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Designing the green supply chain

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Supply chain, Logistics, Environment, Environmental management strategy, USA

Abstract

The supply chain has been traditionally defined as a one-way, integrated manufacturing process wherein raw materials are converted into final products, then delivered to customers. Under this definition, the supply chain includes only those activities associated with manufacturing, from raw material acquisition to final product delivery. However, due to recent changing environmental requirements affecting manufacturing operations, increasing attention is given to developing environmental management (EM) strategies for the supply chain. This research: (1) investigates the environmental factors leading to the development of an extended environmental supply chain; (2) describes the elemental differences between the extended supply chain and the traditional supply chain; (3) describes the additional challenges presented by the extension; (4) presents performance measures appropriate for the extended supply chain; and (5) develops a general procedure towards achieving and maintaining the green supply chain.

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Introduction

Years ago, the concept of environmental quality was almost non-existent in the United States. Then, the concept came to mean cleaner air and cleaner water. Now, environmental quality has come to mean "... safe drinking water, healthy ecosystems, safe food, toxic-free communities, safe waste management, and the restoration of contaminated sites" (Council on Environmental Quality, 1996). Concurrently, there has been increasing public attention placed on the overall condition of the natural environment. This attention may be largely attributed to information provided by the media, through growing numbers of environmental and consumer interest groups (Fiksel, 1996). The most commonly perceived enemy to environmental protection is manufacturing and production operations. That is, manufacturing and production processes are viewed as the culprits in harming the environment, in the forms of waste generation, ecosystem disruption, and depletion of natural resources (Fiksel, 1996). Indeed, waste generation and natural resource use, primarily attributed to manufacturing, contribute to environmental degradation by outstripping the earth's ability to compensate and recover, and thus are not sustainable by the earth's ecosystem.

The current state and trend of environmental degradation (from regulatory, consumer, and moral standpoints) indicate a need for a change in manufacturing philosophy. That is, there must be a fundamental shift in the way production systems operate. There must be a move towards sustainability, achieved through vast reductions in resource use and waste generation, and a move away from one-time use and product disposal. The first step in such a move is to extend the structure of the current one-way supply chain to a closed loop, including supply chain operations designed for end-of-life product and packaging recovery, collection, and re-use (in the forms of recycling and/or remanufacturing). The objectives of this research are to:

(1) describe the current state of the natural environment;
(2) investigate the environmental factors leading to the development of an extended environmental supply chain;
(3) describe the additional challenges presented by the extension;

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(4) present performance measures appropriate for the extended supply chain; and
(5) develop a general procedure towards achieving and maintaining the green supply chain.

The state of the environment

Solid and hazardous waste

The amount of solid waste generated in the United States has been growing steadily over the past 30 years and is expected to continue to grow (Council on Environmental Quality, 1996). According to the United States Environmental Protection Agency (EPA), approximately 12 billion tons of industrial waste (and approximately 208 million tons of municipal waste) is generated every year in the United States. Over 4 billion tons of the total waste generated is hazardous waste, and is increasing at a rate of 10 percent annually (Environmental Protection Agency Office of Solid Waste, no date; Fiksel, 1996). This translates into approximately 10 pounds of total waste per person per day (approximately 4.3 pounds of municipal waste per day). Although disposal fees vary by region, the national average waste disposal fee has increased dramatically during the span of 1985 to 1995, rising from $8.20 per ton in 1985 to $32.19 per ton in 1995 (Council on Environmental Quality, 1996). These costs are largely a result of the fact that, according to EPA estimates for municipal solid waste, only 56 million tons (27 percent) was recovered by recycling or composting and 33.5 million tons (16 percent) was incinerated, while 118.5 million tons (57 percent) was landfilled (Environmental Protection Agency Office of Solid Waste, no date).

