VERSLAS: TEORIJA IR PRAKTIKA
BUSINESS: THEORY AND PRACTICE
ISSN 1648-0627 print / ISSN 1822-4202 online

2011 12(1): 5–14
doi: 10.3846/btp.2011.01

ENVIRONMENTAL REPORTING OF INDUSTRIAL AND SUPPLY CHAIN BUSINESS PROCESSES WITHIN THE CONTEXT OF SUSTAINABLE DEVELOPMENT

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Received 27 October 2010; accepted 23 November 2010

Abstract. Green issues in industrial and supply chain business processes have been receiving exponentially growing attention over the past decade. Consumers are demanding green products and services more and more, and on the other side of the marketplace, businesses and industries are now much more responsive to green issues. Furthermore, businesses and industrial systems are, in present conditions, positively reacting to green issues. From an academic perspective, there are considerable numbers of research on this topic in various disciplines. Thus, for the green strategies with respect to the sustainable development, this paper delves into the literature of the significance of sustainability concept with an emphasis on the ecological dimension and then brings a range of essential perspectives along with the applied framework of environmental reporting of industrial and supply chain business processes.

Keywords: eco-informatics, eco-management, greening, sustainable development, quality management, industrial processes, ERP.

APLINKOSAUGOS ATASKAITA APIE GAMYBOS IR TIEKIMO GRANDINĖS VERSLO PROCESUS DARNIOS PLĖTROS KONTEKSTE

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Įteikta 2010-10-27; priimta 2010-11-23

Santrauka. Per pastarąjį dešimtmetį nuolat didėjo dėmesys ekologiškumo klausimams gamybos ir tiekimo grandinės verslo procesuose. Vartotojai vis daugiau ir daugiau reikalauja ekologiškų produktų bei paslaugų, rinka, verslo ir gamybos sistemos vis labiau jautresnės ekologiškumo klausimams. Esamomis sąlygomis verslo ir gamybos sistemos teigiamai reaguoja į tokio pobūdžio dalykus. Mokslo perspektyvos požiūriu nagrinėjamu klausimu yra atlikta nemažai tyrimų įvairių disciplinų lygmeniu. Taigi siekiant sukurti ekologiškumo strategiją atsižvelgiant į darnią plėtrą, straipsnyje nagrinėjama darnaus vystymosi koncepcija, akcentuojant ekologijos dimensiją, ir nustatomos esminės perspektyvos remiantis aplinkosaugos ataskaita apie gamybos ir tiekimo grandinės verslo procesus.

Reikšminiai žodžiai: informacija apie aplinkosaugą, ekologijos vadyba, ekologiškumo didinimas, darni plėtra, kokybės valdymas, gamybos procesai, įmonės išteklių planavimas.

1. Introduction

Sustainable Development is best defined in a report generated by the United Nations World Commission on Environment and Development of 1987, also known as the Brundtland Commission. The commission defined sustainable development as "a process of change in which the exploitation of resources, the direction of investments, the orientation of technological development, and institutional change are all in harmony and enhance both current and future potential to meet human needs and aspirations. Sustainable development meets the needs of compromising the ability of future generations to meet their own needs". As is obvious, a sustainable approach is not mere growth at any cost, because growth at any cost is not sustainable. Responsible growth is needed to sustain the coming improvements in human welfare – in consumption, in health, in human skills, and in social equity (World Bank 2004). As concerns about environmental protection, natural resource stewardship, and the world's ability to feed its ever-growing population continue to mount, the sustainability of agriculture and natural resources is emerging as a central theme among the public and policymakers alike (Board on Agriculture Staff 1991). Accordingly, there is a growing demand for ecological informatics in business systems processes, including industrial, logistical, and supply chain systems; this is also the aim of the corporate sustainability reporting. Though informatics is rather new in the field of ecological science, representing a computational approach to ecosystems analysis, synthesis, and forecasting, it provides a wide range of methods to support ecological investigations (Recknagel 2003).

Social, ecological, and economical dimensions have been the three keys to sustainable development, as illustrated in Figure 1.

