Extending the Horizons: Environmental Excellence as Key to Improving Operations

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Manufacturing and Service Operations Management

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Abstract

The view that adopting an environmental perspective on operations can lead to improved operations is in itself not novel; phrases such as "lean is green" are increasingly commonplace. The implication is that any operational system that has minimized inefficiencies is also more environmentally sustainable. However, in this paper we argue that the underlying mechanism is one of extending the horizons of analysis, and that this applies to both theory and practice of operations management. We illustrate this through two principal areas of lean operations, where we identify how successive extensions of the prevailing research horizon in each area have led to major advances in theory and practice. First, in quality management, the initial emphasis on statistical quality control of individual operations was extended through TQM to include a broader process encompassing customer requirements and supplier's operations. More recently, the environmental perspective extended the definition of customers to stakeholders, and defects to any form of waste. Second, in supply chain management (SCM), the horizon first expanded from the initial focus on optimizing inventory control with a single planner to including multiple organizations with conflicting objectives and private information. The environmental perspective draws attention to aspects such as reverse flows and end-of-life disposal of products, again potentially improving the performance of the overall supply chain. In both cases, these developments were initially driven by practice, where many of the benefits of adopting an environmental perspective were unexpected. Given that these unexpected side benefits seem to recur so frequently, we refer to this phenomenon as the "law of the expected unexpected side benefits". We conclude by extrapolating from the developmental path of TQM and SCM to speculate about the future of environmental research in operations management.

Introduction

The growing number of recent papers and special issues in the operations management (OM) literature on environmental management demonstrates the rapidly increasing importance of these issues.[1] This observation in itself may justify a survey and synthesis of the literature. However, the main objective of this survey is to answer the question: why and how is this trend relevant and interesting from the perspective of "mainstream" OM research and practice? Are environmental issues just a passing fad, or does the environmental perspective have a more fundamental and far-reaching impact on OM?

We take the latter view, and argue that the nature of environmental issues is such that they are provoking a powerful paradigm shift in OM research as they force scholars, frequently guided by leading-edge practitioners, to adopt a broader, more holistic view of the operations being studied. We support this claim by first revisiting the evolution of total quality management (TQM) and supply chain management (SCM), both important dimensions of lean operations (Shah and Ward 2003). Why focus on these two specific areas? Although at first glance they might appear quite separate, their developmental paths over time share important similarities. From this cursory review, we observe that in both streams a paradigm shift occurred when the scope of analysis was broadened beyond what was customary at that time. By extrapolation, we believe that the expanded awareness of environmental issues in OM research is already leading to a similar broadening of scope of analysis, and will therefore cause a similar paradigm shift. In closing, we speculate on the future development of environmental management research in OM—with the intention of inviting criticism and debate.

[1] For example: *European Journal of Operational Research,* 2000, 121(2); 1997, 102(2); *Computers & Industrial Engineering,* 1999, 36(4); *Interfaces,* 2000, 30(3); 2003, 33(4); *International Journal of Operations and Production Management,* 2000, 21(2); *Production and Operations Management,* 2001, 10(2/3); 2003, 12(3). Several others are in their final stages at this time.

The argument that adopting an environmental perspective can help firms improve their performance has been made before. Porter and van der Linde (1995) provide several examples of how environmental conditions encouraged firms to use resources more efficiently and become more productive as a result. Hart (1995) provides a more detailed discussion of how a focus on environmental performance can be a competitive resource for firms. Larson et al. (2000) invoke the Schumpeterian notion of "creative destruction" to explain how firms, when forced to adopt a new perspective, such as sustainability, become more entrepreneurial and end up discovering new goods and services. Hart and Milstein (1999) and Hart and Christensen (2002) propose that focusing on the "base of the pyramid", i.e. developing products and services tailored for the world's poor, is one way to invoke such creative destruction. A parallel mechanism applies not only to practice but to research as well: when scholarly communities are forced to adopt a broader perspective, the theoretical base of that community is enriched as a result. In fact, both practice and theory of OM seem to be subject to a "law of the expected unexpected side benefits" (which we formalize at the end of this paper) when adopting an environmental perspective: although, *ex post*, there is a multitude of examples of how an environmental perspective has improved practice and enriched theory, it is near-impossible to predict *ex ante* precisely where these benefits will emerge. This paradox may help explain why environmental research, despite having a 30-year track record, has struggled to enter mainstream OM theory and practice for so long.

This paper aims to make two contributions. First, it reviews the intersection between lean operations—particularly TQM and SCM—and environmental management, highlighting selected papers that have extended the traditional scope of analysis. Second, there is some evidence that firms with better environmental performance also achieve better stock market performance

(Klassen and McLaughlin 1996, Derwall et al. 2005), which would contradict capital market efficiency. This paper proposes that the mechanism that underlies the linkage between a broader (environmental) perspective and improved performance makes the precise nature of those improvements unpredictable, which may help explain why capital markets underestimate the value of environmental programs. We believe that these arguments can be extended to the context of social issues in OM, but the very limited research in that area prevents us from verifying that belief (Carter 2005).

The structure of this paper is as follows. First, consciously over-simplifying, the paper begins by considering how environmental issues, strategy, financial performance and operations are intimately intertwined. Next, we paraphrase the evolution of TQM to consist of three stages: an initially narrow scope applying specific tools, followed by the revolution that resulted from the broader horizon emphasized by TQM, leading to the currently emerging further extension of TQM to include environmental perspectives. We then review selected literature on environmental management and TQM in more detail. The next section develops an analogous review and extension of SCM. We conclude with our predictions about the future role of environmental research in operations management.

Role of operations in implementing environment, strategy and performance

Before reviewing the evolution of TQM and SCM, and the role of an environmental perspective in that evolution, it is important to understand the basic linkages between environmental management, firm strategy, and financial performance. The general understanding of both environmental management and firm strategy have shifted significantly in recent years, placing increasing demands on firms to consider many stakeholders.

Environmental management and firm strategy

It is instructive to briefly highlight how our understanding of the firm has evolved. The firm is one of history's great catalysts for innovation and creation of novel products and services, and often, but not universally, for improved standards of living. In particular, the widespread, international movement toward limited-liability joint-stock firms has allowed for unparalleled growth while simultaneously creating complex tensions between investors, employees and society (Micklethwait and Wooldridge 2003). When this basic structure was promulgated into law in the UK in 1862, the primary challenge was aligning a firm's economic interests (i.e., shareholders) with those of professional managers, generally termed the agency problem, not integrating environmental considerations.