Natural resource use

The United States extracts an increasing amount of material from United States lands and territories annually, currently in excess of ten tons of material per person (United States Congress Office of Technology Assessment, 1992). In fact, material consumption has increased by a factor of four since the turn of the century (while population has increased by a factor of three during the same period) (United States Congress Office of Technology Assessment, 1992). During this time, the largest increases in natural resource extraction were derived from mining operations (metals and non-metallic ores) and from organics (plastics, and petrochemicals) (United States Congress Office of Technology Assessment, 1992). Additionally, the types of resources extracted have shifted from agricultural and forestry resources in the early 1900s to mining and organics today (United States Congress Office of Technology Assessment, 1992). It is important to note here that modern product designs are generally more efficient (requiring much less material to produce) and result in products that are lighter in weight; however, these modern products are also highly complex, making them generally more difficult to repair, recycle and/or remanufacture.

Water and air pollution

Water

Although the rivers, lakes, and coastal waters of the United States are cleaner today than they were in the early 1970s, water pollution is still a very real concern. For example (Council on Environmental Quality, 1996):

- Nearly 40 percent of all US waters are still too polluted to support all of their designated functions.
- Contaminated fish advisories or bans were issued in 1995 for over 1,700 bodies of water (representing a 14 percent increase over the previous year) to protect the public from eating contaminated fish.
- More than 4,000 beaches were closed in 1995 due to harmful levels of bacteria and other pollutants.
- Approximately 20 percent of the population receive water from a facility that is in violation of at least one national safety requirement.

Air

Similar to water quality, air quality in the United States has undergone considerable improvement in recent years. However, also similar to air quality, some troubling facts still remain:

- In excess of two-thirds of the global urban population (primarily in developing countries) breathes air that has unhealthy particulate levels at least part of the year (Percival *et al.*, 1992).
- It has been estimated that air particulate levels in the United States are responsible for approximately 3 percent of all deaths in the USA (corresponding to 60,000 deaths per year) (Percival *et al.*, 1992).
- In November of 1993, the EPA designated 42 US areas as non-attainment

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areas for carbon monoxide (41 of which were classified as moderate; Los Angeles was classified as serious) (Council on Environmental Quality, 1993).
- Approximately 59 million people in the USA live in counties in which pollution levels failed to meet at least one air quality standard in 1993 (Council on Environmental Quality, 1993).

Environmental policy

Public pressure

In the United States of America, an estimated 75 percent of consumers claim that their purchasing decisions are influenced by a company's environmental reputation, and 80 percent would be willing to pay more for environmentally friendly goods (Lamming and Hampson, 1996). On a worldwide level, a recent 22-country survey of environmental attitudes found that (Elkington, 1994):

- In half of the countries surveyed, the environment was considered one of the three most serious problems.
- In most countries, the majority of the citizens surveyed said that the state of the environment affects their health, and an even greater majority say that the environment affects the health of their children.
- In 16 of the 22 countries, citizens said that they avoid products that are harmful to the environment.

Thus, in the USA, and worldwide, there is an overall awareness of the worsening state of the environment, as well as a desire to reverse that trend, even if it costs more to do so.

Environmental legislation

In response to growing worldwide concern regarding the state of the environment, including pollution and resource conservation, new environmental legislation was adopted in the United States. The primary pieces of legislation are:

(1) the Clean Air Act (CAA);
(2) the Clean Water Act (CWA);
(3) the Resource Conservation and Recovery Act (RCRA);
(4) the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA);
(5) the Toxic Substances Act (TSCA); and
(6) the Amendment Acts to CERCLA, called the Superfund Amendments and Reauthorization Acts (SARA), which includes the Emergency Planning and Community Right-to-Know Act (EPCRA), as Title III.

Table I below lists each of these major pieces of environmental legislation and the year of original enactment (shown in boldface), the years of subsequent amendments (if any), and the primary provisions it contains.

RCRA represented the first legislative step away from isolated "command and control" policies and towards more integrated life cycle approaches. That is, RCRA was the first piece of legislation that made landfill disposal of hazardous waste cost ineffective, since RCRA established that although the short-term cost of hazardous waste landfill disposal may be small, the long-term environmental cost of such a move is far greater. In fact, the current philosophy of pollution and waste reduction and resource follows this model; environmental management is moving away from risk management and pollution prevention, and towards life cycle management and industrial ecology, as shown in Table II.

Environmental management standards (ISO 14000 series)

In response to more stringent environmental regulations and changes in environmental management philosophy, there has been a corresponding need to develop operational guidelines and standards to assist organizations in moving towards ecologically sustainable business practices. The ISO 14000 series standard is designed to address these needs.

