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ENVIRONMENTAL MANAGEMENT INFORMATION SYSTEMS (EMIS) FOR SUSTAINABLE DEVELOPMENT: A CONCEPTUAL OVERVIEW

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ABSTRACT

Environmental management information systems (EMIS) is defined as 'organizational-technical systems for systematically obtaining, processing, and making available relevant environmental information available in companies'. Such systems evolved out of a growing need to manage environmental information in response to internal and external pressures such as regulations, consumers, stockholders, and changes in the business environments. While over the past decade EMIS have proliferated in the corporate landscape, these systems have received little attention within the information systems research community as whole.

The objective of this paper is to serve as a tutorial providing a conceptual overview of EMIS, highlighting organizational and technical issues, as well as research opportunities. In this paper we suggest that there are significant and relatively untapped research synergies existing between information systems and environmental management for sustainable development at the organizational and technical levels.

Keywords: environmental management information systems, environmental management, environmental management systems, sustainable development, information systems research, environmental management

I. INTRODUCTION

According to the final report of the World Commission on the Environment and Development (also known as the Brundtland report) [WCED, 1987], sustainable development is defined as "development that meets the needs of the present without compromising the ability of future generations to meet their own needs". In effect, sustainability implies an ongoing dynamic development, driven by human expectations about future opportunities, but necessitates a projection based firmly in present economic, ecological and societal conditions and current issues. Subsequent international efforts such as the Rio de Janeiro conference in 1992, the publication of Agenda 21 [UNCED, 1993], the Rio+5 special session of the United Nations (UN) in 1997, and the formation of the World Business Council for Sustainable development in 1997 can be credited with raising environmental concerns to increase public awareness, serving as an initial focus and impetus for collaboration as well as conflict between government, industry, and academia. The Johannesburg "Plan of Implementation," revealed at Earth Summit 2002, affirmed commitment by the UN to the "full implementation" of Agenda 21. This affirmation by the UN espouses the three pivotal processes of sustainable development: economy, ecology, and society. Clearly the notion of sustainable development represents a broadly encompassing view of humanity and its relation to the planet on which we reside. Environmental management information systems are proactive alternatives to help organizations to manage for sustainability.

Traditional management theory has considered environmental agendas such as sustainable development to be largely the responsibility of governments and their associated policy-making entities [Ashford, 1993, Porter and Linde, 1995b]. From a corporate perspective, this has historically translated to a largely reactive role for firms, – the meeting of government imposed environmental standards and regulations. Nevertheless, during the past decade, many corporations have moved towards voluntary compliance and gone "beyond compliance" through leveraging technological innovations not only for sustainable development, but also for competitive advantage [Dyllick and Hockerts, 2002, Porter and Linde, 1995a, Shrivastava, 1995]. Successful market entry into developing countries by global business is recognized to require innovative business models and approaches to production within unique socioeconomic contexts, as well as environmental conditions [Prahalad, 2004]. Sustainable development, by explicitly recognizing the social element, in its agenda, seems well fitted to serve as the foundation of such an approach to global business.

In this environment of compliance and "beyond compliance", environmental management systems standards (EMSS), such as ISO 14001 [ISO, 2002] and the European Eco-management and Audit System (EMAS) [EMAS, 2006] attempt to provide a sound practical basis for environmental management within organizations. In this context, the primary business approaches to issues of ecological sustainability have come from an awareness of the need for improved environmental auditing and accounting capabilities, availability of timely information in regard to relevant policy and legal requirements, and business performance management. In effect, such systems and standards help organizations formalize an environment management system (EMS) comprised of management processes and metrics for improving their environmental performance [Pun et al., 2002], similar thus to quality-based initiatives.

An integral component of EMS is the management of environmental information across the organization. Accordingly, the development of environmental management information systems (EMIS) attempts to simplify and automate environmental management tasks and encapsulate such techniques as environmental cost accounting, lifecycle assessment, as well as auditing and compliance [Rikhardsson, 2001]. While traditionally EMIS has focused on addressing regulatory requirements, the key challenge lies in understanding how to leverage EMIS for strategic advantage via the development, deployment and management of such systems [Moore, 2002b].

Case studies from multiple environmental software vendors, including Data Systems & Solutions, VisionMonitor, and Environmental Software Providers (ESP), repeatedly point out that real business value can be and has been achieved by industrial deployment of EMIS. Major multinationals such as the Arkema Group (industrial chemicals), achieved a savings of 320hr/year merely in reduced time for emissions data collection and reporting through the use of a web-based application to achieve near-real-time compliance visibility for emissions [ESP, 2006d]. GM's deployment of ESP's opsEnvironmental modules for air and waste management performance metrics yielded an estimated 35% time reduction for air emissions reporting and cut the time requirements for the Superfund Amendments and Reauthorization Act (SARA) reporting of environmental health and safety (EHS) data by an estimated 45% [ESP, 2006b]. Shell Chemicals achieved, through reporting automation, a reduction of almost 90% in data collection and specifically cut 75% of time requirement for emissions inventories reporting [ESP, 2006c]. A VisionMonitor solution provided a major Houston-based petrochemicals firm with increased accuracy and real-time visibility of capacity utilization, allowing improved planning and decision-making, and automation of their emissions credit training through environmental asset management [VisionMonitor Software, 2006].

IS RESEARCH AND ENVIRONMENTAL MANAGEMENT

Despite the proliferation of EMS and EMIS in industry which has occurred in the past decade, as of yet, it seems these systems have received limited attention within the IS community (as we will point out within this article in discussing some of the research opportunities). This lack of attention may be attributed to the multi-disciplinary nature of the field of environmental management and the nascent state of the industry. However, other business disciplines such as management [Dyllick and Hockerts, 2002, Porter and Linde, 1995a, Porter and Linde, 1995b, Shrivastava, 1995], operations research [Larson et al., 2000], and operational management [Corbett and Kleindorfer, 2001a, Corbett and Kleindorfer, 2001b, Corbett and Kleindorfer, 2003], have seen extensive coverage of environmental issues from managerial and industrial engineering perspectives. For example, INTERFACES, a journal of the Institute of Operations Research and the Management Sciences (INFORMS) devoted the entire May-June 2000 issue to "Sustainable Business". The issue included a total of 18 articles organized along 4 themes - namely, conceptual and analytical frameworks, insights on implementation issues, insights on product recovery, and strategy, implementation, and innovation [Larson et al., 2000]. Moreover, the Production and Operation Management Journal devoted a series of 3 special issues on operation management and environmental management.

The work presented constituted much of the basis of practices such as 'eco-efficiency', lean-and-green' production, and the popular notion of the 'triple bottom line'. A number of dedicated journals – practitioner- as well as research-oriented – exist for environmental management, and have published works dealing with EMIS [Box, 2002, Moore, 2002b] and environmental decision support applications [Athanasiadis and Mitkas, 2004, Karatzas et al., 2001, Sugumaran et al., 2004, Uricchio et al., 2004]. Clearly, this is a field already of interest to the broader management science community.

In the present work, we advocate that significant research synergies exist between information systems and environmental management for sustainable development from an organizational as well as a technical perspective. We maintain that collaboration and cross-fertilization between these domains can be mutually beneficial and may in fact present unique, timely and socially relevant 'real-world' research opportunities as well as viable public sources of empirical ecological information for interdisciplinary research and application.

