Performance measurement for green supply chain management

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Abstract

Purpose – To introduce and provide an overview of the various issues related to environmental (green) supply chain management performance measurement.

Design/methodology/approach – The work relies on experiences, case studies and other literature related to performance measurement in environmental supply chains. It seeks to integrate works in supply chain management, environmental management, and performance management into one framework. A systems framework forms the discussion outline with a focus on controls/pressures, inputs, tools, and outputs as major categories for evaluation and review.

Findings – Provides an integrative framework for study, design and evaluation of green supply chain management performance tools. The findings also identify a number of issues that need to still be addressed.

Research limitations/implications – We have only one design of the issues in which numerous categorizations could be provided. There is limited research in this area and new and current models/developments can provide additional insight. Implications of the work is that these gaps exist and that significantly more work needs to be completed in this field.

Practical implications – A very useful source of information for practitioners that seek to implement these systems within and between organizations. Also, the paper provides numerous areas which researchers could complete additional research and develop research agendas.

Originality/value – This paper provides some of the very first insights into development of a green supply chain management performance measurement system. Typically performance measurement systems are internally and business focused, we expand on these issues by considering inter-organizational and environmental issues within a business context.

Keywords Performance measurement (quality), Supply chain management, Environmental management

Paper type General review

Introduction

In supply chains with multiple vendors, manufacturers, distributors and retailers, whether regionally or globally dispersed, performance measurement is challenging because it is difficult to attribute performance results to one particular entity within the chain. There are difficulties in measuring performance within organizations and even more difficulties arise in inter-organizational environmental performance measurement. The reasons for lack of systems to measure performance across organizations are multidimensional, including non-standardized data, poor technological integration, geographical and cultural differences, differences in organizational policy, lack of agreed upon metrics, or poor understanding of the need for inter-organizational

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performance measurement. Performance measurement in supply chains is difficult for additional reasons, especially when looking at numerous tiers within a supply chain, and green supply chain management performance measurement, or GSCM/PM, is virtually non-existent. With these barriers and difficulties in mind, GSCM/PM is needed for a number of reasons (including regulatory, marketing and competitiveness reasons). Overcoming these barriers is not a trivial issue, but the long-term sustainability (environmental and otherwise) and competitiveness of organizations may rely on successful adoption of GSCM/PM.

The basic purposes of GSCM/PM are: external reporting (economic rent), internal control (managing the business better) and internal analysis (understanding the business better and continuous improvement). These are the fundamental issues that drive the development of frameworks for business performance measurement. It is important to consider both purpose, as well as the interrelationships of these various measurements.

To address the numerous issues facing GSCM/PM, this paper begins with a general discussion of supply chain management and performance measurement principles. This initial discussion is extended by incorporating supply chain or inter-organizational dimensions to performance measurement principles. Then, presentation of some principles of GSCM will set the stage for the discussion of GSCM/PM and environmental management systems (or GSCM/PMS). Metrics and measures are identified within this context. Management and research issues related to the management of GSCM/PM systems conclude our discussion.

Supply chain performance measurement

Supply chain management

Supply chain management is the coordination and management of a complex network of activities involved in delivering a finished product to the end-user or customer. It is a vital business function and the process includes sourcing raw materials and parts, manufacturing and assembling products, storage, order entry and tracking, distribution through the various channels and finally delivery to the customer. A company's supply chain structure consists of external suppliers, internal functions of the company, and external distributors, as well as customers (commercial or end-user). Firms may be members of multiple supply chains simultaneously. The management and coordination is further complicated by global players spread across geographic boundaries and multiple time zones. The successful management of a supply chain is also influenced by customer expectations, globalization, information technology, government regulation, competition and the environment.

Performance management and measurement

Corporate performance measurement and its application continue to grow and encompass both quantitative and qualitative measurements and approaches. The variety and level of performance measures depends greatly on the goal of the organization or the individual strategic business unit's characteristics. For example, when measuring performance, companies must consider existing financial measures such as return on investment, profitability, market share and revenue growth at a more competitive and strategic level. Other measures such as customer service and inventory

performance (supply, turnover) are more operationally focused, but may necessarily be linked to strategic level measures and issues.

Overall, these difficulties in developing standards for performance measurement are traced to the various measurement taxonomies. Example taxonomic considerations include: management level to measure – strategic, tactical, or operational; tangible versus intangible measures; variations in collection and reporting; an organization's location along the supply chain or functional differentiation within organizations (e.g. accounting, versus marketing or operations).

Similar to the performance measurement used, the performance measurement system may be unique to each individual organization, or unit within an organization, reflecting its fundamental purpose and its environment. Several studies have investigated the universal principles of performance measurement (Adams *et al.*, 1995; Gunasekaran *et al.*, 2001; Sink and Tuttle, 1990). These studies arrived at a number of conclusions related to performance measurement and their systems including: performance measurement systems may have either tangible or intangible measures with a balance of both types used to measure performance; measures should be dynamic and present at multiple levels; products and processes need to be included; systems and measures are best developed with a team approach with derivation from and links to corporate strategy; systems must have effective internal and external communications; accountability for results must be clearly assigned and be understood; systems must provide intelligence for decision makers and not just compile data; and the system should be capable of linking compensation, rewards, and recognition to performance measurement. It has also been argued that performance measurement must evolve to performance management, where the organization develops the appropriate organizational structure and the ability to use performance measurement results to actually bring about change in the organization.

Elements of these efforts are central to total quality and continuous improvement programs, where performance measurement is critical to any organization in managing their operations. Performance measurement has many uses including the determination of the efficiency and effectiveness of an existing system or to compare competing alternative systems. Performance measurement is typically used to plan, design, implement and monitor proposed systems.