Objectives and structure

Recently, the International Organization for Standards (ISO) adopted ISO 14000 series as its international specification standard for environmental management systems, with the objectives of (Alexander, 1996; Pratt, 1997):

(1) Encouraging an internationally common approach to environmental management.
(2) Strengthening companies' abilities to improve and measure environmental performance, through continual system audits.
(3) Improving international trade and removing trade barriers.

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Table I Environmental regulations

Act	Year of enactment, amendments	Primary provisions
CAA	**1967**, 1970, 1977, 1990	National Ambient Air Quality Standards (NAAQSs) Hazardous Air Pollution Standards Motor Vehicle Emissions Standards Fuel and Fuel Additive Standards Aircraft Emission Standards Ozone Protection Provisions
CWA	**1972**, 1977, 1981, 1987	Regulation of wastewater discharges from manufacturing facilities Provisions for federal aid for municipal sewage treatment systems Identification and permit requirements for non-point discharges
RCRA	**1976**, 1984	Regulation of generation, storage, transportation, treatment, disposal, and storage of hazardous waste Ban on landfilling untreated hazardous waste Ban on burning hazardous waste for energy recovery
CERCLA ("Superfund")	**1980**	Provisions for federal funding to clean up sites contaminated from prior unregulated disposal
TSCA	**1976**	Provisions for testing, regulating and screening all substances produced or imported to the United States prior to use Provisions for banning and reporting any chemical substance posing unreasonable risk to health or to the environment
SARA	**1986**	Provisions for increased pace of cleanup Provisions for increased public participation Provisions for more stringent and better defined cleanup standards
EPCRA (SARA, Title III)	**1986**	Provisions requiring companies to report the release and storage of specified chemicals and chemical compounds above certain threshold limits (called "release reporting") Provisions allowing public access to release reports, including chemicals used, and the amount and nature of the releases to the environment

Table II Evolution of environment management

Stage of environmental policy	Primary characteristic(s)	Year(s)
Risk management	Waste management and pollution	1970s-mid 1980s
Pollution prevention	Process improvement to reduce material use, minimize waste, and improve efficiency	mid 1980s-early 1990s
Life cycle management and industrial ecology	Systematic product and process management to maximize profitability and ensure environmental quality Focus on life cycle environmental effects of processes and products	mid-1990s-?

The ISO 14000 series documentation is comprised of five basic components, and is structured as shown in Table III.

Primary requirements

ISO 14000 addresses these three objectives by requiring that organizations develop (Pratt, 1997; Sarkis *et al.*, 1995):

(1) an advance environmental impact analysis of all new activities, products, and processes;
(2) a continuous environmental impact assessment of current activities, products, and process;
(3) standards and objectives, that include policies for pollution prevention and waste minimization, that are defined for and continuously improved at every organizational level;
(4) numerical targets and monitoring procedures for each identified objective;
(5) procedures to be followed in the event of non-compliance with established environmental policies, and in cases of accidental discharge;
(6) procedures to ensure that suppliers and contractors working within or associated with organizational facilities apply environmental standards equivalent to organizational standards.

Table III The ISO 14000 series

ISO 14001	Specific minimum requirements for achieving ISO 14000 certification
ISO 14004	Sets guidelines for developing an environmental management (EM) system
ISO 14010	Establishes the general principles of environmental auditing
ISO 14011	Establishes auditing procedures for the auditing of EM systems
ISO 14012	Establishes qualification criteria for environmental auditors

Source: International Organization for Standardization (1996)

Thus, ISO 14000 is indicative of the recent shift in environmental philosophy; ISO 14000 focuses on procedures and systems, and says nothing of discharge standards, limits, or test methods (Pratt, 1997).

The supply chain re-defined

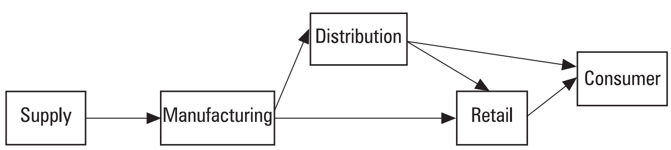
The new environmental era represents a new challenge to manufacturing and production enterprises worldwide. The challenge is to develop ways in which industrial development and environmental protection can symbiotically coexist. The first step in meeting this challenge is to re-define the basic structure of the entire supply chain, by accommodating environmental concerns associated with waste and resource use minimization.