The information systems community possesses a wealth of experience with the design and application of large-scale systems to support strategic decision-making as well as techniques of information management and aggregation that could substantially aid in improving the state of environmental information systems through cross-fertilization from more mature enterprise systems research. From an organizational perspective, the environmental management community can greatly benefit from existing body of knowledge pertaining to technology diffusion, strategic use of IS, IS evaluation, and systems analysis and design. To the IS community, environmental research offers a rich and interesting application domain of growing social and economic significance, and represents an emerging need, as well as an opportunity for leadership in the support of corporate sustainable development.

From a technical perspective, opportunities exist to tailor existing technologies, and to develop new information-based technologies for environmental management. Examples include database issues pertaining to the design and analysis of environmental information systems [Gunther, 1997], model management, business intelligence for environmental decision support, and innovative applications of existing technologies. Such technologies include data mining, geographic information systems, computational intelligence, and intelligent software agents. Applications of such technologies include supporting corporate environmental reporting [Isenmann and Lenz, 2001, Isenmann and Marx-Gomez, 2004, Marx-Gomez and Isenmann, 2004], sharing environmental maps [Orthofer and Loibl, 2004], sharing environmental data and models [El-Gayar and Tandekar, 2005, Xiang et al., 2004], and decision support for environmental investment site selection [Scharl et al., 2004] Real-world applications to be discussed throughout this article include many major themes of IS, including data centralization, automation of data collection for compliance reporting, and integration of heterogeneous systems by companies like GM and Shell Oil, aggregation and delivery of low-level operational data for managerial decision-making, trade-off analysis and forecasting by firms including Siemens and SC Johnson, analytical frameworks for product design, development and assessment such as that developed by BASF for lifecycle analysis, and web-based applications like those developed by Nike and Arkema Group to provide timely, readily-available environmental compliance and performance data to organizational stakeholders.

OBJECTIVES

To facilitate interdisciplinary research, this work presents a conceptual overview of the topic of EMIS within the context of sustainable development from a corporate perspective. The paper presents a framework highlighting EMIS within the context of the demand for and supply of environmental information, as well as the relationship of EMIS to other organizational systems such as EMS. It is also the objective of this work to identify a number of organizational and technical issues related to EMIS in organizations and to discuss research opportunities and possibilities for cross-disciplinary collaboration between information systems and environmental management.

II. A CONCEPTUAL FRAMEWORK

Figure 1 shows the environmental systems support framework as an onion model of information flow in which the outer layers represent demands for environmental management and environmental information by involved stakeholders, while the inner layers depict the support or supply for such demands.

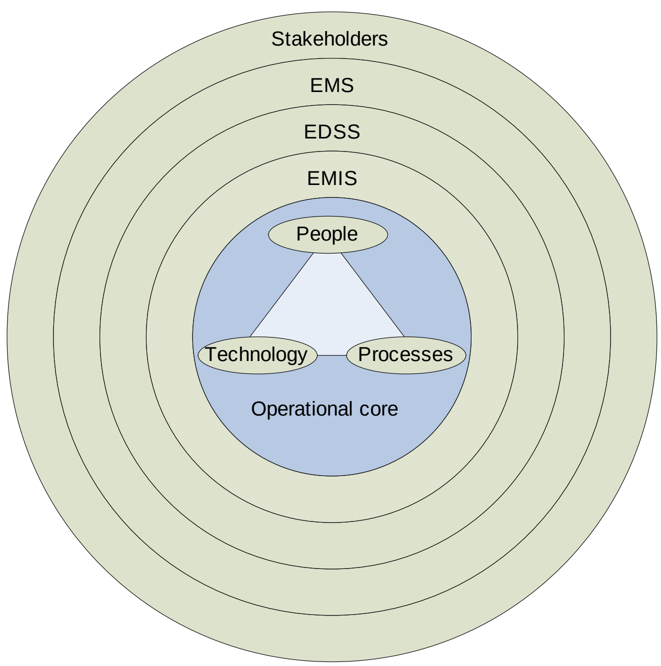

Figure 1. A framework for IS support for EM

The triad of people, processes, and technology forms the central core of the “onion” model for environmental information systems support. It includes the technological and organizational subsystems in addition to the core production processes central to the business model, and relates fundamentally to revenue-generating activity. Here also are found the basic processes that are the source of performance data gathered, aggregated, and synthesized by the higher levels of the organization. The levels of impact upon this core are arranged as follows:

- Environmental Management Information Systems (EMIS) influence. EMIS is concerned with the efficient collection of performance data to directly support performance measurement and process improvement. EMIS data is consumed by higher strategic levels in order to assess the effectiveness of, and in turn, to modify as necessary the EMS that guide operations. For example, process visibility gained by American Airlines, whose system for remote monitoring of real-time compliance data allowed them to more easily identify problem areas and roll up details into summary reporting to support strategies for reducing inefficiency, in addition to gaining time savings in data collection and aggregation [ESP, 2006a].
- Environmental Decision Support Systems (EDSS) influence. EDSS include aggregation, ad-hoc querying, and modeling of environmental data and processes. It facilitates strategies of business process re-engineering, and technological innovation. It supports strategies of process improvement and workflow optimization. For example, US-based multinational Nike implemented a supply-chain integration application for eco-efficiency allowing its engineers to evaluate its production processes and validate analyses with near real-time environmental metrics derived from aggregates of data collection across its factories [BSDGlobal, 2006b], while SC Johnson employed a custom EMIS to assess its products against key environmental indicators to aid in viability assessment, and evaluate performance of suppliers through a business scorecard [BSDGlobal, 2006c].
- EMS influence. The assurance of regulatory compliance as well as meeting of operational performance objectives is enforced and overseen directly at the EMS level. EMS primarily assures compliance and accountability of processes and personnel involved in the operational activities of the firm. For example, the European EMAS standard [EMAS, 2006], like that of ISO14000 [ISO, 2002], is intended as a “live” assessment process which collects on-going performance metrics and supports process improvement through a general framework that becomes specialized to the business context, but maintains general rules and controls which govern this process.
- Stakeholder influence. Stakeholders internal and external to the organization are the primary consumers and drivers of demand for access to environmental information. Increased awareness of environmental issues and the importance of sustainability further fuel corporate accountability and transparency. A recent study of the online presence of 12 major industrials [Faure et al., 2004] assessed the quality of environmental information provided at these sites. The study, which assessed each on 24 criteria involving ease-of-use, availability and accessibility of environmental information, quality and depth of that information, and presentation of materials safety and product technical information, found the quality of available information varied wildly. Isenmann [2004] concurs, finding that the visionary notion of “cybernetic reporting” of real-time environmental performance [Wheeler and Elkington, 2001] available to stakeholders is far from having been achieved. Changes in the stakeholder environment suggest and direct strategic shifts in an organization that may significantly impact operational assumptions or even the core business model itself. An example of which is the growing consumer demand and interest in energy efficiency as well as internal concern with providing fuel-efficient and safe, dependable vehicles led Honda to develop a sophisticated hybrid 'concept car', the Insight, in 1999. With the success of the concept, other manufacturers soon followed suit providing a prime example of consumer-focused product development, where attention to economic and environmental criteria resulted in a unique value proposition [Ottman, 2002] and ultimately a viable and profitable commercial product line.

The following sub-sections provide a description of each of the layers of the framework, and real-world examples illustrating the framework.