More recently, much debate has focused on where the boundary of the firm should be within the overall value chain, often drawing on theories of strategic resources and transaction costs (Besanko et al. 2000). Strategic resources that generate sustained competitive advantage are defined as assets, capabilities and organizational processes, controlled by a firm, which have value, are rare, are difficult to imitate and have few substitutes (Barney 1991). A firm's resources can either be acquired in the case of tradable resources (Black and Boal 1994) or can be path-dependent, accumulating over time (Dierickx and Cool 1989). In parallel, other scholars and practitioners have advanced the need to recognize a broad array of stakeholders, extending beyond investors, management, customers and suppliers, to include local and global communities, regulators, non-governmental organizations (NGOs), and others. This is commonly termed stakeholder theory (Freeman 1984, Clarkson 1998), with stakeholder management representing a potential strategic resource (Hart 1995).

Thus, the complex web of linkages and tensions created among multiple stakeholders forces management to address both social franchise issues and economic franchise issues simultaneously (Kleindorfer and Orts 1998). To have a viable economic franchise, a company must have the requisite capabilities and associated tangible and intangible assets to generate sufficient cash flows to pay for the cost of its inputs and for the transformation of these into the products and services it offers. In contrast, a viable social franchise exists when the company has the requisite capabilities and associated tangible and intangible assets to generate sufficient legitimacy among key stakeholders, such as the public and its NGO surrogates, regulators, and its own employees and customers, that its operations are viewed as compatible with applicable social and legal norms.

Environmental issues clearly affect both types of franchise, as discussed in the following sections. For instance, Hart (1995) identifies continuous improvement and stakeholder management as two key specific organizational resources related to proactive environmental management. These are both knowledge-based resources which can build lasting competitive advantages due to their causal ambiguity and social complexity, while also supporting environmental policies that go beyond compliance and control to proactively focus on prevention (Russo and Fouts, 1997). The rapid widespread acceptance of voluntary environmental programs, including ISO 14000, the Global Reporting Initiative, and various greenhouse gas and other emissions trading schemes, is an immediate consequence of the increased importance attached to the social franchise and its impact on the economic franchise. The next question is how all this relates to firm performance.

Environmental management and financial performance

The research relating environmental management to firm performance is fragmented across the finance, corporate social performance, economics, accounting and environmental management literatures. The traditional economic view suggests that any environmental improvement made by a firm transfers costs previously incurred by society back to the firm (Friedman 1962, Bragdon and Marlin 1972, McGuire et al. 1988). Hence, environmental performance was expected to be negatively linked to operational and, ultimately, financial performance.

Counter to this perspective, others have identified strategies in which environmental management can improve firm-level financial performance and overall competitiveness (Porter and van der Linde 1995, Reinhardt 1999). Moreover, poor environmental performance can reduce a firm's market valuation (Klassen and McLaughlin 1996, Konar and Cohen 2001). Superior financial performance has been found in firms with better environmental performance across multiple industries (Kiernan 2001, Derwall et al. 2005). Although the link between environmental management and financial performance has been discussed for over three decades (e.g., Bragdon and Marlin 1972), the results reported by empirical studies are often conflicting or ambiguous, fostering an ongoing debate in the literature (Russo and Fouts 1997, Derwall et al. 2005).

As a result, a richer and more nuanced picture continues to emerge. In part, these mixed results are indicative of the complex set of relationships that underlie the apparent linkage between environmental management and financial performance. First, the relevant measures must be multi-dimensional, particularly for environmental performance. Second, environmental issues can affect performance either by increasing revenues, through new market opportunities, competitive differentiation and stakeholder management, or by cutting cost, through process improvement, waste reduction and stronger system-oriented capabilities (Klassen and

McLaughlin 1996). Third, these effects can be absolute, in which case they can (in principle) be measured by comparing performance before and after, but often they are relative, in the form of avoided costs or avoided loss of market share, compounding the measurement challenge. Finally, superior environmental performance is often, to some degree, a reflection of good management more broadly, rather than the sole root cause of good financial performance. Even then, though, any initiatives a well-managed firm embarks on, environmental or otherwise, are, by definition, more likely to be valuable.

In particular, as Derwall et al. (2005) point out, finding a positive relationship between environmentally responsible practices and stock market performance, as they do, suggests that the market is not pricing environmental characteristics of firms correctly. In fact, the traditional assumption of market efficiency would require that subjecting a portfolio to any additional constraints, such as limiting it to environmentally responsible firms, would reduce the risk-return efficiency of that portfolio. If proactive environmental management truly leads to better financial performance, an efficient capital market should take that into account, by attaching higher valuations to firms with superior environmental performance, reducing their stock market return as a result. The fact that firms with superior environmental practices outperform others suggests that capital markets underestimate the future benefits of those practices. That would be consistent with the “law of the expected unexpected side benefits”: although such benefits are consistently present in retrospect, the precise nature or magnitude of these benefits are unpredictable in advance. The fact that the business environment in which firms operate is becoming increasingly complex (due to globalization, technological developments, social change, etc.), adds to this unpredictability, but also further strengthens the need for better understanding of these forces surrounding firms and the interactions between them. We return to this issue at the end of the paper.

The role of operations management

Given the importance of environmental issues in the management of the firm, how does operations contribute? Of course, as researchers in OM it is easy and tempting to simply dismiss this question with the riposte that, for a firm, environment *is* operations. Given that processes use resources as inputs, transform energy and materials, and generate goods and services as outputs (not to mention wastes), and that managing processes is increasingly seen as critical for business success (Pall 2000), it is inescapable that environmental excellence can only be achieved through implementing cost-effective changes at the process level (Hopfenbeck 1993). And indeed, the currently dominant view of OM, as focusing processes management (including improvement enabled through TQM and business process re-engineering) has been influential in environmental management, notably in process-oriented certifications such as the ISO 14000 family of standards.

However, simply taking for granted the centrality of OM to environmental improvement would do injustice to the complexity of the linkages outlined earlier. After all, while good operations can lead to environmental excellence, which in turn can improve financial performance, good operations can also simultaneously engender environmental excellence and financial success, without there being a causal link between the latter two. Or, financial success can allow firms to invest in good operations and environmental excellence. Or, a more deep-seated "good management" can drive operational, environmental, and financial success. The list of possible permutations is lengthy. The cursory review offered earlier indicates that there is some truth to each of these views; in this survey, though, we highlight yet another mechanism, that explains the importance of environmental management for the broader operations community: environmental excellence drives operational excellence (and both drive financial success separately and jointly). Below, we turn to the fields of TQM and SCM to support this view.

