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Technical note

Integrating environmental issues into the mainstream: an agenda for research in operations management

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Abstract

Research related to the natural environment in operations management is still in its infancy. The relatively few studies to date have primarily emphasized environmental issues relating to process technologies, quality, new product development, and supply chain management. This paper reports on the work of a focus group of environmental and operations management researchers, which generated a broad framework useful for identifying fruitful research opportunities. This framework is structured along two dimensions: level of analysis and process of environmental improvement. Research areas identified by the focus group to be most promising subsequently were mapped onto this framework. Strong opportunities for building our understanding of environmental issues and improving practice are evident in the areas of manufacturing strategy, quality, supply chain management, and technology management. Research on intra- and inter-firm diffusion of best practices, environmental technology investment and transfer, and measurement of environmental performance promises to lead to a more integrative view of environmental operations management.

Keywords: Environmental issues; Operations strategy; Research agenda

1. Introduction

Over the last decade, the general public and business sector, as well as government and international agencies have begun to embrace the broad concept of sustainable development, with its proposition that economic growth can occur while simultaneously protecting the environment (World Commission on Environment and Development, 1987). In 1991, the International Chamber of Commerce issued 16 environmental principles for managing operations, which by the following year had been endorsed by over 600 firms (International Chamber of Commerce, 1991). These principles called on firms to consider their environmental responsibilities when making decisions about plant location, process and product design, and other operating factors. The World Business Council for Sustainable Development and the Coalition for Environmentally Responsible Economies also have advocated similar principles.

As a result of these pressures, a number of firms are developing explicit approaches to managing environmental issues. For example, BMW recently

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opened a plant to *disassemble* automobiles for reuse and recycling of parts, thereby moving beyond the traditional approach of simply recovering automotive scrap (Cairncross, 1992). DuPont worked aggressively to replace the use of chlorofluorocarbons by 2000, one chemical responsible for damaging the ozone layer (Schmidheiny, 1992). Other firms such as 3M, included an environmental stance in their corporate value statement, rather than just within policy statements on Environment, Health, and Safety (3M Annual Report, 1994).

Environmental operations management has been defined as *the integration of environmental management principles with the decision-making process for the conversion of resources into usable products* (Gupta and Sharma, 1996). Operations managers play a critical role in developing management systems and implementing decisions that affect environmental performance (Klassen, 1993). Product design and process technology typically determine the types of pollutants emitted, solid and hazardous wastes generated, resources harvested and energy consumed (Post, 1991; Sarkis, 1995a; Shrivastava, 1995a). In addition, supplier partnerships, transportation and logistics, and customer relationships magnify or attenuate environmental risks related to production.

Yet, despite the direct impact on and importance of environmental management to manufacturing operations, research in the discipline of Operations Management has only started to address difficult questions related to the natural environment, and remains in a pre-paradigmatic state. Much of the research to date has adopted a prescriptive tone, based on anecdotal evidence, which advises managers to consider the impact of environmental issues within a broad array of operating and performance choices (e.g., Ettlie, 1993; Klassen, 1993) and little attention has been given to environmental performance as a competitive dimension of operations (Angell, 1993).

As in the case of other newly developed fields within operations management, including service operations (Mills, 1986), time-based management (Stalk, 1988), operations strategy (Anderson et al., 1989), total quality management (TQM) (Hackman and Wageman, 1995), and most recently, health and safety (Brown, 1996), a research agenda is needed to synthesize the limited, disparate research that has been published to date, to construct a basic framework, to identify unexplored topics and to propose the most fruitful directions for research. Others, notably in the fields of public policy (e.g., Fischer and Schot, 1993), business strategy (e.g., Starik, 1995) and industrial engineering (e.g., Inoue et al., 1992) have proposed related environmental research agendas. However, this paper addresses the need for a targeted agenda by moving beyond a literature review to draw upon the joint expertise of researchers active in this area using an interactive, focus group format to provide additional face and content validity.

The primary contribution of this paper is to make sense of what research has been done in the area of environmental operations management, and to develop an extended and integrated perspective of environmental operations management which can be used to guide future research. First, we provide a brief summary of operations management issues reflected in environmental management research, specifically identifying four broad underlying research streams that have seeded much of the current thinking in environmental operations management. Second, we identify two distinct perspectives, the Constraint and the Component perspectives, that characterize research to date in environmental operations management. The more comprehensive Component perspective is then used to structure and synthesize an in-depth literature review and to identify the current state of knowledge regarding environmental operations management. Next, we describe the focus group process which resulted in the construction of a unifying framework of promising research opportunities. Finally, a more systemic, Integrative perspective is introduced and proposed to guide future research.

2. Operations management issues in environmental management research

A survey of the literature points to four major environmental management research streams that relate the natural environment to operations management in an increasingly focused manner: sustainable development and industrial ecology; strategy and corporate social performance; environmental tech-

nology and innovation; and total quality environmental management (TQEM). This research has seeded and advanced much of the current thinking on environmental operations management and provides a foundation as the field moves forward.

2.1. Sustainable development and industrial ecology

One of the most sweeping catch-phrases in environmental management is 'sustainable development', defined as meeting the needs of the current generation without compromising the ability of future generations to meet their own needs (World Commission on Environment and Development, 1987). Industrial ecology builds on the theme of sustainable development (Allenby and Richards, 1994; Graedel and Allenby, 1995), by viewing operations processes across several businesses as an ecosystem. Thus, ''. . . wastes from one industrial process can serve as the raw materials for another, thereby reducing the impact of industry on the environment'' (Frosch and Gallopoulos, 1989, p. 94). Hileman (1995) outlined the economic and environmental advantages of eco-industrial parks, which are planned sites where firms locate because of their commitments to reduce resource consumption and emissions. Combined, these concepts point to systemic connections between the natural environment and operations decisions across multiple firms.

2.2. Corporate strategy and social performance

Early research in business strategy proposed that production processes be used to enhance total socio-economic welfare, and that resources be utilized for broad social ends, not the narrow self-interests of the firm (Frederick, 1960). This led to research that measured environmental impact as one key indicator of corporate social performance (CSP) (Wood, 1991). Carroll (1979) identified four management values (i.e., economic, ethical, legal, and discretionary), which, by implication, might influence the approach adopted by operations managers on environmental issues. Other researchers posited a firm's orientation toward environmental management either as a choice along a strategic spectrum, ranging from reactive to proactive (e.g., Logsdon, 1985; Dillon and Fischer, 1992), or as stages in developmental maturity, ranging from naive to sophisticated (e.g., Petulla, 1987; Hunt and Auster, 1990; Marguglio, 1991). The implications for business performance of a proactive or sophisticated environmental management strategy have been explored, but with mixed results (Bragdon and Marlin, 1972; Klassen and McLaughlin, 1996; Russo and Fouts, 1997).

As a result, researchers began to focus on environmental management within the resource-based view of the firm. Strategic, firm-specific resources related to proactive environmental management include: continuous improvement, stakeholder management (Hart, 1995), the deployment of physical assets and technology, organizational culture, interfunctional coordination, and intangible resources (i.e., appeal to green customer segments and political acumen) (Russo and Fouts, 1997). Thus, two dominant approaches to environmental management emerge: proactive pollution prevention, which relies on strategic resources and thereby can deliver sustainable competitive advantage; and reactive pollution control, which cannot impart competitive advantage (Russo and Fouts, 1997). However, much work is required to move theory from firm- to operations-level performance and to clarify the mechanisms that act specifically within operations.

2.3. Environmental technology and innovation

Technological innovation has generally been accepted as one important basis for substantive, sustained, long-term improvements in environmental performance (Kakizawa et al., 1984; Ausubel et al., 1989; Heaton et al., 1991; Ashford, 1993). Shrivastava (1995a) defined environmental technologies as any production equipment, methods, practices, product designs and delivery systems that limit or reduce the negative impacts of products or services on the natural environment. Environmental technologies can drive down operating costs, create competitive advantages with unique environmental strategies, reduce long-term risks, and preempt regulations (Porter and van der Linde, 1995; Shrivastava, 1995b). Nehrt (1996) found that being a first-mover for environmental technologies can positively impact firm-level financial performance. Barriers to further development and implementation include managerial attitudes, organizational structures, and perceptions of

risk (OECD, 1995), although learning through multi-organization networks provides one means of overcoming these barriers (Clarke and Roome, 1995).