Linking the supply chain and performance measurement

Even though significant work has been completed on performance measurement and management on internal organizational operations, the emphasis on supply chain performance measurement (especially with an inter-organizational focus), in either the practitioner or research community, has been relatively limited (Gunasekaran *et al.*, 2004).

Supply chain models, especially those that consider multiple echelon inventory management, have typically focused on performance measures such as cost (Cohen and Lee, 1989; Cohen and Moon, 1990; Lee and Feitzinger, 1995; Tzafestas and Kapsiotis, 1994) and a combination of cost and customer responsiveness (Arntzen *et al.*, 1995; Altiok and Ranjan, 1995; Cook and Rogowski, 1996; Davis, 1993; Towill *et al.*, 1992; Wikner *et al.*, 1991; Lee and Billington, 1993; Christopher, 1994; Nicoll, 1994).

Some of the existing literature does provide initial insights into broader supply chain performance measurement. Particular attention has been paid to supplier

performance evaluation and study of appropriate performance measures (Davis, 1993; Nicoll, 1994; Carr and Pearson, 1999; Carr and Smeltzer, 1997, 1999; Chen and Paulraj, 2002). Most of these studies have also focused on developing and evaluating constructs or supplier performance measurement and what roles they play.

Extending this work, Beamon and Chen (2001) examine the effects of the various factors on supply chain performance and identify the nature of the relationship between these factors and overall supply chain performance. The results of their study confirm the inventory system stock-out risk, the probability distribution of demand, and transportation time, were most important in determining the effectiveness of the chain.

Gunasekaran *et al.* (2001) provide an overview of the various performance metrics across the supply chain and describe sources using these performance metrics. In an integrative model, they look at functions within a single organization's supply chain and provide metrics appropriate to manage the four "basic links" of the supply chain including plan, source, make/assemble, and delivery functions. In their review, environmentally-focused metrics were not discussed, but they did mention the need for further investigation on these general metrics.

In a more recent empirical study, Gunasekaran *et al.* (2004) provide insights into current practice and future requirements in supply chain performance measurement including issues relevant to our later discussion on GSCM/PM. Included among these issues are: successful implementation requires organization-wide coordination; to monitor performance each metric must take a supply chain perspective; each entity in the supply chain should be measured and improved with common goals; non-financial metrics are gaining more attention than financial ones; and additional and creative efforts are needed to design new measures.

Brewer and Speh (2001) posit a number of concerns in applying performance measurement tools and systems across the supply chain, including the following.

- *Overcoming mistrust*. Traditional SCM practices have been adversarial. Trust in data sharing, acquisition and monitoring needs to be built.
- *Lack of understanding*. Multi-organizational measures are difficult to understand for managers focused on internal systems.
- *Lack of control*. Managers and organizations wish to be evaluated on measures they can control. Inter-organizational measures are difficult to manage and thus control.
- *Different goals and objectives*. Differing organizations have different goals and thus would argue for differing measures.
- *Information systems*. Most corporate information systems are incapable of gathering non-traditional information relating to supply chain performance.
- *Lack of standardized performance measures*. Agreed upon measures in terms of units to use, structure, format, etc. may not exist.
- *Difficulty in linking measures to customer value*. Linkage to stakeholder value (expanding to environmental issues) is becoming more complex. The definition of who the customer may be inside a supply chain also is not clear.
- *Deciding where to begin*. Developing supply chain-wide performance is difficult since it is not always clear where boundaries exist.

Overcoming these hurdles can be completed with strong leadership, communication and partnership programs across organizations, but clearly, additional cooperative stances are needed among organizations.

Given this initial overview of performance metrics in the supply chain, issues related to corporate environmental management and performance measurement are introduced within a discussion of issues facing green environmental supply chain management and performance measurement.

Green supply chain management

Several studies have considered the concept of ecological sustainability as a framework for studying management practices in both operational and strategic contexts (Sarkis and Rasheed, 1995; Klassen and McLaughlin, 1996; King and Lenox, 2001). As part of this effort, other studies have examined the greening of supply chains within various contexts including in product design (Allenby, 1993; Gupta, 1995), process design (Porter and Van der Linde, 1995a; Klassen and McLaughlin, 1996), manufacturing practices (Winsemius and Guntram, 1992), purchasing (Handfield *et al.*, 2002) and a broad mixture of these elements (Bowen *et al.*, 2001a).

It is not surprising that GSCM finds its definition in supply chain management. Adding the "green" component to supply chain management involves addressing the influence and relationships of supply chain management to the natural environment. Motivated by an environmentally-conscious mindset, it can also stem from a competitiveness motive within organizations.

In this paper GSCM is defined as:

$$\begin{aligned}&\text{Green Supply Chain Management (GSCM)}\\&\quad = \text{Green Purchasing} + \text{Green Manufacturing/Materials Management}\\&\qquad + \text{Green Distribution/Marketing} + \text{Reverse Logistics}\end{aligned}$$

Figure 1 shows this GSCM equation graphically, where reverse logistics "closes the loop" of a typical forward supply chain and includes reuse, remanufacturing, and/or recycling of materials into new materials or other products with value in the marketplace. The idea is to eliminate or minimize waste (energy, emissions, chemical/hazardous, solid wastes). This figure is representative of a single organization's internal supply chain, its major operational elements and the linkage to external organizations. A number of environmentally conscious practices are evident throughout the supply chain ranging from green design (marketing and engineering), green procurement practices (e.g. certifying suppliers, purchasing environmentally sound materials/products), total quality environmental management (internal performance measurement, pollution prevention), environmentally friendly packaging and transportation, to the various product end-of-life practices defined by the "Re's" of reduction, reuse, remanufacturing, recycling. Expanding this figure, a number of organizational relationships could be found at various stages of this model, including customers and their chains, as well as suppliers and their chains, forming webs of relationships.

