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Resources and Capabilities for Sustainable Operations Strategy

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ABSTRACT: Researchers in OM have made a large effort to incorporate sustainable operations into the mainstream of operations strategy. However, OM scholars and practitioners have no comprehensive framework for sustainable operations strategy to date. This paper attempts to fill this gap by providing a literature review on five dimensions of sustainable operations strategy: external context, competitive dimensions, strategic decisions, operations value chain activities, and organizational learning and knowledge. We provide a framework for sustainable operations strategy, consistent with these five dimensions, and provide research opportunities.

Keywords: *Sustainable operations; Operations strategy; Conceptual paper.*

INTRODUCTION

Sustainability is one of the biggest challenges of operations management in the twenty-first century. We define sustainability, following the principles of the Brundtland's report (World Commission on Environment and Development, 1987), as the ability to achieve simultaneous performance in environmental, social and economic dimensions in the present time, without compromising the ability to maintain this performance in the future. The operations strategy literature (see a recent review in Boyer, Swink, & Rosenzweig, 2005), however, continues to describe as performance parameters only economic indicators such as cost, quality, flexibility and reliability (Wheelwright, 1984). In a review, Dangayach and Deshmukh found 260 articles on operations strategy in 31 international conferences and journals of high reputation (2001). These same authors found an absence of what they termed "manufacturing strategy in the context of green manufacturing": the current model of operations strategy does not address sustainability. Despite ongoing efforts (Angell & Klassen, 1999; C. J. Corbett & Klassen, 2006; Ferrer, 2008; Gavronski, Paiva, Teixeira, & de Andrade, 2013; Klassen, 1993; Sarkis, 1995), sustainable operations strategy was not yet merged into the mainstream of OM research.

However, manufacturing has a great impact on the environment globally. For example, the consumption of fossil fuels in manufacturing is responsible for 15.4% of the total emission of greenhouse gases of anthropogenic origin (Olivier et al., 1996, p.36). Likewise, manufacturing is responsible for 20.2% of the total water withadrawal in the world, although it uses in its products effectively little more than 10% of total water consumption in manufacturing, with the remainder used for other purposes in manufacturing processes (calculated from Shiklomanov, 1999). From the standpoint of energy consumption, manufacturing is responsible for consuming 22.2% of the entire planet's fossil fuel (calculated from Olivier et al., 1996, p.35). From the perspective of land use, environmental liabilities generated by many manufacturing firms are vast. In Europe alone, there are an estimated two million locations that were previously occupied by manufacturing plants with some type of soil contamination, and one hundred thousand of these areas need to be remedied (United Nations Environment Programme, 2007, p. 95). Regarding solid waste, manufacturing activity (compared to mining, oil and gas, agriculture and other activities) is responsible for more than 50% of waste generated in the globe (Hill, 2004). The United Nations Environment Program warned about the risks of e-waste (waste from electrical and electronic), where "more than 90 per cent of the 20-50 million tonnes of the e-waste generated worldwide every year ends up in Bangladesh, China, India, Myanmar and Pakistan" (United Nations Environment Programme, 2007, p. 225)

The media is increasingly emphasizing the environmental impacts of every human activity (including manufacturing) and, by doing that, informing consumers about the different consequences of their acts of purchase. With this new information, consumers and governments are increasingly aware and demanding about the environmental performance of companies. Some companies, in turn, make these demands upstream in their supply chains, such as Wal-Mart, Procter & Gamble and IBM (Wasik, 2010; Winston, 2008). Thus, operation managers need to accommodate these environmental demands both in day-to-day operations and in formulating their strategies.

Social impacts of manufacturing are no smaller. Operation managers must deal with intrafirm social aspects since, perhaps, the approval of the labor laws between late nineteenth century and early twentieth century in most industrialized countries. OM research on these aspects, however, is scarce. Social aspects in the supply chain have received, relatively to intrafirm, more attention from OM researchers, but still is in its infancy, compared to the research of environmental aspects in manufacturing, if number of publications are compared (Seuring & Müller, 2008).

Therefore, we build over operations strategy literature to propose a framework for sustainable operations strategy. focus of this paper. Operations strategy is the set of decisions related to goals, resources and operational capabilities of an organization (Hayes, 2005). Although manufacturing is the engine of modern economies since the eighteenth century, it was not until the end of the 1960s and early 1970s that the first studies in operations strategy Skinner appeared (Hayes & Wheelwright, 1979; 1969, 1974; Wheelwright, 1978). Despite being a young branch of OM, operations strategy has received considerable attention within the area of operations, especially in the years 1980 and 1990 (Dangayach & Deshmukh, 2001). However, operations strategy lacks a comprehensive framework to include sustainability. Our objectives, then, are to provide a literature review of the sustainable operations strategy, to propose a sustainable operations strategy framework, and to identify opportunities for future research in the field.

The structure of this paper is as follows. First, we review the literature of sustainable operations strategy, detailing each of the five dimensions: external context, competitive dimensions, strategic decisions, operations value chain activities, and organizational learning and knowledge. Then, we provide a discussion, research opportunities, and a framework for sustainable operations strategy.

SUSTAINABLE OPERATIONS STRATEGY

Formulation and implementation of strategies for sustainable operations are subject to limited resources, as all other decisions on operations, subject to rules so far from perfection in technical terms, but that meet multiple criteria, often conflicting. All organizational resources are finite, whether capital, labor or knowledge. Therefore, an operation will not deploy the most modern technology simply because it is more efficient from the standpoint of natural resources. There must be a pattern of decisions on environmental investments in a company, especially with regard to investments in operations, i.e., a strategy for sustainable operations.

Sustainable operations strategy is subject to five dimensions we identified for operations strategy: competitive dimensions, strategic decisions, activities of operations value chain (OVC), organizational learning and knowledge, and external context.

The External Context of Sustainable Operations Strategy

We define the external context of the operations as the forces external to the firm that bound the options operations managers have to make their decisions. We divide the external context to operations using the following categories of stakeholders: consumers, suppliers, investors, employees, governments, political groups, business associations, and communities (Donaldson & Preston, 1995). While traditionally operations strategy is buffered from the external context by competitive strategy or other functional areas, such as marketing, (Ward & Duray, 2000), we suggest that sustainable operations strategy is directly exposed to the external context.

Until the late twentieth century, virtually the society and governments responded to occasional events, and businesses operated (and many still operate) in a reactive way to changes in environmental and social regulation. Table 1, for example, shows some important environmental accidents in the twentieth century. Only in times of crisis companies, governments and society were mobilized to establish new environmental regulations, promote environmental remediation actions, and only in such moments, the environmental and social dimensions of performance gained space in media and in consumers' minds.