Finally, a growing body of research has dramatically shifted attention away from end-of-pipe environmental technologies to pollution prevention and cleaner technologies (Royston, 1979; Freeman et al., 1992), which dovetails with the earlier discussed resource-based view of the firm. Cleaner technologies extract and use natural resources more efficiently, generate products with fewer harmful components, minimize pollutant releases to air, water and soil during manufacturing and product use, and design durable goods that can be reused or recycled (OECD, 1995). Like TQEM, discussed in Section 2.4, this research offers much for operations management researchers to draw on as they explore the linkages between process and product technology, environmental management and performance.

2.4. Total quality environmental management

In the TQEM literature, the argument was advanced and developed that the TQM philosophy and tools can be leveraged for environmental management (Welford, 1992; GEMI, 1993; Hemenway and Hale, 1996; Russell and Sacchi, 1997). McInerney and White (1995) illustrated how several major firms view pollution and inefficiency to be identical problems, combining quality and environmental efforts to obtain a competitive advantage. Willig (1994) and Shrivastava (1995b) noted that the majority of environmental impacts are relatively small, and therefore are perfect candidates for continual improvement techniques. TQEM literature covers a wide range of topics such as strategic alliances (O'Dea and Pratt, 1995), the deployment of environmental quality and information systems (Dray and Foster, 1996; Ferrone, 1996; Stock et al., 1997), and performance measurement (Brown and Dray, 1996; Metcalf et al., 1996; Russell and Sacchi, 1997; Schene and Salmon, 1997).

In summary, these four basic research streams represent the context that researchers in environmental operations management draw from as they identify and explore new research opportunities. These broad streams also are, of necessity, interwoven with and have implications for environmental operations management.

3. Research in environmental operations management

When the literature on environmental management in operations is broadly examined and synthesized, two dominant perspectives emerge: the External Constraint and the Component perspectives. The first, which historically dominated much of the operations management literature, considers environmental performance requirements to be an externally imposed constraint on the operating system. In contrast, the Component perspective recognizes environmental issues as legitimate operating factors, with implications for operations strategy. Most importantly, the second perspective explicitly recognizes the potential for operations to plan for, influence and leverage environmental issues for competitive advantage both internally and externally.

Historically, environmental management was viewed as a narrow corporate legal function, primarily concerned with reacting to environmental legislation. Research and managerial action focused on buffering the operations function from external forces in order to improve efficiencies, reduce cost and increase quality. This Constraint perspective (Fig. 1)

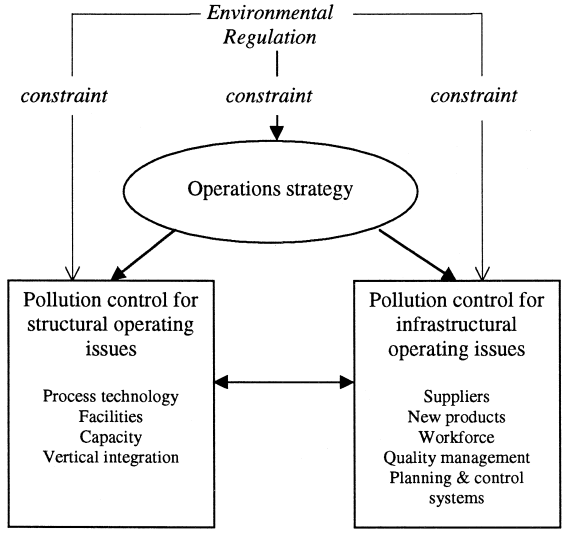

Fig. 1. Constraint perspective for environmental issues and operations management.

was reinforced by early arguments such as that by Porter (1980) and Anderson et al. (1991), in which governments and regulations were viewed as restrictions on any strategic planning process and manufacturing strategy. A constrained operations strategy was reflected in specific structural and infrastructural operating decisions (Wheelwright and Hayes, 1985; Hill, 1994) that focused only on the concept of pollution control (Bragdon and Marlin, 1972).

This original conceptualization was not unlike that of early quality management in North America and Europe, which tended to focus on inspection and control (Feigenbaum, 1961). However, in contrast to the field of quality (Garvin, 1983; Juran, 1988), far less progress has been made thus far in terms of shifting the emphasis of environmental management to prevention and proactive management (OECD, 1995; Lanjouw and Mody, 1996; Statistics Canada, 1996).

Increasingly, research in environmental operations management has moved away from the External Constraint perspective. Building on the corporate strategy and social performance literature, environmental issues can be viewed as an additional component of operations strategy, as depicted in the Component perspective (Fig. 2). Thus, unlike in the Constraint perspective, in the Component perspective operating issues such as pollution control, waste minimization, and material reduction, reuse, and/or recycling form a distinct portion of operations strategy; environmental management guides, impacts or is influenced by structural and infrastructural operating decisions (e.g., Angell, 1993; Klassen, 1995; Sarkis, 1995a; Newman and Hanna, 1996). This perspective also emphasizes that environmental issues must not be driven only by firm-level strategy, but instead, can be either reactively or proactively managed at the operational level.

Using the Component perspective as a framework (Fig. 2), the remainder of this section reviews how environmental issues have been considered in the OM research literature as a component of commonly accepted OM research topics. Although any one of several operations frameworks could have been used to synthesize environment-related research (e.g., Miller and Graham, 1981; Amaoko-Gyampah and Meredith, 1989), the Wheelwright and Hayes (1985) framework was chosen because of its emphasis on a relatively small number of clearly defined, applied decision-making areas of operations management. Their model is based on two broad categories of operating decisions: first, structural decisions (i.e., 'the bricks and mortar of an organization'), including facilities, process technology, capacity, and vertical integration; and second, infrastructural decisions (i.e., policies and systems), including suppliers, new products, workforce, quality management, and planning and control systems. Research propositions that stem from the literature are suggested throughout (see Table 1).

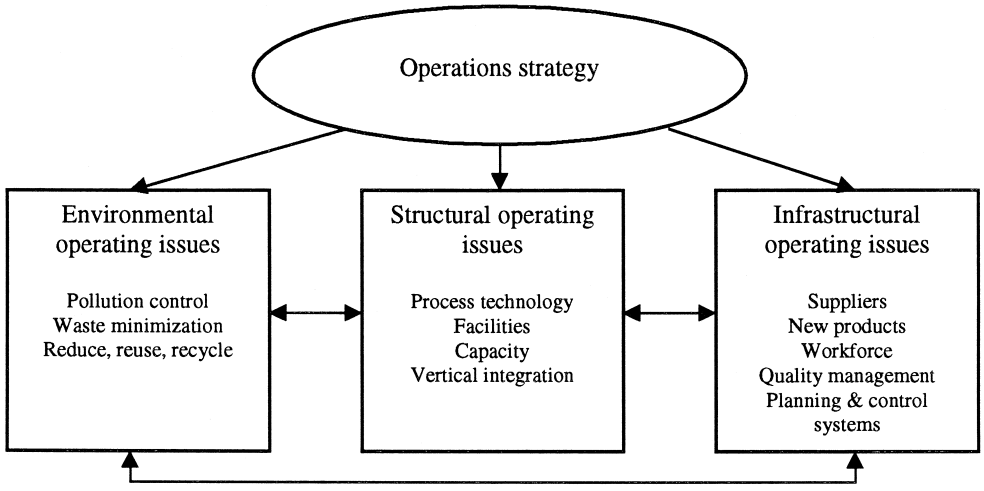

Fig. 2. Component perspective for environmental issues and operations management.

Table 1
Suggested research propositions

Facilities
- End-of-pipe pollution control technologies are favored as a facility matures in its life-cycle.
- The siting of plants within networks increasingly recognizes the importance of recapturing recycled materials.
- Local environmental regulations become less important in siting decisions as international standards (e.g., ISO 14000) are increasingly adopted over time.

Process technology
- Environmentally sustainable technologies can lower the cost of operations.
- Environmental performance is most strongly present as an order winner in batch/assembly line operations.
- Environmental technologies that minimize waste (one form of pollution prevention) are most quickly adopted in continuous process industries.
- Environmental management offers increased competitive advantage when customers are involved in the production or service process.
- Environmental improvement is increasingly costly or offers fewer competitive benefits as process investment declines and capital intensity increases.

Capacity
- Capacity expansion with an operations strategy that competes on quality is more likely to build capacity for recycled inputs than a strategy that competes on cost.
- Increasing demands for improved environmental performance favor adding new capacity while retiring old facilities, rather than reconfiguring existing capacity.
- Type and amount of capacity is related to environmental impact.