The traditional supply chain

The traditional supply chain is defined as an integrated manufacturing process wherein raw materials are manufactured into final products, then delivered to customers (via distribution, retail, or both). Figure 1 illustrates the structure of the traditional supply chain.

Design, modeling, and analysis of the traditional supply chain has primarily focused on optimizing the procurement of raw materials from suppliers and the distribution of products to customers. The issues considered within this scope of analysis include (Beamon, 1998):

Figure 1 The traditional supply chain



- *Production/distribution scheduling:* scheduling the manufacturing and/or distribution schedule.
- *Inventory levels:* determining the amount and location of every raw material, subassembly, and final assembly storage.
- *Number of stages (echelons):* determining the number of stages (or echelons) that will comprise the supply chain. This involves either increasing or decreasing the chain's level of vertical integration by combining (or eliminating) stages or separating (or adding) stages, respectively.
- *Distribution center (DC) – customer assignment:* determining which DC(s) will serve which customer(s).
- *Plant – product assignment:* determining which plant(s) will manufacture which product(s).
- *Buyer – supplier relationships:* determining and developing critical aspects of the buyer-supplier relationship.
- *Product differentiation step specification:* determining the step within the process of product manufacturing at which the product should be differentiated (or specialized).
- *Number of product types held in inventory:* determining the number of different product types that will be held in finished goods inventory.

The extended supply chain

The ultimate objective of extending the traditional supply chain is to allow consideration of the total immediate and eventual environmental effects of all products and processes (known as product and process stewardship, respectively). The stewardship concept is based on the recognition that the environmental effects of an organization include the environmental impacts of goods and processes from the extraction of raw materials, to the use of goods produced, to the final disposal of those goods (Lamming and Hampson, 1996).

The evolution of manufacturing enterprises from traditional, problem-solving environmental management techniques to fully integrated environmental management (EM) is described in Table IV.

Thus, in the earliest evolutionary stages of environmental management, organizations separate environmental performance from operational performance. However, as

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Table IV Stages of environmental management

Evolutionary stage	Characteristics
1. Problem solving	Traditional approaches View regulatory compliance as a burdensome cost of doing business
2. Managing for compliance	Primitive attempts at EM coordination and integration Compliance-oriented
3. Managing for assurance	Visionary/long-range planners Utilize risk management to balance potential future environmental liabilities versus costs
4. Managing for eco-efficiency	Pollution prevention instead of pollution control Waste minimization and source reduction
5. Fully integrated	Environmental quality viewed as an aspect of Total Quality Management (TQM) Global concern about processes and entire product life cyle

Note: Adapted from Fiksel (1996)

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organizations evolve, they begin to integrate environmental objectives within the framework of their existing operational objectives. In this way, the following potential benefits may be realized:

- Reduced product life cycle costs → increased profitability. More specifically, effective environmental management results in the avoidance of the following costs (Cattanach *et al.*, 1995):
  - Cost avoidance of purchasing hazardous materials as inputs, which reflect the internalized costs associated with environmental harm.
  - Cost avoidance of storing, managing, and disposing process waste, particularly as waste disposal becomes increasingly expensive.
  - Cost avoidance of stigmatization or market resistance to environmentally harmful products.
  - Cost avoidance of public and regulatory hostility towards environmentally harmful organizations.
- Reduced environmental and health risks → reduced liability risks (Cattanach *et al.*, 1995; Zhang *et al.*, 1997).
- Safer, cleaner factories (Zhang *et al.*, 1997).

The fully integrated, extended supply chain contains all of the elements of the traditional supply chain (Figure 1), but extends the one-way chain to construct a semi-closed loop that includes product and packaging recycling, re-use, and/or remanufacturing operations. The extended supply chain is illustrated in Figure 2. Figure 2 represents the traditional supply chain links as solid lines, and the links corresponding to the extended supply chain as dashed lines. The "W"s enclosed by diamonds represent waste (or disposed) materials.

