PRODUCTION AND OPERATIONS MANAGEMENT
POMS
Vol. 14, No. 4, Winter 2005, pp. 482–492
ISSN 1059-1478 | 05 | 1404 | 482$1.25

Sustainable Operations Management

Paul R. Kleindorfer • Kalyan Singhal • Luk N. Van Wassenhove
The Wharton School of the University of Pennsylvania, Philadelphia, Pennsylvania 19104, USA
Merrick School of Business, University of Baltimore, 1420 N. Charles Street, Baltimore, Maryland 21201, USA
INSEAD, Technology and Operations Management Area, 77305 Fontainebleau, France
kleindorfer@wharton.upenn.edu • Ksinghal@ubalt.edu • luk.van-wassenhove@insead.edu

Operations management researchers and practitioners face new challenges in integrating issues of sustainability with their traditional areas of interest. During the past 20 years, there has been growing pressure on businesses to pay more attention to the environmental and resource consequences of the products and services they offer and the processes they deploy. One symptom of this pressure is the movement towards triple bottom line reporting (3BL) concerning the relationship of profit, people, and the planet. The resulting challenges include integrating environmental, health, and safety concerns with green-product design, lean and green operations, and closed-loop supply chains. We review these and other "sustainability" themes covered in the first 50 issues of *Production and Operations Management* and conclude with some thoughts on future research challenges in sustainable operations management.

Key words: sustainable operations; closed-loop supply chains; green products; lean and green operations; environmental management and operations; eco-logistics; competitive advantage

Submissions and Acceptance: Accepted by Special Editor, Hau Lee, after one revision.

1. Introduction and Background

The Production and Operations Management Society (POMS) was created in 1989, and one of its first activities was to launch *Production and Operations Management* (*POM*), with the inaugural issue appearing in 1992. *POM*'s objectives were ambitious, with an overall objective "to improve practice" (Singhal 1992). We review what the journal has accomplished in its first 50 issues in the context of sustainability. We use the term sustainability to include environmental management, closed-loop supply chains, and a broad perspective on triple-bottom-line thinking, integrating profit, people, and the planet into the culture, strategy, and operations of companies. We start with a brief account of the trends that have shaped the field of operations management (OM) in the past two decades and influenced the mission of the journal, *POM*.

1.2. Innovations in the 1980s and the 1990s: TQM, JIT, and BPR

POM's launching in 1992 came at an auspicious time for OM, as the 1980s had already underlined the benefits of total quality management (TQM), time-based competition, and just-in-time operations (JIT), imported to Europe and North America from Japan. These philosophies had been refined in the 1960s and 1970s and came to be recognized in Japan as the backbone of the reconstruction of its postwar economy. TQM, JIT, and time-based competition provided both the tools and the elements of the management systems needed to integrate them with company strategy. The locus of control and methodology of these tools and management systems was directly associated with operations. With the growing realization of the impact of these innovations on customers and profit, operations began its transformation from a neglected stepsister needed to support marketing and finance to a cherished handmaiden of value creation. It was becoming a primary focus of strategic importance for companies around the world (Hayes, Wheelwright, and Clark 1988).

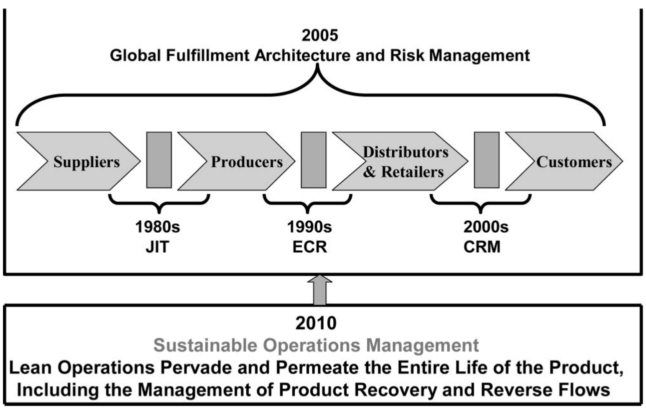
Building on these early innovations, a wave of change began in the 1990s called business process reengineering (BPR) (Hammer 1990), which provided immense benefits to nonmanufacturing processes by applying the time-based and waste-minimization efforts that TQM and JIT had applied to manufacturing. Gradually, this whole evolution came to be known as process management, a name that emphasized the crucial importance of processes in value creation and management. Process management was given further impetus by the core-competency movement (Hamel and Prahalad 1994), which stressed the need for companies to develop technology-based and organizational competencies that their competitors could not easily imitate. The confluence of the core-competency and process management movements caused many of the past decade's changes including the unbundling of value chains, outsourcing, and innovations in contracting and supply chains. People now recognize the importance of aligning strategy and operations, a notion championed by Skinner (1969, 1996).

1.3. Focus on Product Development and Supply Chains

As companies developed their core competencies and included them in their business processes, the tools and concepts of TQM and JIT were applied to developing new product development and managing supply chains, and they typically involved multiple organizations. Generally, they first incorporated JIT between suppliers and production units, then moved to optimized logistics (including efficient consumer response (ECR)) between producers and distributors, then to customer relationship management (CRM), and finally to global fulfillment architecture and risk management. These supply-chain-focused trends inspired similar trends at the corporate level as companies moved from lean operations to lean enterprises and now to lean consumption (Womack and Jones 2005). We show in simplified form these trends and
F1 drivers in Figure 1, based on Kleindorfer and Van Wassenhove (2004). We also show the impact of emerging sustainable OM.

As we look back on the first 50 issues of *POM*, we can see that these trends drive the research published in *POM* and its application and integration in company strategies around the world. The 1980s' introduction of TQM and JIT in manufacturing gave rise to the recognition that the principles of excellence applied to manufacturing operations could also improve business processes and that organizations structured according to process-management principles would also improve. The combination of these process management fundamentals, information and communication technologies, and globalization has provided the foundations and tools for managing today's outsourcing, contract manufacturing, and global supply chains.

