E-BUSINESS WITH SOFTWARE SERVICES FOR SUSTAINABLE MANUFACTURING

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Abstract: With steady changes to the global environmental agenda over the past two decades, manufacturing companies are driven to internalise environmental aspects of their businesses, both to meet local environmental regulations and to conform to emerging international standards and best practices. Information on environmental issues is crucial to assist companies in improving their environmental performance. We propose in this paper the emerging service-oriented approach for establishing e-business by enabling the linking of relevant environmental information to business processes, and to foster the sharing of information between sustainable manufacturing companies. The links between the business functions of a manufacturing company and the environmental dimension of the business are analysed in the paper. Using these links, a simplified service-oriented software model is derived to deliver information on the life cycle environmental impacts of manufactured products. The proposed approach could provide a basis for developing innovative e-business with software services, which could assist manufacturing companies, both large and small, to realise improvements in environmental performance.

1 INTRODUCTION

Manufacturing deals with the transformation of materials into physical products upon which we heavily rely in our daily lives, both at home and in working environment. Manufacturing industry in any country is made up of companies of varying size, from very small ones employing a handful of people to very large ones having operations on a global scale. Manufacturing is thus an important industrial global activity pursued on a trans-national scale in many nations of the world for economic and social wellbeing. Owing to the impact that manufacturing industry has on modern society, the industry needs to be viewed, both at national and global levels, in the light of sustainability goals, and weighed along the well-known triple bottom line (Elkington, 1997) that includes economic, social and environmental dimensions. The environmental dimension is intrinsic to manufacturing because making physical products requires material transformation processes that use many materials, consume energy, and produce wastes and emissions. Furthermore, product users discard manufactured products at the end of product life, thus leading to enormous wastes. Such wastes and emissions generated by manufacturing companies ought to be reduced in our journey towards attaining sustainability. Industrial ecology, an emerging discipline based on sustainability principles, recognizes the essential interconnectedness of industry, economy and the environment (Graedel and Allenby, 1995), and attempts to promote new approaches for internalisation by industry of the principles of triple-bottom line on an integrated basis.

The problem of integrating all the dimensions of the triple bottom line at a business level is indeed challenging. Currently there is considerable effort around the world in finding ways for internalising environmental issues by businesses so that their environmental performance can be improved. Both relevant information and the delivery of such information are important for improving the environmental performance of manufacturing companies, as stressed by many protagonists for sustainable materials production and manufacturing (Graedel and Allenby, 1995).

A way of internalising environmental issues by business into business practices is by conformance to Environmental Management Accounting (EMA), recommended by United Nations Division of Sustainable Development (Burritt, 2004).

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In this paper, we have considered the broader problem of delivering environmental information in different forms and detail via service-oriented software to meet many functional needs of manufacturing companies to assess and improve their environmental performance in conformance with international standards.

The paper, in a conceptual sense, embodies many principles of industrial ecology. The proposed software for delivering environmental information focuses on designing clean processes, green products and eco-efficient systems. The information to be delivered by the software considers the entire life cycle of manufactured products, from materials production, manufacturing, use and closing the materials loop (Figure 1) by shifting from traditional end-of-pipe strategies to a life cycle approach (Schaltegger et al., 2003). Furthermore, the proposed approach for designing service-oriented software enables the processes of internalising environmental issues by linking the influence of the inevitable materials flow cycle associated with manufacturing to many business functions that need to be carried out to improve the environmental performance of entire product value chains (Ramakrishnan et al., 2003; Ramakrishnan, 2003).

In a pragmatic sense, the paper proposes the emerging service-oriented approach for developing an environmental software system for two important reasons. (i) Technologies that can support the development of service-oriented software are increasingly being used in delivering B2B (Business to Business), e-Commerce and intra-enterprise distributed systems. With new developments in web-based services, the exchange of knowledge and software services across value chain actors appears to be improving (Isenmann et al., 2004). (ii) Service-oriented environmental software systems can offer more advantages than product-based or centralised knowledge-based (Carlson et al., 2001) software in meeting the evolving needs of an environmentally responsible manufacturing enterprise in adopting environmental best practices on a continual basis in a cost effective manner.

In Section 2, we derive the links between the business functions of a manufacturing enterprise to required environmental tasks and the environmental software services to be provided to carry out the tasks. We discuss briefly in Section 3 the guiding principles for developing service-oriented software models, and derive a service-oriented model for the core environmental service of estimating the life cycle environmental burdens of products, as viewed from the perspective of a manufacturing plant. A short discussion is provided in Section 4 on the use of service models for developing service-oriented environmental software systems, with some comments on further work. The paper is concluded in Section 5.