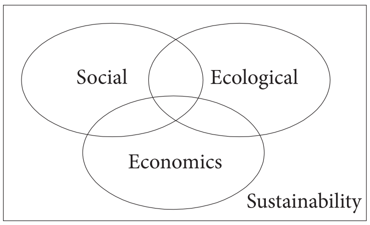

Fig. 1. Elements of sustainability

1. 1. Sustainable development

Sustainable development has evolved over the past two decades as a new way of approaching the environment and its relationship to everything else we care about as a society (Dernbach 2001). It is a dynamic process of change in which the exploitation of resources, the direction of investments, the orientation of technological development, and institutional change are made consistent with future as well as present needs (Rogers *et al.* 2007). The concept of sustainability explores the relationships among economic development, environmental quality, and social equity. This concept has been evolving since 1972, when the international community first explored the connection between quality of life and environmental quality at the United Nations Conference on the Human Environment in Stockholm (Rogers *et al.* 2007). Sustainable development first began to attract significant international attention when it was endorsed in 1987 by the World Commission on Environment and Development. According to the commission's report, Our Common Future, "sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs". This one-sentence explanation, though only a start, has been widely quoted since then as the definitive statement of what sustainable development means (Dernbach 2001). Since then, numerous studies have been done addressing the sustainability, as more recent studies on sustainability issue one might refer to Baltrenas, Kazlauskiene (2009); Burinskiene (2009); Burinskiene, Rudzkiene (2009); Ciegis, Ramanauskiene (2009); Dzemydiene, Maskeliunas *et al.* (2009); Kaklauskas *et al.* (2009); Kavaliauskas (2008); Kaziliunas (2008); Kurlavicius (2009); McDonald *et al.* (2009); Paulauskas, S., Paulauskas, A. (2008).

Sustainable development has three dimensions: economical, environmental, and social. It is critical that each component be given equal attention in order to ensure a sustainable outcome. This balance becomes obvious when each component is examined individually (Rogers *et al.* 2007).

1.1.1. The economical dimension

The core idea of sustainability is that current decisions should not impair the prospects for maintaining or improving future living standards. This implies that our economic systems should be managed so that we can live off the dividends of our resources (Repetto 1986). From the economical dimension of sustainability, an emphasis needs to be placed on a balance between cost factors of a service or a product and the benefits derived from the investment and utilization of resources, with the environment and quality of life also taken into consideration.

Sustainable development is an approach that will permit continuing improvements in quality of life with a lower intensity of resource use, thereby leaving behind for future generations an undiminished or even enhanced stock of natural resources and other assets (Lutz *et al.* 1991). Sustainable development means basing developmental and environmental policies on a comparison of costs and benefits and on careful economic analysis so that environmental protection is strengthened, leading to rising and sustainable levels of welfare (World Bank 1992).

1.1.2. The ecological dimension from an industrial perspective

We need better understanding of the flow in industrial systems from one process to another of those materials and energy that have an impact on the natural environment. Industrial ecology studies those impacts from a range of possible perspectives. Industry cannot be separated from nature. Indeed, there is a growing sense that industrialisation has now caused damage to the environment that is difficult, if not impossible, to rectify (Fineman 2000). Our economic system produces 'bads' along with its 'goods'. Scraping and digging the earth, harvesting the forests and seas, creating and discarding chemicals and gasses, burying our waste, and generally feeding the insatiable industrial-economic machine may be wrecking the very ecosystem on which our supposed good life depends (Fineman 2000).

Industrial ecology is the study of the flows of materials and energy in industrial and consumer activities, of the effects of these flows on the environment, and of the influence of economic, political, regulatory, and social factors on the flow, use, and transformation of resources. The objective of industrial ecology is to understand better how we can integrate environmental concerns into our economic activities. This integration, an ongoing process, is necessary if we are to address current and future environmental concerns (National Academy of Engineering Staff 1994). At the most general level, the reshaping of industrial systems for environmental and economic success is based on the efficient use of materials and energy, substitution of more abundant and environmentally preferable materials for those that are rare or environmentally problematic, reuse and recycling of products and materials, and control of waste and emissions (National Academy of Engineering Staff 1994).