Environmental issues in Total Quality Management

The evolution of TQM

Early work in quality control focuses on methods as acceptance sampling (Dodge and Romig 1929) and control charts (Shewhart 1931). Optimal policies are determined by specifying what levels of Type-I and/or Type-II errors are acceptable (i.e., rejecting a good lot, or accepting a bad one) without explicit consideration of the causes and consequences of such errors.

A critical aspect of the TQM revolution of the 1970s and 1980s (Evans and Lindsay 2001, Juran and Godfrey 1998) was to emphasize the need to take a broader view of “quality”. For instance, quality should be defined in terms of meeting customer requirements, rather than purely in terms of defects. The costs of defects could extend beyond the process that generated the defects, as in the case of a part that fails in the field, triggering a warranty claim, even though it passed inspection before being shipped (Garvin 1983). Moreover, the source of quality problems can lie outside of the process itself. For example, it is usually better to reduce the variability of a supplier’s quality rather than simply accepting or rejecting batches as they are received.

Statistical tools such as acceptance sampling or control charts must be one component of a broader program that integrates organizational culture, employee training, data collection, root cause analysis, and continuous improvement, to name several aspects. In short, the TQM revolution pushed the OM community to adopt a broader perspective, including processes upstream and downstream, as well as the organizational context surrounding those processes. Although any individual aspect or implementation of TQM may or may not have been successful, the principles of TQM have become widely accepted in theory and practice.

Fundamental linkages between TQM and environmental management

The linkages between quality and environmental management are illustrated by the recent emergence of terms as “total quality environmental management” (TQEM), and by the similarity between standards such as ISO 9001 (quality) and ISO 14001 (environment), discussed below. In order to include environmental issues, the frame of reference offered by TQM must be stretched in several directions.

First, the notion of a “defect” must be more comprehensive, and include any waste that is generated within a process or while using or disposing of a product. Where “zero defects” was a central tenet of TQM, “zero waste” is a significant step beyond. However, many of the tools and principles that apply to quality management are equally relevant for environmental improvements (Corbett and Van Wassenhove 1993, Madu 2003). For example, in statistical process control (SPC) the objective is to monitor a process continuously in order to rectify out-of-control situations before they lead to costly problems. The trade-off is between reacting too late (hence incurring costs of defects) and reacting too quickly (with false alarms causing unnecessary stoppages). Applied to pollution control, one faces a similar scenario: many processes face fines or even shutdown once they exceed some regulatory limit on air- or water-borne emissions. SPC can be used to monitor process emissions and take action when they are getting too close to the regulatory limits. One of the benefits of SPC is that it helps operators see and understand problems which (in other contexts) does improve their decision-making (Boudreau et al. 2003). Environmental applications of SPC have similar benefits. Operators can rarely see the physical emissions caused by a process, and hence cannot manage them carefully without having the real-time pollution data available that SPC provides. Corbett and Pan (2002) propose that process capability indices, which measure the degree to which the process is capable of remaining below the existing regulatory limits, can be used as a measure of the environmental quality of a process.

Second, the notion of "customer" needs to be revisited. Sometimes, customers are directly concerned about a firm's environmental performance, as in Kassinis and Soteriou (2003), who document the links between environmental practices, customer satisfaction, and profitability. However, in many situations, "customer" needs to be interpreted in a broader sense, as "stakeholder", in recognition of the fact that processes generate many outputs, which in turn affect many stakeholders. Where TQM defines defects in terms of customer requirements, the environmental perspective tells us to define defects in terms of broader societal concerns. This immediately highlights the tension that runs through much environmental research. On the one hand, the view that environmental issues are a natural extension of quality suggests that the tools and principles of TQM apply equally to improving environmental performance. On the other hand, it is not obvious how to deal with multiple stakeholders simultaneously, some with business ties to the firm, others with regulatory ties, and still others, such as NGOs, with no formal ties at all. Delmas (2001) argues that it is precisely because effective stakeholder management is so challenging that firms can achieve competitive advantage through the tacit and inimitable resources they develop in the process.

In a TQM context, it is clear how a firm can generate higher profits by better understanding customer requirements and modifying processes to better satisfy them. In the environmental arena, if that "customer" is a government, it can still give the firm powerful incentives to improve its environmental performance. But once the "customers" include other stakeholders, such as community groups, NGOs and future generations, tension arises between the narrowly-defined system consisting of the firm and its customer and the broadly-defined system consisting of the firm and its social and multi-generational context. One might think that these tensions are inevitable, but consider the following quote from Fujio Cho, President of Toyota, one of the world's greatest manufacturers: "Since Toyota's founding we have adhered to the core principle of contributing to society through the practice of manufacturing high-quality products and services. Our business practices and activities based on this core principle created values, beliefs and business methods that over the years have become a source of competitive advantage. These are the managerial values and business methods that are known collectively as the Toyota Way."[2] Liker (2004) discusses how the development of the Toyota Prius, the most successful hybrid (and hence environmentally preferred) car to date, is a direct consequence of the Toyota Way.

This three-stage view of the evolution of TQM is summarized in Figure 1. The notion of strong synergies between quality and environmental management is quite intuitive, yet theoretical and empirical questions remain. Angell (2001) offers a detailed analysis of similarities and differences between successful and unsuccessful quality and environmental initiatives; she finds that, although the two types of programs are conceptually similar, they vary significantly on several implementation issues. The rest of this section reviews the research literature on the links between TQM and environmental programs and standards.

[2] Fujio Cho, President of Toyota, from the Toyota Way document, 2001; quoted in Liker (2004), page 35.

TQM and environmental management programs

Klassen and McLaughlin (1993) provide an early discussion of the parallels between TQM and environmental management. For instance, they point out that "cost of quality" includes both cost of defects and cost of prevention, while environmental costs similarly include costs related to pollution and to pollution prevention. They note that, in quality, costs of prevention are often much lower than the costs of defects, and argue that the same holds for environmental costs. They draw several other parallels: both TQM and environmental management are strategic initiatives that need to be properly integrated within the business in order to be successful. Also, environmental management extends TQM's emphasis on the customer to other groups of stakeholders. Finally, holistic product and process design are critical to achieve success in TQM, which corresponds to the environmental importance of life-cycle assessment and process design aimed at pollution prevention rather than end-of-pipe correction.