The development of industrial ecosystems would be greatly supported by GSCM practices. Korhonen and Niutanen (2003) in their study of material and energy flows in the local forest industry in Finland suggested these flows were comparable to other economic and industrial systems. In the last two decades, the product-based systems perspective and the geographically defined local-regional industrial ecosystem have

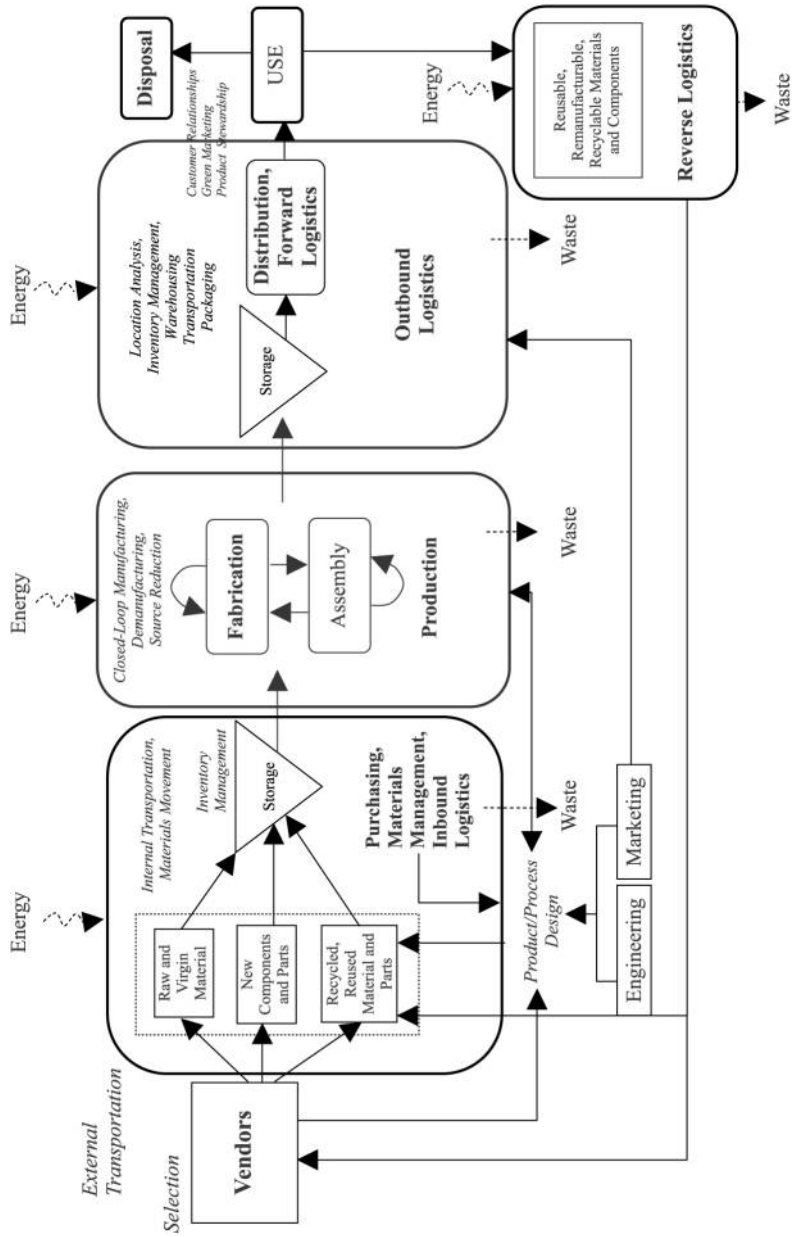

Figure 1.
Graph of the GSCM

emerged. Both approached focus on material and energy flows aiming at reducing the industrial system's virgin resource use and waste and emission outputs. Korhonen (2002) agrees the ideal mirrors the model of a sustainable natural ecosystem.

A major element within GSCM is concerned with inter-organizationally sharing responsibility for various aspects of environmental performance. GSCM should promote the sharing of environmental responsibility and lend itself to achieving a reduced environmental burden caused by industry. Several techniques exist to help managers map the environmental impacts along supply chains, such as the life cycle assessment, product stewardship, and design for environment (DFE) principles, which are also complementary tools and philosophies for each other. Life cycle assessment is a structural approach to define and evaluate the total environmental load associated with providing a service. It also incorporates development of an inventory of data, impact of materials, products and processes, and improvement analysis aspects. GSCM performance measurement and metrics are critical to all these dimensions of life cycle assessment.

The most frequently cited predictor GSCM implementation is the proactivity of the firm's corporate environmental approach (Drumwright, 1994; Cramer, 1996; Ellram and Ready, 1998). Bowen *et al.* (2001b) argue capabilities appropriate for green supply must be developed by a proactive corporate environmental stance and a strategic purchasing and supply chain management approach. Once developed, supply chain management capabilities can ease the implementation of green supply and thus help disseminate environmentally sound practices throughout the complex network of industrial buying and selling.

Hart (1995) and Sarkis and Kitazawa (2000) argue capabilities in total quality management can ease the introduction of pollution prevention programs and capabilities in cross-functional management facilitate product stewardship, essential to GSCM, and are related to organizational capabilities and pressures existing for GSCM introduction. Total quality management requires decisions based on data and continuous improvement through appropriate performance measurement, which is also true of the more specific total quality environmental management paradigm.

In one of the few studies linking GSCM elements and performance measurement, Beamon (1999) suggests the traditional performance measurement structure of the supply chain must be extended and include mechanisms for product recovery (reverse logistics) and the establishment and implementation of new performance measurement systems. Yet, overall environmental performance measurement, and supporting systems, across supply chains has not been as extensively studied.