Vertical integration
- Leading-edge firms actively develop and manage reverse distribution channels (leading to a competitive advantage).
- Vertically integrated operations are more likely to result as the use of recycled materials increases.
- As waste management becomes increasingly costly, operations tend to forward integrate.
- Increasing external pressures, including cost and regulation, drive operations to outsource environmentally sensitive processes.
- Strategic partnerships or joint ventures, instead of outsourcing, are more likely to occur when environmental management has perceived customer value.

Suppliers
- Just-in-time had a negative impact on system-wide environmental performance through more frequent deliveries (energy consumption).
- Operations with more centralized purchasing are more likely to consider the life-cycle environmental implications of material and supplier choices.
- Operations with less centralized purchasing are more likely to capture customer concerns about environmental performance.

New products
- Green product design (design for the environment) can lead to less waste, greater productivity, and greater innovation.
- Life-cycle assessment can direct green design to focus on product or process innovation.
- Greener product designs are most likely to offer competitive advantages when operations compete on the basis of innovation and quality.

Workforce
- Employee suggestion systems within quality management can be effectively leveraged for significant environmental improvements.
- Top–down systems are critical to identify product-related environmental opportunities because of broad implications for the operations system.
- Bottom–up systems, such as those related to quality, are critical to identify process-related environmental opportunities.
- Staff-oriented environmental management is more likely to pursue product-related environmental improvements than line-oriented.
- Inclusion of environmental criteria in the performance evaluation of operations managers improves environmental performance and increases the use of pollution prevention.

Quality management
- The use of quality programs (e.g., Plan–Do–Act–Check, Baldrige criteria, ISO 9000) and tools (e.g., storyboards, Pareto diagrams, control charts, histograms) enhances the diagnosis of environmental problems and improvement of environmental performance.
- The inclusion of environmental criteria in quality programs enhances quality performance.

Table 1 (continued)

Quality management
· Increasing use of recycled materials increases process variability, thereby lowering conformance quality.
· A strong quality management program is a necessary condition for a strong environmental management program.
Planning and control systems
· As environmental audits become increasingly sophisticated, more opportunities for cost-effective improvements are implemented.
· As measurement and incentive systems increasingly include environmental considerations, environmental performance improves, without sacrificing other aspects of operating performance.

3.1. Structural decisions

Structural operating decisions are characterized by their 'long-term impacts, the difficulty of reversing or undoing them once they are in place, and their tendency to require substantial capital investment when altered or extended' (Wheelwright, 1984, p. 84). Structural decisions include facilities, process technology, capacity, and vertical integration.

3.1.1. Facilities

Environmental considerations can influence management decisions related to the size, location, design, or specialization of operations. The location of facilities relative to process inputs, customer markets or waste disposal locations has been considered both analytically and empirically (Schmenner, 1982; Brandeau and Chin, 1989; Appa and Giannikos, 1994; Gianinikos, 1998; Pushchak and Rocha, 1998). Of particular concern is the treatment of hazardous and non-hazardous waste disposal sites. The increasing scarcity of natural resources and/or new regulatory pressures can force facilities to locate so as to accommodate recycled materials, or alternatively to choose 'brownfield' sites (i.e., sites contaminated from earlier operations) (Apsan, 1996).

Locating close to customer markets becomes important as the need for recycling products is increasingly demanded by customers and regulators. While the costs and benefits of developing collection and recycling infrastructure were studied from a public perspective, little research has focused on facility siting, size and capabilities. At the industry-level, Bloemhof-Ruwaard et al. (1996) explored the implications of paper recycling, new technologies and relocation of mills in the European pulp and paper sector. While the relocation of facilities offered significant environmental benefits, investment in environmental technologies were shown to result in similar improvements with less economic impact. Angell (1996) found that German firms, in reaction to the 1991 Packaging Ordinance, tended to locate facilities closer to recycling plants or raw material suppliers to reduce the need for packaging and transportation.

Researchers in public policy have long argued that pollution-intensive processes in the paper, steel and chemical industries tend to locate where environmental regulations are less stringent, thereby lowering the cost of production. Generally, however, findings have been mixed, with little evidence to support the concept of pollution havens (e.g., Pearson, 1987; Bartik, 1988). Additional work must extend this research down to firm-level strategies and individual manufacturing facilities. Moreover, the management of environmental issues throughout the life-cycle of a plant or other operating facilities has been virtually ignored (i.e., initial location, operating life, technology upgrades and final decommissioning). Further research may encourage more robust initial design and later redesign of operations processes (Table 1).

3.1.2. Process technology

Within environmental operations management, process technology is one important area that has received significant research attention. Using limited empirical data, Newman and Hanna (1996) mapped out patterns of environmental management within the classic product–process matrix. Effective management of product and process waste was proposed as an order qualifier for general purpose, low-volume production. Manufacturers using job shop and batch processes can win orders based on customer perceptions of their environmental capabilities. At the other extreme, manufacturers using dedicated, high-volume technologies must have a strong environmental image as a prerequisite of doing business.

Klassen and Angell (1998) found that process flexibility can support environmental management activities. King (1994) found that analysis of waste streams offers important information to develop process innovations. Finally, the development of processes for remanufacturing has received increasing attention (Haynesworth and Lyons, 1987; Lund, 1994; Guide and Srivastava, 1998), as has the implementation of cleaner technologies that prevent pollution (Klassen, 1995; OECD, 1995). Based on these disparate efforts, opportunities remain to explore the linkage between environmental and process technologies and performance outcomes (Table 1).

3.1.3. Capacity

Very little research has explored the influence of the natural environment on decisions about the amount, type and timing of capacity expansion or decommissioning. At first glance, capacity decisions may appear to have little direct linkage to the environment, yet the implications of changing regulations and raw materials can directly affect capacity. For example, air regulations in the US steel industry can lower effective capacity unless additional controls are installed or process modifications are made. Moreover, regulatory limits also vary often with local atmospheric conditions. The relatively recent trend toward permit trading (Ledyard and Szakaly-Moore, 1994; Levinson, 1997), combined with the fact that pollutant emissions vary by product mix, further complicates any capacity planning. A straightforward extension might be to include environmental variables in both the objective function and constraints of traditional capacity planning models.

Operations strategies that entail the installation of new capacity also have become more complex as regulatory and consumer demands for returnable/recyclable packaging increase. Capacity must be added on two fronts simultaneously, first, to produce the product, and second, to recycle all or part of the product. Such requirements have pushed BMW to build an experimental facility in Germany for *disassembling* automobiles (Thierry et al., 1995). Such difficult, inter-linked capacity issues extend to other industries (Brennan et al., 1996), suggesting that the scope of capacity planning must expand to explicitly account for new environmental pressures (Table 1).

3.1.4. Vertical integration

Reverse logistics and environmental supply chain concepts focus on re-engineering the supply chain toward the development of a closed-loop system emphasizing flows of material from consumers back to manufacturers (Sarkis, 1995b; Giuntini, 1996; Handfield et al., 1997), often by way of collection, recycling, and secondary raw material processing. The concept of reverse logistics reflects an extension of the life-cycle management and the cradle-to-grave environmental philosophies. Barry et al. (1993) argued that innovative firms practice design for the environment and develop reverse distribution channels for the recovery of used packaging and products.

The high transaction costs of gathering, controlling the quality of and utilizing recycled materials argue for greater vertical integration in firms. In addition, as waste products become more difficult to handle and carry greater contingent liabilities, operations might be expected to forward integrate, e.g., plants within the steel industry have moved to own and manage their own disposal sites. On the other hand, some organizations respond to environmental pressures by teaming with supply chain partners (O'Dea and Pratt, 1995) and by outsourcing all environmentally sensitive operations, such as the transportation of crude oil. Research is needed to identify contexts where each of the three structural options (i.e., vertical integration, partnering or outsourcing) offers long-term competitive advantage (Table 1).

3.2. Infrastructural decisions

Infrastructural operating decisions are 'viewed as much more tactical in nature because of the myriad of on-going decisions they encompass, the need to link them to specific operating aspects of the business, and their tendency not to require large capital investments at a single point in time' (Wheelwright, 1984, p. 84). Infrastructural decisions include those relating to suppliers, new products, workforce, quality management, and planning and control systems.