Some empirical support for these ideas comes from a survey by Florida and Davison (2001). Plants with both an environmental management system (EMS) and pollution prevention (P2) program in place were more innovative, which was related with extensive adoption of TQM programs and JIT systems. Furthermore, these plants reported better relations with stakeholders as a result of having an EMS, and characterized their relationships with communities, when confronted with potentially sensitive proposals from the plants, as supportive. Kitazawa and Sarkis (2000) document several firms adopting ISO 14001 that, through the resulting focus on employee involvement, ended up reaping benefits more often associated with TQM and JIT programs.

Crosby (1979) is known for the slogan "quality is free", implying that the quest for quality improvement invariably gives rise to unexpected side benefits which offset the costs of the quality improvement process. This is also consistent with Larson et al.'s (2000) Schumpeterian view. King and Lenox (2002) observe a similar effect with environmental improvement: managers often underestimate the magnitude of the indirect benefits of investments in pollution prevention. Similarly, King and Lenox (2001) find that lean manufacturing, as witnessed by ISO 9000 adoption and low chemical inventories, is correlated with greater waste prevention and with lower emissions, lending support to the claim that "lean is green". Rothenberg et al. (2001) find limited statistical support for this view, but strong anecdotal evidence that lean manufacturing is associated with reductions in emissions of volatile organic compounds (VOC). Additional examples are provided by Romm (1999); for instance, upon installing variable-speed motor drives in paint booths, Toyota reduced paint defects by a factor 30 while reducing energy consumption by 50%. Pil and Rothenberg (2004) find that applying quality-related tools to environmental problems also helps to improve quality itself.

Although intuitively it is clear that techniques for pollution prevention, as gathered in Freeman (1995), are economically and ecologically preferable, in practice end-of-pipe treatment often prevails. For example, Klassen (2000b) finds that investment in advanced manufacturing technologies tends to be associated with a shift away from pollution prevention, possibly to mitigate technological risk; in contrast, investment in quality management systems had the opposite effect. However, more favorable outcomes are possible: Rajaram and Corbett (2002) describe a firm's re-evaluation of its manufacturing process in response to new wastewater regulations. A mathematical programming-based approach identified major simplifications, leading to substantial reductions in energy and water usage, thereby avoiding the need for a new wastewater treatment facility. The benefits of simplification also help to reduce accidents that are driven by higher process complexity and tighter coupling of subsystems (Perrow 1984, Wolf 2001). Thus, the pollution prevention approach resulted in unexpected but substantial side benefits. However, some tensions continue between investing in technology or prevention.

Consistent with this, case evidence and survey data from the U.S. furniture industry (Klassen 2000a) identified a linkage between greater investment in just-in-time (JIT) systems (often closely associated with TQM) and improved environmental performance. More surprisingly, an emphasis on pollution prevention, instead of pollution control, improved delivery performance. Thus, production and environmental managers can pursue JIT and pollution prevention as complementary initiatives that can improve performance along multiple dimensions. However, Lapré et al. (2000) describe how a firm's TQM projects only led to process improvements (and waste reduction) if they led to better understanding of the process.

In each of these examples, the boundary expansion lies in extending existing, proven management programs to cover environmental improvement. In much of this research, this extended focus improved the productivity of the original system, illustrating the main argument of this paper about the fundamental benefits of including an environmental perspective.

Quality and environmental management standards

Firms can use a range of voluntary standards to signal the implementation of environmental management systems. One such family of standards is ISO 14000, modeled on the earlier ISO 9000 series of quality management systems standards. Industry-specific voluntary codes of conduct include the chemical sector's Responsible Care program, several sustainable forestry programs, etc. Why do firms adopt these voluntary standards, and do they truly improve firms' environmental performance? While the evidence to date supports a beneficial effect of TQM (Hendricks and Singhal 1996, 1997, 2001, Easton and Jarrell 1998), the case for ISO 9000 is more mixed. Corbett et al. (2005) do find that US manufacturing firms that adopted ISO 9000 outperformed their non-certified peers, but several other studies (cited there) find little or no effect.

The environmental side exhibits even more uncertainty. Corbett and Kirsch (2001) and Mendel (2001) argue that firms seeking ISO 14001 certification are not driven by environmental considerations alone. King and Lenox (2000) find that membership in Responsible Care was not necessarily associated with reduced emissions. Instead, the lack of sanctions in this program allowed some firms to use membership as a means to hide poor performance. Russo and Harrison (2005) find a positive association between ISO 14091 certification and toxic emissions, but their data cannot establish the direction of causality. Potoski and Prakash (2005) do find that ISO 14001 certification leads to lower emissions, after correcting for the selection effect.

Firms that operate in many countries with widely varying environmental regulations must sort out which standard to adopt in any given country. Should a U.S. multinational firm apply EPA regulatory requirements to its operations in developing nations, or adapt to local practices? While there are clearly ethical aspects, Dowell et al. (2000) find that firms which adopted uniform stringent environmental standards throughout their global operations received a higher stock market valuation than firms that adapted to local standards. They attribute this to increased economies of scale in management systems: administering a single standard worldwide is easier than adjusting to different standards for each country.

Collectively, these examples illustrate the boundary expansion of TQM through the development of environmental management systems drawn from earlier quality management systems. We have described the evolution of TQM in three stages with increasingly broad horizons, and reviewed some literature characteristic of the third stage, which adds an environmental perspective to TQM. Next, we do the same for supply chain management.

Environmental issues in supply chain management

The evolution of supply chain management

For purposes of this review, we trace the origins of supply chain management back to the newsboy model (e.g., Arrow et al. 1951), the first attempt to explicitly match supply with uncertain demand. The next two decades saw a major extension of this simple principle into optimal control of multi-echelon inventory systems (see Axsäter 2000). In parallel, mathematical programming methods were used for optimal design of distribution systems (see Geoffrion and Powers 1995). Both streams of work almost always treated the network, however complex, as a monolithic entity under the control of a single, omniscient central planner.

Since the mid-1990s, the field of "supply chain management" has experienced explosive growth, both in the OM research community and in practice. The notion of a supply chain was of course not new. However, a key aspect of the SCM revolution was the recognition that supply chains are not monolithic entities but consist of multiple organizations, each with their own objectives and information. To make supply chains work efficiently, one has to examine information flows and address incentive conflicts.