Though environmental problems have challenged humankind since time immemorial, policy scientists have given serious attention to environmental issues only since the 1960s (Prakash 2000). Responding to public concerns, the United States Congress has enacted a series of laws stipulating environmental standards and technologies. Zealous monitoring and enforcement often backed these policies. The policy community and the regulated industries began articulating their dissatisfaction with the inefficiencies of command and control policies, specifically questioning the capacity of governmental agencies to implement detailed regulations (Prakash 2000). Moreover, in another trend existing since the 1960s, industries have faced ever-increasing environmental demands from their customers. Recently, reflecting these demands, new business control functions are integrated with environmental management systems (EMS) (Pokorny 2006). The automation of data discovery, ingestion, processing, and analysis afforded by enriched and structured metadata coupled with scientific workflow systems will transform ecology (William 2006).

Sustainable development is about the maintenance of essential ecological processes and life support systems, the preservation of genetic diversity, and the sustainable utilization of species and ecosystems (IUCN, WWF, UNEP, 1987). As the term "sustainable development" suggests, the lessons of ecology can and should be applied to economic processes. This encompasses the ideas in the World Conservation Strategy, which provides an environmental rationale through which the claims of development to improve the quality of (all) life can be challenged and tested (Redclift 1987).

1.1.3. The social dimension

Sustainable development involves a process of deep and profound change in the political, social, economic, institutional, and technological order, including a redefinition of the relationships between developing and more developed countries (Strong 1992). The social dimension of sustainable development involves a range of factors with direct impact on the living standards of low-income groups. Sustainable economic development is directly concerned with increasing the standard of living of the poor, which can be measured in terms of increased food, real income, education, health care, water supply, and sanitation, but only indirectly concerned with economic growth in the aggregate (Barbier 1987).

2. Business processes, quality systems and ERP

2.1. Business processes within enterprise systems

A business process is the logical organization of people, materials, energy, equipment, and information into work activities designed to produce a required result, a product or service (Pall 1987). The modelling of business processes is vital not only for business process management, but also for the implementation of enterprise systems (Portougal 2005).

Organisations are fundamentally systems that convert inputs to certain outputs and hopefully, in the process, add value. Inputs may be anything from people, to materials, to money, or to information, while the outputs could be products, services, waste, or even intellectual property (Portougal 2005). On the other hand, in addition to the search for savings within a business, the search for other improvements within a business is a never-ending quest. It occupies the minds and energies of virtually every business, at all times, in every type of enterprise (Poirier 2005).

The design of a process can limit that process' capability to deliver the required performance. Redesigning processes using the power of modern information technology can help achieve dramatic improvements in performance (Hammer 1990; Bider 2005). Companies have been striving to improve their business processes for decades, but, in the past few years, the emergence of a variety of new software technologies and the relentless competitive pressures on large companies to outsource and to develop a worldwide presence has taken the interest in business processes to a new level of intensity (Harmon 2008).

Process-aware information systems, ranging from generic workflow systems to dedicated enterprise information systems, use work lists to offer so-called work items to users (Leoni *et al.* 2008). Information technology in general and information systems in particular deserve an important role in business process management, because more and more activities that a company performs are supported by information systems. Business process activities can be performed by the company's employees manually or with the help of information systems. There are also business process activities that can be enacted automatically by information systems, without any human involvement at all (Weske 2007).

Interconnecting information systems and the heightened need for step-by-step control of business processes have created a demand for fully integrated business functions management that at the same time allows companies to have connections to comply with obligatory external sources, such as relevant legislation (see Fig. 2).

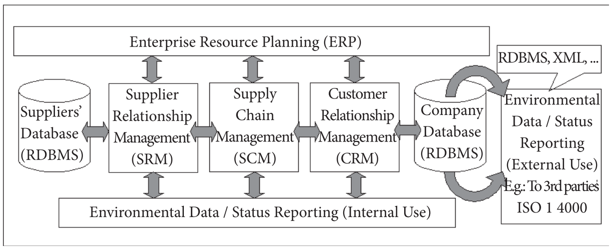

Fig. 2. A simple diagram of common business functions of a supply chain system

Thus, businesses have demanded integrated turnkey systems with material flow analyses, connection to commercial systems and process control engineering, and links to relevant regulatory legislation (Hilty 2004). The application of Internet technology represents a new opportunity in this context to link all levels of a company to these systems and to allow them to participate in the results. It therefore represents an opportunity to make available efficiently and promptly various views of data and results prepared by media and related to interests (Hilty 2004).