3.2.1. Suppliers

Research in supply chain management is an actively growing area for environmental operations

management. This research emphasizes green purchasing decisions and the development of supplier strategies that integrate environmental concerns (Sarkis, 1995b; Bryson and Donohue, 1996; Handfield et al., 1997; Carter et al., 1998). At the simplest level, these concerns add another criterion to the purchasing decision for ancillary materials (e.g., minimum recycled content in paper) (Min and Galle, 1997). However, as the criticality of a particular supplier increases (due to volume, technological capability or cost), demands for improving environmental performance may have significant implications for the cost and quality of the final product or service.

If environmental concerns extend across multiple suppliers and customers in a supply chain, questions arise about the value of and best approach for leveraging environmental capabilities throughout. Hass (1996), for example, developed a generalized 'green' supply channel network model for a British hosiery manufacturer. The US automobile industry pressured its suppliers to implement environmental management programs in preparation for ISO 14000 (Bergstrom, 1996); however, the extent of this trend is currently unclear. ISO 14000 may not become as popular as the ISO 9000 quality standards because environmental management relies less on supplier activities. Other questions also remain about the environmental impact different approaches to distribution and just-in-time supply relationships, where more frequent deliveries increase energy consumption. At a more general level, customer concerns about social responsibility must be integrated with other dimensions of value when managing suppliers (Table 1).

3.2.2. New products

As with process management, research in new product development has started to study mechanisms for, the process of, and outcomes from the inclusion of the natural environment in decision-making. Like process innovation, green product design is an important element in environmental management (Dechant and Altman, 1994; Halme, 1994), with potential benefits including less waste, greater productivity and higher levels of innovation (Porter and van der Linde, 1995). Navinchandra (1990) and OECD (1995) stressed that changes are necessary in engineering design, research, and education as a result of the shift from regulatory-driven, end-of-pipe technologies to more pollution prevention-oriented product technologies. The development of stronger linkages between engineering and operations, using approaches such as concurrent engineering, can provide earlier and better opportunities to minimize the environmental impacts of both production processes and products during use.

Product stewardship, where firms take ownership of their products from 'cradle to grave', has been a centerpiece of efforts to push firms to recognize their environmental responsibilities for any product or service (Barry et al., 1993; Lund, 1994; Hart, 1997). In response, product life-cycle assessment (LCA) has become more widely applied as a tool to analyze the environmental impact from raw material extraction through to post-consumption fate, including intermediate stages of product manufacture, distribution, and use (Fava et al., 1991; Cattanach et al., 1995; Stuart et al., 1999). Using LCA, broad classes of product alternatives can be compared (e.g., cloth vs. disposable diapers), products can be certified as environmentally friendly (e.g., retread tires in Germany), or alternate manufacturing processes can be compared for a particular product (e.g., integrated steelmaking vs. electric arc furnace steelmaking).

As the rigor of LCA continues to develop, research in operations management must identify how this tool can guide product development. To that end, design for the environment (DFE) draws on data from LCA to design products with minimal environmental impact (Allenby, 1996; Fiksel, 1996). Veroutis and Aelion (1996) constructed an implementation framework for DFE and Cattanach et al. (1995) compiled a Handbook of Environmentally-Conscious Manufacturing for managers and design engineers. Other researchers have begun to work on the development of product screening procedures that begin to quantify a product's potential environmental risk, taking regulatory climate and customer perceptions into account (Reinert et al., 1996). Finally, in terms of potential benefits, Gouldson (1994) identified linkages between Volkswagen's history of environmentally-related product innovation and their operating decisions.

While it might appear that environmentally-oriented design should be well-accepted, significant

hurdles remain because DFE and LCA are unfamiliar to product designers and not well-integrated with other design tools (Smith and Melnyk, 1996). Dray and Foster (1996) cautioned that information availability and acquisition will influence the extent to which life-cycle analysis and design for the environment concepts become integrated into operations. Even if the newer DFE/LCA tools are used, product developers struggle to trade-off different aspects of performance. In particular, quality requirements may conflict with environmental performance, particularly when 'green' benefits are not strongly demanded by the customers (Klassen, 1995). Additional research is needed to help managers reconcile these difficult issues (Table 1).

3.2.3. Workforce

Researchers outside the field of operations management have considered the role of culture (Wehrmeyer and Parker, 1996), training and education (Dechant and Altman, 1994) and the importance of measurement systems (Brown and Dray, 1996) for encouraging environmental activities of the workforce. However, little research was found in operations management that has studied the role of operations managers and employees, particularly at the facility level. Similar to quality management (Juran, 1988), the direct involvement of front-line operations personnel may prevent environmental problems from occurring and identify both opportunities and processes for improvement. Yet, public sensitivities, especially to spills and other environmental disasters, frequently demand that senior management carefully coordinate a timely response. Changing regulations also require interpretation and audit by skilled experts. King (1995) found that specialized pollution control departments either insulate operations from environmental pressures or channel information to them for improvement. Thus, contextual variables such as organizational structure may determine the relative effectiveness of centralization or decentralization for managing environmental issues (Table 1).

3.2.4. Quality management

While the relationship between the natural environment and quality management has received considerable attention as noted earlier under TQEM (Section 2.4), researchers are only beginning to explore how these programs can best be integrated. The costs and benefits of quality and environmental management have a number of theoretical similarities, suggesting that a cost of quality model may be applied to environmental issues (Klassen and McLaughlin, 1993; Madu et al., 1995). Green (1993) adapted Deming's 14 points to illustrate how they can provide a foundation for building an effective environmental program.

A recent survey by the Total Quality Management Center of the US Conference Board highlighted several benefits of this synergy, including decreased costs, improved long-term position, increased customer focus, and process simplification (Powell, 1995). Nonetheless, 20% of the responding firms indicated that their environmental programs were not closely linked with quality because of poor organizational design, little implementation of TQM and little awareness of potential synergies. King (1994) also reported that learning in environmental management programs was unrelated to the existence of a TQM program. Moreover, some managers perceived that the demands of consumers and the public were different (Sissell and Mullin, 1995), thus prompting separate programs to better address the needs of each.

Thus, two patterns of thought have begun to emerge. The first proposes that quality tools should be applied as needed to environmental issues based on public, regulator and customer demands. In contrast, the second argues that environmental concerns must be subsumed under a broadened definition of quality (e.g., Hanna and Newman, 1995). The international movement toward certification of environmental management systems (e.g., ISO 14000)—usually based on earlier quality standards (e.g., ISO 9000)—certainly favors the latter view. ISO 14000 has encouraged the application of continuous improvement models such as Plan–Do–Check–Act (PDCA) to ensure environmental improvement. Puri (1996) also pointed to potential synergies and recommended that the implementation of multiple ISO standards be closely coordinated. Empirical evidence is consistent with this advice, as the most proactive 'green' firms in the German Dual System had achieved earlier ISO 9000 certification (Angell, 1996). Future research can explore effective means for capturing any synergies, as well as assess when

independence between environmental and quality programs should be maintained (Table 1).

3.2.5. Planning and control systems

Planning and control systems enable both proactive and reactive environmental activities. These systems often implicitly include structures and procedures that prevent, limit and monitor environmental impacts. Environmental management standards such as ISO 14000 provide guidance for developing environmentally-friendly organizational systems, although individual operations must adapt corporate policies to site-specific risks (Rondinelli and Vastag, 1996). Environmental information and control systems have recently undergone preliminary examination to explore their organizational impact (Petulla, 1987; Marguglio, 1991; Dray and Foster, 1996). Stuart et al. (1999) developed methods for tracking environmental impact using activity-based costing allocations.

For planning, Bryant (1978) offered a methodology for assessing the environmental impact of operational activities. Bodily and Gabel (1982) developed a model for production planning at a steel plant facing environmental controls. In terms of execution, Keeney (1988) outlined a procedure for developing a hierarchy of scheduling objectives based on input from concerned stakeholders. Finally, order release and production control also becomes more complex with re-manufacturing (Haynesworth and Lyons, 1987), leading to additional scheduling constraints (Guide et al., 1997) and inventory challenges (Guide and Srivastava, 1998).

For both control and improvement of the operations system, the environmental audit is a specific operational tool with far-reaching implications for researchers (Table 1). Not only can auditing be used for measurement, regulatory compliance and public disclosure (Obbagy and Bragg, 1993; Fisher, 1994), but operations slowly is recognizing that it can be extended to identify opportunities for cost-effective environmental improvements (Ledgerwood et al., 1992; Smith, 1994).