STAKEHOLDER ANALYSIS

The pressure and demand for environmental management and environmental information can be classified according to the origin of its source as external or internal to the organization (Figure 2).

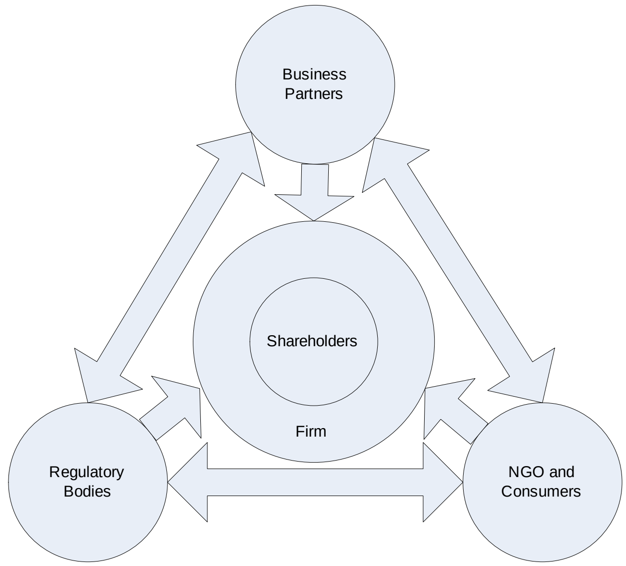

Figure 2. Stakeholder interaction (adapted from [Wrisberg and De Haes, 2002])

External Factors

Adoption studies in the EMS literature, e.g., [Andrews, 2003, Florida and Davison, 2001a] indicate that regulatory compliance at both state and federal levels are almost universally cited as a primary factor driving environmental initiatives. Fear of lawsuits, or reaction to previously suffered penalties for environmental violations and desire to avoid future penalty costs are thus the most obvious motivating factors behind EMS adoption. The general role of regulatory pressure in stimulating technological innovation has also been explored [Jaffe et al., 1995]. Strong arguments for driving environmental initiatives through response to external regulation are also made, as first asserted in the Porter hypothesis [Porter, Porter, and Linde, 1995b], which proposes that competitive pressure to adapt to legislation can serve as a primary driver of environmental innovation. Finally, the need to consider the opinion of consumer groups and the general public is identified as a major driver of environmental initiatives, particularly for publicly traded companies [Florida and Davison, 2001a, Florida and Davison, 2001b, Morrow and Rondinelli, 2002]. The significance of external stakeholders on organizational strategy [Henriques and Sadorsky, 1999] in the past decade applies to environmental initiatives as well as broader strategic concerns.

A majority of the focus of past and present EMIS has been to support mandated reporting requirements and aid in the enforcement of compliance with standards established by powerful external stakeholders. These stakeholders include regulatory bodies, non-governmental organizations (NGO), consumers, and business partners along the supply chain [Wrisberg and De Haes, 2002]. At the national level, government organizations, e.g., the Environmental Protection Agency (EPA) in the United States (US), play a major role in creating environmental polices and regulations. Such regulations create liability implications for firms and create economic incentives and general rules for technologies, products and material use. Porter and Van der Linde [1995b] were among the first to articulate the impact that environmental regulations could have and their potential to spur innovation and new solutions. The EPA's Clean Air Act of 1977 and its amendment in 1990 forced widespread adaptation within US industry, and extinguished industrial niches while introducing others. Similarly, mandates and standardizations for information management and data collection can strongly affect the marketplace. Comprehensive reporting requirements such as SARA place substantial requirements on firms for data collection, a fact which spurred much of the environmental software industry into business and created initial demand for the nascent EMIS market. Returning to our examples, a system for automated reporting was implemented by Shell Chemicals to streamline the process of reporting SARA 313 emissions compliance data due to the overhead introduced by an external regulatory body. Reporting was manageable within existing EMS, but to streamline information flow, Shell was forced to integrate existing data silos into a centralized reporting system in order to meet the increasing demands of compliance, and doing this required adoption of an EMIS.

While government organizations striving for sustainable environmental management may posses the means to directly influence and implement their policies, NGOs and consumers indirectly affect the behavior of firms through public scrutiny, media attention, threat of litigation, and threat of retaliatory actions such as boycotting the products produced by the firm. It is only natural for a firm whose core business produces visible environmental impacts to invest heavily in improving its image as a protector of the environment. A classic example is the ‘Dolphin safe’ symbol adopted by the Tuna industry. Social trends like corporate responsibility movements and stakeholder-focused reporting have become increasingly prevalent, as well as consumer-focused design principles like 'Design for environment' (DfE) and end-of-lifecycle product analysis at the consumer and producer level. Systems for lifecycle analysis such as those developed by Siemens and BASF illustrate the vital supporting role that IS holds in supporting these new disciplines of environmental management and guiding decision-making.

Business partners represent the third group of external stakeholders. According to [Wrisberg and De Haes, 2002], the environmental performance of one firm depends on that of others in the supply chain and thus firms can legitimately impose environmental requirements on their business partners depending upon their position and role within their respective supply chains. The extent of leverage business partners can impose on each other is determined by a variety of economic conditions such as the relative size of the firms and market power of the trading partners, suppliers and buyers. Business partners are also affected in turn by regulatory bodies, NGOs and consumers. For example, supply-chain issues can create environmental liabilities for companies outside the immediate production focus, and concerns of product stewardship can become substantial the further one is removed from either the end-consumer or source producer of the supply chain [Lippman, 2001]. Leverage can also be applied by a manufacturer to upstream raw materials and unfinished goods providers, such as the extensive supply chain of Nike's 750+ direct contractors and vendors, where Nike leveraged its position and used supply-chain integration to force quality management and environmental standards on its downstream suppliers [BSDGlobal, 2006b]. Similarly, British telecommunications giant BT aligned its network of over 1400 worldwide suppliers through an online site publishing standards criteria for supplier evaluation and reformulating of contracts requiring continuous environmental improvement, a project yielding an estimated savings of £100,000 annually [IEMA, 2004].

Internal factors

Internal pressures stem from within the firm and are represented by shareholders’ interests. Such interests may reflect a sincere concern about the environment (that may also be shared by other stakeholders) forcing the management team to consider a ‘double bottom line’, i.e., maximizing profits and shareholders value while minimizing environmental impact.

Stakeholder desire and internal motivation to adopt a system are often the driving forces of organizational change. GM was faced with a monolithic structure but with decentralized data silos at each site, and limited integration provided through a large number of separate spreadsheets. The massive amounts of data they were expected to collect and report on caused issues among employees. These issues built internal momentum and a desire to enable a more efficient way of working. Upper management wanted more visibility into environmental data and the ability to easily share relevant information with stakeholders. The internal momentum for change driven by these two groups of stakeholders resulted in the eventual adoption of an EMIS as a solution to meet the needs of both stakeholder groups.

A “natural resource-based view” of the firm [Hart, 1995] provides the foundation of notions of environmental competitive advantage through the capacity to utilize and develop nonreplicable, nontransferable and unique assets through personnel development, technological and process innovation, and "beyond-compliance" initiatives. Any resource-based view values accrued nontransferable assets such as reputation, public goodwill, and the effects of organizational learning systems [Barney, 1991] as well as tangible material resources or projected financial gain. The development of environmental capital is predicated upon investment of firm resources in hopes of preservation and growth of such assets. Once growth is attained, the sustainability of the asset as a source of competitive advantage must be assured to outpace competitor adoption [Porter, 1985].