2.2. ERP systems, quality management, and environmental systems

An enterprise resource planning (ERP) system is composed of several software packages or modules that help automate, informate, and integrate cross-functional business processes such as human resources, sales and marketing, finance, and production (Parr and Shank 2000). Firms implementing ERP systems hope to enhance the firm's competitive position by improving levels of efficiency and effectiveness within and across core business processes (Davenport 1998). ERP inputs play an important role in the effectiveness of the overall ERP process. Data accuracy of these inputs obviously plays a critical role, and data integrity is a historically proven prerequisite of high performance (Sheldon 2005). Accuracy of data is an asset for process improvement as well as process predictability in all high-performance organizations (Sheldon 2005). ERP systems are quite capable of providing an incoming inspection audit trail and thereby answering a myriad of questions, for example: were the parts inspected? Who inspected them using which test equipment? What were the results? Thus, corrective action can be taken to purge the bad raw material and recall defective products that might have been shipped to customers (Guptaa, Kohlib 2006). More firms are turning to ERP to leverage knowledge assets at all levels in the organization, to such an extent that ERP systems replaced legacy systems in informating and automating core business processes (Holland *et al.* 1999). ERP systems are designed to address business functions of organizations to help them manage and coordinate information flows and resources. However, quality management functionalities within the ERP systems have not been implemented in accord as an integrated environmental information management practice, though quality systems with a set of key procedures, workflows, task allocations, and quality plans are not detached parts of business functions including environmental management.

In addition to the implementation of ERP systems in organizational activities, quality management functionalities need not be considered independently from ERP processes. Workflows defined in the quality documents and environmental management documents are reflections of runtime business processes. The ERP systems organize these data flows in a systematic manner; thus, quality functionalities already have an active place in ERP systems. However, in numerous implementations of ERP systems, these functionalities are not sufficiently well defined to have the ability to map tasks into total quality management systems.

ERP systems generate an imperative to establish integrated business processes across diverse functional boundaries in organizations (Davenport 1998). TQM (Total Quality Management) is an essential cultural framework and foundation for ERP implementation (Schniederjans, Kim 2003). To understand the relationship between ERP and quality, one must understand the essence of quality.

Quality is defined as "an organization wide effort to continuously improve products and services delivered to customers by developing supporting organizational culture and implementing statistical and management tools" (Madu 1998). A major phrase in quality management is to "do things right the first time". ERP helps to accomplish this goal by making every part of the organization responsible to the customer by enabling them to respond in a timely and accurate manner to the needs of the customer without having to re-route customer calls and requests to specialized departments (Seow 2003).

A quality management system (QMS) under the environment of ERP combines the theory of total quality management (TQM), the ideas of ISO9000, and the advantages of information integration and multi-angle data analysis. A power tool for the continuous improvement of quality, it is indispensable to ERP (Yibing 2006). TQM necessitates organizational changes and seeks to improve all processes and every business activity. ERP is a process-based technology initiative. As such, implementing an ERP system requires changes in all processes. In this sense, TQM and ERP are complementary and share many common areas. TQM also precedes ERP implementation in establishing an organizational infrastructure for ERP initiatives (Ling *et al.* 2008).

3. Environmental reporting: process level focus

3.1. Sample environment monitoring and reporting on joint processes

Assumption: A typical process with process-activity attribute (t) follows the normal distribution model. In this case, (t) based normal distribution function of one process-activity (t) component can be exhibited as:

$$f(t) = \frac{1}{2}\frac{\sqrt{2}e^{-1/2\frac{(t-\mu)^2}{\sigma^2}}}{\sqrt{\pi}\sigma} \quad (1)$$

where μ is the expected value, σ^2 is the variance and σ is the standard deviation. See Fig. 3.

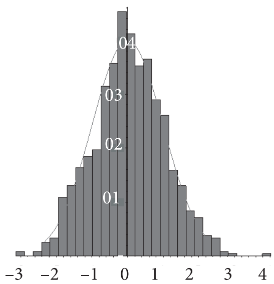

Fig. 3. A sample distribution of *f(t)*. Distribution based on (*t*) component

For instance, for $n = 5$ independent variables, concurrent processes denoted by X with η weighting factor for each processes can be exhibited as:

$$\zeta = \eta_1 X_1 + \eta_2 X_2 + \eta_3 X_3 + \eta_4 X_4 + \eta_5 X_5\,, \quad (2)$$

where ζ is the joint distribution value for the five processes (X_i) with weight factors of η.