2 INTERNALISING THE ENVIRONMENTAL DIMENSION OF BUSINESS

The guiding principle followed in this paper is to add the most appropriate environmental dimension to each of the business functions of a manufacturing company or enterprise, and to relate environmental tasks to services for information delivery.

Materials production and manufacturing companies are required to meet many local or national environmental regulations, and are also expected to conform to emerging international standards (ISO, 2005) and best practices. The new international standards, ISO 14000 series, recommend a framework that can form the basis for adoption of environmental best practices by companies. In order to meet local regulations, and thus remain environmentally responsible in a region, companies should report, and also, reduce the environmental impact of their operations.

The core environmental impact that needs to be reduced by manufacturing companies to remain internationally competitive is the life cycle impact, which represents the environmental footprint of manufactured products over their product life cycles. As shown in Figure 1, various materials and energy in different forms are consumed in making products from raw materials, and wastes and emissions result throughout the life cycle of products. ISO 14040 series standards provide a framework for Life Cycle Assessment (LCA) of products. All the processes in making, distributing and using the product, from the cradle state to end of life, are considered in LCA. All emissions to land, water and air associated with the product are quantified to arrive at the life cycle inventory. The materials in the life cycle inventory are classified into various impact categories (e.g. greenhouse or global warming, ozone depletion, summer smog etc.). The life cycle impact of the product is expressed under chosen impact categories (e.g. Global Warming Impact expressed as kg CO2/product).

LCA requires knowledge of processes and the flow of materials and energy throughout the product life cycle chain. The current situation is that LCA service is provided by expert consultants. Also some LCA software products (SimaPro, 2005, http://www.earthshift.com/tools.htm) are available for use by experts within a company.

However, lack of relevant information and data to conduct an LCA of a manufactured product over its entire life cycle chain poses enormous difficulties. As the estimation of the life cycle environmental impact of a product requires data, information and knowledge resident in several companies in the product value chain, sharing knowledge across the companies and actors of a product value chain becomes mandatory.

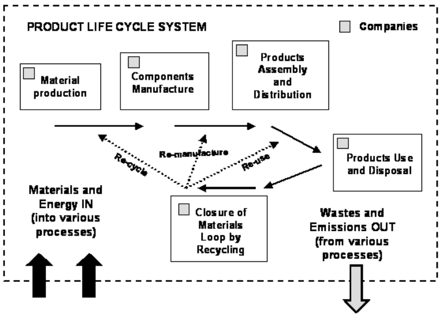

Figure 1: Cradle to grave life cycle of a product.

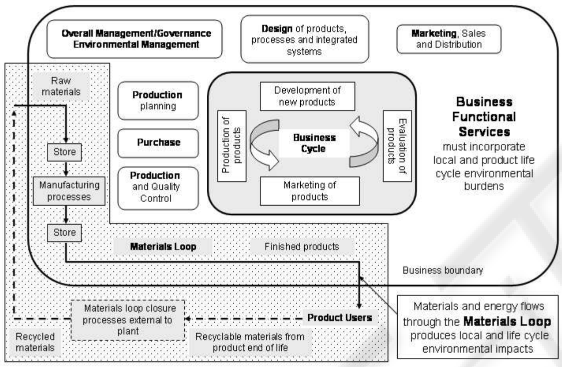

Figure 2: Linking Environmental Services to Business Functions.

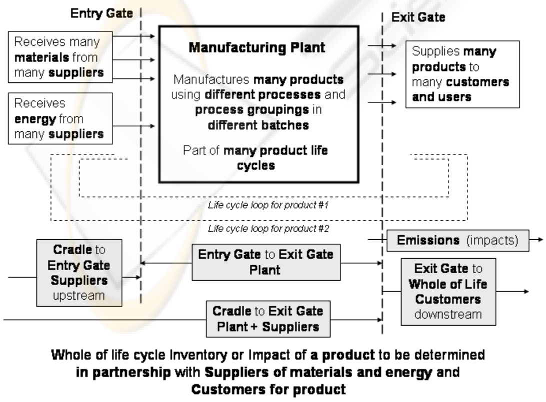

Figure 3: Life Cycle Impact from a Plant Perspective.