Table 1 Main environmental events in the twentieth century

Year	Event
1947	Ship loaded with ammonium nitrate exploded in Texas, resulting in more than 500 lives and leaving 3,000 people injured.
1956	Contamination of Minamata Bay, in Japan, caused cases of neurological disorders in families of anglers, cats, and birds. The contamination occurred since 1939 due to a chemical company installed the river margins. Residents died due to high mercury concentrations, which caused the so-called "Minamata disease."
1966	In the town of Feyzin, France, a leak of LPG (liquefied petroleum gas) has killed 18 people and left 65 intoxicated.
1976	The factory Hoffmann-La Roche released in the town of Seveso, Italy, a dense cloud of Agent Orange, a defoliant that, among other substances, contained dioxin, which is highly poisonous. Around 733 families were removed from the region.
1978	In the city of San Carlos in Spain, a tanker truck loaded with propane exploded, causing 216 deaths, and leaving over 200 injured.
1984	A leak of 25 tons of methyl isocyanate, which occurred in Bhopal, India killed 3,000 people and poisoning of over 200,000. The accident was caused by gas leak from Union Carbide plant.
1984	San Juanico, Mexico, LPG fire followed by explosion caused 650 deaths and left 6,400 injured.
1986	An accident at the Chernobyl plant in Ukraine (then USSR), caused by the shutdown of the refrigeration system with the reactor still in operation, resulted in a fire that lasted a week, releasing into the atmosphere an amount of radiation 30 times greater than the atomic bomb on Hiroshima. The radiation spread, affecting several European countries and even Japan.
1986	In Basel, Switzerland, were spilled 30 tons of pesticides in river Rhine after the fire at the plant of Novartis (then Sandoz), causing the death of half a million fish along 193 km. This was considered the largest environmental accidents in Europe.
1989	The tanker Exxon Valdez hit a reef and ran aground in the Strait of Prince William, Alaska. The open hole in the hull leaked 44 million gallons of oil. The oil spill, the worst in U.S. history by that time, struck an area of 260 km2, polluting waters, islands, and beaches, killing thousands of animals – fish, birds, whales, and sea lions.

Source: ("1986," 2008; Dias, 2008)

In the late twentieth century, however, society's perception began to change with respect to environmental problems. With the United Nations Conference on Environment and Development in 1992 in Rio de Janeiro (Rio 92), evidence began to emerge that policy makers would change their decision making to include sustainability concerns. For example, the Declaration of Rio on Environment and Development (United Nations Conference for Environment and Development, 1992), Principle 8 says: "To achieve sustainable development [...], States should reduce and eliminate unsustainable patterns of consumption and production systems and promote appropriate demographic policies." Principle 16 reads: "National authorities should endeavor to promote the internalization of environmental costs and the use of economic instruments, taking into account the approach that the polluter should [...] bear the cost of pollution." In its Chapter 30, Agenda 21 (report of Rio 92) points to the role of industry in sustainable use of environmental resources, in the maintenance of occupational health and safety, responsible relationship with customers and suppliers, leading to changes in process product development, modification of production processes, and relationships with governments and trade associations. Although not implemented at the expected rate, the principles of Rio 92 has indicated a change of mentality, which shifts the axis of government action from an ex post reaction for an ex ante planning. Until then, the national States were in a position of policing, punishing companies that act inappropriately in terms of environmental and social. From then on economic instruments to promote the activities of production and consumption sustainable would be used by national governments. Therefore, the external context began to signal to companies that attributes of sustainability of product and production process would begin to become more valued and, therefore, should become part of corporate strategies, business and, consequently, the functional strategies, such as operations strategy.

Over time, other international bodies have aligned with the principles of Agenda 21. For example, the World Bank has published six priorities for its activities to support Agenda 21: 1) to make environmental concerns central in the development activities, 2) to integrate the social and cultural dimensions into the development agenda, 3) to invest in effective partnerships, 4) to build and share knowledge more effectively, 5) to measure progress differently, and 6) to mobilize and to multiply the funding (World Bank, 1997, p. 4). The alignment of these international bodies with Agenda 21 reinforces the need for businesses to incorporate sustainability in the formulation of its strategy.

Although the World Bank explicitly acknowledge the importance of industrial production and its full impact on the environment (Wheeler & World Bank, 1999), manufacturing is not included in the environmental strategies of many national and international organizations. For example, the Organization for Economic Cooperation and Development (OECD), outlined as one of their environmental strategies the decoupling between the limits imposed by the environment and economic growth, but the focus is on agriculture, transport and energy, with no mention of industry (OECD, 2004). In Brazil, the Ministry of Environment emphasizes Agenda 21, the Amazon, international affairs, biodiversity, and forests. Nevertheless, there is no explicit reference to the industry as the focus of their policies and strategies (Brasil, 2008). One notable exception is the region of NAFTA (North American Free Trade Agreement). Member countries (U.S., Canada and Mexico) have clear and transparent policies for improvement, audit and control of industrial operations, operated nationally by the agencies of each three countries and regionally orchestrated by the Commission for Environmental Cooperation (CEC - www.cec.org). Since 1990, the United States, with the enactment of the Pollution Prevention Act, have a clear policy to encourage pollution prevention at source instead of controlling pollution generated. Canada, in 1992, created the Canadian Centre for Pollution Prevention (C2P2 - www.c2p2online.com) to encourage practices to prevent pollution at source. All three NAFTA member countries now publicly available emissions data reported by the factories: the United States through the TRI (Toxic Release Inventory), Canada through the NPRI (National Inventory of Emissions of Pollutants) and Mexico through the RETC (Register of Emissions and Pollutant Transfer). Most recent of all, the RETC has only been released in 2007.

Probably the most important external environment factor for the formulation of strategies, even today, is the law. The evidence for this is the fact that Wal-Mart operationalized its sustainability strategy with international suppliers, requiring evidence that they comply with the laws of the countries in which they operate (Winston, 2008). It is through the environmental legislation that governments communicate their environmental policies to companies, either through command-and-control mechanisms or through economic incentives. Command-and-control environmental legislation can include emission limits, permissible limits of hazardous chemicals in products, standards for final products and waste treatment processes (Bonifant et al., 1995). Environmental legislation with economic incentive mechanisms could include government programs to support environmental initiatives in companies, discounts on fees and taxes in return for improved environmental performance of companies, environmental services, etc. An example of payment for environmental services is the city of Extrema, in southern Minas Gerais, Brazil. In this municipality, farmers are paid to not use the land near the headwaters of rivers, which prevents the contamination at the source (SERVICES 2008).

Environmental legislation is a source of difficulty for managing global operations due to differences between environmental laws among countries. Besides that, environmental legislation is different in national, state and municipal levels. Therefore, an operation that complies with all environmental regulations in a given location could be illegal, if it was installed in a location in a neighbor city. This multiplicity of rules to which the multiple operations of a company must meet brings complications to the formulation of operations strategy. This has led manufacturing firms to hire consultants specializing in environmental law, in addition to specialized consulting services in environmental technology. One of the firms we interviewed, for example, had a contract with a consultancy on environmental legislation, which changes periodically, tracks the legislation in three levels (federal, state and municipal), filters the relevant regulation and informs the environmental area for the company that then makes the product and process changes necessary to continue acting legally.