The "beer game" (Sterman 1989) is often used to illustrate these two fundamental challenges, which underlie much recent work in SCM. The models reviewed by Chen (2002) demonstrate how poor information flows can hurt the entire supply chain. Similarly, the work reviewed in Cachon (2002) illustrates that individual firms often will not choose inventory policies that are optimal from the supply chain's perspective.

With many similarities to the previously described evolution of TQM, the SCM revolution also pushed the OM research community to adopt a broader perspective, including explicit coordination of upstream and downstream processes and the recognition of the institutional and economic decision-making context surrounding supply chains. The results of the SCM revolution are well-known: many of the principles of supply chain design, information exchange, and (to a lesser extent) coordination mechanisms are widespread in OM theory, practice and education.

Fundamental linkages between SCM and environmental management

There are several ways in which adopting an environmental perspective affects supply chains. First, the supply chain itself is extended beyond the final consumer to end-of-life fate, such as recycling and disposal. This in turn gives rise to reverse logistics and closed-loop supply chains (Guide and Van Wassenhove 2003), where goods no longer always flow in one direction, whether for environmental or other reasons. Second, as with TQM, the notion of "customer" is being replaced by an acceptance of multiple "stakeholders" in supply chains, including the local communities impacted by any step in the supply chain, the NGOs that represent their interests, governments, and future generations whose quality of life will be affected by the way supply chains are designed and operated today. Figure 2 depicts this three-stage evolution of SCM from coordination within an organization to coordination across a forward supply chain, to coordination embedded in its larger social context of multiple stakeholders.

This expansion of the traditional horizons of SCM gives rise to many of the same tensions noted earlier for TQM. When the SCM revolution revealed that coordination between customers and suppliers could benefit the supply chain, it was clear how they could cooperate (in theory) and make all parties better off. A supplier who understands and meets the customer's preference for frequent deliveries is likely to be rewarded through greater market share or higher prices. Conversely, firms that mismanage their supply chains experience significant loss of market value (Hendricks and Singhal 2003). Environmental surprises can cause financial harm through disruptions (Kleindorfer and Van Wassenhove 2004) or product liability (Snir 2003) in supply chains.

But how will a supplier be rewarded for designing products that take up less space in landfill? Or for more durable products that do not even end up in landfill until much later? In some cases, governments enforce environmentally beneficial behavior. In others, tensions arise between the narrowly-defined supply chain consisting only of suppliers and customers, and the broader social, multi-generational perspective. Below we review studies that address this tension in the context of network design, supply arrangements, and inter-organizational linkages respectively.

Reverse flows and network design

Much recent research has studied reverse logistics, defined as the materials management activities needed to perform product recovery including the upstream movement of materials and source reduction. For extensive reviews, see Fleischmann et al. (1997), Stock (1998), and Carter and Ellram (1998), as well as the books by Guide and Van Wassenhove (2003) and Dekker et al. (2004). Product recovery encompasses the management of all discarded products, components, and materials, which is one aspect of product stewardship (Thierry et al. 1995). Both external and internal stakeholders can promote or constrain the development of more effective reverse logistics processes, with regulation frequently being one principal driver (Barry et al. 1993).

At a minimum, reverse logistics must take into account two aspects: first, collecting and reintegrating used products and waste materials into the forward supply chain, and second, minimizing the system-wide resource consumption and environmental emissions (Carter and Ellram 1998). Geyer and Jackson (2004) discuss when various forms of reuse and recycling of steel sections are both economically and environmentally beneficial. Matthews (2004) presents an example where efforts to reuse packaging materials led to other economic and environmental benefits in the supply chain. Guide (2000) discusses seven characteristics of reverse flows that complicate production planning and control. The tools and frameworks originally developed for end-of-life return flows are proving useful in dealing with the growing problem of customers returning items soon after purchase (Guide et al. 2003). Although the problem of customer returns has been a major one for quite some time, it had been largely ignored by the OM and logistics communities (a notable exception is Rogers and Tibben-Lembke 1999) until the emergence of legislation requiring end-of-life product takeback.

Fleischmann et al. (2001) compare networks in which the forward and reverse flows are optimized sequentially with those in which both flows are optimized simultaneously. In the case of copiers, where production facilities tend to be relatively close to the markets, a reverse flow can be added to an existing forward network with few complications. In contrast, in the paper industry, production locations are typically located close to natural resources (raw materials) and far from customer markets, so adding a reverse flow prompts a drastically different network design.

Caldentey and Mondschein (2003) use mathematical programming to design an optimal supply chain for the smelting and sulfuric acid production stages in the copper industry. Optimizing the entire system, allowing the market price for sulfuric acid to emerge endogenously rather than be imposed exogenously, enabled the copper industry to earn substantially higher profits. Majumder and Groenevelt (2001) analyze competition between firms that compete for returned products to remanufacture, and show that these interactions become substantially more complex as a result of the bidirectional flows.

Much of this research indicates that explicit design and management of an integrated, bi-directional supply chain results in better performance than decomposing the system into two unidirectional chains (one forward, one reverse). This is consistent with our argument that the broader horizon caused by including an environmental perspective leads to better understanding of the original system. However, challenges remain in managing the incentives and relationships between supply chain partners.

Supply arrangements

When reverse logistics (Barry et al. 1993) and the management of relationships between manufacturing firms and end-users (Florida 1996) are considered as extensions of the forward supply chain, the concept of a reverse supply chain emerges. However, firms can take different actions to improve the reverse supply chain, depending on their position along the chain (van Hoek 1999). Upstream firms should emphasize emission rates and efficiency, with direct implications for material selection, process design and reintroducing flows from the reverse supply chain. In the middle portion of a supply chain, transportation and assembly efficiency are critical. Downstream firms tend to stress recycling and packaging. At the same time, all parties should ideally consider the economic and environmental implications of their actions for the entire supply chain. Downstream firms will be immediately affected if an upstream supplier uses a material that is banned under the European Union's Restriction of Hazardous Substances (RoHS) legislation, which will require a new level of information exchange between supply chain partners beyond that related to inventory and logistics.