Recycling and re-use

Recycling is the process of collecting used products, components, and/or materials from the field, disassembling them (when necessary), separating them into categories of like materials (e.g. specific plastic types, glass, etc.), and processing into recycled products, components, and/or materials. In this case, the identity and functionality of the original materials are lost (Thierry *et al.*, 1995). The success of recycling depends on:

(1) whether or not there is a market for the recycled materials; and
(2) the quality of the recycled materials (since most recycling processes actually reduce the value of the material from its original value, as the material itself has degraded).

Re-use is the process of collecting used materials, products, or components from the field, and distributing or selling them as used. Thus, although the ultimate value of the product is also reduced from its original value, no additional processing is required.

Remanufacturing

The process of remanufacturing consists of collecting a used product or component from the field, assessing its condition, and replacing worn, broken, or obsolete parts with new or refurbished parts. In this case, the identity and functionality of the original product is retained. The resulting (remanufactured) product is then inspected and tested, with the goal of meeting or exceeding the quality standards of brand new products. Thus, in some cases, the remanufactured product can exceed the original product in quality and/or function. This is due to the fact that during the remanufacturing process, the design of the replaced parts and/or components may have been improved since the original product was manufactured. The unique advantage of remanufacturing is that, unlike recycling and re-use, the process of remanufacturing does not degrade the overall value of the materials used.

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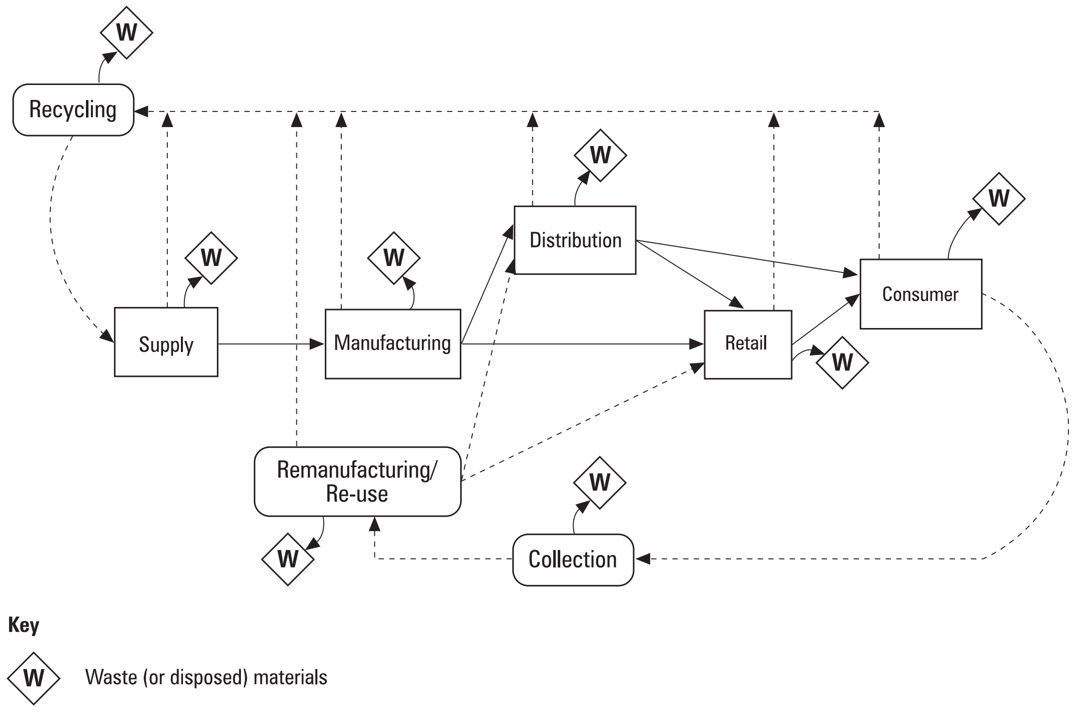
Figure 2 The extended supply chain



The extended supply chain: operational and strategic issues

Extending the supply chain to include recovery operations, such as remanufacturing, recycling, and re-use adds an additional level of complexity to supply chain design, and a new set of potential operational and strategic considerations. These new considerations arise from two basic problems:

(1) uncertainty associated with the replacement/recovery process (in time requirements, quality, and quantity of returned products, packaging, and/or containers); and
(2) the reverse distribution process itself (collection and transportation of used products, packaging, and/or containers).