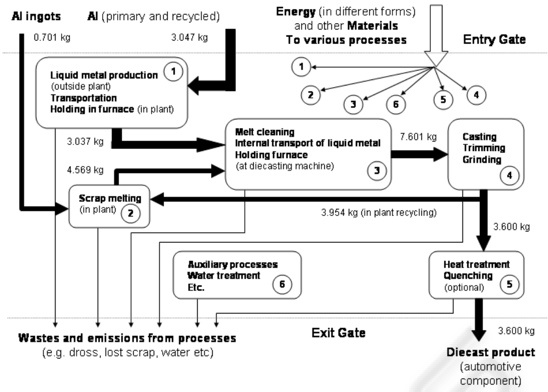

Figure 4: Cradle-to-exit gate Product system for a diecast product.

Furthermore, manufacturing companies often produce different components or products, and hence materials and components from one company may flow into many product life cycle chains. Thus, a company may need to share information with others in different product value chains, depending upon the product in question.

The use of LCA may be for any of the following purposes: Public policy; Corporate goals; Strategic planning; Product disclosure and Green labelling; Marketing; Process and product improvements. Hence, LCA information needs to be presented in different details and forms to the various users who may be conducting different tasks to fulfil the purpose for which the LCA is intended.

2.1 Linking Environmental Requirements to Business Function

The business cycle of a manufacturing enterprise is shown in Figure 2. The business cycle includes the following: (i) Development of new products; (ii) Production of products using processes in facilities with materials and resources; (iii) Marketing the products manufactured; and (iv) Evaluation of products in the market place. This business cycle is accomplished by performing several functions as shown in Figure 2: Design and development of new products, processes and integrated production systems; Production Planning; Purchase of materials for production; Production and Quality Control; Marketing and Sales of products; and Overall Governance and Management. These functions may be performed in different functional silos within an enterprise, using different types of processes and tools to perform the tasks demanded by the functions.

Figure 2 shows the links between the business functions and the materials flow associated with a manufacturing plant. The material loop in the figure shows the flow of materials within a plant, as well as outside the plant. The materials flow within the plant is characterised by the following: all materials purchased enter the store; from the store, materials enter production lines as demanded by production planning; products are manufactured using manufacturing processes and their quality assessed; and manufactured products are stored as inventory for dispatch to other plants or users. Outside the manufactured plant, the materials loop consists of processes for production of raw materials outside the plant, transportation of raw materials to the manufacturing plant, transportation of products manufactured in the plant to users and/or other plants, and recycling of used products to close the materials loop. The overall material loop, which is responsible for the environmental burdens caused by a manufactured product, determines the life cycle impact of the product. The addition of the environmental dimension to a manufacturing business results in many environmentally related functions and tasks that require services. As all the business functions and services shown in the table support the entire business cycle of a sustainable manufacturing company, the different services are essentially interlinked, and hence, need to be integrated in developing the service-oriented software system.

2.2 Core Environmental Services For Sustainable Manufacturing

A new business function, called Environmental Management is required to internalise environmental issues into business practices. This new business function requires certain core tasks, which can be fulfilled by the two fairly large granular level core environmental services, which are termed as Total Environmental Quality Measurement Service (Task 1) and Life Cycle Impact Service (Task 2). The Environmental Quality Measurement Service is aimed at providing quantitative information associated with the environmental burdens. As shown in Figure 3, the materials and energy flow through the part of the materials loop that is within the plant create environmental burdens, which may be allocated to the products manufactured or the processes used, or to the total plant itself. Although the various environmental burdens are highly interlinked, we have divided the Total Environmental Quality Measurement Service into three independent services, viz. Product Environmental Quality Measurement Service, Process Environmental Quality Measurement Service and Plant Environmental Quality Measurement Service, to support various business functions as dictated by the environmental business policy of the company. For example, if the company policy at some given time is to reduce the environmental impact of the plant, then environmental burdens resulting from the various locations or processes within plant need to be measured, quantified in terms of the units required by regulations, and allocated to various locations so as to make effective measures for reducing environmental burdens. The Plant Environmental Quality Service is aimed at providing relevant information for improving the environmental performance of the company at the location where the manufacturing plant is situated.

3 SERVICE-ORIENTED MODELS FOR CORE ENVIRONMENTAL SERVICES

Model-based approaches have been recommended by researchers (Koehler et al, 2003) for realising flexible service-oriented software architectures to meet any application need. These model-based approaches allow achieving a seamless integration of software service functionalities required by a business enterprise in developing a technical software solution. The first step in using the model-based approach is to derive models for the software services to be provided to meet application requirements. Also, the derived models should enable business functions to be factorised as independent services, having clearly defined interfaces, which can be invoked in predefined sequences to form a business workflow process (Koehler et al., 2003; Cardoso et al., 2004).

