Abstract. Growing awareness of the global environmental agenda over the past two decades is driving manufacturing enterprises to internalise environmental aspects of their businesses, both to meet local environmental regulations and to conform to emerging international standards and best practices. One of the challenges for an enterprise moving to SOA is the management and visibility of business processes end-to-end. Using the links between the business functions of a manufacturing enterprise and the environmental dimension of the businesses, a simplified service-oriented software model is derived to deliver information on the life cycle environmental impacts of manufactured products. We explore the business process ontology for modelling software services.

Keywords. environmentally sustainable manufacturing, life cycle impacts, business process ontology, service-oriented enterprise

1. Introduction

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 ought to be reduced in our journey towards attaining sustainability. 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 [3,8].

The main objective of the paper is to consider business processes and service models that form the basis for developing a service-oriented enterprise to provide different types of environmental information to many actors and users in an enterprise. All actors in the supply chain (cradle-to-exit-gate) should conform to environmental standards (ISO14000 series) as a service contract.

The proposed software models 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. 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 [6].

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

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life cycle environmental burdens of products. A short discussion is provided in Section 4 on model-based approach for developing service-oriented environmental software systems. Section 5 discusses the importance of embedding the business process in SOA for managing the service orchestration process. It also considers dynamic architectures for automated service invocation. The paper is concluded in Section 6.

2. Internalising the environmental dimension of business

Materials production and manufacturing enterprises 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. 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 enterprises 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. As the estimation of the life cycle environmental impact of a product requires data, information and knowledge resident in several enterprises in the product value chain, sharing knowledge across the enterprises and actors of a product value chain becomes mandatory. Furthermore, manufacturing enterprises often produce different components or products, and hence materials and components from one enterprise may flow into many product life cycle chains.

The use of LCA may be for any of the following purposes and needs to be presented in different forms and details for: Public policy; Corporate goals; Strategic planning; Product disclosure and Green labelling; Marketing; Process and product improvements.

2.1. Linking Environmental Requirements to Business Function

The business cycle of a manufacturing enterprise is accomplished by performing several functions: 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.

The material loop in Figure 1 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 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, labelled Environmental Management and Governance is required to internalise environmental issues into business practices. The manager has to adopt the environmental standards (ISO14000 series) for reporting and communicating to corporate, clients, governments and society. This 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 and Life Cycle Impact Service. The Environmental Quality Measurement Service is aimed at providing quantitative information associated with the environmental burdens. As shown in Figure 1, 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 enterprise. For example, if the enterprise 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.

3. Service-oriented models for core environmental services

A service-oriented software system is often a distributed software system, containing software services and components, published properties of the services and components, and the relationships between these services and components. Model-based approaches have been recommended by researchers [5] for realising flexible service-oriented software architectures. The first step in using the model-based approach is to derive models for the software services to be provided. Also, the derived models should enable business functions to be factorised as independent services, having clearly defined interfaces, which can be invoked in prede-
fined sequences to form a business workflow process [4]. Features such as autonomy, course granularity and process awareness that characterise a service-oriented design enable the integration of many autonomous services that are developed by different teams in different organisations, distributed across the globe. The modularized and self-describing nature of the web services makes the web-based services a suitable technology for realising service-oriented architectures.

3.1. 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 1, 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 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 #1 and #2 shown in Figure 1), 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) associated with a product consists of the following life cycle gate burdens that contribute towards the whole of life cycle impact (Figure 1): (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 services: Product Environmental Quality Measurement (PEQM) Service, Supplier Service and Customer Service. An example of a product system is shown in Figure 2 for manufacturing aluminium components for a car using diecast technology.

4. Model-Based Approach For Environmental Software Development

The proposed model-based approach requires establishing clear relationships between the service models for the core environmental services to other client services. The interconnections between the services can be illustrated by means of a LCI Service model example. 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.

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 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. Our software services will have to interface with some existing supply-chain management systems.

5. Business Process Ontology

An ontology is used for describing and mapping between application’s domain terms and the service’s terms. We draw from ontologies such as OBELIX (Ontology-Based Electronic Interaction of Complex Products and Value Chains) for developing a generic component-based ontology for environmentally sustainable manufacturing. It suggests an interdisciplinary approach to services and draws from Computer Science and AI as well as from systems theory and business. OBELIX ontology uses component notions for specifying functionality of service elements with client and supplier of services with ports for connecting and composing services with typing and topological rules. Non-functional aspects are also important for service selection and composition. Once they have modelled the individual service elements with their dependencies, and the customer requirements, their configuration tool is able to produce all the service bundles that are possible under the given constraints and requirements [1]. The knowledge encapsulated in the ontology must be adequately integrated into the application [1]. A couple of approaches used are: 1) Libraries such as in Jena (http://jena.sourceforge.net/, which support browsing the ontology through generic concepts such as Concepts, Relations etc, and allow semantic queries of contents) ; 2) mapping concepts defined in the ontology into semantically equivalent objects of an OO language, such as in the Semantic web Development Environment (SWeDE). The composition of services is envisaged from a business point of view. Some of the popular approaches are languages such as BPEL4WS and OWL-S.

Automated service invocation needs to be aware of the input parameters and the methods to be called. The use of ontologies of the application domain and application process domain assist with the definition of these parameters and for semantics to the methods, and so with automated service invocation.

5.1. Service-oriented enterprises

In SOA-based applications, the application developer builds target applications through service discovery and service composition rather than through the traditional process of software design and implementation. Since the architecture of an SOA-based application is dynamically determined and changed at run-time, it enables services to be composed to meet with any revised
requirements at run-time. In SOA, communication amongst services is controlled by a control center, which is also attached to the communication backbone. IBM WebSphere uses this architecture style. SOA on its own does not provide a framework for implementing business processes within an enterprise or a framework for exposing these processes for collaboration in a federated enterprise. Collaboration in a federated enterprise is made difficult by the complexity and costs associated with extending business processes throughout the network of clients and suppliers. A set of open source, standardized integrated process and technology frameworks or reference models is needed for enabling an organisation to design and maintain business processes. [2] provides a roadmap for achieving this.

The architecture must evolve to provide a framework for the various processes for a service-oriented enterprise (SOE). The application and operational infrastructures are merged into a unified service-oriented infrastructure (SOI). A development infrastructure deals with the model-driven engineering aspects such as modelling, analysis, design, architecture, code generation, verification and validation. An operational infrastructure deals with code deployment, execution, policy governance and system reconfiguration [7].

6. Summary and Conclusion

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 enterprise. We have derived a software service model at the manufacturing plant level for estimating the life cycle burdens of a manufactured product by a enterprise in partnership with other enterprises in the life cycle chain of the product. We are exploring the business process ontology for environmentally sustainable manufacturing to deliver a merged model and process engineering method for service-oriented enterprise. Taking diecast automotive components as a case study, we are currently deriving a business process ontology for manufacturing with a focus on internalising environmental issues in manufacturing enterprises and on how ontologies can be used to describe and later discover services.

References