3.3. Summary

Research activity directed toward environmental operations management certainly has gained momentum since the early 1990s. However, the field remains largely undeveloped, with many research gaps in and extensions possible from the literature (Table 1). In fact, scholars outside of the field of operations management have often been responsible for initially identifying critical linkages between environmental issues and operations. At this time, the bulk of empirical research on operations environmental management issues has been directed toward quality, strategy, supply chain and process management, and to a lesser extent to product development. In contrast, analytic modeling has emphasized facility location and scheduling decisions.

Environmental management stands in stark contrast to the field of quality management, which has undergone dramatic development over the last three decades. Based on extensive theoretical and empirical research, customer focus, prevention, high standards and continuous improvement now are generally accepted by academics and practitioners as the principle objectives and enablers of strong competitive performance. No such common paradigm yet exists for environmental operations management, although the need for and benefits of a commonly accepted foundation cannot be overemphasized for sustained theoretical progress. Such a foundation would serve to integrate strategic and tactical issues of environmental management into operations research frameworks.

4. Research methods

The central goal of this paper is to develop a research agenda focused on environmental operations management, and in doing so, spur debate about the direction for future scholarly investigation in this field. A focus group was employed to begin structuring questions concerning the research relationships between operations and environmental management. The focus group process also served as a counterpoint and extension of the preceding literature review.

The focus group technique has been used for many years in marketing research (Goldman, 1962), and involves convening a small group of six to eight participants for a structured but open-ended discussion about a particular topic. Focus group research can adopt several forms, including exploratory, clini-

cal or phenomenological approaches (Calder, 1977; Morgan and Krueger, 1997). An exploratory approach was used with a three-fold purpose: first, to critique the basic issues raised in the literature review; second, to identify and structure new research questions raised by the group as important; and third, to derive a vision for future research.

This initiative was part of a larger effort within the Academy of Management (AoM), which sought to prepare research agendas for incorporating environmental issues into all of the major AoM research disciplines through a literature review and an interactive focus group. To that end, 2 days of conference sessions entitled 'Seeing 20/20: Casting the Academy's Environmental Research Agenda into the Next Millennium' were sponsored by the Organizations and the Natural Environment (ONE) Interest Group at the AoM meeting in Boston, MA, in August, 1997. In addition to Operations Management (OM), the Business Policy and Strategy, International Management, Organizational Behavior, and Social Issues in Management divisions participated.

Five basic steps were followed. First, facilitators prepared a basic summary of the relevant literature as an input to the OM focus group discussion. However, the detailed literature review (Section 3) was not distributed to the participants to avoid overly biasing their views. Second, an announcement for the two pre-conference sessions was published in the Academy's printed program and sent by e-mail to members of the ONE interest group, as well as the OM and Technology and Innovation Management (TIM) divisions. Participants who were unable to attend were requested to respond by e-mail to four basic questions about significant contributions to date, research opportunities, relevant literature streams, and appropriate research methodologies. Third, the first pre-conference session involved parallel focus group sessions, separated by discipline, to develop environmentally-related research agendas. Fourth, during the 20-h period between the two sessions, the facilitators synthesized comments from the focus group and prepared briefing notes for two leading operations management experts to provide a critique and additional insight during the second session. Fifth, the second pre-conference session involved a series of half-hour panel discussions where the facilitators from each discipline presented their agendas and received feedback from all participants, discussants, and other attendees.

4.1. Focus group

The first pre-conference session involved parallel focus group sessions, separated by discipline, to develop environmentally-related research agendas. After a 15 min plenary session, the operations management focus group met for 3 h with the authors as facilitators.

To begin, the five focus group participants and two moderators introduced themselves and outlined their thoughts regarding the most significant contributions to date at the interface between operations management and the natural environment (Two additional researchers responded by e-mail to queries prior to the focus group). Then, to initiate discussion, the facilitators led a structured brainstorming session (Brassard and Ritter, 1994) during which participants took turns answering the following question: what are the research opportunities for integrating the natural environment into research in operations, innovation, and technology? Each opportunity was written on a separate piece of paper; all ideas were recorded without critical evaluation.

Next, these opportunities were aggregated using the Affinity Diagramming technique (Brassard and Ritter, 1994), where participants took turns clustering them according to their perceptions of 'natural', as yet unlabeled, categories. When participants differed, the preliminary categorization was challenged and debated within the group as a whole. As such, this process forced participants to articulate their criteria for categorization. After achieving a general consensus, participants were encouraged to further structure these aggregated categories into a general research framework. Finally, the group was directed to brainstorm to identify key elements of a 'vision' for how environmental issues should be viewed in operations management over the longer term, along with research priorities, methodological approaches, and potential barriers.

To ensure the successful conduct of the OM focus group, we employed the recommended principles of Axelrod (1975) for a focus group (see also Byers and Wilcox, 1991).

(1) A Clearly Understood Objective: At the outset, all participants agreed that the objective was 'to develop a research agenda for incorporating environmental considerations into operations management and technology research'.

(2) Effective Recruiting of Participants: An announcement for the focus group was published in the printed conference program and via e-mail. The announcement asked for participation by management scholars who were experienced and interested in the interaction between operations management and issues relating to the natural environment.

(3) Homogeneity Within the Group: Descriptive profiles of the participants are summarized in Table 2. All participants had previous direct involvement in theoretical or applied research related to environmental operations management.

(4) Active Listening: The moderators employed quality tools, including the brainstorming and affinity diagramming techniques (Brassard and Ritter, 1994), as the focus group discussion progressed to ensure that every participant had an opportunity to provide substantive input.

(5) Well-Prepared Moderators: In preparation for guiding the focus group session, the moderators prepared a basic summary of the previous research on environmental operations management (Section 3). The two e-mailed responses to our call for participation also served as preparation material of the focus group and were later integrated into the focus group outcomes.

(6) Free Flowing Dialogue: After generating ideas using the structured brainstorming technique, the participants used the Affinity Diagramming technique to generate a higher level classification scheme. Brainstorming was also critical in identifying important contributions to date and the key elements of a 'vision' for how environmental issues should be viewed in operations management over the longer term.

(7) Restrained Group Influence: The moderators led the brainstorming session and each participant provided ideas, in turn, along with the moderators. Each participant had the same number of opportunities to provide ideas for research areas which are most important for understanding the interface between operations management and the natural environment. Participants were allowed to pass if they had no further ideas when it was their turn to brainstorm (Brassard and Ritter, 1994). When it came time to aggregate and compile these ideas into a framework, the use of the Affinity Diagramming technique ensured that every individual had an opportunity to sort the data, provide input, and critique

Table 2
Descriptive profiles of focus group participants

Participant #1 (moderator)
- Assistant professor of OM
- Public research university, USA
- Environmental operations management

Participant #2 (moderator)
- Assistant professor of OM
- Public research university, Canada
- Environmental operations management

Participant #3
- Director
- World Resources Institute, USA

Participant #4
- Senior lecturer in Technology Management
- Public research university, UK
- Environmental influences on innovation and strategies

Participant #5
- Doctoral student in OM
- Public research university, Canada
- Hazardous waste management

Participant #6
- Associate professor of Strategic Management and Public Policy
- Public research university, USA
- Environmental policy and management

Participant #7
- Chaired professor of OM
- Public research university, USA
- Global operations and environmental management

Participant #8 (e-mail)
- Associate professor of Political Science (doctorate in Management Science)
- Public research university, USA
- International environmental politics

Participant #9 (e-mail)
- Associate professor of Commerce and Business Administration
- Public research university, Canada
- Organizations and the natural environment

the results. The subsequent open discussion offered additional opportunity for each participant to add ideas.