3.1 Deriving Software Models For Environmental Services

We have derived service-oriented models to assist in developing service-oriented environmental software:

Factorisation and service interactions: We have considered requirements for further factorisation of the services and the relevant interactions between several services for any chosen service to support business functions.

Autonomy, granularity and process awareness of services (Dijkman and Dumas, 2004): The granularity of service is considered at the environmental task level so that a one-to-one correspondence can be maintained between the software service to be provided and the environmental task to be conducted by an actor. The process awareness of a software service is included at the level of the procedures required to perform the environmental task. Autonomy of a software service is addressed by embedding the environmental procedures and the information required into the service. While environmental procedures, based on international standards, are generic to all enterprises or companies, the information and data are specific, and may even be confidential, to a specific company. Hence, we have considered software service models at the plant level of a company to provide autonomy to software services.

Description of services: Each service is defined by the output information generated by the service; the client or client service that receives the information; the procedure used to produce the information; the input information received from server services to carry out the procedure and the output; and the server services that provide the input information.

3.2 Model For Life Cycle Impact Service

The Life Cycle Impact Service provides information on the life cycle inventory and impacts associated with a product for each of the product that is manufactured in a plant. LCI Service needs to deliver information to support many interlinked environmentally related tasks, such as reporting, design of products and processes, purchasing etc. This information may be provided to many clients, both inside and outside the plant, via client services.

As shown in Figure 3, a plant that manufactures a product is located between its own entry and exit gates for materials flow, and hence forms only one element of the whole of life of the product. Hence, the whole life cycle impact (Figure 3) of a product can be estimated at the plant level only in partnership with: (a) the suppliers of materials and energy, from the upstream of materials flow into the plant, for manufacturing the product; and (b) the customers for the product in the downstream of materials flow from the plant. As life cycle impacts are estimated on product basis, it is necessary to exchange life cycle information with the suppliers and customers corresponding to the materials life cycle loop for the product in question. A plant often manufactures many products, and hence is a part of many product life cycle loops (Loops $\#1and$#2 shown in Figure 3), requiring interaction with suppliers and customers in different materials loop on a product basis.

Viewing from the plant perspective, the whole of life cycle burdens (inventory or impact, in the parlance of Life Cycle Assessment based on ISO14040) associated with a product consists of the following life cycle gate burdens that contribute towards the whole of life cycle impact (Figure 3): (i) Cradle-to-Entry Gate life cycle burdens of the materials and energy supplied to the plant by the suppliers for making the product; (ii) Exit Gate-to-Whole of Life burdens of the manufactured product as received by the product customers in further transformation of the product, use of product and closing the materials loop by recycling (iii) Cradle-to-Exit Gate life cycle burdens of the product which may be estimated by adding the Entry Gate-to-Exit Gate burdens resulting from the emissions produced by the plant in making the product to the Cradle-to-Entry Gate burdens of the materials and energy received by the plant. We have considered these three life cycle gate burdens in deriving the model for the Life Cycle Impact Service, which has three server services: Product Environmental Quality Measurement (PEQM) Service, Supplier Service and Customer Service.

An example of a product system is shown in Figure 4 for manufacturing aluminium components for a car using the diecasting technology (Ramakrishnan, 2003).

4 MODEL-BASED APPROACH FOR ENVIRONMENTAL SOFTWARE DEVELOPMENT

The proposed model-based approach for software development requires establishing clear relationships between the service models for the core environmental services to other client services in order to deliver relevant information in the most appropriate way to carry out the business functions of a sustainable manufacturing enterprise. The services shown at a large granular level need to be factorised, keeping in mind the environmental business task required for a specific client application. The interconnections between the various factorised services need to be described in terms of clearly defined interfaces, which need to be invoked in specified sequences (Benatallah et al., 2004; Milanovic and Malek, 2005) to produce the workflow process to carry out the environmental task. These actions form the basis for developing the required software.

The interconnections between the services can be illustrated by means of an example for the LCI Service model discussed earlier. In this example, we have included a new client service, Report Service, which requires the life cycle report of a product to provide service for the task of purchasing materials and energy having low Cradle-to-Gate life cycle impact. For the sake of illustration, we have included a Supplier Registry service that can seek and find green suppliers.