Business associations also have an important role in the formulation of environmental strategies of firms. Business associations are institutions that both restrict the actions of its members and allow certain types of actions - in other words, “institutions define and limit the choice set of individuals” (North, 1990, p. 4). There are business associations with broader scope, such as WBCSD, the Global Compact, Ceres, GRI, etc. There are also business associations that set voluntary rules that impact the formulation of strategies of firms’ operations. For example, in the chemical industry, the American Chemistry Council (ACC) created in 1988 the Responsible Care program, established in response to image problems generated by the accident at Bhopal (Barnett & King, 2008). Over time, the program has become a global action of the chemical industry and today is managed globally by the International Council of Chemical Associations (ICCA), and in each country, the national association of chemical industries. In Brazil, the program is maintained by the Brazilian Association of Chemistry (ABIQUIM), Responsible Care in Canada is managed by Canada’s Chemical Producers Association and so forth. According to the website of the program, the goal of Responsible Care is to help the chemical industry “to operate safely, profitably and with care for future generations”, ie a sustainable manner. King and Lenox (2000), however, found more improvement in environmental performance (measured by the sum of emissions recorded in the database TRI) in firms not participating in the Responsible Care companies than in the participants, suggesting that the program actually serves only as an institutional defense than an effective source of continuous improvement. In a more recent study, Barnett and King (2008) found that the chemical companies participating in Responsible Care had fewer accidents after the creation of the program, which also served as a fence between the parties, avoiding that an accident in a member created image problems for the rest of the industry. Anyway, business associations contribute to the formulation of operations strategy, affecting the sustainability of operations.

Political groups are also important in the external context in the formulation of sustainable strategies. Among them, there are NGOs (nongovernmental organizations), which are formal institutions, private, and considered by the UN itself as being of “particular importance to the implementation and review of sustainable development, environmentally sound and socially responsible as envisaged throughout Agenda 21” (United Nations Conference for Environment and Development, 1992, ch. 27, Item 27.3). Examples include the Sierra Club, founded in 1892, the United States, Greenpeace, founded in 1971 in Canada, among others. Another form of political group that greatly influences the formulation of operations strategy, are the unions. Managers had to undertake several changes in production, work organization, and the products, because they suffered external pressure of these groups. In the early nineteenth century in England, workers formed unions to improve working conditions in industrial and extractive activities (Donkin, 2001). Some authors state that the participation of workers in unions improve the health and safety of operations (eg Cunningham, 2008) and competitive conditions of the firms themselves (Wood & Glaister, 2008). Some authors contend, there is concern that unions have their own agenda of power and self interest that is unrelated to the interests of employees (Drucker, 1974), and that the unions end up reducing the performance of firms (Doucouliagos & Laroche, 2009), that would eventually avoid places heavily unionized, which in the long term also hurts workers and the community. Preuss (2008) noted that in Europe unions have begun to link the practice and discourse of the CSR with their own goals, but the skepticism with CSR is still dominant. Some authors in management (especially in the area of strategy) have addressed the problem of how political groups influence companies (eg Frooman, 1999; Zietsma, Winn, Branzei, & Vertinsky, 2002). For Porter and Kramer (2006), it is more important for political groups that the company would be able to be targeted, because of its visibility, than its actual impact. As an example, these authors provide the case of Nestle, the largest bottled water supplier in the world, the main target of the debate on access to drinking water, but accounts for 0.0008% of world consumption of drinking water, while agriculture uses 70% the same resource and is highly inefficient in their irrigation management. However, agriculture is a target far less desirable than a large firm.

Organizational clients are also extremely important stakeholders: its requirements may change the performance of firms in the area of sustainability. Lloyd (2008), for example, found that the pressures for cost reductions by major retailers in suppliers of private label brand products led them to a rhythm of work that caused occupational health problems to their workers. Moreover, Gavronski et al. (2008) found that most ISO 14001-certified plants in Brazil have sought the certification of their EMS to make sure they meet their clients' requirements.

The relationship between external environment and the formulation of operations strategy remains a relatively unexplored area, and the results are mixed. Ward and Duray (2000) found no direct relationship between the external context and operations strategy. Zhao and colleagues (2004) found that the type of quality system adopted in a service firm is associated with the context. In sustainable operations strategy, Gavronski and colleagues (2008) found that plants that sought ISO14001 certification motivated by legal concerns also perceived benefits in their relationship with external stakeholders.

Despite the scarce research about the external context, it is central to the operations strategy, because it will define the relative importance of each competitive dimension, the very existence of each competitive dimension, and is by reading the external context that the operations managers make strategic decisions in operations.

Competitive Dimensions in Sustainable Operations

Competitive dimensions are the performance characteristics customers or organizational clients evaluate in a vendor. Such competitive dimensions are performance measures manufacturing firms should use to compare themselves with their competitors. However, markets are dynamic both temporally and spatially. Society changes with time, so change the requirements of consumers, which, incidentally, belong to different social groups with distinct cultures. Organizational buyers are no different: companies to which they belong place different requirements on the products and services they purchase according to the geographic location of the company and according to the strategic positioning the company is pursuing at the moment. Thus, competitive dimensions of operations should change their importance according to new markets the company wants to meet, or with the evolution of currently served markets.

Therefore, it is imperative defining under what conditions an attribute linked to sustainability will be an important competitive dimension in operations. Jimenez and Lorente (2001) proposed two criteria: a) this dimension of performance should be within the operations function, and b) should provide a competitive advantage to the company. To be a source of competitive advantage, an attribute should be minimally valuable to customers. In other words, the attribute needs, minimally, to be perceived by customers. Therefore, an invisible capability would not be a competitive dimension. For example, if a plant has an industrial effluent treatment station impeccably maintained, able to restore the levels of pollutants in the water far below the minimum levels required by environmental laws, and nobody else knows besides the environmental agency and the plant's environmental department, this capability can not be considered a competitive dimension. On the other hand, if the effluent treatment station allows the company to create a better reputation with the environmental agency so that the costs of chemical analysis report of the effluent are reduced and this reduction in costs can be passed on to customers in the form of lower prices, these lower prices are the competitive dimension in question and not the effluent treatment station. This capability, although support the reduction of prices, is one of the many components of the capability to offer lower prices. This distinction is consistent with the distinction between dimensions of competition and competence dimensions (C. Corbett & Van Wassenhove, 1993). In this example, both the reputation as the lower prices are competitive dimensions that are mutually reinforcing, resulting from cumulative expertise (Carter & Rogers, 2008). However, some dimensions can also generate competitive trade-offs. For example, the addition of tetraethyl lead as anti-knock agent has increased the compression ratio of engines and, thus, increase power and reduce energy consumption (Sloan, McDonald, & Stevens, 1990) but it is a polluting additive (Hill, 2004; Mavropoulos, 1999). The Toyota Production System, by introducing a greater variety of products in less time, causes more products disposals, and by involving frequent movements with suppliers of inputs, increases energy consumption and congestion on the roads (Cusumano, 1994). In both cases, both an improvement of product performance (quality at GM) and the production process (delivery at Toyota) have negative impacts on environmental performance.