(8) Competent Researchers: As evidenced above, the focus group moderators ensured that the necessary details encouraged an effective focus group session. During the 20-h period between the two conference sessions, the moderators synthesized comments from the focus group and prepared briefing notes for two leading operations management experts to provide a further critique of the focus group output during a second plenary conference session. The senior faculty discussants for the focus group-generated operations management research

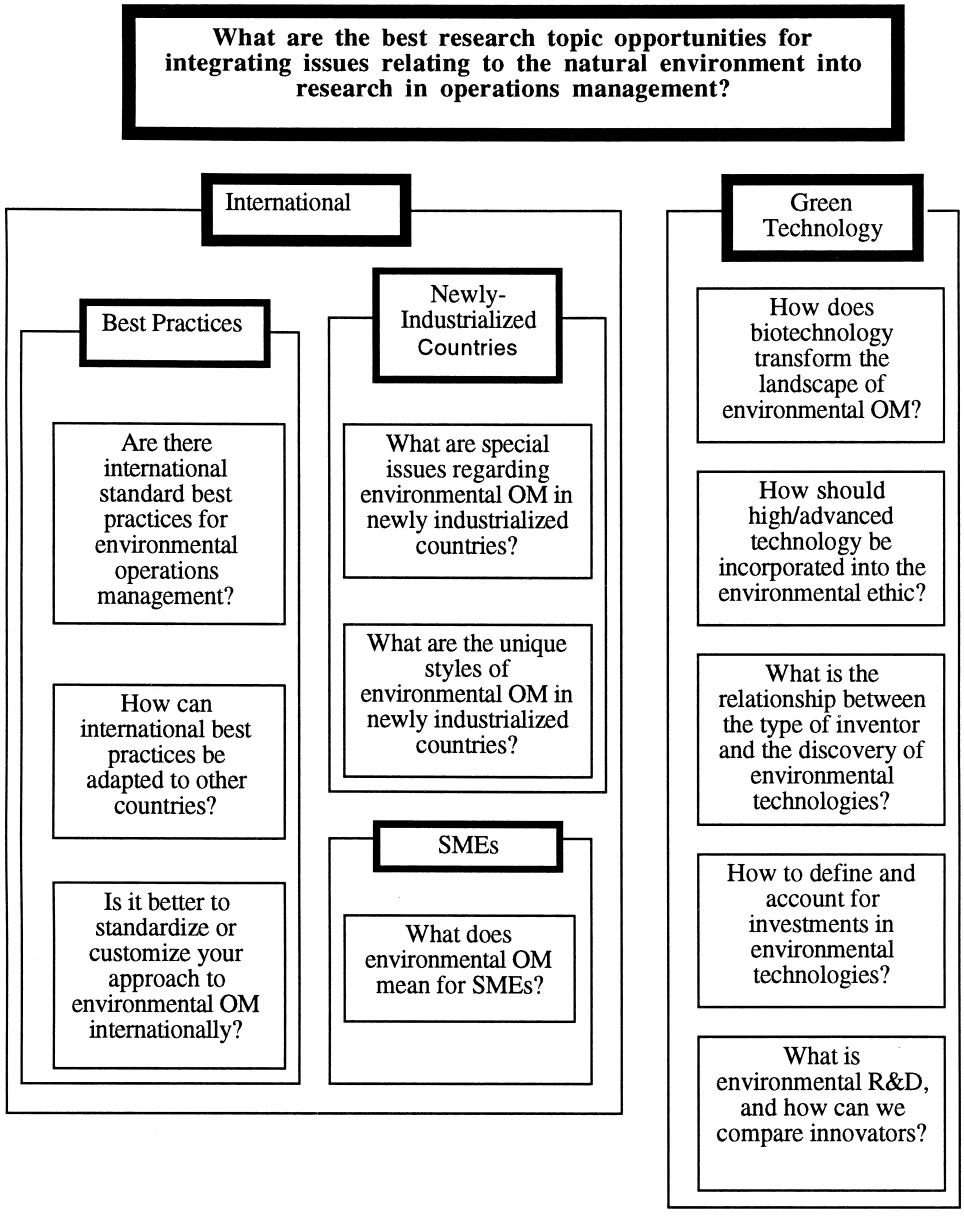

Fig. 3. Results of brainstorming and affinity diagramming techniques.

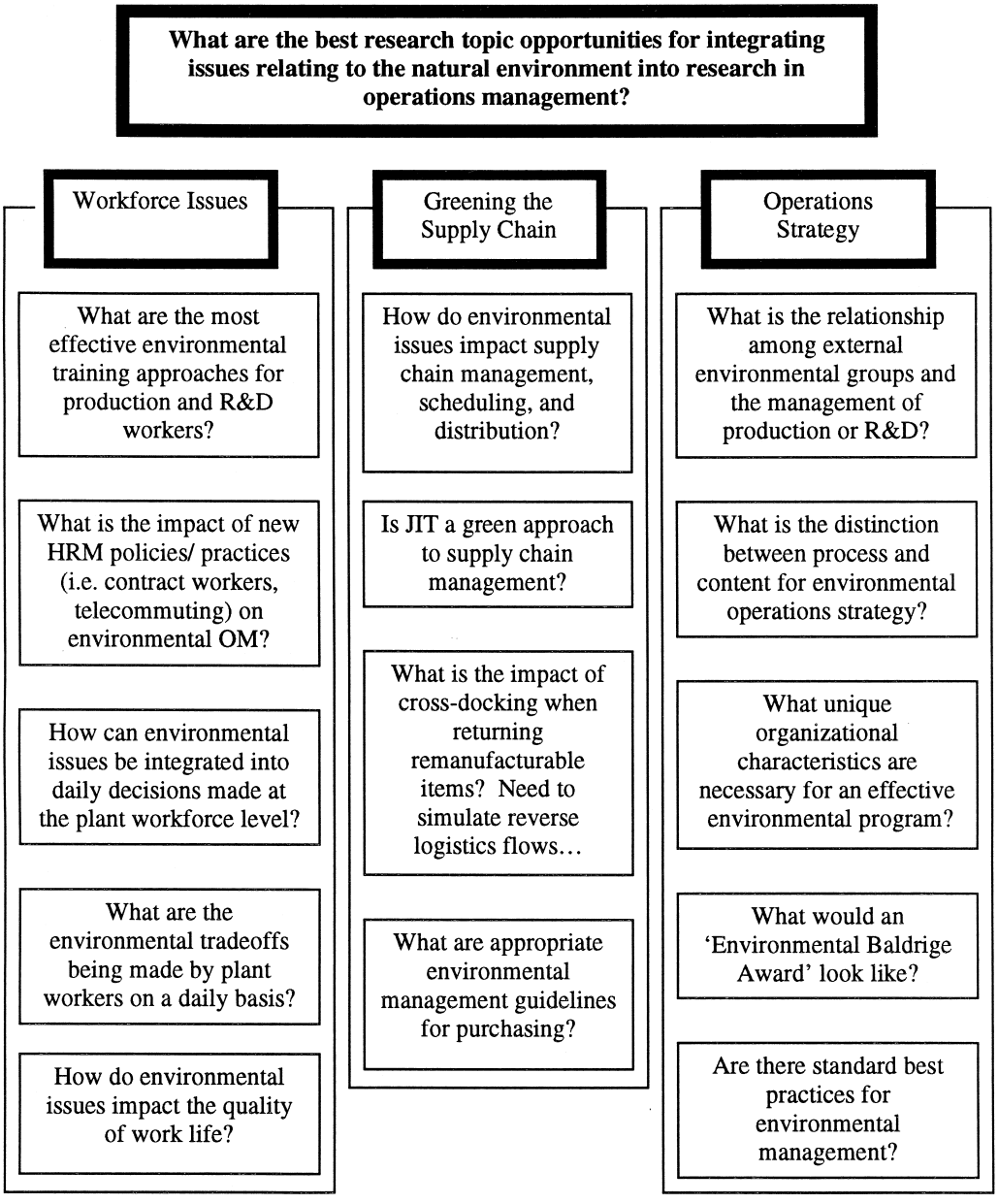

Fig. 3 (continued).

agenda were Dr. Jeffrey Miller of Boston University, and Dr. Clay Whybark of the University of North Carolina at Chapel Hill. Their feedback comments and ideas were used to further refine the output of the focus group, particularly with regard to the proposed research agenda framework.

