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An XML based supply chain integration hub for green product lifecycle management

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ABSTRACT

The emergence of new regulations for the disposal of electrical and electronic equipment, directives on the use of certain hazardous substances, and the Kyoto Protocol are changing industries approach to product design and manufacturing. Traditionally, product lifecycle management systems provide a platform for the management of data related to the creation and disposal of products. These systems assist the participants of the products' life cycle processes (manufacturers, suppliers, customers, and regulators) to use data efficiently for planning and control. However, most data collected do not resolve the environmental issues which arise when selling the products or arranging the products to be replaced and disposed. In this paper, we present an Integrated Green Parts Information Platform (IGPIP) framework (The frame work revisited here was published as "A Framework for a Green Product Lifecycle Management System", Issues in Information Systems, Vol. IX, No. (2), 2008, 123–131.) and a working prototype of the system. This system uses XML file transmission to improve the quality, cost and time-to market issues for green designs.

1. Introduction

In June of 1992, the United Nations held a conference on Environment and Development in Rio de Janeiro. The goal of this conference was to gather policy makers and arrive at a general consensus to limit pollution at its source which includes product inception and manufacture. Thus, the environmental scientists' task is no longer limited to the post event management of environmental pollution, but also to determine sources, control, repair, and effectively stop environmental pollution. The Society of Manufacturing Engineers (SME, 1996) also supports green technology with the aim of controlling pollution by taking into account the impact of products on the environment during the design phase. The environment is not only impacted by the use of resources to manufacture the product but also by its use by the consumer and finally its disassembly and disposal. On July of 2006 the Restrictions of Hazardous Substances directives (RoHS, 2006) went into effect. Although this law only applied to the European industries, its implication on supply chain is global. The RoHS regulations will require all manufacturers in Europe to evaluate their supply chain; thus complicating the supplier selection problem. Sony spent more than $80 million to replace its playstation cables which had higher cadmium than permitted by the Netherlands environmental laws – which is very close to the RoHS standards (Busch, 2007). In the push to become green, researchers have expanded the multi-criteria decision model for supplier selection to include the green performance criteria (Lee, Kang, Hsu, & Hung, 2009).

The US Environmental Protection Agency (US Environmental Protection Agency website, 2009) describes green engineering as the design, commercialization, and use of processes and products which are feasible and economical while minimizing (1) generation of pollution at the beginning and (2) the risk to human health and the environment. Green engineering embraces the concept that decisions to protect human health and the environment have the greatest impact and cost effectiveness when applied early in the design and development phase of a process or product. From another perspective, Hamner (1996) describes environmental management as a staircase where the underlying concepts of the practice make up the steps. The lower steps include waste disposal, pollution control, recycling and pollution prevention and higher steps include cleaner production and industrial ecology. The environmental factors to be considered when designing green products include material, production methods, packaging and transportation, usage, waste, and recovery.

In addition to governments, corporate and academia interest in improving the environmental impact of manufactured goods has increased significantly. The literatures for sustainable supply chain management covering topics of product development, design for

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environment, supplier selection, packaging, among others has been increasing at a significant rate since 2000 (Seuring & Müller, 2008).

The Environmentally Conscious Business Practice (ECBP) model is a valuable framework to use for evaluating and selecting green strategies. The ECBP model integrates several factors of enterprise decision making related to environment. The factors defined by the model are design for the environment, life cycle analysis, total quality environmental management, green supply chain management, and ISO 14000 environment management system requirements. The detailed components of ECBP are listed in Table 1.

2. Product data management (PDM)

According to the definition of CIMdata (1997), PDM is used to organize, save and control all information related to the product design, manufacturing and its life cycle management. Managing the product data is a complicated challenge for the manufacturing industry, which needs to frequently design, re-design and manufacture products to better satisfy changing market demand. The related information includes the component list, the classifying rules, multi-layered bill-of-materials (BOM), all engineering files (CAD/CAE/CAM), electronic documents and other information related to product life cycle. The product data needed to integrate the relevant information among the prime manufacturers, sub-contractors, suppliers, customers and other partners (Trappey, 2001), particularly for the design teams to manage product information electronically. PDM also integrates, exchanges, and facilitates the management of all product-related data and procedures across heterogeneous platforms and organizational boundaries.