For n independent variables, concurrent processes' joint distribution value can be denoted as:

$$\zeta = \eta_1 X_1 + \eta_2 X_2 +,\dots, + \eta_{n-1} X_{n-1} + \eta_n X_n. \quad (3)$$

If we apply the three sigma rule where the t value falls into the range of [$\mu - 3\sigma$, $\mu + 3\sigma$,], this means that with 99.73% probability, the *t* value will be in the specified range. $\mu - 3\sigma$ indicates the lowest possible *t* value and $\mu + 3\sigma$ indicates the highest possible *t* value of the normal distribution function *f(t)*.

The concurrent sum of the (*t*) component values of all n processes (based on a normal distribution) is

$$\psi = \sum_{i=1}^{n}\left(\frac{1}{2}\frac{\sqrt{2}e^{(-1/2\frac{(t_i-\mu)^2}{\sigma^2})}}{\sqrt{\pi\sigma^2}}\right), \quad (4)$$

whereΨ here denotes the joint distribution output of processes variables. See Fig. 4 below.

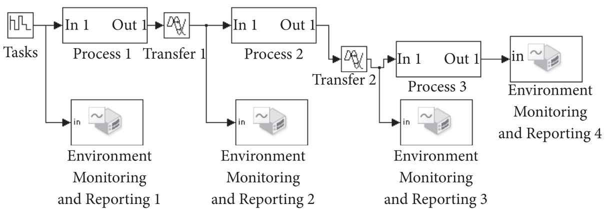

Fig. 4. Typical *n* concurrent processes design with Ψ joint distribution value at its final output

3.2. Environmental reporting on processes

Environmental information systems (EIS) is a generic term that describes the class of systems that perform one or more of the following tasks: environmental monitoring, data storage and access, disaster description and response, environmental reporting, planning and simulation, modelling, and decision making (Gomez 2004). All business activity creates flows of energy and materials, whose management forms an integral part of how a company interacts with its environment. Industrial Environmental Information Systems, also referred to as Environmental Management Information Systems (EMIS), are designed to detect, evaluate, and prevent a wide range of environmental dangers and stresses. In more concrete terms, EMIS consist of computer programs that support management by collecting, documenting, and evaluating all relevant data about an enterprise's strategic plan and its interaction with the environment. As a part of this task, the system initiates and controls all activities related to environmental protection (Wohlgemuth 2005; 2006). There exist numerous engineering solutions, which are based on robust data and knowledge modeling (Mili 2001; Mineau 2000; Yang *et al.* 2003; Xindong *et al.* 2000). A focus on a single process level is the exact and the right place where not only environmentally sensitive reporting data is generated but also the first step of a measured process that supplies data to the next process or a group of processes in the system. For instance, with the focus of every single process in the system, green logistics systems or environment monitoring systems in the whole enterprise cannot only be limited to a group of processes or to just one major process that provide green or environmental data capabilities.

At the core part of each task definition inside an organization, the main workhorse is the process, which has an input, an output, and a feedback mechanism. Inputs of a process can be in the form of a single piece of data, an attribute, or a material input over a small fraction of a time. Outputs are the expected outcome of the process. Feedback mechanisms provide further control over the process by closely monitoring the output and at the same time providing necessary feedback to the input section of the process in order to keep the outcomes of the process inline with its specifications. In business environments, every process is under strong or weak influences of uncontrolled and controlled variables. With numerous variables around a process in business operations, large-scale enterprise-level systems applications require solid and systematic systems definitions (see Fig. 5).