5. Research agenda for environmental management in operations

5.1. Proposed research themes

The majority of the discussion focused on identifying promising avenues of research and then syn-

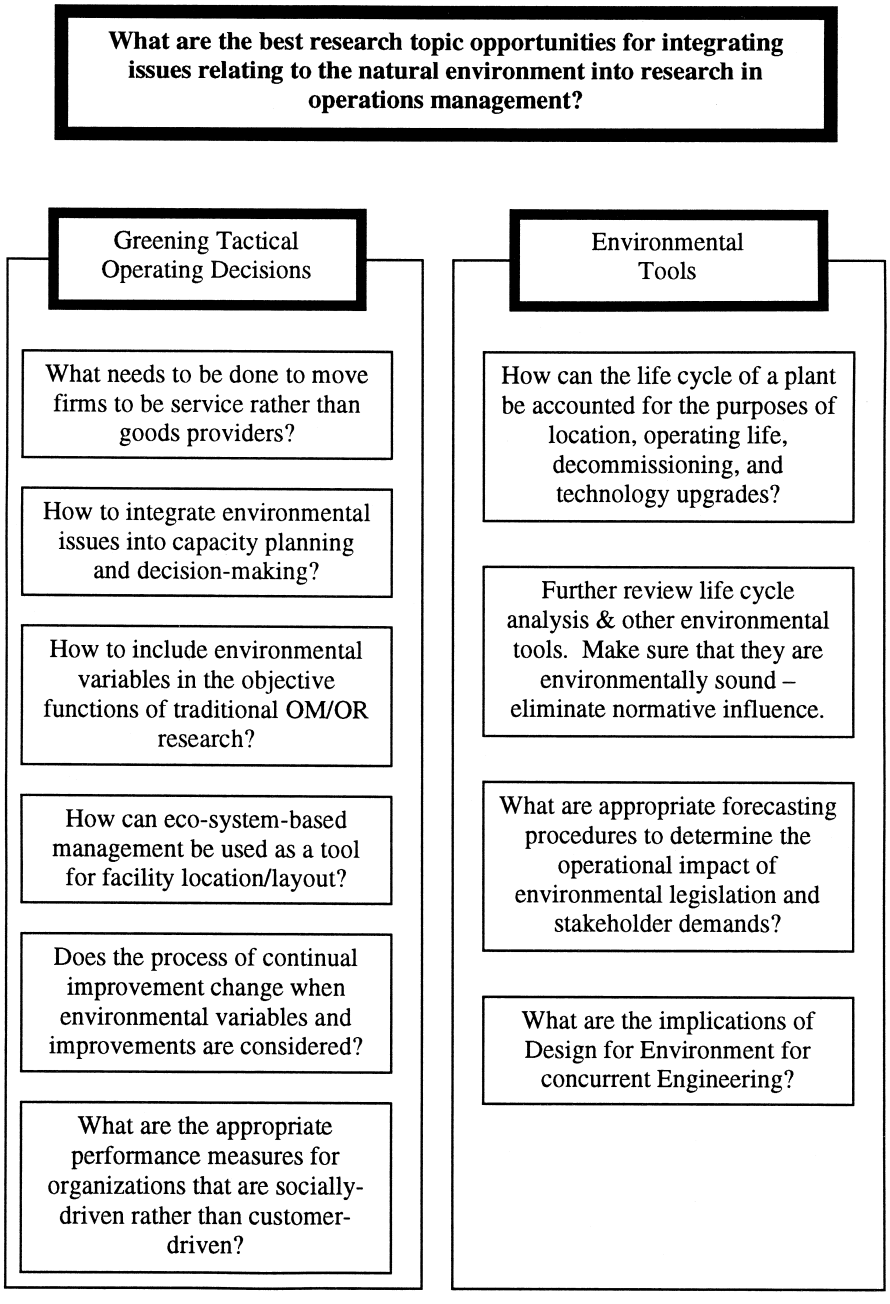

Fig. 3 (continued).

thesizing these ideas. Seven major clusters or themes were identified, most with multiple items. Subsequently, based on consensus, the group labeled each theme (Fig. 3): international environmental issues, green technology, workforce issues, greening the supply chain, operations strategy, greening tactical operating decisions, and environmental tools. The international environmental issues category was it-

self aggregated from several sub-themes, namely best practices, newly-industrialized countries, and small- and medium-sized enterprises (SMEs).

A number of points of convergence and divergence were immediately evident between the focus group output and the literature review summarized earlier. First, the overarching research themes of greening the supply chain, operations strategy, greening tactical decisions and environmental tools, along with the more detailed underlying research questions, fit nicely into the Component perspective. Second, the dominant areas of earlier research cited in the literature review, namely product development, process management, strategy and quality, also were highlighted by the focus group as important ongoing opportunities. However, the focus group theme of green technology has been developed only to a very limited extent under process technology and product development. Finally, the more challenging areas of research that explore the implications of the international context or multi-firm operations systems have not been effectively captured in the literature review. These findings emphasize an important advantage of developing a future research agenda based on a comprehensive literature review together with the input of a focus group; a richer set of ideas emerge that is more likely to balance both historical and emergent trends.

5.2. Conceptual framework for research opportunities

The focus group was encouraged to provide more general theoretical structure for these seven research themes. These content-based research themes (Fig. 3) provide many familiar 'handles' onto which OM researchers can readily extend their current research. Yet, research in operations strategy and quality—two more advanced fields of operations management—have developed a richer conceptual foundation, in part, through the explicit recognition of both 'content' *and* 'process'. Thus, the focus group participants stressed the need to capture the process dimension of environmental management. The seven different research themes can be seen as part of an important cyclical process of strengthening environmental management. After extensive discussion, the group reached consensus around two key dimensions to help structure the research framework, namely the process of environmental improvement and the level of analysis (Fig. 4).

In terms of the 'process of environmental improvement' dimension, the group's thinking was not unlike that espoused by Deming (1986) in the PDCA cycle for quality improvement, although on a much larger scale. First, operating managers must become aware of the importance of environmental issues and specific areas needing improvement. Once awareness and values have been built within an organization, strategic planning can take place. Strategic planning then leads to technological development, broadly defined, and then to operational implementation and deployment throughout the operations of the firm. The final step is monitoring and follow-up, which fosters an increased awareness of areas needing further and continual improvement. The expectation is that as management cycles through this process, organizational learning enables a shift from reactive adjustment to proactive innovation (Post and Altman, 1992).

The level of analysis dimension reflects much of the current diversity in the environmental operations management literature, which spans from narrower product- and process-level issues to operating strategy, and ultimately to broad international concerns. The highest two levels noted here, nation and economic region, were explicitly included by the group because environmental management was viewed as both transcending national boundaries and varying by geo-political setting. Explicit recognition of the level of analysis was thought to guide researchers toward appropriate literatures and research methods.

As a final step, the most promising research opportunities identified earlier (Fig. 3) were mapped onto the resulting two-dimensional conceptual framework (Fig. 4). The plotted opportunities are not meant to be exhaustive, but do reflect focus group consensus on important priorities for future research. For each of the research opportunities, respondents argued for a rich diversity of approaches to compensate for the inherent drawbacks of any one methodology (Meredith et al., 1989). The measurement of environmental performance is expected by the group to be particularly problematic, and an area that could benefit from coordinated multi-disciplinary research

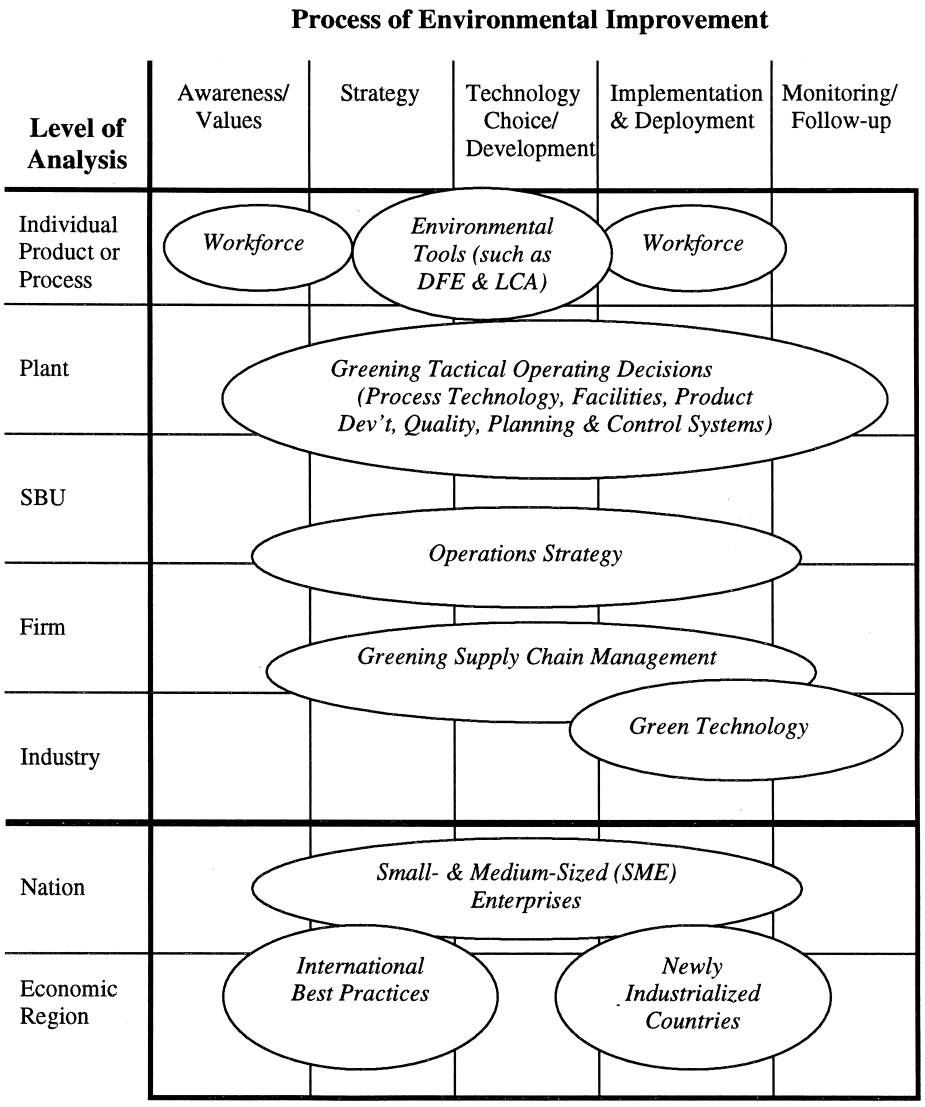

Fig. 4. Research opportunities for integrating environmental considerations into operations management.

in operations management, accounting, strategy, and environmental management.