Product lifecycle management (PLM) further expands the scope of PDM. CIMdata (2002) defines the experience to include a strategic business approach, support for the extended enterprise, and integrate people, processes, business systems, and information. The data management is a very complex issue since manufacturers routinely manage thousands of products. Thus, there is a need for a system which facilitates the upload and management of product information without too much human interaction. One solution is to use XML files to upload the manufacturer's products information. The XML file is generated by the enterprise system or component information system and typically conforms to the manufacturer's schema definition. This paper reviews the Integrated Green Parts Information Platform (IGPIP) first proposed by Trappey, Taghaboni-Dutta, and Trappey (2008). The paper then discusses the prototype hub implemented for XML supply chain integration and green product lifecycle management.

Table 1
ECBP components and sub-components.

ECBP components	ECBP sub-components
Design for the environment	Design for recyclables Design for reuse Design for re-manufacturability Design for disassembly Design for disposal
Life cycle analysis	Inventory analysis Life cycle costing Impact analysis Improvement analysis
Total quality environmental management (TQEM)	Leadership Strategic environmental quality planning Environmental quality management systems Human resources development Stakeholder emphasis Environment measurements Environment quality assurance
Green supply chain management	Inbound logistics/procurement Materials management Outbound logistic/transportation Packaging Reverse logistics
ISO 14000 EMS requirements	Environmental policy Planning Implementation and operation Checking and corrective action Management review

3. Integrated Green Parts Information Platform (IGPIP)

Companies are pursuing environmentally sound product development either due to regulation or for reaching out to customers who have become more conscious about their buying habits and the impact on environment. In 1994 when Sony received a "reasonable" buy rather than "best buys" only due to its environmental performance from a Dutch consumer magazine, its market share plummeted by 11.5%. Following this, Sony launched the "Greenhouse Project" which focused on improving the environmental impact of its products. Sony's performance was rated higher and it began to improve its market share (Elwood & Case, 2000). However, while the environmental performance is important, companies will have to grapple with what can be achieved in a cost effective manner. By using Life Cycle Analysis (LCA) tools which includes environmental performance of the product through using multi-criteria decision-making methodologies, one could achieve a cost effective product while meeting environmental objectives (Choi, Niels, & Ramani, 2008) or address the green impact by revisiting the modular design practice (Tseng, Chang, & Li, 2008).

To achieve a cost effective way of improving the environmental impact companies have developed a corporative relationship with their supply base by sharing information (Cheng, Yeh, & Tu, 2008). However, the knowledge sharing is organized around software systems that are used by these organizations and does not allow the companies to easily evaluate any alternative outside of the known supplier base. While research shows that much of the potential for improving the environmental performance of products is through the supply chain (Rai, Patnayakuni, & Seth, 2006; Yang & Sheu, 2007), the ease by which all alternatives (i.e. those outside of the firm's current supply chain partners) can be considered is hindered due to the absence of data interoperability among the software systems.

The proposed Integrated Green Parts Information Platform (IGPIP) presented in this paper enables companies to share and manage product information, including environmental related (green) data, among multiple users in the supply chain network. This system can work across differing platforms since the users will send and receive the green parts information effectively via an XML-based exchange module.

3.1. IGPIP system architecture

IGPIP is built around three layers, i.e., the user interface layer, the functions layer, and the data layer (Fig. 1). The user interface provides a web-based interface for executing system functions. The functions layer includes the XML schema exchange module which automatically generates the eXensible Stylesheet Language Transformations (XSLTs) files allowing two parties to exchange data across platforms. Finally, the data layer contains the green part database and the XSLT database. The green part database stores information related to the green part. The XSLT database holds data which has been parsed from the XML files,