Green supply chain management performance measurement system (GSCM/PMS)

The issues surrounding the green supply chain performance measurement system, or GSCM/PMS, form the core contribution of this paper. Figure 2, which shows a framework for the remainder of our discussion, represents a systems model based on one activity "Implementation and Operation of GSCM/PMS". The discussion begins with the major boundaries associated with managing this system, including "external pressures" and "internal controls/pressures". The next set of elements discussed, critical inputs to the system, includes various "metrics and measures", as well as the design of a GSCM/PMS. To aid the GSCM/PMS management, "tools" are also identified. Expected results represent outcomes of such a system and are discussed.

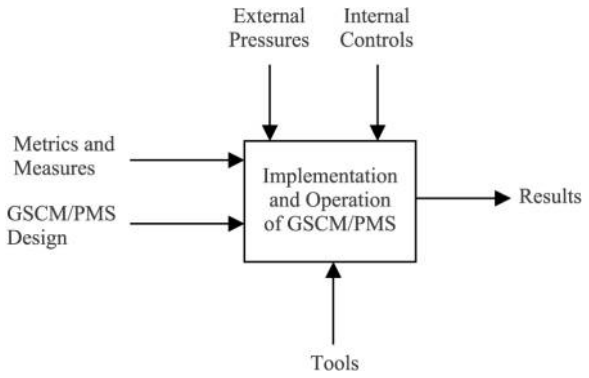

Figure 2.
GSCM/PMS flow and pressures

Pressures and controls facing a GSCM/PMS

Internal issues. Pressures for internal controls for GSCM/PMS are largely cost and profit driven. Waste streams, costs for disposal, and the overall waste and excess from not recycling drive the needs. Internal controls are numerous, and include all forms of legacy systems, data management systems, linkages to other performance systems including those based on ISO 9000:2000, total quality management, and other industry-specific standards. Assessment of environmental programs, either reactive or proactive, are internal controls as are costs, employee interest, and activity toward green programs.

Organizational factors influence a firm's decision to adopt innovative practices. Many of these innovative adoptions may lead to improvements in environmental outcomes and overall business performance. Florida *et al.* (2000) conclude that two organizational factors, organizational resources and capacity along with organizational monitoring, play an important role in a firm's adoption of environmental practices. Related to the adoption of these typically innovative practices, numerous studies have examined the adoption of organizational innovations by firms (Womack *et al.*, 1990; Osterman, 1994).

Many studies focus on the role of "organizational capabilities" in both organizational innovation and organizational performance (Cohen and Levinthal, 1990; Teece and Pisano, 1994; Winter, 1987). These studies suggest organizations vary in their internal resource base and procedures, affecting their ability to respond to internal and external changes or challenges. Organizational capabilities include factors such as: organizational resources, organizational innovativeness and organizational monitoring systems. Organizational resources and capacity refer to overall level of resources and specialized environmental resources and capacities possessed by firms. Organizational innovativeness refers to firm's previous commitment and track record in implementing advanced organizational practices. Organizational monitoring refers to the methods by which organizations measure, analyze, and monitor their performance in key dimensions. In addition, Hemmelskamp (1999) concludes internal sources of information as well as certain external sources are important for environmental product innovation. It is within this scope and requirement that GSCM/PMS are needed and will limit much of the capability to introduce such an innovation within an organization, and increasingly across organizations.

Factors influencing adoption of environmental innovation such as GSCM/PMS have been summarized by Angel del Brio and Junquera (2003). They argue that a lack of small and medium sized enterprises innovation with respect to environmental strategy may be a consequence of a number of factors: limited financial resources, the type of organizational structure, little influence of the strategic adaptation competence against changes in the enterprises, managers' lack of environmental training and short-term orientation, staffs' lack of environmental awareness and training, the status of the environmental issues in the company, these enterprises' lower abilities to obtain innovations, and their lack of relationships with external stakeholders. These characteristics also need to be overcome in larger organizations (see Sharma, 2000; Bansal and Roth, 2000, for example), and need to be managed.

Overall, firms must develop appropriate organizational structures for environmental innovations, defined as any innovation which reduces the environmental impact of carrying out particular kinds of activities in terms of consuming fewer resources, producing less waste, and creating less environmental harm (Clayton *et al.*, 1999). Environmentally beneficial innovations are motivated by environmental as well as economic motives (Malaman, 1996; Hemmelskamp, 1999; Clayton *et al.*, 1999). A successful environmentally beneficial innovation requires new combinations of knowledge about product characteristics, process and material characteristics, and available technologies and markets.

Knowledge processes are keys to environmental innovations and the availability of substantial bodies of internal expertise within firms can be an important resource for these environmental innovations. Internal sources of knowledge are important for both product and process innovations. For example, the technical skills and competences of purchasing personnel may be a critical resource in building green supply capabilities.

Organizations require appropriate structures to enable both assessment and application of external measures. There is also a need for internal absorptive capacity or the capacity to accept change and modify or adapt operations at various levels to external or internal shocks. For change to be institutionalized and profitable, it needs to become rooted within firms. A top management focus on the importance of GSCM performance management, as well as corresponding measurement, assessment, and rewards at all levels will reinforce their importance. As in other process implementations, use of suggestion systems, corporate internal communication, and championing of green practices are necessary to reinforce the importance.

External issues. There are a number of sources of external pressures for GSCM/PMS and other environmental innovations. They can be grouped in numerous ways, but are essentially those of external "stakeholders" and competitors. Pressures can either be from regulatory pressures or from market pressures (which would include influences by numerous stakeholders such as communities, employees, customers, suppliers and competitors, to name a few). Some of these pressures are greater for different size organizations and specific industries (Henriques and Sadorsky, 1996, 1999; Hall, 2000). Many of these external concerns and pressures can be traced to corporate legitimacy issues.

Porter (1991) argues the pressure to innovate from an environmental perspective comes from regulatory pressure, as firms respond in creative and dynamic ways to environmental regulation by introducing innovations improving environmental outcomes. Other studies concluded environmental innovation is the result of market

pressures causing firms to become more efficient. Porter and Van der Linde (1995a, b) concluded firms respond to competitive conditions and regulatory pressure by developing strategies to maximize resource productivity, enabling them to simultaneously improve their industrial and environmental performance.

