103 (1), 1–17.

Fleischmann, M., Krikke, H.R., Dekker, R., Flapper, S.D.P., 2000. A characterisation of logistics networks for product recovery. Omega 28 (6), 653–666.

Florida, R., 1996. Lean and green: the move to environmentally conscious manufacturing. California Management Review 39 (1), 80–102.

Frosch, R.A., 1994. Industrial ecology: minimizing the impact of industrial waste. Physics Today 11, 63–68.

Frosch, R.A., Gallopoulos, N.E., 1989. Strategies for manufacturing. Scientific American 261 (3), 94–102.

Geisel, T.S., 1971. The Lorax. Random House, New York.

Guide Jr., V.D.R., 2000. Production planning and control for remanufacturing: industry practice and research needs. Journal of Operations Management 18 (4), 467–483.

Guide Jr., V.D.R., van Wassenhove, L.N., 2003. Business Aspects of Close-loop Supply Chains. Carnegie-Bosch Institute, Pittsburgh.

Guide Jr., V.D.R., Jayaraman, V., Srivastava, R., Benton, W.C., 2000. Supply-chain management for recoverable manufacturing practices. Interfaces 30 (3), 125–142.

Guide Jr., V.D.R., Jayaraman, V., Linton, J.D., 2003. Building contingency planning for closed-loop supply chains with product recovery. Journal of Operations Management 21 (3), 259–279.

Gungor, A., Gupta, S.M., 1999. Issues in environmentally conscious manufacturing and product recovery: a survey. Computers and Industrial Engineering 36 (4), 811–853.

Handfield, R.B., Nichols, E.L., 1999. Introduction to Supply Chain Management. Prentice Hall, Upper Saddle River, NJ.

Harding, G., 1968. The tragedy of commons. Science 162, 1245–1248.

Hart, S.L., 1997. Beyond greening. Harvard Business Review 1, 66–76.

Hasek, G., 1997. Closing the loop: corporations use innovative methods to reduce waste. Industry Week 246 (8), 13–16.

Huisingh, D., Martin, L.R., 1986. Proven Profits from Pollution Prevention: Case Studies in Resource Conservation and Waste Reduction. Institute for Local Self Reliance, Washington, DC.

Jayaraman, V., Patterson, R., Rolland, E., 2003. The design of reverse distribution networks: models and solution procedures. European Journal of Operational Research 150, 128–149.

Johansson, A., 1992. Clean Technology. Louis Publishing, Boca Raton, Florida.

Karna, A., Heiskanen, E., 1998. The challenge of 'product chain' thinking for product development and design: the example of electrical and electronics products. Journal of Sustainable Product Design 4 (1), 26–36.

Kemp, R., 1994. Technology and the transition to environmental sustainability. Futures 26 (10), 1023–1046.

King, A.A., Lennox, M.J., 2001. Lean and green? An empirical examination of the relationship between lean production and environmental performance. Productions and Operations Management 10 (3), 244–256.

Kitazawa, S., Sarkis, J., 2000. The relationship between ISO 14001 and continuous source reduction programs. International Journal of Operations and Production Management 20 (2), 225–248.

Kleindorfer, P.R., Singhal, K., van Wassenhove, L.N., 2005. Sustainable operations management. Production and Operations Management 14 (4), 482–492.

Kocabasoglu, C., Prahinski, C., Klassen, R., in press. Linking forward and reverse supply chain investments: the role of business uncertainty. Journal of Operations Management, doi:10.1016/j.jom.2007.01.015.

Krikke, H.R., van Harlen, A., Schuur, P.C., 1999. Business case OCE: reverse logistics network redesign for copiers. OR Spectrum 21 (3), 381–409.

Kroon, L., Vrijens, G., 1995. Returnable containers: an examination of reverse logistics. International Journal of Physical Distribution and Logistics Management 25 (2), 56–68.

Leenders, M.R., Blenkhorn, D.L., 1988. Reverse Marketing: The New Buyer Supplier Relationship. Free Press, New York.

Lennox, M., King, A., Ehrenfeld, J., 2000. An assessment of design-for-environment practices in leading U.S. electronic firms. Interfaces 30 (3), 83–94.

Liew, E., Zaman, F., Thanupillai, S., 2006. Outsourcing RoHS-compliant production at a distance. Circuits Assembly 17 (2), 56–59.

Linton, J.D., Jayaraman, V., 2005. A conceptual framework for product life extension. International Journal of Production Research 43 (9), 1807–1829.

Linton, J.D., Johnston, D.A., 2000. A decision support system for the planning of remanufacturing at Nortel. Interfaces 30 (6), 17–31.

Linton, J.D., Yeomans, J.S., 2004. Materials recycling and industrial ecology. Nature Materials 3 (4), 199–201.

Louwers, D., Kip, B.J., Peters, E., Souren, F., Flapper, S.D.P., 1999. A facility location allocation model for reusing carpet materials. Computers and Industrial Engineering 36 (40), 1–15.

Lund, R., 1982. Remanufacturing: United States Experience and Implications for Developing Nations. The World Bank, Washington, DC.

Lund, R., 1984. Remanufacturing. Technology Review 87 (2), 18–23.

Maine, 2005. Title 38. Section 1610. Electronic Waste Statute, State of Maine 122((2)1Rogtur4(sl3(Nat4),)-368.9(30)-330Juemb65)63.6(,)-333AugInda,2((29D(Ma(DC.)TJ-1.5009-1.2519TD.5(ojens,9-516(J.S..4(9DH.6(.L.,)-