Figure 1 **Locus of Value Chain Restructuring 1980–2010.**



1.4. Supply Chains as the Business Model

Many successful and innovative companies now formulate their strategies and business models in simple operational terms (for example, Amazon.com, Dell, Li and Fung, Southwest Airlines, Toyota, and Zara). Asked about Zara's business model, a senior executive said, "At Zara, the supply chain is the business model." OM has moved from a narrow focus on costs to an appreciation of the customer (service, willingness to pay) and to a closer scrutiny of assets. OM provides the methods for analyzing and improving value drivers at the process level and for measuring and balancing costs, revenues, and assets. These methods include integrated financial and operations-driven metric systems, such as economic value added (Stern and Shiely 2001).

1.5. Sustainability: A Key Element in Supply Chains

As the new economic order unfolded, people recognized that profits and profitability were only one element in the long-term success of companies and the economies (Hay, Stavins, and Vietor 2005). Also important are the future of people (internal and external to companies) and the future of planet Earth. These new legitimacy concerns are captured in measures such as the triple bottom line (3BL), the three Ps of people, profit and the planet, and the goal of maintaining viable social franchises (the trust of employees, customers, and the communities) as well as viable economic franchises (the ability to pay from the cash flows it generates for capital and other inputs it uses to produce its outputs). OM is increasingly connected to sustainability, and it now concerns both the operational drivers of profitability and their relationship to people and the planet. The emerging synthesis gives researchers in OM exciting opportunities to make a difference.

2. Roots and Branches of Sustainability Theory

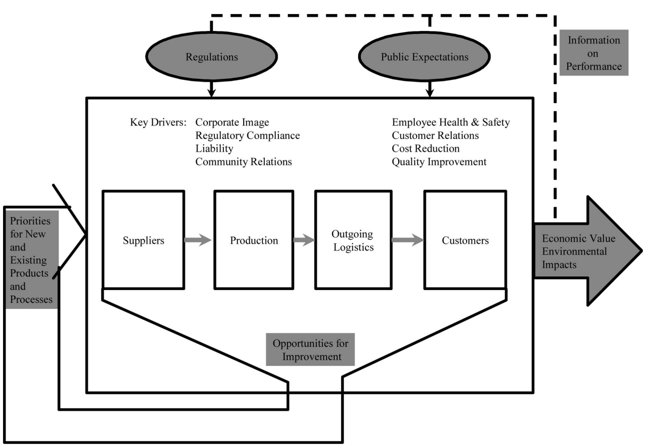
2.1. Convergence of Social Needs and Competitive Advantage

The World Commission on Environment and Development (1987) (the Brundtland Commission) defined sustainable development as "development that meets the needs of the present without compromising the ability of future generations to meet their own needs." Criticized by some for its all-encompassing scope, the sustainability movement has nonetheless gained traction because of the evident inefficiency of our current products and production processes in their use of the planet's resources. This is as true for the industrialized countries as it is for the less industrialized ones and provides huge opportunities for creating new value (Hart 2005; Prahalad 2004). For example, about one percent of all material that originates at the top of the supply chain serving the United States remains in use six months after sale of the products containing it (Hawken, Lovins, and Lovins 1999).

Because of these growing concerns, business enterprises are under strong pressure to measure their impacts on the environment and to engage in 3BL reporting to account for the energy and other resources they use and the resulting footprint they leave behind. Primary activities that contribute to their footprint are producing and transporting current products; recycling, remanufacturing, and reusing used products; and designing new products. Naturally OM has contributed to measuring and reducing this footprint. The
F2 basic drivers of this movement are evident in Figure 2 below, reproduced from the first special issue of *POM* on Environmental and Operations Management (Corbett and Kleindorfer 2001a).

We begin with the people part of 3BL. Employees need to take pride in their work and need to believe that their companies operate in a prudent and responsible manner and care about employee health and safety. Concerning the planet, aligning sustainability goals with employees and market incentives can be difficult. Community pressures and the threat of liability, however, can drive companies to improve their environmental performance (Snir 2001). Clearly, companies are most likely to improve their environmental performance when public pressure results in strong regulations. Sometimes, companies themselves lobby for regulations if they have developed an environmentally friendly technology and believe that regulations requiring their technology would give them a competitive advantage.

Figure 2 Sustainability and the Extended Supply Chain.



Strategy and public-policy experts debate the ultimate cost and benefits of environmental regulations. Many early discussions about sustainable technologies focused on trade-offs between sustainability and economic competitiveness. Parkinson (1990), Porter (1991), and Makeower (1993) challenged the view that trade-offs were inevitable. Porter (1991, p. 96) argued that the "conflict between environmental protection and economic competitiveness is a false dichotomy based on a narrow view of the sources of prosperity and a static view of competition." He argued that tough environmental standards can trigger innovation and upgrading of sustainable technologies, noting: "Properly constructed regulatory standards, which aim at outcomes and not methods, will encourage companies to re-engineer their technology. The result in many cases is a process that not only pollutes less, but also lowers costs or improves quality. Processes will be modified to decrease use of scarce or toxic resources and to recycle wasted by-products" (Porter 1991, p. 96). Porter and van der Linde (1995a, 1995b) elaborated on this in two later works (Porter and van der Linde 1995a, 1995b) linking this view to the concept of resource productivity and to the environment, innovation, and competitiveness. They used examples from several companies to show that environmental improvements can lead to improved process, products, and profits.

Since the early 1990s, this debate on whether synergies exist between profits and sustainable practices has become muted, primarily because the public has been largely indifferent to the economic and policy arguments. Throughout the world, the public and its political representatives have been demanding improved performance on environmental, health, and safety issues. The question for companies has become not whether to commit to a strong environmental, health, and safety record, but how to do so in the most cost-effective manner.