Examples of operational and strategic issues associated with recoverable product systems are:

- Inventory control policies (including lot-sizing, scheduling, and safety stocks) given highly uncertain timing, quality, and quantities of replenishments (Guide *et al.*, 1997a, 1997b; Haynsworth and Lyons, 1987; Perry, 1991).
- Impact of uncontrollable recovery processes on inventory composition, production planning, and scheduling (i.e. the demand and recovery processes are not perfectly correlated, potentially resulting in uncontrolled growth of unwanted parts and non-availability of critical parts) (Van der Laan *et al.*, 1996a, 1996b).
- Disassembly planning (including scheduling, sequencing, and disassemblability analysis) for material recovery (Gupta and Taleb, 1994; Johnson and Wang, 1995).
- The number and location of collection/recovery facilities.
- Collection procedures and customer incentive systems for retrieval operations.
- Effects of traditional supply chain strategies (e.g. decentralized versus centralized business functions, facility location, purchasing strategies) on environmental performance (e.g. energy use, solid waste, pollution, product recovery).
- Simultaneous operational/environmental supply chain optimization; merging environmental and operational goals into traditional analysis.
- Level and location of buffer inventories must be considered on both sides of the extended supply chain (forward and reverse) (Fleishmann *et al.*, 1997).
- New criteria for vendor selection and certification.

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Performance evaluation

An important component in supply chain design and analysis is the establishment of appropriate performance measures. A performance measure, or a set of performance measures, is used to determine the efficiency and/or effectiveness of an existing system, or to compare competing alternative systems. Performance measures are also used to design proposed systems, by determining the values of the decision variables that yield the most desirable level(s) of performance.

Traditional supply chain performance measures

Available literature regarding traditional supply chain systems identifies a number of performance measures as important in the evaluation of supply chain effectiveness and efficiency. These measures are typically concerned with:
(1) customer satisfaction, service, or responsiveness; or
(2) cost.

The interested reader is referred to Beamon (1996) and Beamon (1998) for a discussion of these measures.

Performance measures for the extended supply chain

Although a number of performance measures appropriate for traditional supply chains have been developed, these existing measures are inadequate for use in the extended chain. The existing measures are inadequate in capturing the dual extended supply chain objectives of economic efficiency and environmental protection. This identifies a need to develop new, more inclusive, measures to describe supply chain performance. ISO 14000 identifies the need for these measures implicitly in its certification requirements. In fact, these certification requirements (as previously identified), refer directly to requiring environmental impact analysis and assessment, continuous measurement, targets, and monitoring procedures. Table V describes and classifies the existing performance measures for the extended supply chain.

The types of performance measure(s) used by an organization will largely depend on their evolutionary stage in Environmental Management. Table VI lists each of the organizational evolutionary stages (as shown in Table IV) versus the performance measure type(s) with which that stage is most likely associated.

Towards the green supply chain

In general, the impact of manufacturing operations on the environment may be categorized as follows:
(1) waste (all forms);
(2) energy use; and
(3) resource use (material consumption).

In order to achieve the green supply chain, manufacturing organizations must follow the basic principles established by ISO 14000. In particular, organizations must develop procedures that focus on operations analysis, continuous improvement, measurement, and objectives. An implementation procedure for extending the supply chain includes the following tasks:

- *Identify processes.* For each product within the supply chain, identify all inputs, outputs, by-products, and resources.
- *Develop a performance measurement system.* Given the complexity of most supply chains, a single performance measure will likely be inadequate in assessing the true performance of the supply chain. Thus, a system of performance measures will be necessary. Such a performance measurement system must include measures for the three environmental categories given above, as well as existing operational measures. The interested reader is referred to Beamon (1998) for a discussion of performance measure criteria and selection.
- *Measure the supply chain system.* Calculate the actual composite performance at each step in the supply chain process for each product. The composite performance, as calculated at each supply chain process step, will be a function of the performance measures developed above. The composite performance, therefore, may be a single numerical value, or (more likely) a vector of numerical values.
- *Prioritize.* After all processes for all products have been measured, prioritize the process steps in order of increasing composite performance, as calculated above.

