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Extension of Computer-Aided Process Engineering Applications to Environmental Life Cycle Assessment and Supply Chain Management

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Abstract

The potential of computer-aided process engineering (CAPE) tools to enable process engineers to improve the environmental performance of both their processes and across the life cycle (from cradle-to-grave) has long been proffered. However, this use of CAPE has not been fully achieved, largely because of the complexity of the systems being modeled. Traditional approaches to this problem often prove to be inadequate due to the inability of component simulations to interact and share data amongst various stakeholders. This current effort involves toward developing and implementing a data model that will enable users to conduct environmental evaluations not just of a single process, but on the entire supply chain. This project utilizes and expands emerging information technology paradigms such as web services, web agents and distributed computing for use by the various stakeholders to evaluate individual industrial facilities within the context of the industrial supply chain and across industrial sectors.

Keywords

Life-cycle assessment, Supply chain management, Life-cycle inventory, Data model, Web services, Web agents, XML

1. Introduction

The benefits of improved environmental performance on manufacturing operations can extend beyond improving the quality of the environment. Potential benefits include cost savings resulting from more efficient material use, reduced energy costs, reduced product development time, improved workplace safety, and simplified compliance with international environmental regulations. Indeed, the concept of Profitable Pollution Prevention (P3) [4] is widely accepted. Reductions in energy costs through recycling materials such as steel, glass and aluminum can be 30 to 40 percent of the costs of raw material extraction and processing. Waste materials are paid for three times, once in purchasing the raw materials converted to waste, second in processing costs and finally as disposal costs.
Life Cycle Assessment (LCA) uses environmental emissions data for a product supply chain, use, and disposal to estimate the total environmental burden of a product from "cradle to grave" [6]. The cradle-to-grave approach evaluates all resource use and emissions that occur in product manufacture, use and disposal, starting from the extraction of natural resources (raw materials) from the earth and ending when products are returned to earth. LCA can also help companies identify opportunities to reduce material and energy costs through identifying where material and energy are added to the system. One of LCA's biggest challenge is that the data available is typically not detailed enough to optimize the environmental performance of a specific supply chain or aid in product stewardship activities.
The primary issues faced by manufacturers with respect to the environmental life cycle of a product include:

- Logistical challenges of the reverse supply chain that results from product take-back requirements
- Evolving product environmental requirements, such as the European Union's product take-back requirements and the Registration, Evaluation and Authorization of Chemicals (REACH) [5]
- Location of emissions data for process inputs for use in compilation of an environmental life cycle inventory
- Protection of confidential business information that may be required to perform a detailed life cycle assessment.
- Reconciliation of the fact that relatively small, often economically insignificant emissions can have significant environmental implications.

Data for evaluating environmental life cycles are often limited, and primarily focused on product manufacture, not de-manufacture as required in product take-back. Typically, generic, industry-wide average emissions data, such as the USEPA's Toxic Release Inventory (TRI), are often used to prepare environmental life cycle assessment for a specific product. Basing the

environmental footprint of a particular product on such broad data sources can be misleading, particularly if inputs to the subject manufacturing process are selected to enhance environmental performance, and is not useful in supporting product disassembly and recycling.
The focus of this paper is the development of a data model intended to support the needs of supply chain management while providing the information required to conduct environmental study of the impacts that result from the supply chain involved in the manufacture and potential reverse supply chain that results from product take-back requirements.

2. Data Model Requirements

Data required for supply chain management and environmental life cycle assessment varies based upon a number of factors, including whether a material being used is a broadly available commodity or highly specialized product, and companies are often reticent to provide confidential information about their process for fear of losing intellectual property. Generic process inputs, such as electricity generation or commodity chemical usage, are often modelled using industry-wide life cycle data that provide sufficient detail to evaluate a specific product life cycle and support stewardship activities. This level of detail is typically not sufficient to minimize the environmental emissions, or manage product take back. Often, reducing environmental emissions for a particular product involves considering different process operations and material supplies. Clearly, specific data about the exact supply chain being considered must be used to provide sufficiently detailed emissions data and evaluate competing process inputs. Research needs to be conducted to aid the transfer of relevant data about process inputs; aid the identification of alternate, more environmentally friendly, material inputs; and ease collection of life cycle data for these inputs.
Data availability is complicated by the fact that vendors are often concerned about sharing information about their processes to protect confidential business information and trade secrets. More detailed sources of life cycle data that can be utilized include process simulation models and environmental compliance reports. These sources often contain process information that could be used by competitors to duplicate proprietary or trade secret manufacturing procedures. Companies have to be careful to whom they provide this information to ensure maintaining competitive advantages. Mechanisms to protect confidential information while allowing a company to provide a potential customer needed life cycle data are required.
Given the above considerations, the basic paradigms of object oriented programs, including encapsulation and modularity are required. Encapsulation will hide the details of how the data are determined, while modularity will enable the replacement of a given input with a replacement input. Further, as suppliers are often remote, distributed computing and data exchange

mechanisms available over the internet, such as web services are important in the application.