We must enlarge our perspective in OM to include people and the planet because companies will be expected to do so. We can expect the opportunities to invest in sustainable technologies, operations, and supply chains to increase rapidly because of the following factors:

1. The costs of materials and energy will continue to grow as the world economy expands and as rapidly industrializing countries, such as China and India, make strong demands on these resources.
2. Public pressure for environmental, health, and

safety performance is likely to remain strong, leading to strengthened property rights, additional regulations, international agreements on controlling negative externalities and preserving resources, and reductions in subsidies.

3. Increasing awareness of 3BL issues could increase consumer demand for products made by companies subscribing to 3BL practices.

4. People's growing antipathy to globalization is leading to strong non-government organization activity regarding businesses' sustainability performance.

2.2. A Dynamic Framework for Pursuing Sustainability

Facing the call for sustainability, how will businesses and operating managers respond? Some researchers published by POM have addressed this question, and early papers concerning the emergence of OM presage the current discussion. Hayes (1992) discussed the emergence of manufacturing in the 1980s as a pillar of strategy rather than a residual cost center. Hayes and Wheelwright's (1985) framework for the four stages of acceptance of the operations function captured its contribution to creating value and strategic success. Wheelwright and Bowen (1996) developed this idea further. The four stages progress from "internally neutral" (catch-up or reactive mode) to "externally neutral" (matching but not exceeding industry practice and standards) to "internally supportive" (setting appropriate priorities to support the business strategy) to "externally supportive" (providing externally recognized superior operational capabilities for competitive advantage).

Hart (2005) suggested that we might expect a similar slow and grudging acceptance of sustainable OM. While he does not use the term "sustainable OM," the evolution he envisages is similar to Hayes and Wheelwright's. We reformulate the Hayes-Wheelwright-Bowen framework in the context of sustainable operations:

1. *The current internal strategies* are to improve internal operations with continuous process improvements related to sustainability, such as, employee involvement, waste reduction, energy conservation, and emission control.

2. *The current external strategies* are to improve extended supply chains by analyzing upstream supply chains to make trade-offs in the choice of materials and processes and pursuing closed-loop supply chains for remanufacturing and safe disposal.

3. *Internal strategies for the future* include investing in capabilities to recover pollution-causing chemicals during manufacturing, to develop substitutes for non-renewable inputs, and to redesign products to reduce their material content and their energy consumption during manufacturing and use.

4. *External strategies for the future* include developing core capabilities in products, processes, and supply chains for long-term sustainability and pursuing strategies to facilitate it.

Assuming that corporations follow this framework, some central OM areas will be reinforced. How particular companies will evolve will depend on company- and sector-specific factors. These changes are already affecting our discipline, as is evident in some contributions to the first 50 issues of *POM*.

3. Sustainable OM in the First 50 Issues

Sustainable OM integrates the profit and efficiency orientation of traditional OM with broader considerations of the company's internal and external stakeholders and its environmental impact. The evolution towards sustainable OM is clear in three areas that integrate the three Ps of sustainable OM.

1. Green product and process development
2. Lean and green OM
3. Remanufacturing and closed-loop supply chains

Although the focus here is on the first 50 issues of *POM*, we also cover work published in other premier OM journals.

3.1. Green Product and Process Development

3.1.1. Uncertainty, Lead Times, and Investment. As a company moves to long-range strategies and moves beyond its own internal opportunities, the technologies it invests in will involve more money, longer lead times, and greater uncertainties about benefits and outcomes of development efforts. Whether a firm invests in sustainable technologies or not, its competitors may do so. The issues the firm faces are similar to those it would face in developing any new technology, particularly those whose development seems inevitable (Singhal et al. 1987), and it may want to employ game-theoretic models of technology acquisition (Gaimon 1989).

Product design is often complicated by the uncertainty inherent in the evolution of environmental trends and regulations; Noori and Chen (2003) developed a scenario-based method for addressing this uncertainty while deciding on product and process designs.

3.1.2. First Mover Advantage. The first-mover advantage for sustainable innovations includes royalties for licensing technology; development of manufacturing capabilities that a competitor would be unable to copy or unable to copy quickly; a head start on the next generation of technologies, including the creation of proprietary information that would provide competitive advantage. Once the firm develops and markets a product successfully, learning effects would lead to improvements in technology, lower prices, mass markets, and entry of competitors, similar to the well-studied case of the impact of short product-development cycles in the automotive industry (Womack, Jones, and Roos 1990). In the case of Toyota's hybrid petrol-electric car, Prius, for example, compared to a gasoline powered counterpart, it consumes half as much gasoline, releases half as much carbon dioxide, and lowers the release of smog-forming nitrogen oxides and hydrocarbons by 90 percent. Its competitors, such as Ford Motors, General Motors, Mercedes, and Porsche, which initially focused on a few sustainable technologies and did not pursue hybrid cars, are now rushing to market them, although the idea of a hybrid car is far from new. Piper, an American engineer, first proposed it in 1905. Similarly, when new regulations required a reduction of 90 percent in solvent emissions, 3M simply eliminated the use of solvents by coating products with water-based solutions that were safer (Porter and van der Linde 1995b). It gained a first-mover advantage over competitors who followed the same approach several years later.

3.1.3. Sustainable Product Design. Essential to developing sustainable products is sustainable design. The early history of product design is replete with examples of inefficiency over its total life-cycle. As the ratio of labor costs to material costs went up, it became uneconomical to replace or repair most products' individual parts, and their designs reflected that. The solution to most malfunctions or breakdowns was simply to replace the entire assembly or subassembly. Manufacturers are now moderating this practice, developing designs that avoid environmentally hazardous components and make it economically possible to save components that have high reuse value. Modular designs increasingly facilitate remanufacturing; automated diagnosis of problems; and repair or part replacements by users, original manufacturers, and third parties (Chen, Navin-Chandra, and Prinz 1994; Ferrer and Whybark 2001; Guide and Van Wassenhove 2001; Krikke, Bloemhof-Ruwaard, and Van Wassenhove 2003).