Given this requirement for sustainable competitive advantage, it is not surprising that many firms and multinationals in particular, have moved towards voluntarily compliance and beyond it. These attempts represent self-interest of firms in taking a leadership position in order to anticipate and potentially preempt regulatory actions, and further to garner strategic advantage by erecting barriers to entry through technological development and related environmental capital [Hart, 1995]. An example of this is Nike, which leveraged its own supply chain internally to force suppliers to meet its own beyond-compliance production and safety standards, though there was not a legal requirement for them to do this. The expansion of multinationals business interests into developing economies is recognized to require product and process innovation and provides opportunities for pioneering business models, services and products operating within unique socioeconomic contexts as well as diverse and varying environmental conditions [Prahalad, 2004], thus creating further sources of potential environmental capital, economic development, and social change. The controversial Rainforest Alliance, which began a cooperative effort between agricultural producers, Chiquita Brands International and various NGOs to create an internal environmental certification task force, is an example of a program that resulted in widespread social changes in the agricultural communities it affected. Another example is the joint effort of Statoil and BP, who cooperated with a major NGO in using sophisticated modeling technologies to identify areas which would be most impacted by its proposed operations and reduce the impact on the communities of Akassa people in the Niger delta region which the models had pinpointed, and to foster community development, enterprise and education among the Akassa village communities as well as financial support. Finally, a recent project by the New Zealand Business Council for Sustainable Development engaged several New Zealand industrials in biodiversity planning and greenhouse gas emissions reduction in cooperation with regional land-owners desiring to preserve the New Zealand bushland, which made their emissions data accessible via a web-based database to ensure wide-scale availability of this information. These are but a few examples of the unique approaches towards sustainable development undertaken by modern industrials augmented and enabled by IS.

The need for environmental information

A careful examination of the requirements of the aforementioned stakeholders indicates a shared need for environmental information. Ideally, all stakeholders (internal and external) require transparent access to environmental information. Simply put, Stakeholders need to know how the firm operations are impacting the environment. This implies the need for processes and systems for meeting the information demands of the various stakeholders.

These stakeholders need access to environmental information to evaluate and assess the environmental dimension of business decisions, both at an operational and strategic level. In addition to raw environmental data, various environmental management models, tools and techniques are required for processing this data and providing meaningful conclusions and recommendations for business decisions. Environmental management systems (EMS) and environmental management information systems (EMIS) can address these needs by using IT resources to improve the integration of the information value chain from real-time operational sensor data, through performance metrics and EMS assessment, to sophisticated decision support and planning applications, ultimately enhancing and accelerating the delivery of information to facilitate near-real time decision making.

ENVIRONMENTAL MANAGEMENT SYSTEMS (EMS)

According to the ISO 14001 standard, an environmental management system (EMS) is "the part of the overall management system that includes organizational structure, planning activities, responsibilities, practices, procedures, processes and resources for developing, implementing, achieving, reviewing, and maintaining the environmental policies." An integral component of EMS is the management of environmental information across the organization. Accordingly, the development of EMIS attempts to simplify and automate environmental management tasks, as well as auditing and compliance [Rikhardsson, 2001].

Environmental management systems standards (EMSS), such as ISO 14001 [ISO, 2002] and the European Eco-management and Audit System (EMAS) [EMAS, 2006] attempt to provide a sound practical basis for environmental management within organizations. In this context, the primary business approaches to issues of ecological sustainability have come from an awareness of the need for improved environmental auditing and accounting capabilities, timely information in regard to relevant policy and legal requirements, and business performance management. In effect, such systems and standards help organizations formalize an environment management system (EMS) comprised of management processes and metrics for improving their environmental performance, similar thus to quality-based initiatives.

A typology for EMS system goals

System goals of EMS are suggested as a continuum of system evolution to support ever-more encompassing goals [Sharma, 2000]. Achievement of a higher goal is dependent upon previously achieving a lower one. This concept is developed further by Gallagher [2002] into a typology which follows broadly the historical development and articulation of business goals for environmental responsibility from the 1970's to today [Andrews, 2003]. We can in turn extend this from the literature of environmental management to encompass EMIS and decision support that could potentially enable and support such developments, as shown in Table 1.

The goal hierarchy suggested in Table 1 suggests a progressive development and a deployment of information technologies in which environmental compliance stands as the initial goal, and simply means that a company can ensure it is not in violation of environmental codes and regulations, and more importantly that it can assess its own condition in relation to these regulations. Examples of EMIS in this role would include EHS databases, auditing tools, and template-based policy creation tools which support common standards, as well as systems for technology selection for environmental control devices. We note the examples of compliance reporting automation engaged in by companies like Shell Oil, Arkema Group and GM as representatives of this level of development.

Focus on Pollution Prevention follows, where the concern for reducing and tracking emissions and waste production predominate. EMIS for pollution prevention support environmental accounting and process tracking and redesign for waste disposal functions of business operations. GM and Arkema Group, used systems for automating reporting of compliance data for further advancements in highlighting inefficiencies and generating "exceptions" that could in turn be responded to and managed.

These efforts lead toward the concern with Eco-efficiency – creating systematic cost efficiencies through material substitution and conservation of natural resources consumed by business processes. These steps require more comprehensive monitoring of inputs and outputs and focus on development of performance indicators [Andrews, 2003] to assess environmental performance, and aim at incremental process improvement. At this stage, environmental performance indicators, with underlying data flow from operational systems, can be used for business intelligence purposes, including process analysis, OLAP tools, scorecard- and dashboard-based applications, and ad-hoc query based decision support for business analysts.

Table 1. Progression of EMS [Gallagher, 2002] and its relation to EDSS/EMIS.

Goal Stage	Description	Technologies	Case Study Examples from Industry
Environmental Compliance	Ensure regulations are followed. Find and correct violations.	Legal and Environmental Health & Safety (EHS) databases, auditing systems, template-based policy generation.	GM (automated reporting for SARA compliance) [ESP, 2006b] Arkema Group (web-based emissions compliance reporting) [ESP, 2006d] Shell Oil (emissions and wastewater reporting) [ESP, 2006c]
Pollution Prevention	Reduction of waste products and byproducts, emissions. Process optimization.	Environmental Cost Accounting (ECA), Waste management, Emissions tracking	GM (emissions and wastewater management), Arkema Group (EMIS for operational env. mgmt.) American Airlines (ECA, operational mgmt) [ESP, 2006a]
Eco-efficiency	Consideration of the "double bottom line" – economic value and ecological costs. Process redesign.	Business performance metrics, balanced scorecards, Online Analytical Processing (OLAP) and query tools for business analysts.	Siemens (eco-efficiency matrix, materials balance) [WBCSD, 2002b] SC Johnson (product environmental impact assessment, business scorecard for suppliers) [BSDGlobal, 2006c]
Product Stewardship	Company responsibility extends to consideration of product design and its environmental impact.	Design-for-engineering decision support, Product Lifecycle Analysis, Impact forecasting, Supply chain integration.	Nike (supply chain integration) [BSDGlobal, 2006b] BT (online supplier standards and evaluation) [IEMA, 2004] BASF (design evaluation tool and lifecycle analysis) Siemens (lifecycle analysis) [WBCSD, 2002b]
Sustainable Development	Social element creates the "triple bottom line". Consideration of long-term systematic effects.	Stakeholder-focused Multiple Criteria Analysis (MCA), Large-scale systems modeling, Simulation, Information-sharing with stakeholders and the public at large	BP & Statoil (Akassa environmental impact assessment and ensuing planned community development) [WBCSD, 2005] Chiquita Brands Int'l (independent quality certification authority of NGO and shareholders) [BSDGlobal, 2006a] Nike (public visibility of factory EHS reporting) [BSDGlobal, 2006b]

Examples include Siemens, which developed an eco-efficiency assessment and trade-off matrix, and SC Johnson and Company, which used a scorecard-based approach to assess the performance of downstream members of its supply chain.