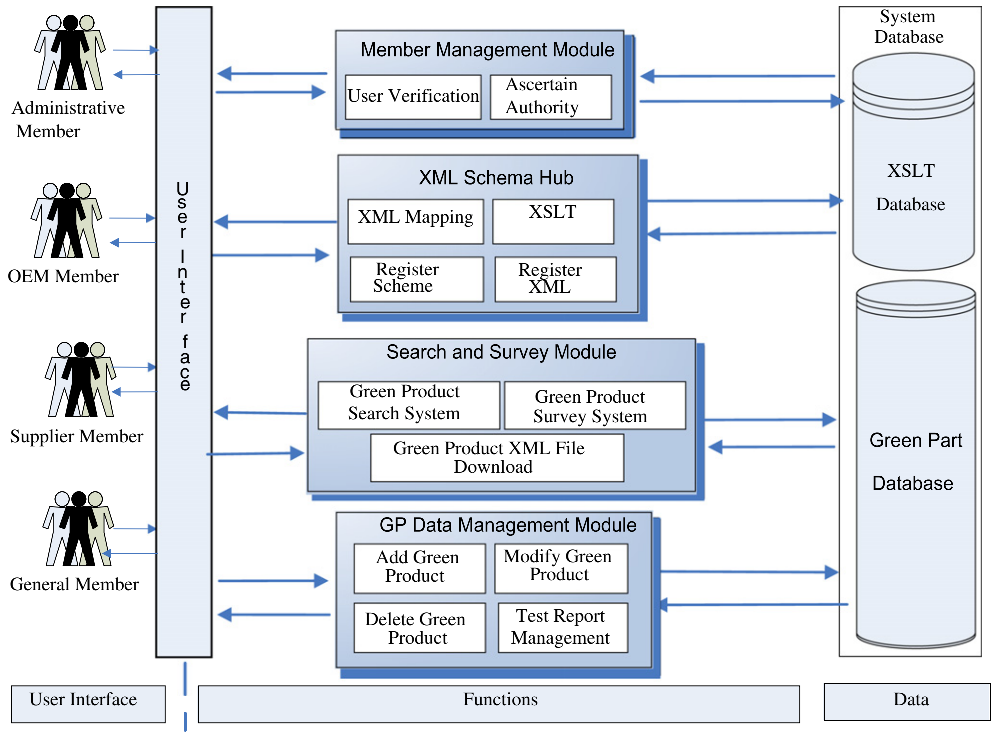

Fig. 1. The three layers of IGPIP system.

information from test reports, and the schema mapping rules for each company.

The function layer contains four major modules: Member Management Module, XML Schema Hub Module, Search and Survey Module, and Green Part (GP) Data Management Module. Table 2 shows the relationship between the modules, their functions, and the members.

Table 2
IGPIP function list.

Module name	Function name	Member level authority
Member Management Module	Add member	Administrator
	Member management	Administrator
	Maintain member data	General member
	Log-in	General member
	Log-out	General member
XML Hub	XML file upload	Supplier, OEM member
	XML file download	Supplier, OEM member
	Registry schema	Supplier, OEM member
	Schema mapping service	Supplier, OEM member
Search and Survey Module	Green part search	General member
	Green part survey	General member
Green Part Data Management Module	Add green part	Supplier, OEM member
	Maintain green part	Supplier, OEM member
	Delete green part	Supplier, OEM member
	Test report upload	Supplier, OEM member
	Test report download	General member

3.2. IGPIP process flow

When green products are designed and developed, a large quantity of parts information is provided. The availability of green parts information allows designers to effectively select substitutes and alternatives that can substantially lower the cost of development and production of environmentally friendly products. Most companies use an enterprise management system or a component information system which contain parts specifications. The products' designers use these systems to locate parts that can be included in new products. If the designers cannot find suitable parts, then they reference vendors' databases. When a green part is located, it is added to the enterprise or component information system. In these systems, the interfirm information exchanged is through point-to-point (i.e. customized) interfaces and routines. These unique interfaces are developed to allow for the data transfer; the number of these interfaces increase at a rate of $n(n-1)$ thus a system with 20 software entities would have 380 interfaces (Li, Gao, & Zhang, 2002). Li et al. (2002) introduced a "plug and play" model which will replace the one-to-one relationship to a many-to-one relationship. In another research, an agent-based system addresses the data interoperability within the supply chain (Xu, He, & Qiu, 2005). However, these proposed systems while by using XML create data interoperability; they don't allow information from other suppliers (i.e. outside of the current partners) to be evaluated when looking for alterative green components. The IGPIP platform developed in this research uses XML to accommodate data interoperability but, additionally, the web-based hub allows any manufacturer and supplier to enter their green data. Thus, by using IGPIP, the search for suitable replacements is easily extended beyond current suppliers in the PLM's Component Information System (CIS) to a large web-based repository of all suppliers community, called the Approved Material List (AML).