Frameworks for designing conventional products can be modified for designing green products. For example, Singhal and Singhal (2002) developed a framework for analyzing compatibility in modular product design that is analogous to analyzing compatibility of product designs for recyclability and reuse (Di Marco, Eubanks; Ishii 1994).

3.1.4. The Impact of Sustainable Design on Supply Chains. Resources lost in later stages of the supply chain imply dependent losses also upstream, and thus downstream savings lead naturally to higher savings upstream in the supply chain (Lovins, Lovins, and Hawken 1999). Identifying and managing environmental impacts throughout the supply chain is now a focus of OM research (Reiskin et al. 2000; Corbett and DeCroix 2001; Klassen and Vachon 2003).

Modular design and easy disassembly also facilitates disposal. According to the World Future Society (2005, p. 3), "The U.S. faces a tidal wave of e-waste. Some three-quarters of all the computers, televisions, and PDAs ever sold in the U.S. are no longer in use and await disposal. These devises all contain substantial amounts of toxic materials and are thus prohibited from most landfills. Disposal cost estimates already stand at $50 billion with no clear solution on how these costs will be covered." With easy disassembly, it is economical to remove parts that contain toxic materials and making the rest of the product acceptable in landfills. Safe and easy disassembly would ameliorate a scourge inflicted on emerging economies as developed economies dump their toxic waste on such countries as China and India (Brigden et al. 2005).

3.2. Lean and Green Operations

OM is attempting to use the tools and concepts of lean operations to add green metrics to the measures of excellence companies use in evaluating business processes. Several *POM* authors have written about whether the lean and green approach is evident in practice, how best to achieve it, and what its net benefits are.

Corporate Image and Profitability. Mitigating environmental, health, and safety impacts of a company is socially responsible and good business. Promoting environmental care can enhance a company's and an industry's image (Chinander 2001) as shown by chemical industries' adoption of codes of responsible care and the rapid spread of ISO 14000 (Angell 2001; Corbett and Kirsch 2001, 2004; Vastag 2004). Kassinis and Soteriou (2003) show that environmental practices in the hospitality industry enhance profitability by improving customer satisfaction and loyalty.

Synergies between Lean and Green. Improved environmental, health, and safety performance can aid plant-level productivity efforts (Klassen 2001) and increase revenues and market share (Delmas 2001, 2004). To gain these positive results, the firm must establish management systems and tools that integrate environmental, health, and safety metrics with other process metrics within the company and across the supply chain (Bowen et al. 2001). King and Lenox (2001) and Rothenberg, Pil, and Maxwell (2001) examined the links between lean manufacturing and green manufacturing and found some synergies, but also found that harvesting them is not simple. People generally assume that improving quality practices improves environmental performance. Pil and Rothenberg (2003) suggest that the causality can also work in the other direction, with improvements in environmental practices leading to improvements in quality. Sroufe (2003) analyzed the link between environmental management systems, environmental practices, and operational performance and found that this link is substantially stronger for some practices than for others.

Regulatory Compliance. To comply with regulations, companies must track their use of hazardous substances and emissions of pollutants. Because regulatory scrutiny is costly, many companies are going beyond compliance (XL and 33/50 programs in the U.S. and other voluntary programs elsewhere; Rothenberg, Pil, and Maxwell 2001). By going beyond current regulations, companies reduce the costs of changing technologies and operating policies to comply with new regulations (Woensel, Creten, and Vandaele 2001 and Delmas 2001, 2004).

Liability and Negligence. Another factor driving companies to improve their environmental performance is the risk of being held liable or found negligent for accidents or environmental damage, a risk they face even when they act prudently and use state-of-the-art technology. To limit liabilities, many companies implement strict risk-reduction mechanisms, lowering the levels of pollution, biocides, and toxics (P, B, and T) associated with their supply chains and products (Snir 2001; Wolf 2001; Kleindorfer and Saad 2005).

Employee Health and Safety. Similar to community concerns, employee health and safety is a key focus of risk reduction and risk communication initiatives (Chinander 2001; Wolf 2001). Employee health and safety is not limited to company workers or onsite exposures, but includes all parties in the supply chain who may be exposed to a company's product.

Improved Tools and Management Systems for Better Product and Process Design. To achieve sustainable OM, companies must integrate employee health and safety metrics with key business processes, measure results, and obtain the commitment of top management. They may use life-cycle analysis, gated DfX screens (where design for X (DfX) includes such factors as environment, safety, disassembly, and recycling), and eco-logistics to promote sustainable products and supply chains.

Concerning new management systems to promote employee health and safety excellence and sustainable industrial practices, the papers in *POM*'s first 50 issues have investigated two synergies with OM concepts. The first is lean production or the process of discovering and eliminating waste that originally focused on time, quality defects, and excess inventory, but is now being used effectively to ferret out environmental wastes (Rothenberg et al. 2001; King and Lennox 2001; Klassen 2001). The second source of synergy is between quality and environmental management systems, focused on the Environmental Management System under the international standards ISO 14000 and the related Eco-Management and Audit Scheme of the European Union (Angell 2001; Corbett and Kirsch 2001; Pil and Rothenberg 2003). ISO 14000 began development in 1991, after the successful deployment of ISO 9000 standards, and the aspirations underlying ISO 14000 were motivated by the experience with ISO 9000. While it is still too early to say whether ISO 14000 and other systemic approaches to managing employee health and safety impacts are effective in a 3BL sense, there are several promising indicators that it may (Klassen 2001; King and Lennox 2001; Melnyk et al. 2003). These include the increasing evidence that process excellence, as embodied in the ISO 9000 quality standard, can be a significant aid to discovering process defects and fixing them. By extension, this same logic of process excellence appears to apply to impacts on employee health and safety and their associated Environmental Management System, and industrial practice is increasingly reflecting this belief (Angell 2001; Corbett 2005; Hart 2005).