Furthering this issue, Greffen and Rothenberg (2000) suggest suppliers can be an important source of enhanced competency for radical environmental innovation, which, in relation to an integrated technological system, demands capabilities beyond those likely to exist within a single company. The added competency brought by the supply chain partners is important.

Other external pressures do exist and include environmental compliance, liability, issues of business continuity, the call for benchmarking to national, international, or industry standards, customer attitudes toward product take-back, and even pressures from inter-organizational information technology/data management systems.

The innovation of GSCM/PMS is necessary for a number of reasons in response to external pressures. For example, business performance measurement, for purposes of external reporting, is fundamentally driven by the creation, maximization and defence of economic rents or surplus. These surpluses or rents in business come from distinctive capabilities such as brands and reputation, strategic assets, innovations, and the distinctive structure of relationships firms enjoy both internally with their employees and/or externally with their customers and suppliers. External reporting is also necessary to maintain organizational legitimacy with respect to environmental issues (Harvey and Schaefer, 2001). Regulatory requirements (in many countries throughout the world) require mandatory reporting of information gathered from GSCM/PMS type sources. For example, the toxics releases inventory (TRI) data and waste from the United States Environmental Protection Agency; and the waste electrical and electronic equipment (WEEE) directive in the European Union, are influenced by the information and performance of supply chain activities. Monitoring supply chain environmental performance may also add competitive advantages to organizations seeking to show final customers and other stakeholders how well they are performing and the continuous improvement of performance, and their long term goals to reduce risk of closure due to environmental penalties.

Metrics and measures

Environmental performance indicators are core requirements of a GSCM/PMS when evaluating the environmental performance of activities, processes, hardware and services. Environmental performance indicators are described in ISO 14031 (environmental management-environmental performance evaluation of the ISO 14001 accreditation guidelines). Environmental performance indicators are needed when evaluating the environmental performance of activities, processes, hardware and services.

The following is a list of selected metrics of environmental performance from the TRI and the Global Reporting Initiative (a multi-stakeholder process by an independent institution whose mission is to develop and disseminate globally applicable sustainability reporting guidelines) ranging from air emissions to energy recovery and recycling:

- fugitive non-point air emissions;
- stack or point air emissions;

- discharges to receiving streams and water bodies;
- underground injection on-site;
- releases to land on-site;
- discharges to publicly owned treatment works;
- other off-site transfers;
- on-site and off-site energy recovery;
- on-site and off-site recycling;
- on-site or off-site treatment;
- non-production releases;
- source reduction activities;
- spill and leak prevention;
- inventory control;
- raw material modification;
- process modifications;
- cleaning and decreasing;
- surface preparation and finishing;
- product modifications;
- pollution prevention opportunity audits; and
- materials balances audits (Selected metrics of environmental performance used by TRI and the Global Reporting Initiative)

Additional general measures are detailed in the list below:

- employee and participative management;
- publicly available missions and values statement(s);
- management systems pertaining to social and environmental performance;
- magnitude and nature of penalties for non-compliance;
- number, volume, and nature of accidental or non-routine releases to land, air, and water;
- costs associated with environmental compliance;
- environmental liabilities under applicable laws and regulations;
- site remediation costs under applicable laws and regulations;
- major awards received;
- total energy use;
- total electricity use;
- total fuel use;
- other energy use;
- total materials use other than fuel;
- total water use;

- habitat improvements and damages due to enterprise operations;
- quantity of non-product output returned to process or market by recycling or reuse;
- major environmental, social, and economic impacts associated with the life cycle of products and services;
- formal, written commitments requiring an evaluation of life cycle impacts;
- programs or procedures to prevent or minimize potentially adverse impacts of products and services; and
- procedures to assist product and service designers to create products or services with reduced adverse life cycle impact.

Selected measures and metrics must be implemented within a framework much like the strategic planning model beginning with an organization's mission and vision as the leading point for developing appropriate measures.

These metrics and measures have implications for all levels of management (e.g. strategic, tactical, and operational) and have tangible and intangible characteristics. Thus, environmental indicators are plentiful. Yet, there is a difficulty in determining which to use, when to measure them, and how to measure them. Many of these issues must be addressed. Even though there are recommended approaches for some of the more tangible measures, there may be idiosyncratic approaches evident for each organization (i.e. some organizations may calculate values using different assumptions). Documentation of these measures is necessary for either internal (e.g. continuous improvement) or external purposes (reporting to regulatory agencies).

The types of environmentally-based performance measures used by an organization will depend largely on the organization's evolutionary stage in environmental management. Reactive organizations with a focus on complying with new laws may base performance measures on factors related to meeting the regulations. Thus, the amount of regulated emissions or disposal of hazardous wastes would be core performance metrics. Organizations seeking to be more proactive may focus not only on performance measures for compliance issues but may also provide information related to the greenness of products and processes and metrics for green supplier evaluation.

Another level of complexity specifically attributed to GSCM/PMS is the inter-organizational and product life cycle characteristics of this system. Even though many of the measures from the above list can be used across organizational boundaries and product life cycles, the inclusion of customer/supplier input is necessary. Agreement and negotiation on the metrics selected and other design issues (e.g. collection of data) must be completed by major supply chain members. Even though this is unique, supply chain performance measures may be determined through supplier certification processes or surveys completed for current practices among organizations in the negotiation of future contracts.