When a customer buys products from a particular supplier and in the process of purchase, takes into account an attribute of the product or production process that is linked to sustainability, then this attribute is a competitive scale in operations. Examples of consumer products that have sustainable competitive dimensions are organic agricultural products, produced without pesticides or chemical fertilizers, which achieve a premium price, usually because their consumers accept paying more for the conviction that they are getting a healthier product. Even within the consumer products, the cosmetics manufacturer Body Shop is an example of a company that competes with not only product attributes (such as recycled packaging) but also for the production process (Wycherley, 1999). However, Body Shop's consumers have little means to identify whether the company actually does what it promises.

The environmental label (Loureiro & Lotade, 2005) is a way to refrain the problem of opportunism that arises from asymmetric information between producers and buyers. The buyers, especially consumers, cannot check if the vendor is doing what it promises either in the product or in the production process. An environmental label certifies such practices. From the standpoint of the buyer, there is a guarantee, provided by a third party to the transaction, that what the vendor claims is correct. From the standpoint of operations strategy, the environmental labels enable providers to transform their capabilities related to sustainability in a competitive dimension. Both the advertising and labeling provide capabilities related to sustainability an important feature to be competitive dimensions: visibility.

Another feature is the criterion of additionality. Approximately 80% of steel produced by Gerdau Steel comes from recycled scrap metal. Between 10% and 30% of injected PU soles used in footwear comes from waste from the process of injection (branches arising from the injection channels), micronized. Up to 30% of the inputs for the production of brake pads are recycled material. However, no buyer of steel, PU soles, or brake pads takes into account the percentage of recycled material used in its production. In such markets, recycling is an economic necessity, and all manufacturers engage in greater or lesser degree. On the other hand, paper manufacturers, up to recently, charged premium prices for recycled or non-bleached paper, until all manufacturers had at least one brand of paper with such characteristics. The additionality criterion is also required for projects to reduce greenhouse gases from the Clean Development Mechanism (CDM) in order to receive Certified Emission Reductions (CERs) in such a way to market them in the market for carbon credits under the Kyoto Protocol (Lopez, 2002).

In short, an attribute related to sustainability would be an important competitive dimension in operations if it comes from the area of operations, buyers directly value it, is visible, and is additional.

Strategic Decisions in Sustainable Operations

We define strategic decisions as the basic capabilities operation managers should develop in order to cope with the performance objetives they have set for the competitive dimensions of operations. Wheelwright (1984) provided a traditional classification of categories of decision in operations. Angel and Klassen (1999) established links between environmental decisions and strategic decisions in OM. They showed that environmental capabilities have a systemic impact in the formulation of sustainable strategies. Table 2 shows excerpts from the research agenda proposed by those authors.

Table 2 Research Propositions for Environmental Strategic Decisions

Decision Category	Decision Category
Facilities	End-of-pipe pollution control technologies are favored as a facitility matures in its life cycle.
Process technology	Environmental improvement is increasingly costly or offers fewer competitive benefits as process investment declines and capital intensity increases.
Capacity	Type and amount of capacity is related to environmental impact.
Vertical Integration	As waste management becomes increasingly costly, operations tend to forward integrate.
Suppliers	Operations with more centralized purchasing are more likely to consider the life-cycle environmental implications of material and supplier choices.
New Products	Greener product design is most likely to offer competitive advantage when operations when operations compete based on innovation and quality.
Workforce	Inclusion of environmental criteria in the performance evaluation of operations managers improves environmental performance and increases the use of environmental protection.
Quality Management	Increasing use of recycled materials increases process variability, thereby lowering conformance quality.
Planning and control systems	As environmental audits become increasingly sophisticated, more opportunities for cost-effective improvements are implemented.

Source: adapted from Angell e Klassen (1999)

For Hart (1995), there are three strategic environmental capabilities that companies should develop in order to gain competitive advantages: pollution prevention, product stewardship, and sustainable development. According to Hart, there are two ways to reduce pollution generated by a business: implementing end-of-pipe controls, ie only dealing with pollution generated at the end of the production process, or pollution prevention, ie preventing the generation of pollution. The later requires the mobilization of basic resources, such as employee involvement and continuous improvement approach. Pollution prevention presents, as a competitive advantage, reducing costs by avoiding investment in expensive control equipment, and but also increases efficiency by using better inputs of the production process, reduce cycle time by eliminating unnecessary operations to process, and reduce the risk of fines for reducing emissions of pollutants. Product stewardship is the capability to reduce the environmental impact of products throughout their life cycle. This capability allows a firm to: 1) leave businesses environmentally hazardous, 2) redesign products and production systems available to reduce the environmental risk, and 3) develop products with lower impacts along the life cycle. This capability depends on the integration of stakeholders and creating a competitive advantage to have access to a consumer market's more environmentally demanding. Finally, the capability of sustainable development is expanding firm's activities in developing countries, while not depleting natural resources or not increasing energy consumption in their markets. For Hart, this capability brings the wider implications, especially for multinational companies because it allows these companies to grow their markets, even in developing countries, without increasing the environmental impact of its new economic activity.

Shrivastava (1995) defined environmental technologies as "production equipment, methods and procedures, product designs and delivery mechanisms for products that conserve energy and natural resources, minimize the environmental load of human activities and protect the natural environment" (Shrivastava, 1995, p. 185). Shrivastava classified environmental technologies in design for disassembly, environmental production, total quality environmental management, industrial ecosystems, and life cycle assessment. The design for disassembly is to design products that allow a recycling of its components at an acceptable cost. The environmental production is the redesign of production processes to reduce environmental impact, the use of cleaner technologies, the use of more efficient production techniques, reduction of waste at source, and maximizing energy efficiency. Total quality environmental management applies a systems perspective and principles of quality management to environmental problems. Industrial ecosystems are ways to integrate different companies so that the waste in a plant are used as inputs in the production process of another plant. Life cycle assessment is to "evaluate the risks to health and the environment, impacts of specific projects and facilities, potential for effluent releases and hazardous waste costs and life cycle of products" (Shrivastava, 1995, p. 189).