Several industry-specific studies of sustainable OM have also appeared in *POM*'s first 50 issues. Forestry managers make extensive use of mathematical models to optimize harvesting patterns. Caro et al. (2003) discuss using these models to take environmental regulations into account and quantify their costs and benefits. Flowers and Linderman (2003) consider how to turn hazardous waste into fuel for cement kilns to dispose of the waste while respecting air-quality regulations. Wolf (2001) and Kleindorfer and Saad (2005) discuss risk methodologies being implemented in the chemical industry to reduce environment, health, and safety related accidents and to promote sustainable operations.

POM's first 50 issues show that lean and green are kin to process excellence.

3.3. Remanufacturing and Closed-Loop Supply Chains

3.3.1. The Genesis and the Architecture of Closed-Loop Supply Chains. As profit margins shrink, product life cycles shorten, and environmental concerns increase, businesses consider product take-back. The increasing costs of handling product returns may offset small profit margins, and short life cycles may increase the costs of obsolescence. Companies are increasingly expected, or legally required, to take responsibility for the entire lives of their products, including proper recycling and disposal (e.g., the European Union's end-of-life vehicle and waste electrical and electronic equipment directives).

From a business perspective, the reverse supply chain begins when the customer returns the product and ends when the company has recovered the maximum value. Product returns can include packaging returns; recalls and consumer (convenience) returns in the distribution phase; repairs; and end-of-lease, end-of-use, and end-of-life returns. Consumer returns may be unused products, and sellers must put time-sensitive products back on the shelves quickly. PCs lose one percent of their value per week and become obsolete very quickly. Their small margins force companies to pay attention to the returns process. End-of-use returns occur, for example, when customers wish to upgrade to newer versions of the product. A customer's old machine, say, a copier, may still be in perfect working order and, when suitably remanufactured, may start a second life with another customer. End-of-life products typically land in the waste stream. While it may be difficult to recover value from them by reusing modules or components, companies may recover value by recycling materials or recover energy through incineration. Waste disposal is increasingly being regulated and can sometimes be costly. We take a business perspective on recovery of value through the reuse of the entire product, some of its modules, or individual components. We do not pay attention to the end-of-life recovery of materials or energy, nor to proper disposal issues. These green supply-chain issues are important, and a separate industry recycles packaging and other reusable materials, runs waste-to-energy systems, and designs disposal practices.

Reverse supply chains include used-product acquisition, reverse logistics (moving to reprocessing facilities), inspection and disposition (determining whether to repair, remanufacture, use of spare parts, or recycle), remanufacturing, and remarketing (Guide and Van Wassenhove 2001). Forward and reverse supply chains form a closed loop when they are managed in a coordinated way toward the common goal of maximizing profits. Companies must proactively pursue value from return streams and coordinate forward and reverse flows, and deal with increased uncertainty as to timing, quantity, and quality of returns and poorly developed secondary markets.

3.3.2. A Multidisciplinary Perspective. Research into closed-loop supply chains (CLSCs) parallels early research in supply chain management. Early researchers focused on the middle part of the process (reverse logistics, disassembly and testing, and remanufacturing) while paying little attention to product acquisition and remarketing. Now researchers increasingly take a broad business process perspective and integrate all steps from product acquisition to remarketing (Guide and Van Wassenhove 2001). In addition, they have shifted from a focus on minimizing costs to creating value. They seek to remove the bottlenecks to coordinating product returns so that the CLSC becomes a profitable business proposition. Researchers understand the importance of design in improving products (Debo et al. 2005) and the process (e.g., designing return networks for rapid response; Blackburn et al. 2004). Designing a profitable CLSC requires careful balancing of product design issues (for example, product durability), product acquisition (for example, the collection rate), the cost of the reverse logistics and remanufacturing processes, and remarketing decisions (such as the length of the product life cycle and the timing of remanufactured product introduction) (Geyer, Van Wassenhove, and Atasu 2005).

Early CLSC researchers, focusing on minimizing the costs of such subprocesses as reverse logistics, product disassembly, and remanufacturing, made substantial contributions by using traditional IE/OR modelling. They viewed CLSC research as a natural extension of existing OM research. When they focused on less traditional subproblems, such as product acquisition (Guide, Teunter, and Van Wassenhove 2003) and remarketing (Savaskan, Bhattacharya, and Van Wassenhove 2004), and when they looked at the entire process, they included other approaches, such as economic (e.g., game-theoretic) models.

Recently researchers have considered the large strategic issues associated with CLSCs, building on the earlier work on managing individual processes to designing entire systems. This has gone from minimizing costs to creating value and from separate disciplines to a multidisciplinary approach. To design profitable CLSCs, they must understand the underlying accounting issues (for example, valuing recovered products or components) and the related marketing issues (for example, how remanufactured products affect primary markets for those products and how to price them). OM researchers in CLSCs are driving a growing interest in such disciplines as accounting and marketing for studying CLSC problems (Atasu, Sarvary, and Van Wassenhove 2005).

3.3.3. The First 50 Issues of POM. Since *POM* began in 1992, a strong community of researchers has developed. For a good introduction to this quickly growing field, see a managerial book edited by Guide and Van Wassenhove (2003), a research oriented book edited by Dekker et al. (2004), and a book with business cases edited by Flapper, van Nunen, and Van Wassenhove (2005).

POM's first special issue on environmental management and operations (Volume 10, Number 2, 2001, edited by Corbett and Kleindorfer) featured four articles on CLSCs. Ferrer and Whybark (2001) focused on MRP for a remanufacturing facility facing uncertain supply and demand for used products. Fleischmann et al. (2001) discussed the use of a location-allocation mixed-integer linear program to examine the impact of product recovery on logistics networks. Majumder and Groenevelt (2001) used game theory to analyze competition in remanufacturing, i.e., the market side of the system. Finally, Guide and Van Wassenhove (2001) advocated a global business process perspective and provided a framework for analyzing the profitability of reuse. They also highlighted the importance of upstream product acquisition and downstream remarketing problems.