Much of the existing research in environmental operations management has concentrated on mid-level issues and questions. In contrast, much less attention has been given to front-line workforce issues and environmental tools. Operations management researchers should seek to understand the impact of environmental pressures, issue awareness, and individual environmental values on workforce stress, conflict, management, and learning. To what extent do human resource policies impact the ability to effectively implement environmental initiatives? In addition, much can be learned about the appropriate role of individual workers and self-directed work teams in developing environmental plans for operations strategies, and in monitoring and evaluating environmental performance. A related issue has to do with workforce training requirements for environmental tools such as design for environment and

life-cycle analysis. Research directed at the individual product- or process-level will often require, however, that data be collected at an initiative-, process-, or even the individual worker-level rather than at the more-commonly-used and easier-to-reach firm-level.

Firm- and industry-level issues have also been largely left to researchers outside the field of operations management. Particular challenges and significant opportunities for theory development were highlighted for the difficult task of integrating environmental issues with operations management at the highest levels. The challenges primarily involve controlling for the numerous cultural differences between various nations and economic regions. The research opportunities are noted in the lower portion of Fig. 4, where the unit of analysis extends beyond the functional level into issues that, while they may impact operations within the firms, also transcend firms and industries. Focus group participants specifically identified intra- and inter-firm diffusion of best practices and the transfer of environmental technologies as critical areas needing research. For example, increasingly through international treaties, industry associations and certification processes such as ISO 14000, environmental management practices have become more standardized, particularly for large multinational firms. Yet, questions remain as to whether these practices should be simply transferred to the manufacturing operations of newly industrialized countries (NIC) which have different public policies, societal pressures and environmental concerns. Local adjustment for internal and external environmental risks may be necessary (Rondinelli and Vastag, 1996). Thus, international issues such as these are likely to present the greatest research challenges.

5.3. Integrated perspective

As a final major topic of discussion for the focus group, participants were asked to identify elements of a vision of environmental operations management for the longer term. Focus group participants proposed that the environment should be included on an equal basis with current concerns about cost, quality, service and flexibility. Environmental considerations must be endemic rather than merely external constraints. Participants expected that the short-term will likely reflect a Component approach to tactical changes (Fig. 2), while in the long-term, management should evolve toward a more fundamental integration of environmental concerns into the transformation process. Subsequently, this thinking was illustrated by the moderators as what we termed the Integrated perspective (Fig. 5).

With this perspective, environmental management is more than a series of individual operational activities, but also involves an integration with corporate

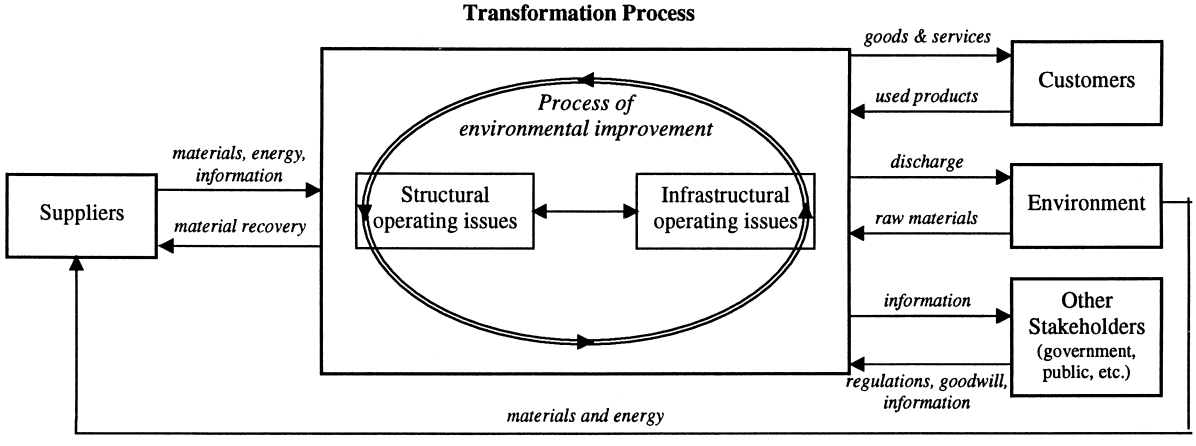

Fig. 5. Integrated perspective for environmental operations management.

level concerns throughout the operations system. Hence, environmental considerations are relevant at multiple levels of an organization, encompassing operations strategy, including structural and infrastructural dimensions, and the broader value chain of customers, suppliers *and* other external stakeholders. Focus group participants indicated a general consensus that the natural environment must be incorporated into the fundamental model of operations as a transformation process. As such, the choice of inputs, type of outputs and responsibility for these outputs, and environmental costs and implications must be considered as a fundamental part of this model.

Probably the most difficult set of issues was raised near the end of the focus group discussion. While operations have frequently been forced to manage synergies and trade-offs, the overarching objective has always been to improve customer value. Focus group participants therefore argue that the environment must be integrated with management's efforts to address the needs and concerns of all stakeholders, including customers, suppliers, employees and stockholders, a challenge which in the past has received little research attention.

These important ideas were synthesized by the moderators after the workshop into the following vision statement: *Considerations related to the natural environment are integrated into all transformation processes, at both strategic and tactical levels, so that these processes are increasingly efficient and effective, thereby creating value for all stakeholders*. Clearly, researchers in operations management face a daunting challenge to redefine and extend our theoretical and empirical base to capture this broadly inclusive objective.

6. Conclusions

One of the biggest challenges facing the field of environmental operations management is extending the historical 'common wisdom' about managing operations. Much research, management education, and practical application has focused on buffering the operations function from external influences, including the natural environment, in order to improve efficiencies, reduce cost and increase quality. When the natural environment was considered, it was typically recognized or modeled as an external constraint, requiring operations to work within prescribed limits. Once this basic assumption is relaxed, a fundamental question arises about how best to pursue research on environmental issues in operations: should environmental management be considered a separate research stream with its own strategic framework, or should environmental issues be integrated into existing operations management research frameworks and areas? While the complexity of environmental issues might favor the former approach, the greatest contributions can be achieved by pursuing opportunities within a more integrative framework.

Researchers can no longer ignore the importance of this inquiry. Research to date into environmental considerations is most easily compartmentalized into content areas drawn from operations strategy. The primary areas of emphasis have been quality, along with operations strategy, supply chain management, and product and process technology, which are collectively beginning to contribute to a more systematic knowledge base. It is reasonable to expect that these research areas will continue to hold the greatest promise for advance in the short-term. However, more integrative contributions are needed in the longer term including intra- and inter-firm diffusion of best practices, environmental technology transfer, and environmental performance measurement. Yet, these content areas represent only one portion of the challenge, as the process by which operations can develop new capabilities in environmental management also must be thoroughly explored.

We propose an important, but not unachievable, transformation for operations management. By viewing environmental issues in a multi-dimensional manner as constraints to be addressed, issues to be influenced and competitive opportunities to be leveraged, many new research streams and questions are raised. The inherent complexity of environmental issues—with their multiple stakeholders, uncertain implications for competitiveness and international importance—present significant challenges to researchers. Yet, by pursuing such research, both theory and practice can make significant progress toward

achieving the vision of environmental operations management.

Acknowledgements

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