Sarkis and Rasheed (1995) identified five elements of responsible production: reduce, remanufacture, recycle, reuse and disposal. The reduction of resources required to produce a good or service, such as raw materials or energy, achieved through product design or production processes is aligned with the work and philosophy of TQM and JIT. The remanufacturing is the reuse in the production process of parts and components removed from products previously used (although the practice brings problems of supply variability, complicating production planning. See Ferrer & Whybark, 2001). Recycling is to transform an input material in the production process. Examples of recycling include obtaining aluminum from beverage cans or empty glass from empty bottles. The reuse is to return to inputs to the production process or parts or whole products. Examples of reuse include using paint booths with closed water cycle (a curtain of water is needed after being painted pieces to collect the rest of the paint) and use of empty bottles of drinks, post-consumption for the canning of drinks. Already available is the treatment of waste from the production process. Examples include the construction of the hazardous industrial waste landfill, the hiring of companies authorized to dispose of waste, etc. Sarkis and Rasheed (1995) was also suggested that several environmental performance indicators such as percentage of recyclability of materials used, materials remanufactured, degradation, pollution from the process, use of resources / energy and legal compliance, among others.

Klassen and Whybark (1999a, 1999b) proposed a typology of environmental technologies for operations: pollution prevention, environmental management systems, and pollution control. Pollution prevention requires structural investments involving fundamental changes in the basic product or primary process. Environmental management systems are infrastructural investments that affect the way operations are managed. Include formalizing procedures, interfunctional coordination, stakeholder involvement, monitoring, internal and external disclosure of results, training, certification and other activities related to environmental aspects in the plant. Certification to ISO 14001 standard is an example of investment in environmental management systems. Pollution control investments are structural investments that recover waste in the final process. Examples would be of end of pipe controls, such as filters for smokestacks or effluent treatment stations, or activities to mitigate effects to clean up environmental damage from past activities, such as cleaning or removal of leaking.

Cleaner production (Nagel, 2003; United Nations Environment Programme, 2002) is a methodology for continuous improvement in environmental performance with an apparent inspiration in TQM.

Hill (2004) systematized the technological options for zero waste / zero emissions into three major groups: dematerialization, industrial ecology and detoxification. While recognizing the impossibility of having a 100% efficient process, the author suggested that pursuing goal of 100% efficiency in production processes will cause fewer natural resources needed to provide the level of well-being necessary to the population of the planet - the dematerialisation. Industrial ecology approach is a closed loop approach to operations: instead of considering the plant as a linear, open system, with products and waste to be disposed, the philosophy of industrial ecology proposes that plants can be connected, forming ecoindustrial parks (Lambert & Boons, 2002), on which the byproducts of a plant are used as inputs in another plant. This idea was first proposed by Pauli (1998) with the name of ZERI (Zero Emissions Research Initiative). As tools to support industrial ecology, Hill suggested the use of Life Cycle Analysis (LCA) and Design for Environment (DFE). LCA is an environmental impact analysis of a product from cradle to grave, ie from natural resource extraction to final disposal of the product through all the impacts of all intermediate processes: purchasing, production, distribution and use (Sarkis, 2001). The DFE is the inclusion of reducing the impact of product and production process in product development (Sarkis, 2001). Detoxification, or green chemistry, is the substitution of hazardous chemical inputs and non-degradable end products. Examples include the replacement of petroleum-based plastics to bioplastics (Hill, 2004).

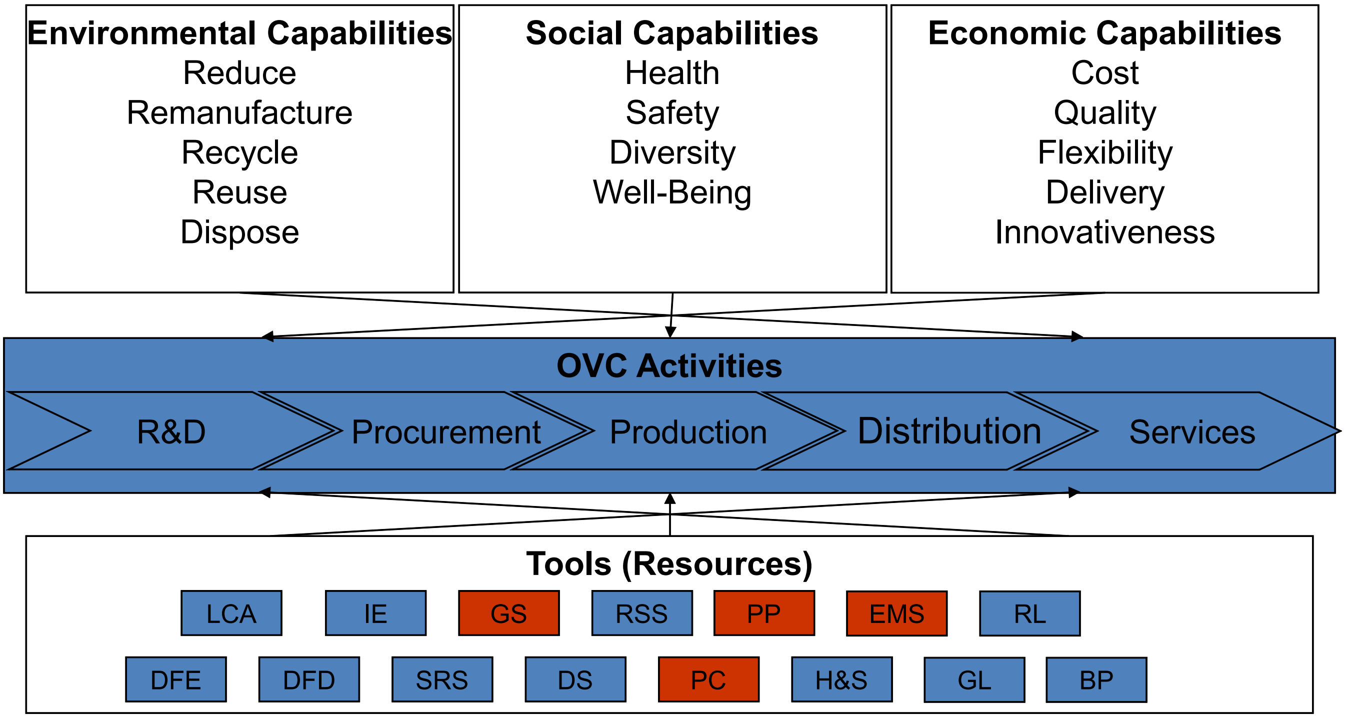
In summary, we divide environmental capabilities in operations into two major groups: pollution controls and pollution prevention. The pollution control technologies are those designed to treat waste and emissions from the production process after their generation. They fall into two broad groups of technologies: remediation technologies and end of pipe. Pollution prevention technologies try to avoid the generation of waste and emissions. They fall into three broad groups of technologies: environmental management systems (EMSs), modifications of product, and modifications of the production process. EMSs are a set of policies and organizational systems that seek to standardize the organization's response to the environmental aspects of their production processes, reducing its impact. The changes in product design minimize the environmental impact of a product during its production, use, or after consumption. May include increasing recyclable/recycled materials in a product, life cycle analysis (LCA), reducing the use of materials or energy or the selection of inputs and components environmentally responsible. The process modifications are changes in the production process that reduces the environmental impact of this process. Examples include the use of industrial ecology, the use of cleaner production techniques, environmentally responsible purchasing and logistics, among others.