In a subsequent special issue also edited by Corbett and Kleindorfer (2003), Ketzenberg, Souza, and Guide (2003) discussed mixed assembly and disassembly operations for remanufacturing. This paper is similar to Ferrer and Whybark mentioned above in that it also uses a traditional IE/OR approach (queuing model and simulation) to tackle a new problem arising from assembly of new and remanufactured products on the same line. Recently, Guide and Van Wassenhove asked 15 CLSC researchers to list 10 most influential articles in the field. They named three articles published in *POM* (Fleischmann et al. 2001, Guide and Van Wassenhove 2001, and Majumder and Groenevelt 2001) testifying to its impact on the field. This influence will continue with the planned publication in 2006 of two special issues on CLSC research being edited by Guide and Van Wassenhove. They will show the richness of problems and approaches, as well as the progress this sub-field has made over the past decade in terms of relevance, quality, and depth of research.

3.3.4. Shifting Paradigm and New Opportunities. In the future, researchers will need to integrate decisions over the life cycle of products. Indeed, for low-margin, short-life-cycle products it is necessary to carefully integrate the forward and the reverse supply chain and to dynamically maximize product recovery potential over the entire life cycle. For instance, in many sectors, companies can use convenience returns from consumers soon after product launch to replace defective products returned under warranty. That way, new product manufacturing would not be disrupted. Later in the life cycle, companies should probably remanufacture and remarket returned products through secondary market channels. Toward the end of the product life cycle, they can use returns to supply spare parts. Such dynamic optimization depends on designing product and processes carefully and developing marketing, accounting, and performance-tracking tools.

CLSCs foster sustainability. Product recovery and reuse reduces the damaging effects on environment of waste disposal, of extracting raw materials, and of transport and distribution. Closed-loop supply chains not only increase profits, but also benefit the planet. Given that recovery operations are typically labour intensive, CLSC can have a positive effect on employment, particularly in less industrialized economies. We expect that closing the loop in supply chains will change business models. One outcome is the increasing trend toward leasing and installed base management, as opposed to selling the product. All this spells new challenges for OM researchers with interests in CLSCs.

4. Conclusions and Directions for the Future

The first 50 issues of *POM* have contributed substantially to sustainable operations management. OM, in both research and practice, can and should contribute to sustainability. In the past, it has been particularly good at helping us to understand and build dynamic capabilities, including the following:

- Modeling and measuring action-outcome links;
- Designing and managing processes to achieve agility, adaptability, and alignment (Lee 2004);
- Executing strategies;
- Integrating, conceptually and operationally, the many dispersed activities needed to achieve the goals mentioned above; and
- Building bridges with other functions and disciplines, including strong historical links to engineering and, more recently, to economics.

These capabilities may be difficult to develop. OM as a profession and POMS as a society for the profession have promoted them and lived them in research, teaching, and practice. These capabilities are the basis for a sustainable OM framework that combines the 3 Ps of 3BL thinking at the operational level of business processes. Indeed, in the spirit of the original Brundtland Commission definition of sustainability, we might define sustainable OM as the set of skills and concepts that allow a company to structure and manage its business processes to obtain competitive returns on its capital assets without sacrificing the legitimate needs of internal and external stakeholders and with due regard for the impact of its operations on people and the environment.

We are just beginning to understand and map the territory for sustainable OM. The issue is not "will all of the things we mention happen in the future?" As in global warming, we have passed this stage. The questions are when and how big will the impact be and how fast will the transition be? As the world changes, managers must make some tough bets in deciding how to position their companies for the long-haul on the sustainable OM spectrum, from internal neglect to external advantage, from being reactive to proactive as a company. Whatever their stance, companies need time to prepare for the uncharted road, especially if they want to be pioneers or early adopters.

Sustainable operations management must help companies to become agile, adaptive, and aligned in balancing the people and the planet with profits. The people part is notably absent from OM research to date; the recent renewed emphasis on behavioral OM may bring this element back into focus. The integration of management systems for safety and environmental objectives with ISO 9000, ISO 14000, and other process management systems (Rosenthal et al. 2006) indicates the growing recognition of all three Ps in promoting sustainable operations.

OM builds bridges. First, it is where all other disciplines come together as OM plays a central role in executing a company's strategy. Second, OM constructs bridges with other fields such as economics and game theory, marketing, finance, and behavioral sciences. Sustainable operations will need building further bridges with other fields, such as industrial ecology. To achieve sustainable operations, which covers design, life cycle analysis, and so forth, OM must reinforce its original links with engineering. These bridging exercises will need new approaches to the challenges at hand. For example, as Corbett (2005) suggests, it may be time to look "beyond trade-offs" to derive solutions that alleviate or avoid traditional trade-offs and in the process produce better and stronger outcomes for the company as well as for the discipline.

Once companies accept and embrace sustainability, they can rely on OM to apply it and integrate it into the lifeblood of the enterprise and its employees. Finally, the modelers (the OR-based OM population) must revisit the classical models to cope with the people and the planet related issues. For example, one will have to reformulate the objective function and the set of constraints in global production-distribution models in the new context.

We have some hard work ahead of us, but we are a strong discipline and we have solid foundations, as shown in the first 50 issues of *POM*. POMS is well positioned as a professional society to play a key role, and the *POM* Department of Sustainable Operations and the newly created POMS College for Sustainable Operations speak to our members' lively and continuing interest. Let the future begin!

Acknowledgments

We thank the special editor, Hau Lee, and six anonymous reviewers for their comments and suggestions on an earlier draft of the paper.

References

Angell, L. C. 2001. Comparing the environmental and quality initiatives of Baldrige Award winners. *Production and Operations Management* **10**(3) 306–326.

Atasu, A., M. Sarvary, L. N. Van Wassenhove. 2005. Remanufacturing as a marketing strategy. Working Paper, INSEAD 2005/63/TOM/MKT, Fontainebleau, France.

Blackburn, J., V. D. R. Guide Jr., G. Souza, L. N. Van Wassenhove. 2004. Reverse supply chains for commercial returns. *California Management Review* **46**(2) 6–23.