Designing a GSCM/PMS

Next, design issues and implementation issues must be addressed by the organization. When designing the GSCM/PMS, top management should address the questions posited below:

- What are the goals of the GSCM/PMS?
- How does the GSCM/PMS fit within the strategy of the supply chain?
- How should GSCM/PMS be designed?
- How should external stakeholder concerns and preferences be integrated?
- What metrics levels and decomposition should be included?
- Who should design the measures?
- Who should monitor the measures?
- How should information generated by system be used and disseminated?
- How should information be linked up to other internal and external performance measurement systems, environmental management systems and other information systems (e.g. enterprise resource planning systems)?
- What are relationships between GSCM measures and organizational measures (e.g. customer satisfaction)?

The design of a GSCM/PMS should begin by defining the overall goal(s) of the system. The GSCM/PMS design should fit the environmental management systems of organizations. These environmental management approaches range from ISO 14000 to total quality management programs. In fact, there have been many situations, where players within a supply chain have been encouraged, or forced, to adopt environmental management systems, by external players. Part of the reason is that the evidence is growing, environmental management systems influence environmental performance (Ammenberg, 2001; Hamschmidt, 2000; Florida and Davidson, 2001; Russo, 2001; Andrews *et al.*, 2003), even though many do not guarantee environmental performance improvement. ISO 14000 environmental management system requirements are typically associated with one organization, thus, agreement on the types of systems for GSCM must occur inter-organizationally. Within the ISO 14000 family of certification requirements and guidelines are environmental performance management guidelines codified as IS0 14031.

ISO 14031 guidelines – a GSCM/PMS design foundation. Putnam (2002) distinguishes ISO 14031 from the ISO 14001 standard and explains ISO 14031 as a process/guideline for measuring environmental performance and not a standard for certification. He stresses its use as a tool to provide management with key metrics for assessment. It is appropriate for all sizes and types of organizations even for those entities without an environmental management system in place. The central design principles of the ISO 14031 is the Plan-Do-Check-Act (PDCA) model for implementing an environmental management system. This PDCA cycle also defined as the Deming Cycle, is part of the continuous improvement aspects of quality management (Deming, 1986).

ISO 14031 focuses on evaluation of environmental performance. This section of the ISO 14000 family of standards focuses on trends and changes in environmental performance over time. The core document focuses on planning, applying, describing, reviewing and improving the environmental performance evaluation with guidance from the process of collecting, analyzing and communicating data. This is a dynamic process and forms the core of what a design team should consider in a GSCM/PMS (as shown in Figure 3).

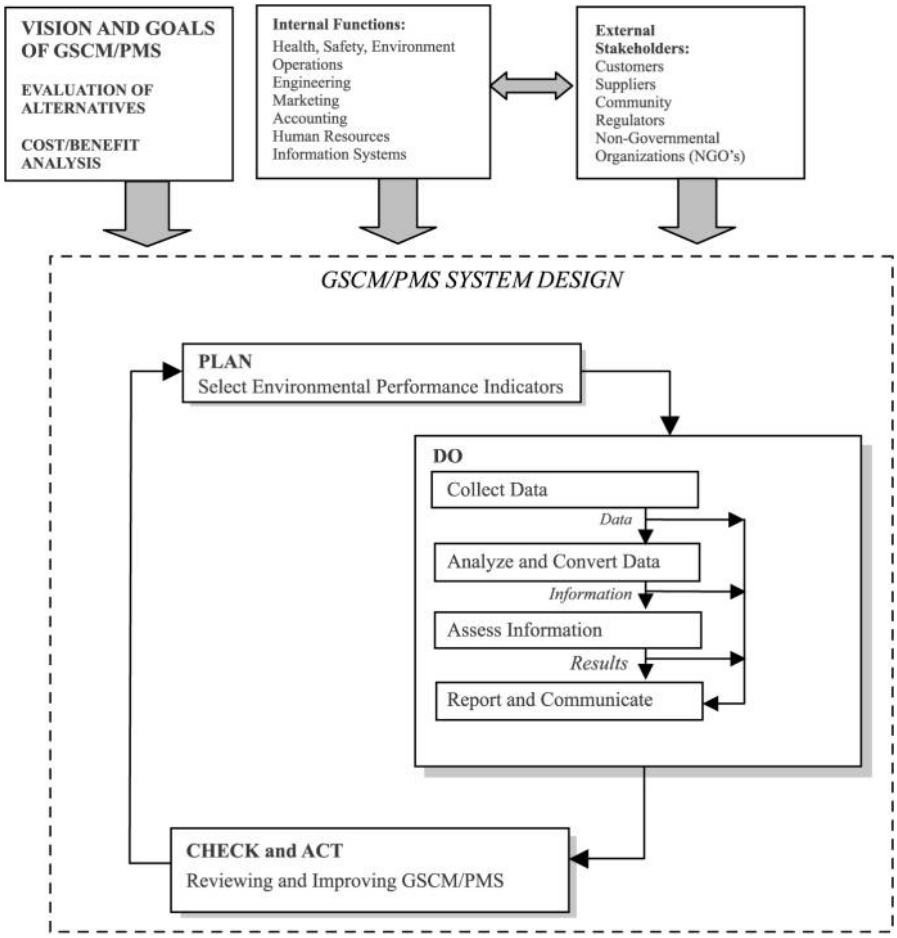

Figure 3.
Design of a performance measurement system utilizing the continuous improvement plan-do-check-act process from ISO 14031 guidelines

The ISO 14031 performance management system design involves collecting information and measuring how effectively an organization manages its environmental aspects on an ongoing basis. ISO 14031 is designed for use in environmental performance evaluation with indicators in three key areas:

(1) environmental condition indicators;

(2) operational performance indicators; and

(3) management performance indicators.

In addition six subcategories identify inputs of materials, energy and services, the supply of inputs, the design installation, maintenance, and operation of the physical facilities and equipments, output of products, services, wastes, and emissions, and finally the delivery of outputs. Bennet and Martin (1998) mention that changing drivers for environmental performance management must include stakeholders' growing expectations about contentious issues, the need to respond to environmental pressures,

the need to measure life cycle analysis and take-back programs, and general links between the environments as other typical business performance indicators, and need to be designed into an environmental management system and especially a GSCM/PMS. Thus, not only should team members in design of a GSCM/PMS be from internal functional areas of an organization, but should preferably include customer and supplier functional representatives and other stakeholders as shown in Figure 3.