The capabilities related to social aspects of sustainability have a much smaller research tradition in management or operations strategy. Intrafirm aspects (occupational health and safety, for example) are much more regulated and implemented by firms, but receive much less attention from scholars in the area, while the interorganizational social aspects (supply chain social responsibility), although less regulated and still in its infancy in most companies, receive far more scholarly attention. For example, a search in a leading research journal in OM, the Journal of Operations Management, using the keywords "health" or "security" in the title of articles published from 1995 to 2009, returned only three relevant articles. One, with over ten years (Brown, 1996), was a research call, inviting researchers in operations to include occupational safety in their research, providing an agenda for research structured along three dimensions: TQM, change in technology and change in operations (such as JIT). This author had no answer to his invitation: the only article published in the twelve years that followed, was from Brown and colleagues (Brown, Willis, & Prussia, 2000). The third paper, published recently (Das, Pagell, Behm, & Veltri, 2008), noted the deficiency of knowledge about occupational safety in OM and identified a relationship between safety and quality.

The studies in operations that focused on social aspects in the supply chain are much more abundant than intrafirm social aspects, although social aspects are less explored than environmental aspects (Seuring, Sarkis, Müller, & Rao, 2008). Perhaps as a response to the public concern in the late 1990s with the working conditions of contractors in Asia for known brands, as was the case of Nike (Burns & Spar, 2000), the literature on operations has been most prolific on social responsibility in the supply chain than in such intrafirm aspects. More recently, media attention also raised concern with the quality of products that are imported from those countries, such as the toy maker Mattel (eg Bapuji & Beamish, 2008a; Bapuji & Beamish, 2008b), pet food, tires, and toothpaste (Hoyt, 2008). Carter and Jennings (Carter, 2004; Carter & Jennings, 2002b, 2004), for example, identified the dimensions that social responsibility of the firm's supply area should consider: environment, diversity, human rights, philanthropy, and safety. Environmental concerns relate to the inclusion of environmental criteria in supplier relations and product design. Diversity is the inclusion of criteria for valuing the minority suppliers. Human rights include ensuring that suppliers do not require work of slaves or children and that pay a living wage. Philanthropy is the inclusion of actions to support the community in the company activities, such as volunteering. Security is ensuring that suppliers provide a safe workplace and to transport supplies safely for the workers.

In summary, strategic decisions in sustainable operations require a broader set of categories than the traditional operations strategy categories of decision. Figure 1 depicts the most basic tools, or resources, the activities in the OVC where they can occur, and the top-level capabilities they can create.

Figure 1 Resources and Capabilities for Sustainable Operations



BP – base of pyramid; DFD – design for disassembly; DFE – design for the environment; DS – disassembly systems; EMS – environmental management systems; GL – green logistics; GS – green supply; H&S – worker health and safety; IE – industrial ecology; LCA – life cycle analysis; PC – pollution control; PP – pollution prevention; RL – reverse logistics; RSS – recognition and sorting systems; SRS – socially responsible sourcing

Sustainable Operations Value Chain

We define operations value chain (OVC) as the set of activities that consist the core activities in operations: R&D, procurement, production, distribution, and services (De Toni, Filippini, & Forza, 1992; Paiva, 2003; Paiva & Vieira, 2011). A firm can decide performing OVC activities entirely within the firm, outsource all OVC activities, or a combination of internal and outsourced activities. From sustainability standpoint, it is important mapping OVC activities performed by a firm and identifying potential social and environmental aspects and impacts.

Carter and Jennings (2002a) identified activities that procurement, transportation, and materials handling should perform to ensure a sustainable operation in five dimensions: environment, diversity, human rights, philanthropy, and safety. Such activities include, for procurement, purchasing of environmentally responsible suppliers, ensuring that suppliers do not use forced or child labor, and ensuring that suppliers' facilities are safe for their employees. For transportation activities, activities would include identifying the environmental impact of each modal, signaling of hazardous materials, and designing work schedules that allow drivers to spend adequate time at home. For materials handling, activities would be finding profitable uses for obsolete materials in inventory, training in safety procedures, and certifying the use of materials handling equipment (storage, etc.). Zhu et al. (2005) identified four dimensions of green supply chain management: internal environmental management, external environmental management, investment recovery, and eco-design. Activities in the internal environmental management would include commitment of top management, functional cooperation for environmental improvement, and ISO 14001 certification. External environmental management would include activities such as cooperation with suppliers to achieve environmental objectives and cooperation with clients for eco-design. Eco-design activities would include designing products to reduce consumption of materials and energy and designing products for reuse, recycling and recovery of materials and components. Investment recovery would include activities such as sales of surplus stock and materials, and sale of idle equipment.

Kleindorfer et al. (2005) proposed three areas for improving sustainabity of operations: green product and process development, lean and green OM, and remanufacturing and closed-loop supply chain. Vachon and Klassen (2003) suggested that both the ecodesign (Vachon & Klassen, 2006b) as the cooperation and monitoring activities (Vachon & Klassen, 2006a) should occur downstream and upstream in the supply chain, thereby involving more than one activity of the OVC. Corbett and Klassen (2006) identified environmental aspects both in TQM – OVC activities internal to the firm – and in the management of the supply chain –external activities of the OVC. For supply chain management, they proposed three groups of activities to incorporate environmental management into operations management: network design, supply arrangements, and strategic linkages. For network design, reverse logistics is an important theme, which consists minimally of two related activities: collecting and re-integrating products and minimize waste, resource consumption, and environmental emissions. Research on the subject showed that the design and management of a supply network and integrated bidirectional result in better performance than decompose the system into two separate networks, one direct and one reverse. For supply arrangements, firms further upstream in the supply chain tend to emphasize emission rate and efficiency with direct implications for materials selection, process design and reintegration of reverse flows. Companies in the intermediate portion of the supply chain would emphasize efficiency of transport and assembly. Finally, downstream firms in the value chain would emphasize recycling and packaging. Therefore, the impacts of environmental management would be different for each activity of OVC, generating expertise in addressing the problems.

Porter and Kramer (2006) have a more direct mapping of environmental and social impacts of each activity in the value chain, using the original model of the value chain of Porter (1980). In value chain activities directly related to the OVC, as technology development, logistics, supply, operations, distribution logistics, and after-sales services, there are several opportunities for managing sustainable operations. Table 3 presents a summary of such opportunities.

Gavronski et al. (2011) identified three green supply management processes: environmental supplier selection, environmental supplier monitoring, and environmental supplier collaboration. They found that green manufacturing capabilities are positively related to these green supply management processes. Green manufacturing capabilities, in turn, are positively related to plant resources.