Reaching product stewardship, environmental concerns impact R&D and design decisions directly. Marketing system and product development become increasingly integrated with EMIS systems and product features take into account environmental concerns over the entire product lifecycle, from production to disposal, salvage, or recovery. Marketing, in turn, brings the concerns of public image and consumer demand. Nike's effort at enforcing beyond-compliance standards on its supply chain (thus taking responsibility for the quality and work conditions of its own suppliers) is an example. BASF and Siemens' employment of product lifecycle analysis in their design processes also demonstrate the more pro-active side of this level of development.

At the “visionary goal” of sustainable development, the “triple bottom line” is encountered and eventually managed. The social element is incorporated into business decision-making based already on the “double bottom line” of economic and environmental interests, and the opinions of stakeholders as well as the general public are taken directly into account. Information-sharing pre-dominates the organizational culture and relevant environmental impact information of the firm is made publicly available. It is difficult to give “real-world” examples of this level, however we suggest that the direction taken by companies like Nike, Statoil, BP and Chiquita Brands International do represent preliminary and pioneering steps toward dealing with the sensitive issue of the social element of the “triple bottom line” and corporate social responsibility.

ENVIRONMENTAL DECISION SUPPORT SYSTEMS (EDSS)

In this framework, we define EDSS as decision support systems (DSS) specifically designed for and pertaining to sustainable development and environmental management. Following Simon’s general decision-making process [Simon 1960], such systems may support all or parts of the phases comprising the decision process, namely, intelligence, design, choice, and implementation (as shown in Figure 3). The VisionMonitor software provides a concise example of support of several such areas, its Operational Intelligence and Compliance Intelligence modules support the “intelligence” phase (automated reporting of compliance based upon real-time or near-real-time data), with its performance metric summary and aggregate reports for environmental managers presenting the inefficiencies and problems to facilitate further inquiry in the “design” phase (exploration and problem domain inquiry clarifying possible actions). Systems such as BASF's eco-efficiency analysis matrix [WBCSD, 2002a], or that of Siemens' eco-design module for product lifecycle analysis [WBCSD, 2002b], support the “choice” phase by providing analysis frameworks to support prioritization, planning, and production decision which incorporate environmental concerns.

EDSS may follow the general framework for DSS proposed by Sprague and Carlson [1982]. In this framework, a DSS is comprised of a dialog, database and modeling components. The dialog component represents the user interface of the system. The database component can be an internal, external (relying on an underlying EMIS to provide the necessary data), or hybrid system (where parts of the data are stored in an EMIS or in other problem specific information systems, and result data are internally stored inside the EDSS itself). The modeling component accommodates the modeling needs of the decision maker by incorporating a variety of environmental management tools and techniques such as life cycle assessment (LCA), material flow accounting (MFA), life cycle costing (LCC), and multi-criteria analysis (MCA) common to environmental management and auditing.

Examples of areas of EDSS application include performance benchmarking, modeling and optimization of production processes, and simulation and forecasting. Such systems often require interfacing with scientific and engineering software, and frequently incorporate mathematical models, and the use of business intelligence tools for information analysis and visualization. For example, European industrial BASF deployed a custom-developed system for eco-efficiency lifecycle analysis allowing for a balance of considerations of economic import as well as environmental impact which is used to evaluate and assess future actions as well as support product development and innovation [WBCSD, 2002a].

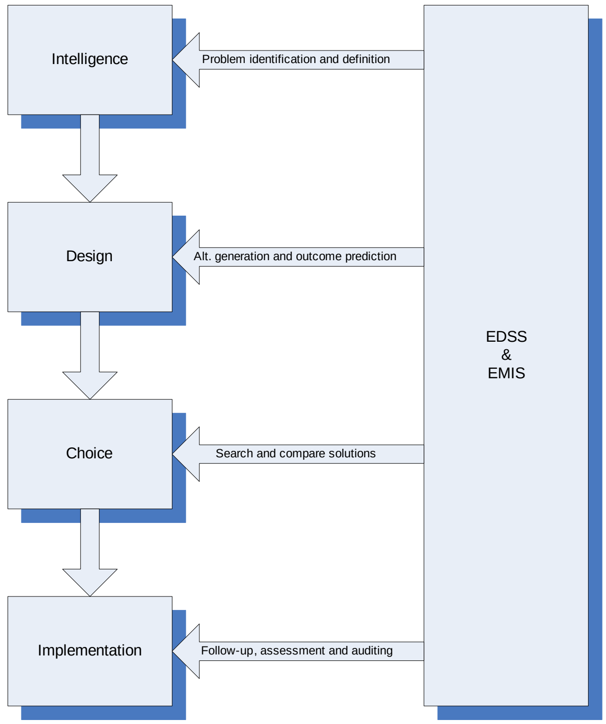

Figure 3. EDSS and EMIS support to the Simon's [1960] decision model

ENVIRONMENTAL MANAGEMENT INFORMATION SYSTEMS (EMIS)

In his report entitled "Management information software targets an environmental market", Cottrill [1994] reports the growing recognition of the strategic value of managing environmental information. This early report identifies a number of well-known suppliers such as Oracle and mentions applications by corporations such as Dow Chemical. Nevertheless, almost a decade later, Mock and Schroeder [2002] still refer to EMIS as a nascent industry.

Definitions (What is EMIS?)

As a nascent industry, there are a number of competing and complementary definitions for EMIS. We can see an evolution of the concept through several such definitions:

> "… [Are] systems to administer environmental information within the enterprise" [Gunther, 1998]

> "Involves the use of technology to manage critical EHS data for record keeping and reporting" [Gilbert, 1999]

> "A tool that can enhance an organization's EMS" [Gilbert, 2001]

> "Environmental Management Information Systems (EMIS) represent a combination of computer hardware, software, and professional services to manage the environmental function within an organization. EMIS systematically gathers, analyzes, and reports business information related to environmental management, allowing a company to track, refine, and methodically improve its environmental management practice. EMIS represents all computer-driven information systems that control environmental management at a company – from stand-alone PCs with a waste tracking spreadsheet to fully globally networked computer systems designed to integrate environmental, health and safety functions into the company business operations information system (IS)." [BTI Consulting Group, 2001]

> "[An] organizational-technical systems for systematically obtaining, processing and making environmentally relevant information available in companies" [Page and Rautenstrauch, 2002]

Accordingly, EMIS may encompass a wide range of systems from stand-alone end-user developed systems and specialized computationally intensive systems, to enterprise-wide integrated information systems. These systems use a range of information technologies including real-time data acquisitions systems, database systems, geographic information systems, as well as EDSS-oriented business intelligence tools, computational intelligence, and enterprise systems integration. From an organizational perspective, these systems may exist in relation to and in support of a corporate-wide EMS implementation effort, or in support of a specific environmental management function such as hazardous waste management or environmental health and safety. For example, GM employed software for EHS compliance automation, and through the centralized data repository developed in the process were able to automate the creation of SARA reports and air emissions reporting, while Shell Chemicals similarly automated reporting of Greenhouse Gas (GHG) emissions and wastewater discharge [ESP, 2006c].