Terms as green or environmental purchasing (Min and Galle 1997), green value chain practices (Handfield et al. 1997), spectrum of environmental management programs (Beckman et al. 2001) and green supply (Bowen et al. 2001) are used to characterize environmental aspects of supplier arrangements; all of these implicitly or explicitly focus on improved environmental performance through better supplier management. Changes to reduce environmental impacts in the supply chain can focus on specific inputs, such as raw materials, or outputs, such as products, services and by-products (Min and Galle 1997). Case research in the furniture industry identified five areas that directly link purchasing with environmental performance: materials used, processes used for product design, supplier process improvement, supplier evaluation, and inbound logistics processes (Walton et al. 1998). Drawing on a sample of UK firms, Bowen et al. (2001) find that supply management capabilities impact product-based initiatives directed toward improving environmental performance. For example, material reduction (or source reduction) includes primary raw materials, as well as ancillary materials such as packaging.

Yet improvements are not limited to just product-related changes or to manufacturers. Process changes related to supplier selection and management can extend changes upstream in the supply chain (Bowen et al. 2001). Green et al. (1998) stress the influence that service firms, particularly in the retail sector, can exert on the environmental practices of manufacturers. For example, the use of audit systems can encourage simultaneous improvements in quality, environment and safety, with poor suppliers being dropped. These process changes also can result from pressure from external stakeholders beyond suppliers and customers.

Purchase agreements are often loaded with incentives against environmental improvement (Reiskin et al. 2000). Typical examples are cases where suppliers of harmful chemicals are paid based on volume sold, and hence want to sell as much as possible. When these chemicals are indirect materials, customers would rather buy less, but often do not know how to reduce their consumption, and the supplier has no incentive to help them to do so. A recent trend is to change purchase contracts from product-based to service-based, or "servicizing": instead of purchasing chemicals, the customer buys a chemical management service, in which the supplier keeps the customer's inventory at the desired levels, and offers additional value-added services such as ensuring compliance with regulatory reporting requirements.

This transition from selling products to providing services offers potential economic and environmental benefits. In turn, this requires a corresponding shift by management from simple product volumes to the explicit recognition of complex inter-linkages between design, consumption, and efficiency that create function and value for customers. This is a natural outgrowth of industrial ecology, with its holistic view of material and energy flows and the concomitant aim to reduce the environmental impact of products from cradle to grave (Ayres and Ayres 2002).

Reiskin et al. (2000) provide several examples of servicizing in the chemical sector, while Corbett and DeCroix (2001) use game theory to analyze when such contracts lead to environmental improvements. Service-based contracts are often attractive to suppliers, as they allow them to be more integrated with the customer's operations, hence increasing switching costs. Thus, better alignment of the financial incentives for both supplier and customer favors a leaner system by fostering faster and more creative movement toward dematerialization and closed-loop processes. Here again, the environmental perspective helps to improve the original system.

Strategic linkages between organizations

Lean supply emphasizes the need to build inter-organizational relationships that extend beyond transactional arrangements to environmental issues (Lamming and Hampson 1996). In their boundary-spanning position, supply chain managers can play a critical role in assessing the impact of product and process changes related to the natural environment, ultimately with strategic implications for the firm. Just as supplier development has been linked to the development of underlying strategic resources (Krause et al. 2000), the same is true for effective integration of environmental management into supply chain management (Bowen et al. 2001).

Recall that strategic resources are defined as assets and organizational processes that add value, are rare, are difficult to imitate and have few substitutes (Barney 1991); these resources can be physical, human, organizational, technological, financial and reputational (Grant 1991). Resources are distinct from capabilities, with the former being basic building blocks such as employee skills and purchasing processes, and the latter being bundles of resources brought to bear on value-added tasks (Hart 1995, Bowen et al. 2001). Hart (1995) and Lamming and Hampson (1996) argue that strategic resources for green supply include continuous improvement and product stewardship, which encompasses product responsibility from cradle to grave.

Thus, green supply chain management can be a source of competitive advantage, although it must be linked to other dimensions of operations strategy (Newman and Hanna

1996). Other empirical evidence links the use of environmental criteria in purchasing to improved financial performance (Carter et al. 2000). However, Min and Galle (1997) report that competitive advantage plays a relatively minor role for managers considering green purchasing, compared to liabilities and product disposal costs.

The arguments collected here indicate how extending the scope of analysis to include environmental impacts can lead to strategic advantage in managing supply chains. Though the set of examples of this in the context of supply chains is still limited, the fact that this link relies on well-established strategic theory indicates that that will change with time.

Linking lean supply to environmental management

The literature points to at least four distinct elements that link lean supply with environmental management (Klassen and Johnson 2004). First, these linkages involve interactions between the buying firm and its upstream suppliers, ideally to achieve sustained environmental improvements (Handfield et al. 1997). Second, the interaction also extends downstream, ideally to the extent that the end-user becomes a supplier of used products or components to create a closed loop between suppliers, manufacturers and customers (Vachon et al. 2001), necessitating reverse logistics and planning (Guide and Van Wassenhove 2002).

Third, information must be gathered on the environmental performance of suppliers, possibly through audits or external certifications such as ISO 14001 (Walton et al. 1998, Bowen et al. 2001). This might extend to distributors, shippers or customers, if risks related to mishandling or misuse of the product exist. Finally, a firm does not just rely on suppliers, but integrates internal and external environmental systems and investments (Geffen and Rothenberg 2000), both upstream and downstream. Although the direction of causality can be debated, in practice green supply is more likely to develop from integrated, partnership-oriented supply chain relationships (Florida 1996), rather than vice versa.

Discussion and conclusions: the future of environmental research in OM

In the preceding review, it is readily apparent that research and practice in both TQM and SCM have experienced ever-expanding boundaries of analysis. Both research streams started with small, well-defined problems, gradually expanded to include a much richer set of issues and interactions within and between firms, and have begun to address environmental issues. This review and synthesis of characteristic research in TQM and SCM provides a basis from which to speculate on how environmental research will evolve within the field of OM and on why the precise nature of the link between environmental perspectives and operations management has been so elusive. Starting with the latter, recall that throughout we have presented examples of how adopting an environmental perspective led to improvements in OM theory and practice, improvements that in principle could often have been found without an environmental perspective but that, for whatever reason, had not been uncovered otherwise. We formalize this as follows:

Conjecture 1: The benefits to OM theory and practice of adopting an environmental perspective are subject to the "law of the expected unexpected side benefits."

With this we mean that there is ample evidence that adopting an environmental perspective is beneficial, but that these benefits usually materialize in unexpected forms, and hence are usually greater after the fact than can be accurately predicted in advance. This outcome is consistent with Crosby's (1979) claim that "quality is free" (i.e., the view underlying programs such as "zero defects" and "zero waste"), and is supported by King and Lenox (2002) and other work cited earlier. However, we postulate a specific mechanism, that of boundary expansion, as the main driver of this effect, which more clearly highlights the fundamental unpredictability of these side benefits.