Table V Extended supply chain performance measures

Performance measure classification	Performance measure (measured over product and process life cycle, except where indicated)
Resource use	Total energy consumed
	Total material consumed (e.g. water, timber, steel, etc.)
Product recovery	Time required for product recovery
Remanufacturing	Percent recyclable/re-useable materials (volume or weight) available at end of product life
Re-use	Percent product volume or weight recovered and re-used
Recycling	Purity of recyclable materials recovered
	Percent recycled materials (weight or volume) used as input to manufacturing
	Percent product disposed or incinerated
	Fraction of packaging or containers recycled
	Material recovery rate (MMR)[1]
	Core return rate (CRR)[2]
	Ratio of virgin to recycled resources
	Ratio of materials recycled to materials potentially recyclable
	Materials productivity: economic output per unit of material input
Product characteristics	Useful product operating life
	Total mass of products produced
Waste emissions and exposure hazard	Total toxic or hazardous materials used
	Total toxic or hazardous waste generated
	Solid waste emissions
	Percent product (weight or volume) disposed in landfills
	Concentrations of hazardous materials in products and by-products
	Estimated annual risk of adverse effects in humans and biota
	Waste ratio[3]: the ratio of wastes to all outputs
Economic	Average life-cycle cost incurred by the manufacturer
	Purchase and operating cost incurred by the consumer
	Average total life-cycle cost savings associated with design improvements
Economic/emissions	Eco-efficiency[4]: adding the most value with least use of resources and the least pollution. Generally, "The ability to simultaneously meet cost, quality and performance goals, reduce environmental impacts, and conserve valuable resources"

Sources: Fiksel, 1996; Guide *et al.*, 1997b; Krupp, 1992; Schmidheiny, 1992

Notes: [1] See Guide *et al.* (1997a); [2] See Krupp (1992); [3] See Fiksel (1996); [4] See Schmidheiny (1992)

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Table VI Evolutionary stage vs performance measure classification

Evolutionary stage	Performance measure classification
1. Problem solving	Waste emissions and exposure hazard; economic
2. Managing for compliance	Waste emissions and exposure hazard; economic; product characteristics
3. Managing for assurance	Economic; product characteristics; economic/emissions
4. Managing for eco-efficiency	Product characteristics; economic/emissions; resource use
5. Fully integrated	Product characteristics; economic/emissions; resource use; product recovery

- *Develop alternatives and select approach.* Develop alternatives for performance improvement (targeting first those process steps exhibiting the worst composite performance, based on prioritization above), and select a preferred approach.
- *Establish auditing and improvement procedures.* Establish schedules and procedures for auditing and continuous improvement, including emergency and non-compliance procedures.

Conclusion

The supply chain concept grew out of the recognition that the process of transforming raw materials into final products and delivering those products to customers is becoming increasingly complex. As such, it became increasingly apparent that analysis (and subsequent improvement) of the individual

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supply chain stages did not lead to improvement of the chain as a whole. Thus, the concept of the supply chain emerged to describe all production stages from raw material acquisition to final product delivery. Changes in the state of the environment, leading to subsequent public pressure and environmental legislation have necessitated a fundamental shift in manufacturing business practices. No longer is it acceptable or cost effective to consider only the local and immediate effects of products and processes; it is now imperative to analyze the entire life-cycle effects of all products and processes. Therefore, the traditional structure of the supply chain must be extended to include mechanisms for product recovery. This extension presents an additional level of complexity to supply chain design and analysis; more specifically, the addition of the product recovery mechanism gives rise to numerous issues affecting strategic and operational supply chain decisions. Consequently, the extension of the traditional supply chain requires the establishment and implementation of new performance measurement systems. These new measurement systems will serve as the centerpieces of environmentally conscious implementation plans, based on continuous improvement, that will enable organizations to become and remain competitive while achieving sustainable processes.

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