Bowen, F. E., P. D. Cousins, R. C. Lamming, A. C. Faruk. 2001. The role of supply management capabilities in green supply. *Production and Operations Management* **10**(2) 174–189.

Brigden, K., I. Labunska, D. Santillo, M. Allsopp. 2005. Recycling of electronic wastes in India and China. Greenpeace International, Amsterdam.

Caro, F., R. Andalaft, P. Sapunar, M. Cabello. 2003. Evaluating the economic cost of environmental measures in plantation harvesting through the use of mathematical models. *Production and Operations Management* **12**(3) 290–306.

Chen, R. W., D. Navin-Chandra, F. B. Prinz. 1994. A cost-benefit analysis of product design for recyclability and its application. *IEEE Transactions on Components, Packaging, and Manufacturing Technology*, Part A **17**(4) 502–507.

Chinander, K. R. 2001. Aligning accountability and awareness for environmental performance in operations. *Production and Operations Management* **10**(3) 276–291.

Corbett, C. J. 2005. Extending the Horizons: Environmental Excellence as Key to Improving Operations. Working Paper, Anderson School, UCLA, August.

Corbett, C. J., G. DeCroix. 2001. Shared-savings contracts for indirect materials in supply chains: Channel profits and environmental impacts. *Management Science* **47** 881–893.

Corbett, C. J., D. A. Kirsch. 2001. International diffusion of ISO 14000 certification. *Production and Operations Management* **10**(3) 327–342.

Corbett, C. J., D. A. Kirsch. 2004. Response to "Revisiting ISO 14000 diffusion: A new "look" at the drivers of certification". *Production and Operations Management* **13**(3) 268–271.

Corbett, C. J., P. R. Kleindorfer. 2001a. Introduction to the special issue on environmental management and operations (Part 1: Manufacturing and Eco-Logistics). *Production and Operations Management* **10**(2) 107–111.

Corbett, C. J., P. R. Kleindorfer. 2001b. Introduction to the special issue on environmental management and operations (Part 2: Integrating Operations and Environmental Management Systems). *Production and Operations Management* **10**(3) 225–227.

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

Debo, L., B. Toktay, L. N. Van Wassenhove. 2005. Market segmentation and production technology selection for remanufacturable products. *Management Science* **51**(8) 1193–1205.

Dekker, R., M. Fleischmann, K. Inderfurth, L. N. Van Wassenhove (eds.). 2004. *Reverse logistics: Quantitative models for closed-loop supply chains.* Springer-Verlag, New York, New York.

Delmas, M. D. 2001. Stakeholders and competitive advantage: The case of ISO 14001. *Production and Operations Management* **10**(3) 343–358.

Delmas, M. D. 2004. Erratum to "Stakeholders and competitive Advantage: The case of ISO 14001". *Production and Operations Management* **13**(4) 398.

Di Marco, P., C. F. Eubanks, K. Ishii. 1994. Compatibility analysis of product design for recyclability and resuse. Proceedings of the 1994 ASME Computers in Engineering Conference, Minneapolis, Minnesota.

Ferrer, G., D. C. Whybark. 2001. Material planning for a remanufacturing facility. *Production and Operations Management* **10**(2) 112–124.

Flapper, S. D., J. A. Van Nunen, L. N. Van Wassenhove (eds.). 2005. *Managing closed-loop supply chains.* Springer-Verlag, New York, New York.

Fleischmann, M., P. Buellens, J. Bloemhof-Ruwaard, L. N. Van Wassenhove. 2001. The impact of product recovery on logistics network design. *Production and Operations Management* **10**(2) 156–173.

Flowers, A. D., K. Linderman. 2003. Hazardous waste disposal: A waste-fuel blending approach. *Production and Operations Management* **12**(3) 307–319.

Gaimon, C. 1989. Dynamic game results of the acquisition of new technology. *Operations Research* **37**(3) 410–425.

Geyer, R., L. N. Van Wassenhove, A. Atasu. 2005. The Economics of Remanufacturing under Limited Component Durability and Finite Product Life Cycles. Working Paper, INSEAD, Fontainebleau, France.

Guide Jr., V. D. R., R. Teunter, L. N. Van Wassenhove. 2003. Matching supply and demand to maximize profits from remanufacturing. *Manufacturing and Service Operations Management* **5**(4) 303–316.

Guide, Jr., V. D. R., L. N. Van Wassenhove. 2001. Managing product returns for remanufacturing. *Production and Operations Management* **10**(2) 142–155.

Guide, Jr., V. D. R., L. N. Van Wassenhove. (eds.). 2003. *Business aspects of closed-loop supply chains.* Carnegie Mellon University Press, Pittsburgh, Pennsylvania.

Hamel, G., C. K. Prahalad. 1994. *Competing for the future: Breakthrough strategies for seizing control of your industry and creating the markets of tomorrow.* Harvard Business School Press, Boston, Massachusetts..

Hammer, M. 1990. Re-engineering work: Don't automate, obliterate. *Harvard Business Review* **68**(4) 104–112.

Hart, Stuart. 2005. *Capitalism at the crossroads.* Wharton School Publishing Co., Philadelphia, Pennsylvania.

Hawken, P., A. H. Lovins, L. H. Lovins. 1999. *Natural capitalism.* Little Brown & Company, Boston, Massachusetts.

Hay, R. L., R. N. Stavins, R. H. K. Vietor. 2005. *Environmental Protection and the Social Responsibility of Firms: Perspectives from Law, Economics and Business.* Resources for the Future, RFF Press, Washington DC.

Hayes, R. H., S. C.Wheelwright. 1985. *Restoring our competitive edge: Competing through manufacturing.* Wiley, New York, New York.

Hayes, R. H., S. Wheelwright, K. Clark. 1988. *Dynamic manufacturing: Creating the learning organization.* Free Press, New York, New York.