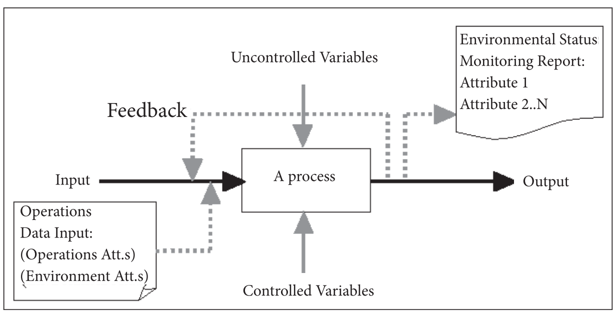

Fig. 5. A single business process

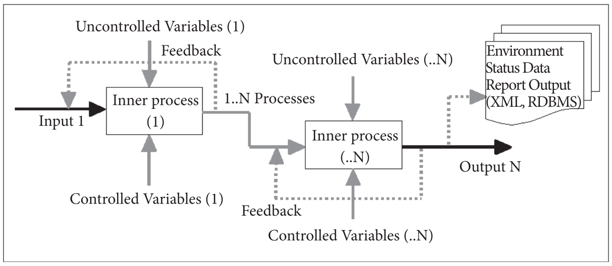

Fig. 6. Interconnected business processes that behave as a single process

An important component of each environmental report is a systematic representation and evaluation of the substantial material and energy flows within an enterprise (Gomez 2004; 2001; see Figs 5, 6).

From the heightened demand for monitoring processes with feedback and feed forward mechanisms, supplying the processes with the required data to correctly utilize and enable every other processes (see Fig. 6) plays a crucial role in process chains.

3.3. Environmental reporting and ERP systems

Today, most enterprise-level systems software is built on relational database management systems that ultimately implement every specific detail of the functional bodies and their specific, detailed relationships, enterprise-wide. Flexible and scalable fields, attributes, tables, views, queries, and so on are used to define processes or a group of processes in the system. Independent of the vendors of database systems, relational database management systems have one important outcome: interoperability. Enterprise systems application development plans are being initiated with a focus on environmentally sensitive issues (Fig. 7), such as retrieving standard reporting data from each process, evaluating the data, and sending feedback signals back to the processes.

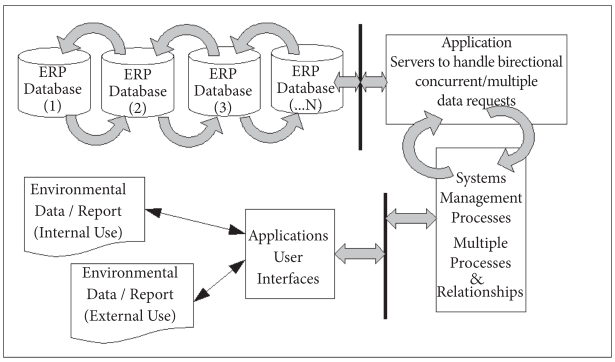

Fig. 7. Multi-tiered ERP system: databases, application server, and user interfaces, with Environment Status Data Report Output

Environmental data treatment consists of identification, acquisition and conversion (if necessary) of the environmental data required to generate a model (Santana *et al.* 2008). In the software development market, there are various modelling tools and software development environments available to construct the building blocks of process-based business operations and to address environmental reporting mechanisms in each process (Yildiz and Yercan 2009).

Identifying critical ecological factors and judging the likely effectiveness of corrective measures often requires a model, which must reveal relevant structures and flows (Wohlgemuth 2006). If the datasets of separate studies have one or more common database templates, the data integration necessary for synthesizing those studies would be significantly easier than if each were developed idiosyncratically. Templates contain rules on how one template can be composed with others into a database design or what elements might be needed for a particular visualization; they are currently represented as XML documents (McIntosh *et al.* 2007; Nottrott *et al.* 1999). For efficient handling of environmental documents, XML technology offers an outstanding initial foundation. The basis of structured environmental reports is a document type definition (DTD) for environmental reports (Gomez *et al.* 2001; Isenmann *et al.* 2003). XML-tagged eco-balance data is, thanks to international standardization, platform-, system, and field-of-use-independent. That ensures a high potential for further use of that data, whether in publication, quality control, or information retrieval (Gomez 2004).