Table 3 Sustainable Activities vs. OVC Activities

Sustainable Activities vs. OVC Activities	Supply	Production	Distribution	R&D	Services
Transportation impacts: emissions, traffic jams, etc. (Carter & Jennings, 2002a; Cusumano, 1994; Porter & Kramer, 2006)	*		*		
Use e disposal of primary packaging (Porter & Kramer, 2006)			*		*
Supplier’s waste and emissions(C. J. Corbett & Klassen, 2006)	*				
Product waste and emissions (Zhu et al., 2005)				*	
Production waste and emissions (C. J. Corbett & Klassen, 2006; Porter & Kramer, 2006; Sarkis, 1995; Sarkis & Rasheed, 1995)		*			
Procurement and supply chain practices, such as bribery, child work, blood diamonds, prices paid to farmers, etc. (Porter & Kramer, 2006)	*				
Use of certain inputs, such as fur (Porter & Kramer, 2006)	*				
Natural resource utilization (Porter & Kramer, 2006; Zhu et al., 2005)	*	*	*	*	*
Water and energy use (Porter & Kramer, 2006)		*			
Worker’s health and safety (Carter & Jennings, 2002b; Porter & Kramer, 2006)	*	*	*		
Hazardous materials (Porter & Kramer, 2006)		*			
Relations with universities (Porter & Kramer, 2006)				*	
Research ethics, such as tests with animals, use of genetically modified organisms (GMOs), etc. (Porter & Kramer, 2006)				*	
Product safety (Porter & Kramer, 2006)				*	
Conservation of raw material (Porter & Kramer, 2006)				*	
Recycling (Porter & Kramer, 2006)				*	
Obsolete product disposal (C. J. Corbett & Klassen, 2006; Porter & Kramer, 2006)					*
Handling of consumables, such as oil, ink, etc. (Porter & Kramer, 2006)					*
Consumer privacy (Porter & Kramer, 2006)					*
Eco-design tools: LCA and DFE (Sarkis, 2001)				*	
Suppliers’ process changes (C. J. Corbett & Klassen, 2006)	*				
Collection of performance data from suppliers (C. J. Corbett & Klassen, 2006; Vachon & Klassen, 2006a)	*				
Collaboration with suppliers for eco-design (Vachon & Klassen, 2006b)	*			*	
Collaboration with clients for eco-design (Vachon & Klassen, 2006b)			*	*	*

Organizational Learning and Knowledge for Sustainability

We define organizational knowledge as the information and know-how of a firm (Kogut & Zander, 1992), while organizational learning is the acquisition and recombination of organizational knowledge. The purpose of organizational learning is to adjust the firm to its context (Fiol & Lyles, 1985). Organizational learning has been related to manufacturing performance (Schroeder, Bates, & Junttila, 2002), cross-functional orientation of manufacturing (Paiva, Roth, & Fensterseifer, 2008), quality management (Molina, Llorens-Montes, & Ruiz-Moreno, 2007), and supplier development (Modi & Mabert, 2007), among others.

Williander (2007) compared how Ford and Volvo looked into alternative energy, adopting methanol as fuel in their projects. These two companies, despite the natural differences between the projects, have adopted the same logic: methanol offered as an alternative engine for a pre-existing line of cars. Due to loss of performance, the higher price, the less autonomy, supply difficulties, and the feeling of taking the same car for a higher price, methanol-powered cars have never had success with consumers. Ford discontinued its line of cars to methanol in 2004. Starting from a completely different set of assumptions, Toyota started its eco-design project in the 1990s, with the challenge of launching a vehicle that consumes at least 50% less gasoline. The Toyota Prius is a hybrid car (gasoline/electricity), where the gasoline engine charges the batteries that power electric motors. This allows consumers to use the same infrastructure of pre-existing gas stations, widely available. Furthermore, the autonomy and the fuel efficiency are higher than in gasoline-powered cars. Finally, it is an exclusive line of cars, not a hybrid powertrain option of a pre-existing line. Therefore, the consumer perceives the Prius as a differentiated product and his/her peers perceive him/her as a distinguished consumer. Despite having the same price of a car running on methanol, therefore higher than a gasoline-powered equivalent car, the Toyota Prius has been widely accepted by consumers. Technological trajectories and learning paths chosen by these firms in launching of their eco-products were fundamental to the success of each venture.

Sarkis (2001), in a conceptual paper, stressed the importance of organizational change and interfunctional cooperation for operations reach sustainability goals. Clarke and Roome (1999) presented a case study of a Canadian firm in which the EMS was observed from 1989 to 1994. In that firm, EMS has had three distinct stages: the passage of the environmental management of a dispersed set of actions for a strategic direction (identification), the integration of existing environmental management activities (operational), and changes in the concept of environmental responsibility more wide sustainable development (corporate citizenship and responsibility). In this process, the authors noted that a number of internal and external conditions enabled the company to change and learn to develop their skills in environmental management and sustainable development. Among the pre-internal conditions, the authors drew attention to the firm's values and its strategic process, which identified environmental aspects as a future strategic direction. Furthermore, the authors highlighted the company's ability to acquire new knowledge from multiple perspectives and multiple stakeholders.

Siebenhüner and Arnold (2007) performed case studies in six European companies of medium and large to identify the causes of learning-oriented organizational sustainability. They used four broad categories: structural factors (company size, staff structure, and mechanisms of learning), cultural factors (values and norms, internal networks, leadership styles, and conflict), behavioral factors (change agents), and external factors (market pressures, government regulation, stakeholder demands, and public opinion). The authors found that company size influences the learning process. Midsize businesses are more prone to radical changes. Larger companies, on the other hand, have more resources allocated to R&D department and R&D better structured. The staff structure had little explanatory power in the learning processes observed. The existence, however, of a structure for the initiation and dissemination of learning processes and interdisciplinary cooperation proved to be beneficial to the learning processes. The following learning mechanisms were relevant in sustainability: guidance to ambitious environmental targets, integration of environmental goals for projects in R&D, formalized instruments of communication, self-organized working groups, corporate guidelines (for multi-divisional companies) and project teams. The authors also noted the importance of change agents, individuals in the organization making the connection between the various organizational units and levels of hierarchy. In mid-sized firms, these agents were at the managerial level and, in larger enterprises, the departments of sustainability or R&D. The participative style of leadership seems to have contributed more to the processes of learning styles. They also noted the importance of internal organizational networks in promoting higher levels of learning (double-cycle and radical changes). Regarding external factors, large firms seem more concerned with the pressure (real or anticipated) of the stakeholders, while internal factors seem to contribute more to learning in mid-sized companies. In both sizes of firms, customers are not requiring environmental performance, with the exception of some niche markets and few industrial mass markets such as Scandinavia. Environmental legislation has different effects in the sample companies: in the electronics industry and construction, the legislation was an important determinant of learning, while in the transportation sector was not important.

Carter (2005) showed that organizational learning mediates the relationship between sustainable practices with suppliers and performance.