As stand-alone applications, these systems generally take the form of simple report generators with basic database functionality to record environmental information and generate reports satisfying corporate and legal compliance requirements and auditing. Other systems may also provide access to legal documentation or environmental data [Gunther, 1998]. Such systems, while relatively inexpensive to acquire, may have high operating cost primarily associated with providing these systems with the needed data, and selecting and calibrating appropriate indicators for performance measurement.

As integrated enterprise systems are in some ways similar to enterprise resource planning (ERP) systems, EMIS transcend functional areas to provide cross-organization integration of environmental data. These systems implement environmental management processes as required by the underlying extant environmental management system (EMS). In effect, EMIS represent the backbone for environmental management efforts by supporting the firm's internal EMS and by meeting the reporting needs for various stakeholders.

These enterprise systems can be broadly classified as accounting-oriented or production-oriented systems [Gunther, 1998]. Accounting-oriented systems are based on the concepts of 'eco-balances' and life cycle assessments (LCA). In effect, LCA is a "framework for the identification, quantification, and evaluation of the inputs, outputs, and the potential environmental impact of a product, process, or service throughout its life cycle" [ISO, 1996]. The emphasis is on recording the material and energy use and environmental releases of the system under consideration. LCA may transcend organizational boundaries along the supply chain [Gunther, 1998].

Production-oriented systems target production planning by extending the functionality of production planning and control (PPC) systems for process and resource management. In addition to optimizing the efficiency of production processes, production-oriented systems seek to optimize emissions and waste creation, and monitor and monetize the value of recycling options, and record the environmental impact of the production processes under consideration [Gunther, 1998].

EMIS functionality

Much of the evolution which has occurred in EMIS thus far has been driven by regulatory and compliance needs. In this capacity, EMIS have been used primarily as repositories for environmental, health and safety data supporting compliance with environmental regulations such as air, water, and waste management standards, and broader federal policies such as SARA and the Clean Air Act. Serving as data repositories, EMIS can enhance environmental management capacities and support EMS standards like EMAS and ISO 14001. In conjunction with their function as data repositories, EMIS provide standard management and regulatory reports, track regulatory requirements, and manage and control documents [Gilbert, 1999]. The latter is particularly important in reduction of overhead associated with adopting environmental standards such as ISO 14000 [Gilbert, 2001].

EMIS industries and applications

While any industry can benefit from the adoption of EMIS, the diffusion of EMIS is more apparent in industries with significant environmental impact. Such industries include pharmaceuticals, petroleum, chemical, automotive, utilities, primary metals, and semiconductor industries. These industries account for 80% of all environmental spending [BTI Consulting Group, 2001]. Early adopters tend to be industrials with a high degree of environmental capabilities to begin with [Florida and Davison, 2001a]. Examples of some of these early adopters include Shell, Dow Chemical, SC Johnson and GM. Innovative factories and “green” companies comprise of the remainder of this segment.

Areas of application of EMIS in support of production-oriented systems are diverse and extensive. Mock and Schroeder [2002] conduct an online survey of 3000 facilities from a cross-section of industries. Their results indicate that 74% of the respondents use some form of EMIS to handle air quality data management needs, 66% to manage waste data, 55% to manage waste water, 34% to handle storm water, 55% to handle hazardous material, and 58% to support SARA reporting requirements.

III. ORGANIZATIONAL ISSUES

ADOPTION AND DIFFUSION

While EMIS has been around since the early-mid nineties, EMIS technologies and markets are still maturing. In spite of the increasing number of EMIS implementation, there are no systematic studies about the adoption and diffusion of EMIS in organizations. Results from EMS adoption studies such as [Andrews, 2003, Florida et al., 1999, Leal et al., 2003, Rivera-Camino, 2001] highlight a number of drivers for EMS adoption such as fulfilling legal requirements, enhancing corporate image, improving product quality, realizing efficiency gains, and demonstrating social responsibility. These drivers are also relevant as rationales to EMIS adoption.

Moreover, we know that existing organizational systems and technology investments play a role in facilitating successful EMS adoption, as briefly summarized in Table 2. As with any new and maturing technology, people and organizations tend to respond differently to EMIS [Moore, 2002a]. Within the context of EMIS, many questions pertaining to adoption and diffusion remain unanswered. For example, do similar factors aid in determining success of EMIS initiatives? What factors facilitate or hinder the adoption and diffusion of EMIS? What are the characteristics of early adopters of EMIS? What factors, elements, and structures are needed for EMIS adoption? How do the results compare to the technology adoption and diffusion literature, and what are the similarities and differences between stakeholder expectations for EMIS in comparison to environmental management systems?

Table 2. Relationships of organizational systems to EMS adoption.

Organizational asset	Correlation to EMS adoption
Just in-Time (JIT) systems	EMS adoption is nearly 2x as likely among firms with existing investment in JIT inventory systems. [Florida and Davison, 2001a]
Total Quality Management (TQM) practices	Past success with TQM strongly influences success of ISO14001-based EMS. [Melnyk et al., 1999]
ISO 9000 compliance	Significant and bi-directional association between ISO 9000 and ISO 14001 adoption. [Corbett and Cutler, 2000, King and Lenox, 2001]

COST/BENEFIT OF EMIS

Acquisition and deployment of EMIS (as with any IS) requires resources. Mock and Schroeder [2002] report EMIS deployment cost ranging from $50,000 to $100,000 per functional unit. Aside from acquiring such systems in response to regulatory mandates and requirements, the question remains as to whether it pays to acquire EMIS. In that regard, Gunther [1998] indicates that there are indeed potential savings from such systems, quantifying the benefits in terms of resource efficiency and waste disposal. Mock and Schroeder [2002] report that 42% of respondents indicate some sort of benefit from deploying EMIS with an average labor reduction of 20-25% from efficiency gains. This parallels the benefits seen from industry EMS implementation. Within the UK forest and paper products industry, companies with above-average environmental management standards outperformed companies with sub-par standards by 43% [White and Klernan, 2004]. Additionally, superior environmental management capacity possessed by publicly-traded US electric companies led to stock market performance gains 3-30% above the norm [White and Klernan, 2004]. So far, there is no study to date evaluating the costs and benefits of EMIS. Such studies paralleling the developments in EMS can support the adoption and diffusion of EMIS and contribute to a better understanding of the role of EMIS in organization.

EVALUATION OF EMIS

So far, Mock and Schroeder [2002] provide the only study to date to report on satisfaction with existing EMIS implementation. The results of their survey indicate that while EMIS adequately satisfied the needs of environmental managers, there are opportunities for improvements with respect to areas such as reporting capabilities, speed, and navigability. Further research is needed to evaluate the efficacy and quality of EMIS. Such research could further support EMIS adoption and highlight areas for improvements.