3. LCA Data Model

There have been prior efforts at developing data interchange formats suitable for life cycle assessment, but most of these are not incorporated into process engineering software. A review of these data interchange formats, however, is useful from the standpoint of helping identify common elements of the supply chain and environmental LCA that may be used to develop a data model and accompanying web service schema. The following is a list of LCA-based data models:

- Spine [1] (Sustainable Product Information Network for the Environment) has been developed by the Swedish Environmental Institute, Chalmers University of Technology and Chalmers Industriteknik. In the Spine data model, two crucial and central concepts are activity and flow. Activity is defined as any kind of a technical system, such as raw material extraction, production, use, waste treatment or transports. An activity can be indivisible or aggregated. An aggregated activity is made by grouping other activities, both indivisible and aggregated. Flow is defined as material or energy flows entering or leaving an activity. Spine data model enables only partial universality and LCA data exchange, because this data model is supported only by the Swedish EPS System Tool and Chalmers Industriteknik's LCA Inventory Tool.
- Spold [2] (Society for the Promoting of LCA Data) is a data model and a database network of local data-suppliers, who make their data available in SPOLD format. SPOLD data model consists of five parts: data identification, system model, system structure, data (inputs, outputs and other) and balances. This data model is compliant with the following LCA software tools: SimaPro 5, TEAM 3.0, KCL-ECO and Umberto. A modified version of this data model is called EcoSpold [3]. It is based on XML documents. Content of data sets that are based on EcoSpold data model can be easily verified using XML Schema. EcoSpold data model is supported by the following LCA software tools: Gabi, SimaPro, Umberto, Regis and EMIS.

Although the previously mentioned data interchange formats enable certain level of data reuse and interchange, they are only limited to certain number of applications. The LCA data model proposed in this paper is shown in Figure1. Processes are the primary feature of the proposed LCA data model. The data model describes any activity related to extraction of natural resources, production, product utilization and transportation. Each process has its inputs that are transformed, under the process activities, into outputs. Each input contains a group of flows for all known input elements from nature and/or those elements that are produced by other processes. The elements that are taken from nature (raw materials) are labeled as 'natural resources' in our model. Each natural resource for a process input contains information about its properties and supplier. Elements that are produced by other processes are called products. Product is a desired part of a process output. Each product has a certain market value and it contains information about its supplier, manufacturer and properties. Elements in output flows that do not have market values are called emissions. Manufacturers and suppliers are entities that manufacture or supply products, respectively.

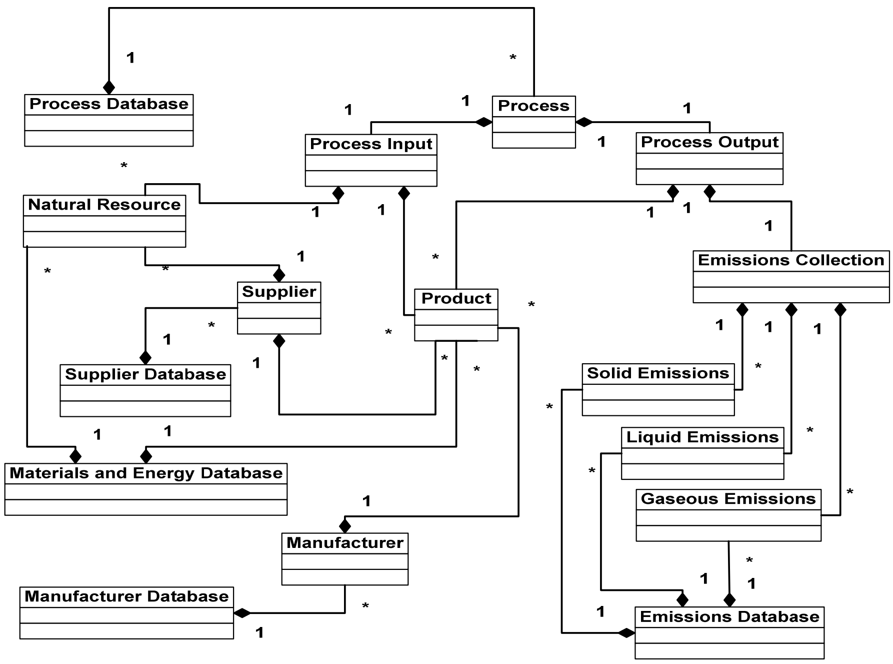

Figure 1. UML Entity-Relationship model of LCA Data Model

4. Data Exchange Format

The above referenced data model can be created using XML-based web services utilizing the Extensible Markup Language (XML) and local- or wide area computer netowrking as a communication mechanism. XML is very easy to use, extensible, transportable and can be a very secure way of transporting data if the data is encrypted and transported over a secure channel. Web services are registered using UDDI (Unified Description, Discovery and Integration)

Registry. Functionality of each web service is described using WSDL (Web Service Description Language). WSDL for each service describes public methods for that web service.
Proposed format for storing LCA data is XML. Using XML format for storing data enables using XML Schema for checking validity of XML documents. XML Schema is a set of rules to which an XML document must conform in order to be considered valid, according to that Schema. Validation of an XML document, for a given schema, is done automatically, using one of the numerous XML Schema validators, such as MSXML, Xerces, Microsoft .NET Xml Tools (System.XML) etc.

5. Conclusions and Future Work

In this paper a data model for environmental evaluation of a supply chain is proposed and its components are explained. The proposed data model is aimed to enable data interchange across the supply chain, which is very much needed but still not completely accomplished with existing software tools and projects. The proposed format for storing data is XML. The connection of the proposed data model for LCA and the use of XML-based web services for LCA data interchange is briefly mentioned in this paper. This project is work in progress. The future work includes finishing design and implementation of the XML-based web services for LCA data interchange and running experiments.

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