Meanwhile, Unified Modelling Language (UML) is well established and widely in use in defining system entities and relationships. UML has attracted widespread attention and become the standard modelling language for software engineering. In nature, the applicability of UML is not restricted to software development, but can be extended to other process modelling tasks (Favre 2003). The UML specifications are for modeling object-oriented systems and it is an open standard maintained by the Object Management Group. The UML consists of graphic elements that are combined using explicit rules to form diagrams. The diagrams are classified based on their ability to represent the structure and dynamics of a system or process (Balram, Dragićević 2006). UML is a prime candidate for Information System design (Khosrow-Pour 2005). The UML diagrams and notations allow specification and construction of system design processes. In addition, UML models document the system with consistent notation. The visual UML diagrams can be used for training, reviews, planning, and general process improvement; with the diagrams, designers can represent their individual perspectives and communicate shared ideas (Balram, Dragićević 2006).

By laying out operations logic into the development application, it is possible to clearly define and visualize business processes (see Fig. 8).

The de facto standard of the Global Reporting Initiative (GRI) guides companies on how and what to report. Reporting in accordance to the standard obligates a detailed, well-balanced publication of sustainability indicators (GRI 2006; Süpke *et al.* 2009). In addition, the focus of environmental management is not a limited procedure

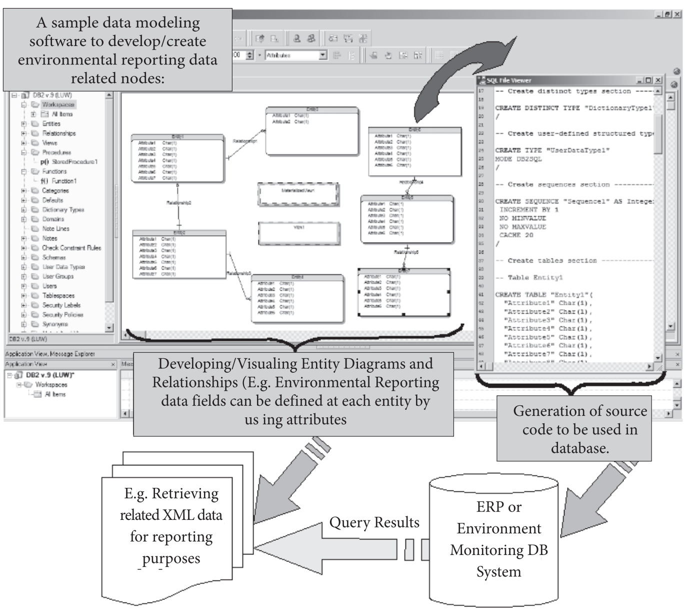

Fig. 8. Visually modeling business processes with environmental status updates in each process and binding the source code (output) to the existing ERP software backbone

of certain major common supply chain functions. Every major process, including their sub processes, is a crucial part of meeting the requirements set by the environmental management standard. On the other hand, for many large companies, when it comes to measuring performance levels with respect to meeting total environmental prerequisites, procurement departments are considered to be the major performers, as these departments provide direct material or service inputs to business operations which have undoubtedly direct influence on the environmental management policies of a company. And for many large companies, environmental performance is integrated into the procurement function, whether for services or for raw materials. These large companies affect whole supply chains and cross many industries with their requirements for improved environmental performance. Some of this is being driven by environmental management systems (ISO 14000 or EMAS), while other parts are driven by consumer pressure or even market differentiation (Waters 2006).

4. Conclusions

Environmental reporting from the view of sustainability, literature background, and technical approaches have been presented in this article about enterprise level systems integration. The capacity to reveal the overall enterprise-wide performance on environmentally specific tasks can be limited if strategists, systems planners, systems enablers, and practitioners have at any stage overlooked the opportunities presented by core processes design. For the green strategies with respect to the sustainable development, this paper has dealt with the literature of the significance of sustainability concept with an emphasis on the ecological dimension and then has brought a range of essential perspectives along with the applied framework of environmental reporting of the business processes.

Development of processes with an emphasis on environmental concerns is a successive task and at no stage, it can be introduced as an ultimate service. Exactly like any other construction projects, improvement efforts in any phases require proficiency of on-site experience.

Acknowledgements

The authors kindly acknowledge that this study is part of the research conducted by the co-author and is entitled, "Integration of Turkey with the European Union Green Logistics, Transportation and Maritime Policies: Applications in Leading Markets" with project number TUB/108K349 of The Scientific and Technological Research Council of Turkey – TUBITAK.

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