Kassinis, G. I., A. C. Soteriou. 2003. Greening the service profit chain: The impact of environmental management practices. *Production and Operations Management* **12**(3) 386–403

Ketzenberg, M. E., G. C. Souza, V. D. R. Guide, Jr. 2003. Mixed assembly and disassembly operations for remanufacturing. *Production and Operations Management* **12**(3) 320–335.

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

Klassen, R. D. 2001. Plant-level environmental management orientation: The influence of management views and plant characteristics. *Production and Operations Management* **10**(3) 257–275.

Klassen, R. D., S. Vachon. 2003. Collaboration and evaluation in the supply chain: The impact on plant-level environmental investment. *Production and Operations Management* **12**(3) 336–352.

Kleindorfer, P. R., G. H. Saad. 2005. Disruption risk management in supply chains. *Production and Operations Management* **14**(1) 53–68.

Kleindorfer, P. R., L. N. Van Wassenhove. 2004. Managing risk in global supply chains in *Strategies for building successful global businesses*, Chapter 12, H. Gatignon, J. R. Kimberley (eds.), Cambridge University Press, Cambridge, Massachusetts, pp. 288–305.

Krikke, H., J. Bloemhof-Ruwaard, L. N. Van Wassenhove. 2003. Concurrent design of closed loop supply chains: A production and return network for refrigerators. *International Journal of Production Research* **41**(6) 3689–3719.

Lee, H. L. 2004. The triple-A supply chain. *Harvard Business Review* (October) 102–112.

Lovins, A. B., L. H. Lovins, P. Hawken. 1999. A road map for natural capitalism. *Harvard Business Review* **77**(3) 145–158.

Majumder, P. M., H. G. Groenevelt. 2001. Competition in remanufacturing. *Production and Operations Management* **10**(2) 125–141.

Makeower, J. 1993. *The E-factor: The bottom-line approach to environmentally responsible business.* Times Book, New York, New York.

Melnyk, S. A., R. P. Sroufe, R. J. Calantone. 2003. A model of site-specific antecedents of ISO 14001 certification. *Production and Operations Management* **12**(3) 369–385.

Noori, H., C. Chen. 2003. Applying scenario-driven strategy to integrate environmental management and product design. *Production and Operations Management* **12**(3) 352–368.

Parkinson, G. 1990. Reducing wastes can be cost-effective. *Chemical Engineering* **97**(7) 30.

Pil, F. K., S. Rothenberg. 2003. Environmental performance as a driver of superior quality. *Production and Operations Management* **12**(3) 404–415.

Porter, M. 1991. America's green strategy. *Scientific American* (April) 96.

Porter, M., C. van der Linde. 1995a. Towards a new conception of the environment-competitiveness relationship. *Journal of Economic Perspectives* **9**(4) 97–118.

Porter, M., C. van der Linde, 1995b. Green and competitive: Ending the stalemate. *Harvard Business Review* **73**(5) 120–124.

Prahalad, C.K. 2004. *The fortune at the bottom of the pyramid.* Wharton Publishing, Philadelphia, Pennsylvania.

Reiskin, E. D., A. L. White, J. K. Johnson, T. J. Votta. 2000. Servicizing the chemical supply chain. *Journal of Industrial Ecology* **3**(2&3) 19–31.

Rosenthal, I., M. R. Elliott, and P. R. Kleindorfer. Predicting and confirming the effectiveness of systems for managing low-probability chemical process risks. *Process Safety Progress* (AIChE). Forthcoming.

Rothenberg, S., F. K. Pil, J. Maxwell. 2001. Lean, green, and the quest for superior performance. *Production and Operations Management* **10**(3) 228–243.

Savaskan, C., S. Bhattacharya, L. N. Van Wassenhove. 2004. Closed-loop supply chain models with product remanufacturing. *Management Science* **50**(2) 239–252.

Singhal J., K. Singhal. 2002. Supply chains and compatibility among components in product design. *Journal of Operations Management* **20**(4) 289–302.

Singhal, K. 1992. Introduction: Shaping the future of manufacturing and service operations. *Production and Operations Management* **1**(1) 1–4.

Singhal, K., C. H. Fine, J. R. Meredith, R. Suri. 1987. Research and models for automated manufacturing. *Interfaces* **17**(6) 9–14.

Skinner, W. 1969. Manufacturing—missing link in corporate strategy. Harvard Business Review **47**(3) 136–45.

Skinner, W. S. 1996. Manufacturing strategy on the "S" curve. *Production and Operations Management* **5**(1) 3–14

Snir, E. M. S. 2001. Liability as a catalyst for product stewardship. *Production and Operations Management* **10**(2) 190–206.

Sroufe, R. S. 2003. Effects of environmental management systems on environmental management practices and operations. *Production and Operations Management* **12**(3) 416–431.

Stern, J. M., J. S. Shiely. 2001. *The EVA challenge.* John Wiley & Sons, New York, New York.

Vastag, G. 2004. Revisiting ISO 14000 diffusion: A new "look" at the drivers of certification. *Production and Operations Management* **13**(3) 260–267.

Wheelwright, S. C., H. K. Bowen. 1996. The challenge of manufacturing advantage. *Production and Operations Management* **5**(1) 59–77.

Woensel, T. V., R. C. Creten, N. Vandaele. 2001. Managing the environmental externalities of traffic logistics: The issue of emissions. *Production and Operations Management* **10**(2) 207–223.

Wolf, F. G. W. 2001. Operationalizing and testing normal accident theory in petrochemical plants and refineries. *Production and Operations Management* **10**(3) 292–305.

Womack, J. P., D. T. Jones. 2005. Lean consumption. *Harvard Business Review* **83**(3) 58–68.

Womack, J. P., D. T. Jones, D. Roos. 1990. *The machine that changed the world: The story of lean production.* Harper Collins, New York, New York.

World Commission on Environment and Development. 1987. *Our common future.* Oxford University Press, New York, New York.

World Future Society. 2005. Forecast for the next 25 years, Winter issue. Bethesda, Maryland.