SELECTION OF EMIS

Mock and Schroeder [2002] indicate that 30% of respondents use commercial off-the-shelve (COTS) systems, e.g., Enviance systems, VisionMonitor Operational Intelligence, and Dixon Environmental , 47% use custom developed systems, while 22% use spreadsheets and commercial databases, e.g., Oracle and IBM's DB2. Selection criteria for EMIS as with other types of information systems include functionality, vendor experience, client base and references, support and maintenance, scalability, security, user-friendliness, ease of customization, ease of integration, and underlying technology. However, the mere acquisition of EMIS does not necessarily ensure compliance or improved performance [Gilbert, 1999]. From an organizational perspective, EMIS selection must take into account the existing organizational infrastructure supporting environmental management and the chosen system must interoperate with existing systems. From a research perspective, opportunities exist to extend existing research in an EMIS context. Examples include questions such as: what are the selection criteria, which factors are most important in selecting an EMIS, and what are the factors affecting buy versus build decisions?

IV. TECHNICAL ISSUES

It may be argued that many of the technical issues encountered in EMIS are of general IS/IT nature and does not warrant a separate discussion. Nevertheless, we suggest that EM in general and EMIS in particular pose unique challenges as well as interesting application domains for IS research. The following sub-sections identify and discuss some of these areas.

DATA MANAGEMENT

Within the context of environmental information systems (EIS) (information systems for managing regional environmental information, usually supporting public policy and decision making), Gunther [1998] acknowledges the parallels between the data processing need for environmental information and that in business applications, but advocates the need for a wider adoption and use of information technology (IT) in EM. Specifically, he highlights a number of issues that are particularly relevant from an environmental data management perspective, namely:

- The size of environmental data involving satellite imagery and spatial data can pose significant processing and storage requirements
- Data management is highly distributed. In an organizational setting, environmental data may be captured using specialized sensors at the source. However, data processing may be performed at different locations within the organization to satisfy specific data processing needs.
- Data management is heterogeneous in terms of the hardware and software used. While this situation may be more prevalent in EIS than in EMIS, different parts of the same organization tend to develop or acquire environmental systems independently resulting in 'islands of automation'. The situation is more significant when sharing or using environmental resources (data or models) developed by external entities.
- Environmental data are frequently encountered with spatial and temporal dimensions (spatio-temporal). In effect, environmental measurements are often location specific and time specific. Analysis of such data requires aggregation across space and time, an operation which can be hampered if data from different sources have inconsistent spatial and temporal scales.
- Environmental data is often uncertain and fuzzy. Computational intelligence (such as neural networks and fuzzy logic) and statistical analysis techniques are critical to model and analyze this uncertainty. Examples of fuzzy systems in environmental applications include [Bardossy and Duckstein, 1995, Dragicevic and Marceau, 2000, Enea and Salemi, 2001, Guesgen and Albrecht, 2000, Salski, 2003] while illustrations of environmental applications of neural network can be found in [Keller, 1995].

DECISION SUPPORT

After data management for compliance and regulatory purposes, Environmental Decision Support Systems (EDSS) as standalone systems that are integrated with EMIS - or as components within EMIS - are the logical next step along the information value chain. Environmental decision making and topics such as environmental impact assessment, water resource management, and forestry, and agriculture are viable application areas for DSS. Environmental decision making and topics such as environmental impact assessment, water resource management, and forestry, and agriculture are viable application areas for DSS. Examples of such applications can be found at [Kersten and Lo, 2000].

Such systems pose specific design challenges on all three fronts of the Sprague/Carlson framework [Sprague and Carlson, 1982]. From user interface perspective, the diversity of stakeholders with respect to information needs (level of detail) and the level of expertise is particularly relevant. As mentioned above, environmental data sources are often distributed and are characterized as heterogeneous, time and data dependent, and multidisciplinary (such as biological, physical, chemical, geological, and economical). Likewise, the environmental models span a variety of modeling paradigms and can be difficult to integrate. EDSS often employs a variety of decision models and techniques as their core analytic engine. Besides system integration issues (to be discussed), the management of heterogeneous and distributed models poses significant model management challenges. Despite the recent developments within the model management literature, further research into areas such as web-based and distributed model management, and leveraging emerging technologies such as XML and intelligent mobile agents for model composition is warranted [Krishnan, 2000]. Techniques such as structured modeling and XML are already showing promise [El-Gayar and Tandekar, 2005, Kim, 2001].

The wealth of environmental data at the corporate, national and international levels is a fertile area for the application and development of emergent technologies such as soft-computing, intelligent data mining, and software agents. Shim et al. [2002] identify these technologies as foundations for intelligent systems seeking to screen, sift, and filter the overflow of data, and to support an effective and productive use of executive information systems (EIS).

Environmental decision problems are prime candidates for multiple criteria decision making (MCDM) techniques identified in Keen [1987] as at the core of decision support. These problems involve multiple stakeholders, conflict in preferences, ethical choices, and trade-offs among economic, social, and environmental objectives. Addressing such problems require communication, team support, and increased emphasis on interactive MCDM methods. Applying and extending such techniques in an environmental context can reap benefits for both the EM and DSS communities.

Environmental management is a knowledge intensive endeavor including knowledge about government regulations and reporting requirements, environmental abatement and assessment techniques, and scientific research results. The knowledge is often scattered throughout the organization and is subject to change over time. While knowledge management (KM) is an expanding research topic [Coakes, 2004], applications in environmental management are rather limited. In that regard, Schaefer and Harvey [2000] set the stage for knowledge management in a corporate greening context by studying organizational learning in six British water and electricity utilities. Uddameri [2002] develops a KM framework to support fate and transport modeling efforts necessary for risk-based corrective action approaches. It is worth noting that KM is a technology as much as it is an organizational issue. Socio-technical aspects associated with knowledge management solutions are equally important to the underlying technical solutions. As a relatively newer area of interest, and along the lines of medical information systems, bioinformatics, and enterprise systems, EM offers a new application domain for computational ontologies.

Overall, in setting a broad agenda for DSS research, Keen [1987] emphasized the need to look for areas where the proven skills of DSS builders can be applied in new, emergent or overlooked areas, to exploit emerging software tools and to re-emphasize the value of DSS practitioners. Such agenda is echoed several years later by Shim et al. [2002]. It is clear that environmental management offers a rich context for testing and developing model and data management approaches. Examples of prior work include Bill [1995] regarding the processing of spatial data for environmental information systems, Gunther et al. [1997] for sharing statistical modules on the web, Abel et al. [1997] for modeling EMIS, Bhargava [1997] for recycling and waste disposal, Kramer et al. [1997] for meta-information systems, Riekert [1997] for managing distributed and heterogeneous environmental resources and El-Gayar and Tandekar [2004] for sharing Biocomplexity models on the Internet.

INTEGRATION WITH OTHER SYSTEMS

Although EMIS evolved as standalone systems, the industry soon realized the benefits and need for integration with other systems. There is a distinct demand for comprehensive and integrated systems [Challener, 2000]. Of particular interest is integration with existing enterprise resource planning (ERP) systems as much of the data required for environmental management already exist within such systems [Scheraga, 1999]. BTI Consulting Group [1999] reports that 20% of survey respondents already have EMIS integrated with the corporate IT infrastructure, and 48% are working towards such integration.