The effort required to put together a GSCM/PMS can be quite extensive. A key aspect of the early planning stages will be a form of evaluation and justification for such a system using strategic and operational cost/benefit analyzes. For example, Lokkegaard (1999) in a case study of a Malaysian glove manufacturer indicated only a few key environmental aspects and an ability to visualize the performance trends over time using the indicators was required. Thus, smaller organizations and their supply chain elements may not require as extensive a system. Yet, large multinational firms like advanced micro devices with complex supply chains may require more complexity in their performance measurement systems. In fact, the dynamic design characteristics may also mean varying requirements depending on product, component and material characteristics. Advanced micro devices requires their chemical suppliers, especially of hazardous chemicals, to be more involved in performance evaluation and data gathering than their office materials suppliers (Trowbridge, 2001).

The other steps of the ISO 14031 environmental performance management system requirements include assessment and documentation delivery. Next, our discussion shifts focus to these items with a discussion on tools (for assessment) useful in GSCM/PMS design in the next section. The "results" discussion in the following section focuses on documentation and other deliverables as outputs from a GSCM/PMS.

GSCM/PMS tools

The existing performance measurement tool set for environmental operations is growing, but may not yet be adequate to fully assess GSCM. Tools, from the literature and practice, include such items as the analytical hierarchy process, activity-based costing, design for environment analysis, balanced scorecard, and life cycle analysis type tools. Some tools have seen, or could be, directly applied to aspects of GSCM and performance, and others require adjustments and extensions.

For example, Faruk *et al.* (2002) investigated the impacts of environmental management along supply chains through the introduction of "ecological supply chain analysis" (ECOSCAN), a management tool based in the life cycle analysis model, which emphasizes the close linkage between life cycle analysis and GSCM methods. The core aspect of this an assessment matrix that scores various emissions stressors and data confidence values for six major steps within an organization's individual supply chain including, material acquisition, pre-production, production, use, distribution and disposal. Maps are an output of this process and graphically represent the values of the environmental impacts along the supply chain. The tool can evaluate various products for comparison, but it is not clear the tool's applicability extends to multiple partners within the supply chain. The scoring methodology may also be rather subjective on many dimensions.

Handfield *et al.* (2002), Pineda-Henson *et al.* (2002) and Sarkis (1998, 2003), illustrate the use of the analytical hierarchy process as a decision support model helping

managers understand the trade-offs between environmental dimensions. The analytical hierarchy processes was originally developed by Saaty (1980) and is a benefit measurement (scoring) model integrating subjective managerial inputs and data with tangible quantifiable information on multiple criteria. These inputs are converted into scores used to evaluate each alternative. The methodologies related to applying the analytical hierarchy process can be used to evaluate the relative importance of various environmental traits and to assess the relative importance of several suppliers along these traits. The analytical hierarchy process has been incorporated into a comprehensive information system supporting environmentally conscious purchasing (Handfield *et al.*, 2002); evaluating environmental impact for a manufacturing portion of the life cycle analysis (Pineda-Henson *et al.*, 2002) and for selection of environmentally sound practices and technology (Sarkis, 1998, 2003) all within organizations and some considering supply chain issues. Yet, the extension of analytical hierarchy process beyond dyadic organizational boundaries to further supply chain evaluation has not been completed. Issues relating to incorporating management judgment from across organizational boundaries in the analytical hierarchy process need to be advanced.

The "balanced scorecard" is another popular tool within the corporate performance management literature. It is a management/measurement system purporting to aid organizations develop corporate visions, strategy and cascading them into action. It provides feedback on internal business processes and external outcomes in order to continuously improve strategic performance and results (Kaplan and Norton, 1992). The balanced scorecard suggests organizational performance be viewed from four perspectives, and to develop metrics, collect data and analyze the organization relative to each of these perspectives:

(1) the learning and growth perspective;

(2) the business process perspective;

(3) the customer perspective; and

(4) the financial perspective.

Extensions to the balanced scorecard to incorporate environmental performance measures have also been significantly advanced (Epstein and Wisner, 2001; Zingales *et al.*, 2002). Examples of the environmental metrics definition into categorizations as defined by the balanced scorecard approach are shown in Table I. The US Environmental Protection Agency identified the balanced scorecard approach as their chosen methodology for deploying strategic direction, communicating expectations, and measuring progress towards agreed-to objectives (Kanji, 2003). Brewer and Speh (2001) extended the balanced scorecard approach and linked it to general (rather than green) supply chain management. Thus, this approach may prove promising if effectively implemented and agreed upon by organizations and could fit within a GCSM/PMS design as related to ISO 14031 requirements.

A robust quantitatively focused benchmarking and performance measurement tool called data envelopment analysis relies on the evaluation of the relative efficiency of units characterized by multiple inputs and outputs (Charnes *et al.*, 1978). Data envelopment analysis mathematical programming models are based on inputs and outputs and are designed to be utilized as a tool for multiple criteria

Financial	*Internal process*
Percentage of proactive vs reactive expenditures	Percentage of production and office materials recycled
$ Capital investments	# Certified suppliers
$ Operating expenditures	# Accidents and spills
Disposal costs	Internal audit scores
Recycling revenues	Energy consumption
Revenues from "green" products	Percentage of facilities certified
$ Fines and penalties	Percentage of product remanufactured
Cost avoidance from environmental actions	Energy use
	Greenhouse gas emissions
	Hazardous material output
Customer	*Learning and growth*
# Green products	Percentage of Employees trained
Product safety	# Community complaints
# Recalls	Percentage of renewable resource use
Customer returns	# Violations reported by employees
Unfavourable press coverage	# Employees with incentives related to environmental goals
Percentage of products reclaimed after use	# Functions with environmental responsibilities
Functional product eco-efficiency	Emergency response programs