A client application can invoke a service request from the LCI Service directly and request LCI information or invoke a Report Service, which in turn requests LCI data. The Report service needs to accommodate various reporting requirements for corporate internal clients (e.g. environmental manager or environmental auditor); external clients (e.g. partners interested in purchasing products with low environmental impact) or for government authorities (eg. for governance purposes). LCI service provides details of measured and estimated energy and wastes and emissions from processes in making products (on product by product basis). The Green Purchasing Service interface requires the web method, get-supplier-impact-data to be implemented by the Supplier Registry to get the impact rating for an item. The Green Purchasing Service interface requires another web method, get-green-material to be implemented by the Supplier service. The above illustration can be seen to correspond to the current day requirements of voluntary reporting and greening supply chains. Life cycle impact analysis and various reporting requirements may need to be split into subprocesses. The ensuing tangling of behaviours will be dealt with using a model-driven approach to aspect-oriented design in a service-oriented architectural context (Chavez et al., 2005).

5 SUMMARY AND CONCLUSION

Materials production and manufacturing are highly important for the economic and social wellbeing of modern society, but such activities are inherently environmentally burdensome. The concept of servicising a manufacturing business has been propounded by experts in the field of industrial ecology and adopted by some companies to improve their environmental performance. Information industry has already progressed well along the service-oriented path, driven by the advancements in web-based technologies. Taking cognizance of these developments in two different industry areas, we have offered some conceptual thoughts for modelling the delivery of environmental information to sustainable manufacturing businesses and for synthesis into service-oriented software.

We have shown the links between the business functions of a manufacturing enterprise and the environmental requirements relevant to the business. We have identified the core environmental tasks to be performed by a sustainable manufacturing company. We have derived a software service model at the manufacturing plant level for estimating the life cycle burdens of a manufactured product by a company in partnership with other companies in the life cycle chain of the product. Taking diecast automotive components as a case study, we are currently following the model-development approach for developing service-oriented environmental software in implementation, testing and validation. We believe the proposed approach could form the basis for developing future software e-business to meet evolutionary sustainability requirements faced by manufacturing companies.

REFERENCES

Benatallah, B., Casati, F., Skogsrud, H., and Toumani, F. (2004). Abstracting and Enforcing Web Service Protocols. *International Journal of Cooperative Information Systems*, 13(4):413–440.

Burritt, R. L. (2004). Environmental Management Accounting: Roadblocks on the way to Green and Pleasant Land. *Business Strategy and the Environment*, 13(1):13–32.

Cardoso, J., Sheth, A., Miller, J. A., Arnold, J., and Kochut, K. (2004). Quality of Service for Workflows and Web Service Processes. *Journal of Web Semantics,Elsevier Publications*, 1(3):281–308.

Carlson, R., Erixon, M., Forsberg, P., and Palsson, A. C. (2001). System for integrated business environmental information management. *Advances in Environmental Research, Elsevier Science*, 5:369–375.

Chavez, C. F. G., Garcia, A., Kulesza, U., and andC J P Lucena, C. S. (2005). Taming Heterogeneous Aspects with Crosscutting Interfaces. In *19th Brazilian Symposium on Software Engineering*.

Dijkman, R. and Dumas, M. (2004). Service-oriented Design: A Multi-Viewpoint Approach. *International Journal of Cooperative Information Systems*, 13(4):337–368.

Elkington, J. (1997). *Cannibals with forks: the triple bottom line of 21st century business*. Capstone Publishing Ltd, Oxford.

Graedel, T. E. and Allenby, B. R. (1995). *Industrial Ecology*. Prentice-Hall: Englewood Cliffs, NJ.

Isenmann, R., Beisel, M., Brosowski, J., and Gomez, J. M. (2004). Software tool for single source multiple media and multiple requirement sustainability reporting. In *18th International Conference Informatics for Environmental Protection, EnviroInfo2004*.

Koehler, J., Hauser, R., Kapoor, S., Wu, F. Y., and Kumaran, S. (2003). A Model-Driven Transformation Method. In *Proceedings of 7th International Enterprise Distributed Object Computing Conference (EDOC 2003)*, pages 186–197. IEEE Computer Society 2003.

Milanovic, N. and Malek, M. (2005). Contract-based Web Service Composition Framework with Correctness Guarantees. In *2nd International Service Availability Symposium (ISAS2005)*.

Ramakrishnan, R. (2003). An industrial ecology framework to assist transferring environmental technologies. In *Technology Evaluation and Commercialization, TEPC 2003-2, University of the Pacific, California, USA*, pages 323–368.

Ramakrishnan, R., Tharumarajah, A., Koltun, P., and Roberts, M. J. (2003). Eco-Efficient Light-Metals Component Manufacturing. In *Light Metals Technology Conference (LMT 2003), Brisbane, Australia*, pages 281–286.

Schaltegger, S., Burritt, R., and Peter, H. (2003). *An Introduction to Corporate Environmental Management. Striving for Sustainability*. Sheffield: Greenleaf.