However, integration with ERP systems poses a number of technical and organizational issues. First, the amount of customization required of either system may not be feasible from a technical and economic perspective. Second, traditionally, EMIS systems were developed as standalone systems with little if any provision for exchange (let alone integration) with other systems. Third, from a technical administration perspective, integration of two standalone systems can pose a maintenance nightmare as different systems are often only informally related; COTS solutions often follow different upgrade/release schedules and there are no guarantees that future releases are necessarily compatible. For example, prior to implementing an enterprise-wide EMIS at Arkema, the company relied on a home-grown system comprised of multiple spreadsheets, hand calculations, and a handful of separate application-specific databases. This system in time became too cumbersome to remain viable, as regulatory and reporting requirements became increasingly complex. An integrated EMIS helped the company realize efficiency gains, increase compliance visibility, and streamline corporate reporting.

Environmental management, by its nature employs a wide variety of information technologies ranging from spreadsheets and database systems to simulation systems, mathematical programming tools, expert and knowledge-based systems, computational intelligence tools (such as neural networks, fuzzy systems, and genetic optimization) and other artificial intelligence techniques such as case-based reasoning, intelligent agents, and visualization software [Chabanyuk and Obvintsev, 2000]. These systems do not operate in a vacuum, but require integration as often the output of one system is an input to another. Integration is often hampered as these tools are often deployed throughout the organization, by various departments, using various standards for data representation and exchange.

Componentization, object-oriented design, web services, eXtensible Markup Language (XML), and service-oriented architecture are technologies that can improve the reuse and integration of EMIS with other systems within the organization. The distributed and heterogeneous environment in which EMIS operate creates rich research opportunities for testing and advancing the aforementioned technologies.

V. OPPORTUNITIES FOR RESEARCH

In addition to the specific research opportunities already identified, the conceptual framework in Figure 1 depicting IS support for environmental management in terms of the supply and demand for environmental information can also be used as an underlying framework for identifying research issues pertinent to environmental management information systems. Research issues can be identified for each layer in its own right as well as at the interface among the layers. The following identifies a number of research opportunities along the framework presented in Figure 1. The list is not meant to be inclusive, but a primer for some of the IS related research questions within the context of environmental management.

STAKEHOLDERS

With respect to stakeholders, research issues revolve around identifying their informational needs and how best to meet these needs including:

- What are the information needs for the various stakeholders?
- What are the implications of these needs on the supporting information systems?
- How can environmental portals and e-learning systems improve environmental awareness and meet the informational needs of various stakeholders?
- What are the implications of concepts and initiatives such as eco-management, the triple bottom-line, and ethical investing on the demands for environmental information?

EMS

In addition to identifying and fulfilling the research needs of various EMS, research issues include aspects related to regulatory and security of supporting EMIS. Examples include:

- What are the specific informational needs of various EMS?
- How best to meet these informational needs?
- What are the regulatory and security implications for EMIS supporting EMS?

EDSS

With the diversity of decision support technologies and the specific demands of environmental planning and management, research issues focuses on developing and adapting various technologies to improve the quality of environmental decision making. Examples include:

- How can we simplify and streamline the acquisition and transfer of environmental knowledge?
- How can we leverage the developments in semantic web and ontologies to develop multi-lingual terminology and environmental ontologies?
- How can we apply technologies and approaches to improve environmental planning systems?
- Likewise, how can we extend such techniques and approaches to meet the unique demands of environmental management, e.g., temporal and spatial dimensions?
- What are the issues surrounding the adoption and diffusion of EDSS in organizations?
- How can we leverage business intelligence technologies in environmental management?

EMIS

EMIS applications are often characterized as complex applications. Sources for complexity include data management issues mentioned earlier, the need for integration with other organizational systems, often ambiguous requirements, and diversity of stakeholders. EMIS related research issues spans organizational and technical dimensions including:

- How can we improve the sharing and integration of environmental data through environmental meta-data standards?
- What are the issues and approaches to integrating business process modeling tools to EMIS?
- What are the issues and approaches in integrating legacy and specialist systems with EMIS?
- What are the issues and approaches in integrating product data management systems and product lifecycle systems?
- What are the issues and approaches in EMIS selection and adoption?
- What are EMIS post-implementation challenges, issues and critical success factors?
- What are the organizational change, culture and leadership issues involved in EMIS adoption and how to address them?
- What are the organizational and business impacts of EMIS and how to address them?
- What are the business costs and benefit of EMIS and approaches to evaluate and maximize benefits and minimize costs?
- What are the issues surrounding the adoption and diffusion of EMIS in organizations?
- What are the implementation issues and approaches in small and medium enterprises (SME)?
- Extending the work of Maul [1999] and Argent [2000] regarding the development of environmental software, we have questions such as what is the suitability of various software development processes to EMIS?, how to adapt existing processes to the specific needs of EMIS?, and what are the architectural design issues supporting enterprise EMIS?

OPERATIONAL CORE

Research issues at the operational core level are primarily concerned with the supply of environmentally relevant information including:

- How do existing environmental and business process affect the design of EMIS and vice versa?
- What is the nature of the environmental information generated at the operational core?
- How best to capture such information for environmental management and decision support?

VI. CONCLUSION

In the preface of their edited book, Rautenstrauch and Patig [2002] inquire as to whether computers and environmental protection are two different worlds. Judging from the situation in the United States, they conclude that a handful of scientists are working in the field of environmental information systems and they play a minor part of the IS community. Judging from the publications in the information systems field, the synergy between environmental management and information systems has not yet been realized to the extent which is possible.

The framework proposed in this tutorial is a step towards bridging this gap. The framework highlights the role of IS in supporting the broader agenda of environmental management and sustainable development within firms. The framework also serves as the basis for an interdisciplinary research agenda and for collaboration between information systems and environmental management. As presented, opportunities for interdisciplinary research abound which span the technical and organizational spectrum.

While this paper highlighted a number of issues pertaining to information systems for environmental management in corporations, the list is not meant to be inclusive. Instead, the list is meant to provide examples of the research opportunities that exist for IS research within the context of environmental management. Future research in this arena will inevitably shape the research agenda as current issues are answered and newer issues arise in light of advancements in information technology, environmental innovation, and growing and changing demands for environmental information.

VII. REFERENCES

> *Editor's Note:* The following reference list contains hyperlinks to World Wide Web pages. Readers who have the ability to access the Web directly from their word processor or are reading the paper on the Web, can gain direct access to these linked references. Readers are warned, however, that
>
> 1. these links existed as of the date of publication but are not guaranteed to be working thereafter.
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LIST OF ACRONYMS

COTS	Commercial off-the-shelve
DfE	Design for environment
DSS	Decision support systems
ECA	Environmental Cost Accounting
EDSS	Environmental Decision Support Systems
EHS	Environmental Health & Safety
EIS	Environmental information systems
EMAS	European Eco-management and Audit System
EMIS	Environmental management information systems
EMS	Environment management system

EMSS	Environmental management systems standards
EPA	Environmental Protection Agency
ERP	Enterprise resource planning
ESP	Environmental Software Providers
GHG	Greenhouse Gas
INFORMS	Institute of Operations Research and the Management Sciences
IS	Information Systems
ISO	International organization for standardization
IT	Information technology
JIT	Just in-Time
KM	Knowledge management
LCA	Life cycle assessment
LCC	Life cycle costing
MCA	Multi-criteria analysis
MCA	Multiple Criteria Analysis
MFA	Material flow accounting
NGO	Non-governmental organizations
OLAP	Online Analytical Processing
PPC	Production planning and control
SARA	Superfund Amendments and Reauthorization Act
SME	Small and medium enterprises
TQM	Total Quality Management
UN	United Nations
US	United States
XML	eXtensible Markup Language

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