Source: Epstein and Wisner (2001)

Table I.
Environmentally based performance measures by the balanced scorecard categories

decision evaluation. Application and recommendation of this tool for environmental performance evaluation has been summarized by Sarkis and Talluri (2004). Extensions of the basic data envelopment analysis approaches have been completed for supply chain evaluation, along and within supply chains, but inclusion and evaluation of environmental characteristics has yet to be completed. Other, more recent works have posited tools for performance measurement using ratios for evaluating supplier environmental performance (Nagel, 2004) or a business value perspective of strategic sourcing and environmental issues (Harris, 2004). Yet, even these other tools have focused only on one element and one level of supplier evaluation.

Overall, there is no one perfect tool for a GSCM/PMS (which in itself is a tool), but similar to any tools that are to be used for planning, assessment, and management, their usage is heavily dependent on agreement across organizations and the ease and accessibility of data and knowledge to apply these tools.

Operational and implementation issues

The discussion, thus far, has alluded to the complexities and hurdles of operating and implementing a GSCM/PMS. They range from mistrust and communication issues to technological and standardization questions facing organizations within a supply chain. To overcome these issues, specific responsibility for implementation and operation is needed, whether it is internal (e.g. a GSCM specialist) or external (a GSCM broker, partner or consultant). Following the supply chain model, measures should try to address each supply chain element. To overcome many of the internal organizational limits and pressures, as mentioned earlier, top management must provide financial and strategic support for environmental performance measurement and realize the types of

support may vary along the implementation life cycle. Fiscal affairs personnel must be involved in understanding the measurement costs involved. These costs include not only time of employees to gather and evaluate the metrics but also costs of tools and special equipment for performing measurement. Operational and human resource personnel must be involved in training and data acquisition to effectively implement this system. Issues facing any strategic system need to focus on team implementations and include benefits and concerns from a long term strategic perspective.

Each player within a GSCM/PMS has a specific role. For example, supplier selection is typically based on a measure of their performance on a number of quality and both on-time and on-quantity delivery variables. Over time, supplier ratings emerge. Some organizations certify suppliers based on their long-term delivery and reliability performance. The same certification criteria are used to screen and select new suppliers. Such maintenance is also required for environmental issues. Key characteristics of performance are continuous improvement and the strength of the linkages between the supply chains, especially with respect to product life cycles, need to be considered. The lessons learned from internal environmental management systems and external supply chain management systems need to be applied to GSCM/PMS situations.

Results of a GSCM/PMS

The final elements of our discussion are the results, or outputs, of a GSCM/PMS. These results may serve numerous purposes including external communications, internal improvements, and regulatory compliance. For external communications, companies will have metrics, as well as longitudinal data to benchmark and show performance and improvement over time in both environmental awareness and actions. Corporations are frequently targeted by NGO's, communities, and other stakeholders and asked to discuss the impact of their operations on the environment, their waste streams, and to assess their corporate green programs and environmental stewardship. The GSCM/PMS may be the source of the data to deliver the message of change toward more environmental actions. This can be communicated via press releases and in important corporate documents including but not limited to annual reports to shareholders and other stakeholders.

The GSCM/PMS data may also be used internally for assessing improvements in waste elimination, recovery, recycling, cost containment, elimination of extra processing time (including energy and raw materials), and other key measures of waste. These results, used by teams representing companies within the supply chain, are a baseline measure for continuous improvement. Regulatory compliance with local, regional, national and international laws is another use of the performance measurement system data. Companies certified under ISO 14000 also are required to maintain such data and such a system may enhance certification and performance of these systems.

Summary and conclusions

Growth in organizational performance measurement from stand-alone operational systems to include strategic and inter-organizational (supply chain) requirements has been discussed. Competitive forces have caused organizations to look externally to determine how to sustain long-term competitive advantage. Inter-organizational

performance management systems play a role. Part of this broadened focus of competitiveness necessarily begins to focus on the natural environment. Stakeholders (internal and external) over the last few decades have caused organizations to explicitly consider the environment in their strategic and operational planning and execution. This pressure has extended across the supply chain and is responsible for the increased growth and interest in GSCM. To aid GSCM implementation and introduction, there is a need to at least plan for and conceptualize performance measurement systems and their requirements. This issue leads to the major contribution of this paper, which is the introduction of various topics and concerns of GSCM/PMS ranging from the various internal/external pressures, types of metrics that need to be developed, potential designs of GSCM/PMS, as well as tools and results of a GSCM/PMS. These systems have yet to fully exist and operate within many organizations, yet their development and introduction may be inevitable as further integration and pressures cause organizations to seriously consider them for their long term well-being.

To aid practitioners and researchers a number of emerging areas of research have been identified. Future studies must address the business and environmental results of a GSCM performance measurement system and their impact within the organization, industry, and society at large. If studies indicate no immediate differences, further studies should address when and if they will make a difference. Industry-specific research is needed to address which where the performance measurement systems work best.

Other issues for future research are:

(1) inter-organizational agreement on performance management and measurement;

(2) managing the entire supply chain beyond the single dyadic relationship (with numerous questions that need to be answer such as: who is in charge? who decides? how important is it? global issues? what should be the baseline? do industry differences exist – e.g. chemical versus electronics?);

(3) tools needed for further GSCM/PMS enhancement and development;

(4) linkages to product stewardship, life cycle analysis and design for the environment;

(5) development of data and information with respect to GSCM;

(6) adequacy of the tools and management of supply chain management for incorporating environmental management dimensions; and

(7) roles of new technologies including information technology.

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