King and Lenox (King & Lenox, 2001) studied the effect of lean production on environmental practices. Environmental practices were the adoption of an EMS based on ISO 14000, waste generation, and treatment on site of emissions. Of these, lean production is positively related to the adoption of EMS and negatively related with the generation of waste and emissions. The marginal cost of improving environmental performance is less when adopting the practices of lean production, ie, the knowledge gained with lean production is reused in improving environmental performance. Later, the same authors (Lenox & King, 2004) studied the effect of providing central (corporate) information on pollution prevention in the adoption of pollution prevention by business units (plants). Both the adoption of the practice in the industry in which the factory operates and the experience gained from past experiences moderate the relationship between central provision of information with the adoption of pollution prevention, reducing its effect.

Rothenberg et al. (2001) related the practices of lean production and environmental performance. Lean production is positively related to eco-efficiency because lean production emphasizes continuous improvement and waste elimination, while lean production would be negatively related to atmospheric emissions, especially of VOCs (volatile organic compounds), since these structural aspects require more expensive investments, such as end-of-pipe pollution controls. The results were not statistically significant for any of the proposed relations. Nevertheless, the authors found evidence from interviews in plants of their sample that the elements of lean production, especially related to learning, both contribute in increasing eco-efficiency and in reducing emissions. Pil and Rothenberg (2003) found evidence that improvements in environmental performance are positively associated with quality (compliance) performance, because both performance indicators are based in the same knowledge base. Rothenberg and Zyglidopoulos (2007) found a positive correlation between the adoption of environmental innovations and productive innovations, two elements with high knowledge content. Hull and Rothenberg (2008) identified a moderating effect of innovation on the relationship between CSR and corporate financial performance.

Chen (2008) studied the impact of environmental intellectual capital on the competitive advantages of firms. The author has defined environmental intellectual capital as the total stock of intangible assets, knowledge, skills, relationships, etc. related to environmental protection and environmental innovation. Environmental intellectual capital can occur both at the individual and at organizational level. Environmental intellectual capital is an multifaceted construct consisting of environmental human capital, environmental structural capital, and environmental relational capital. Environmental human capital belongs to the individuals (knowledge, skills, etc..), the environmental structural capital belongs to the company (systems, policies, etc.). Environmental relational capital is the relationship between the company and its stakeholders (customers, competitors, suppliers, government, research institutes, etc.). All three environmental dimensions of intellectual capital (human, structural and relational) were positively correlated with the achievement of competitive advantages.

Vachon (2012) studied the impact of technological capacity and concluded it is positively related to environmental performance. Gavronski et al. (2012) evaluated how the different learning antecedents and learning processes were related to the choice of environmental technologies and found that organizational learning is related only to softer technologies, not explaining the choice of hard technologies, such as end-of-pipe, pollution control technologies.

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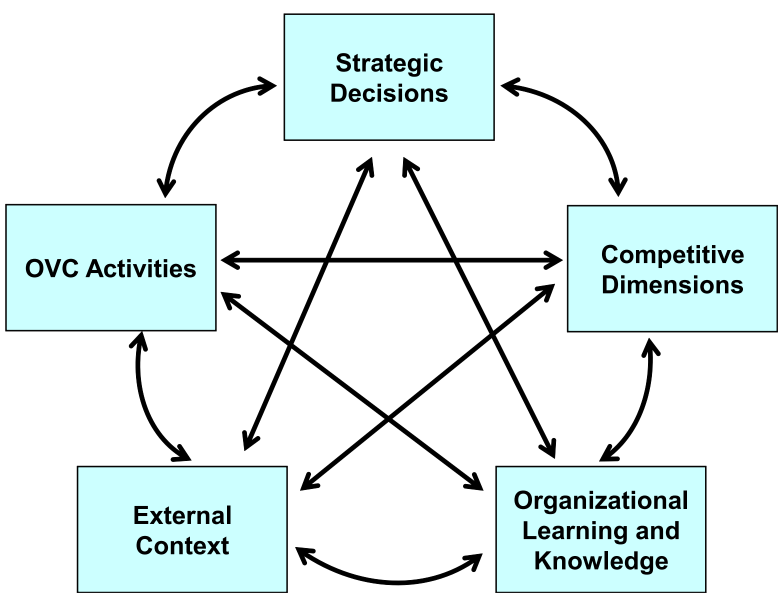
DISCUSSION AND CONCLUSION

In this paper, we built on the operations strategy literature, identifying five dimensions, namely: external context, competitive dimensions, strategic decisions, operations value chain (OVC) activities, and organizational learning and knowledge. Then, we reviewed the literature in sustainable operations strategy on each of the five dimensions. We identified an uneven proportion of research on each dimension, which we deem as one research opportunity.

The research on the influence of the external context in sustainable operations remains scarce. Operations managers are bound to the regulatory system for most activities performed inside their plants, such as environment, health, and safety procedures. However, even these regulated activities have different approaches among plants. Some plant managers emphasize safety, or environment, for example, more than others do. What is the effect on the performance of the traditional competitive dimensions for these plants? Other opportunity for research would be evaluating the proactivity of operations managers for sustainability. For example, governments in general regulate sustainable impacts on supply chain management less than in production management. Is there a difference in performance for plants proactively looking for minimizing their impacts on the supply chain?

Research is still scarce for industrial ecology. Most studies in this field are anecdotal and show success stories, such as industrial ecoparks. In ecoindustrial parks, the byproducts of a factory are used in other processes, such as the often cited Kalundborg park (this is a recurring example in literature – see, for example, Hill, 2004). In Kalundborg, the cement production benefits from the ash generated by a plant to generate electricity, which also provides hot water for a salmon farm, steam to a refinery and a factory for gypsum building materials . There is, however, a clear indication of what to do with the plates of plasterboard of the houses demolished, with the remains of salmon consumed in homes and restaurants or to the refinery product used outside the park. This omission becomes even more complicated to solve the farther products are consumed from the eco-park (e.g., exported to other countries).

Figure 2 depicts a comprehensive framework for sustainable operations strategy. Strategic decisions, to incorporate sustainable operations, must go beyond the traditional decisions of operations strategy, adopting decisions about the environmental and social impact of operations. The external environment must be considered in sustainable operations strategy, besides the traditional link with the corporation and business strategies, communicating with a wider range of stakeholders, such as governments and NGOs. Competitive dimensions must incorporate the concept of triple-bottom performance: economic, environmental, and social. Managers should design the organizational learning and knowledge system to incorporate environmental and social awareness. Sustainable operations strategy should include workers of the firm's own operations and environmental and social responsibility in the activities of OVC.



Sustainable operations strategy is becoming an important field of research for OM, and an increasing challenge to operations managers. If correctly addressed, sustainable operations can become a key to competitive advantage. Consequently, there is a need for research that sheds light in the complex interfaces between the five dimensions of sustainable operations strategy. In this paper, we aimed to contribute toward this end. We hope that this paper stimulates further research in this important field.

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