Recall that Derwall et al. (2005) found that firms with environmentally responsible practices consistently experience better stock market performance than others, which cannot be explained in the usual risk-return paradigm of capital market theory, but which is consistent with this notion of recurrent but unpredictable benefits. This inherent unpredictability does pose a fundamental challenge in promoting environmental perspectives in operations management. However, with this understanding, we can speculate on how environmental research should evolve within the field of OM. To ground our predictions, consider the general cycle of scientific revolutions (Kuhn 1970), which has also been adapted and applied to efforts to build theory in TQM (Handfield and Melnyk 1998, drawing from Wallace 1971):

1. *Pre-paradigmatic inquiry*. Several conflicting schools of thought with competing views are debated and considered.
2. *Dominant paradigm emerges.* A unified community coalesces around shared values, philosophies, methods and relationships. Scientific progress occurs at a rapid pace over an extended period of time, with a growing depth of understanding of increasingly detailed phenomena, with ever greater specialization. Conventional wisdom forms the basis for continued inquiry and practice.
3. *Anomaly and discovery*. Observation and anecdotal evidence are uncovered that counter the accepted paradigm. (In OM, such observation tends to occur in managerial practice, fueling

tensions between theory and practice, as during the early development of TQM and SCM.) Debate ensues, pushing inquiry in several competing directions.

4. *Crisis and the emergence of new theories*. As discoveries of alternative views, relationships and methods emerge and then accumulate, each is assessed for its ability to both account for prior discovery, as well as explain unresolved questions and issues. Active debate about the merits of alternative theories continues, similar to pre-paradigmatic inquiry.
5. *Shift to new paradigm* (sometimes termed revolution). The ability of the new paradigm to both encompass much of prior knowledge, as well account for unresolved problems of the old paradigm propels the community of practitioners and researchers toward a unified acceptance of the new paradigm.

At the risk of over-generalizing, quality underwent a paradigm shift from "high quality equals high cost" to the now accepted TQM paradigm. The roots for the original paradigm were established in the statistical process control of the 1920s (phase 2), going through a crisis in the early 1980s as Japanese firms appeared as consistent anomalies (phases 3-4). The new TQM paradigm became established by the late 1980s (phase 5). In a similar fashion, SCM, with its roots in single-party inventory management in the 1930s and the newsboy problem of the 1950s (phase 2), arguably entered the fifth phase with a new paradigm of multi-party systems by the late 1990s.

The initial paradigm for research in environmental management in OM was based on the common assumption that environmental improvement requires pollution control, which equals cost. Thus, firms should oppose any improvement on financial grounds, leaving regulation as the primary option (and much new regulatory activity did indeed take place in the 1970s), with management grudgingly absorbing this as an operating constraint. While controversy surrounding environmental issues raged in other fields such as political science during the 1970s, it only entered the third phase in operations management, that of anomaly and discovery, in the mid-1990s. Now, given the enormity of the issues ranging from concerns over global warming, to mandated product take-back in Europe, to local problems with water pollutants and hazardous waste, there are signs that research is just beginning to move into the fourth phase with increasing controversy, diversity of insights, and emergence of new theoretical frameworks.

Specifically, once the boundaries are drawn widely enough to include environmental issues, research methodology and measurement become two critical concerns. To begin, how do we define and measure environmental performance? A balanced scorecard approach is one alternative, which can be linked to broader corporate strategy (Kaplan and Norton 1996) and which has been applied to environmental management (Epstein and Wisner 2001), although identifying, monitoring and acting on specific measures remains a challenge.

Expanding the boundaries also implies integrating the concerns of more stakeholders. Traditionally, one might include a manufacturer (or service provider), and perhaps suppliers and/or customers; we now have to account for governments, local communities, public interest groups, and future generations. How can their interests be integrated into such areas as product and process design and operational decision-making? This is a key concern of the environmental justice movement, which has been imported into OM in the research program by Kleindorfer et al. (2003) on accident epidemiology in the chemical industry, by linking facility characteristics, operating practices, and demographics of neighboring communities.

Translating the values held by these various stakeholders into quantifiable objectives is therefore often both necessary and challenging, but recent developments in contingent valuation methods (Venkatachalam 2004), sometimes drawing on consumer research methods such as conjoint analysis (Farber and Griner 2000), are addressing this issue. However, when identifying the rationale for particular actions after the change is implemented, motives and reported benefits can still be colored with social desirability (Fischhoff 2000). Several other research questions on the role of environmental issues in OM emerged from the focus groups reported in Angell and Klassen (1999).

Just as the TQM revolution brought OM into contact with views from human resource management and organizational behavior, and the supply chain revolution did the same with system dynamics, industrial organization and game theory, the environmental perspective is beginning to make the OM community aware of other fields including risk analysis, life-cycle assessment, industrial ecology, contingent valuation methods, and consumer research tools for eliciting environmental preferences. These fields have already developed important insights related to OM, and progress in OM, in turn, is dependent on effectively leveraging and integrating their discoveries and methods. Based on this trend to date, and extrapolating from the TQM and SCM timelines, we make the following testable predictions.

Conjecture 2: Environmental management in operations will have become an established and accepted part of mainstream OM by 2015: by that time, it will have received widespread acceptance as an integral part of core courses and mainstream textbooks in the OM field.

Conjecture 3: During this time, environmental issues will force more interdisciplinary research in OM. As a result, a significantly higher proportion of research papers focusing on OM and environmental issues will be co-authored with scholars in other disciplines including economics, political science, engineering, and others.

All three conjectures made here could also apply to social issues or sustainability. The current state of research in OM with a social perspective is too limited to support that, but we hope that will change soon. To conclude, we predict an important transformation for operations management. The inherent complexity and interdisciplinary nature of environmental issues present significant challenges, but despite its difficulty, this research has fundamental implications for OM theory and practice. By viewing environmental issues as part of the mainstream concerns of TQM and SCM, many new research questions and opportunities are raised, which in turn will lead to better understanding of "mainstream" TQM and SCM. We hope this survey will contribute to making our predictions come true.

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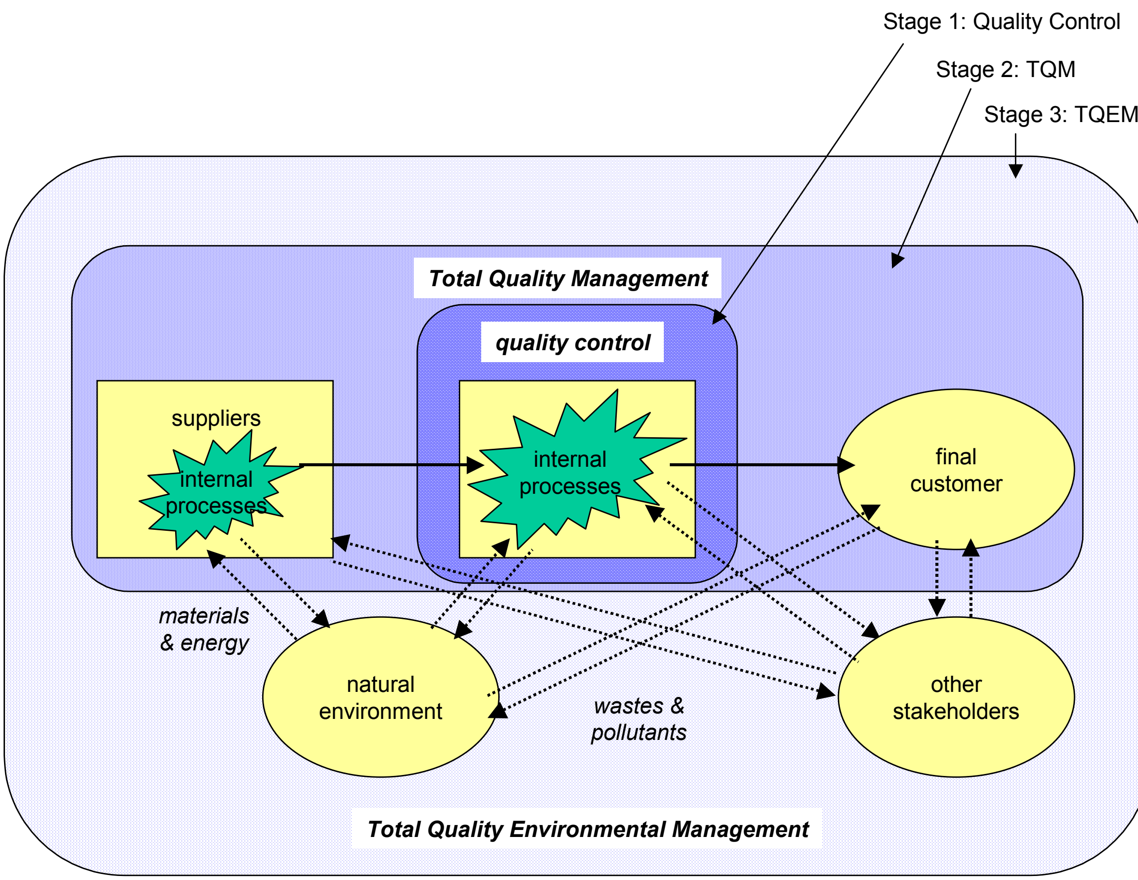

Figure 1: Extending the horizons of TQM

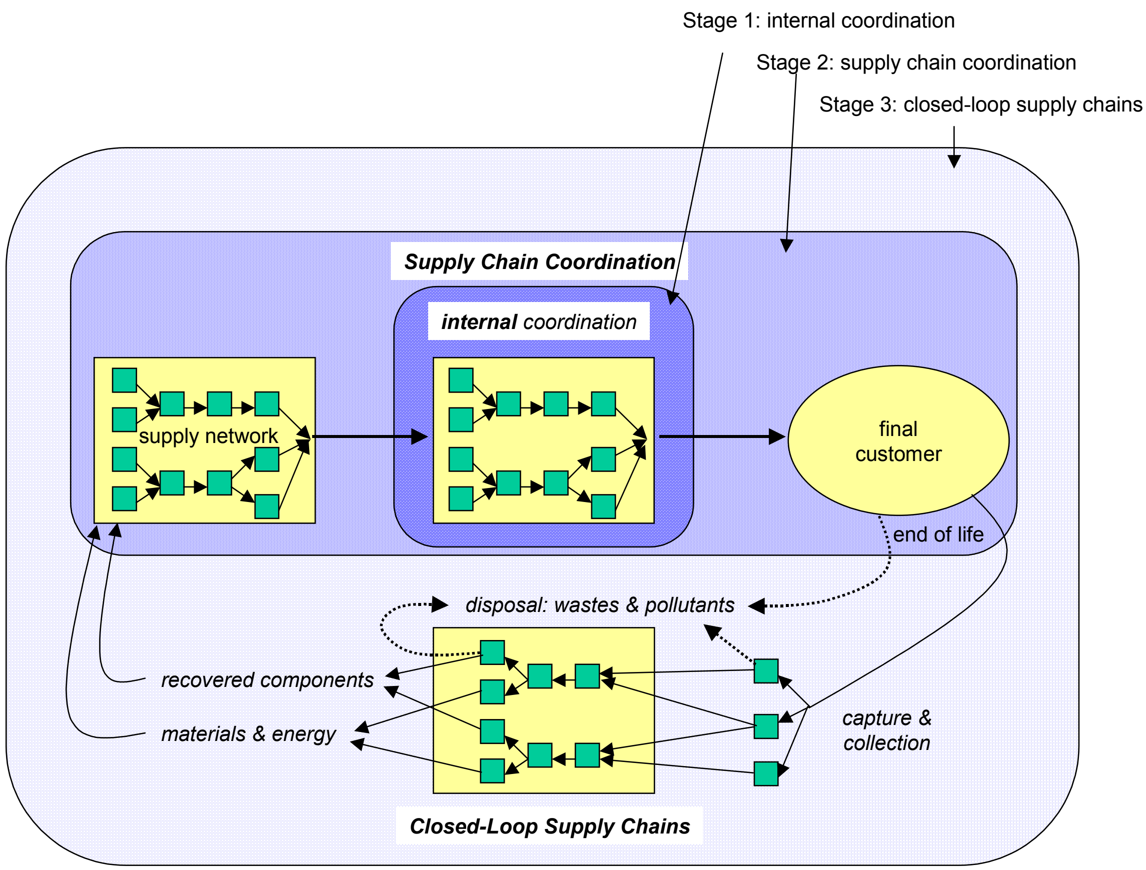

Figure 2: Extending the horizons of supply chain management