First, the user enters the system homepage and activates the login interface. The system reads the account number and password and ascertains the user's appropriate level of authority. The user can access the part of the system appropriate for their role and level of authority. The four different role classifications include general members, supplier members, OEM members, and administrators. Table 3 summarizes the authority levels of the different roles. The general members use the Search and Survey Module to access green part data from the information platform. Suppliers have the same authority as the manufacturers, and as the primary users of the system, they also have authority to execute the schema mapping service and use the XSLTs to upload and download the XML green parts files. Using their own schemas, suppliers can upload their green parts to the system and manufacturers can download parts data. The administrators maintain the member data and the system.

The Green Part Data Management Module enables the suppliers to add green parts information and let others access their information. This function is limited to the suppliers. The suppliers upload their XML files from their own systems and the IGPIP then automatically translates the uploaded XML files and saves the green part information into the database. If a supplier cannot automatically generate an XML file for their green parts, then they can add parts information using the web-based interface. The Green Part Data Management Module and the XML hub Module facilities all these transactions seamlessly.

The Test Report function, performed within the Green Part Data Management Module, enables the suppliers to upload test reports for green parts. These test reports are generated by the international organizations which verify that the green parts follow environmental regulations. The Search and Survey Module provides a search interface for the manufacturers. OEM members log in, enter the search interface, and input the supplier's name, green part's name and their restrictions. The system lists all green parts that fit the search which significantly reduces the time and effort required to find suitable green parts early in the design stage. The XML Schema Mapping service is to be used by suppliers and manufacturer; members log into the system and then access the Schema Mapping interface. The green part XML schema, including data elements of material compositions, is generated using the international product material composition declaration standard, RosettaNet 2A13 (2005). The green part XML schema uses this intermediary XML standard to simplify translation and exchange. From the Schema Mapping Interface, the users upload an XML schema and the system parses the document and displays a structure tree. Supply chain members check the rules and save the XSLT document and generate the XSLT files.

Table 3
Authority levels of different users.

Roles	Limit of authority
General member	Modify members own data. Search and survey green parts and suppliers
Suppliers and Primes (OEM)	Manage information related to green parts. Execute the XML schema mapping services
Administrator	Manage all members data and set their assess authority levels

Fig. 2 shows the architecture of the XML (schema and translation) hub. The schema combines manufacturing process information, green part information, suppliers information, and information for related test reports. The green part information includes part ID, material composition (e.g., metal, PCA, recycled/non-recycled plastic, glass, wires), RoHS chemical substances (e.g., Pb, Cd, Hg, Cr6, PBB, PBDE), weight/size, sub-part list, and 3R (recovery, reuse and recycle) level.

The XML schema and translation hub provides members with XML mapping services. The mapping interface is a web-based mapping tool which allows the users to finish their XML schema and, afterward, XML data mapping over the web. To accommodate a seamless data sharing platform, the IGPIP provides capabilities to automatically translate and map data between different XML schemas. The interface provides the rules for mapping and allows users to define their own rules. After the relations between schema files are linked and defined, the mapping services generate two XSLTs: company-to-hub XSLT and hub-to-company XSLT. These two hubs execute the translations based on the generated XSLTs. The architecture of the mapping interface is shown in Fig. 3.

There are three major tasks performed by the Mapping Service (Table 4). As the first step, the suppliers register their green parts XML schemas. As members request mapping services, the system automatically loads the source and the target XML schema into the Schema Parser. The Schema Parser performs the analysis based on the definition inside the schema which regulates the content and structure shown in XML documents. The Schema Parser records the properties of the tags defined in schema documents for future reference. The tag properties include element type, name, data type, name space, occurrence, default value, fixed value, limitation and description. First the Schema Parser records the tag data, and then the data is used to build a tree for representing

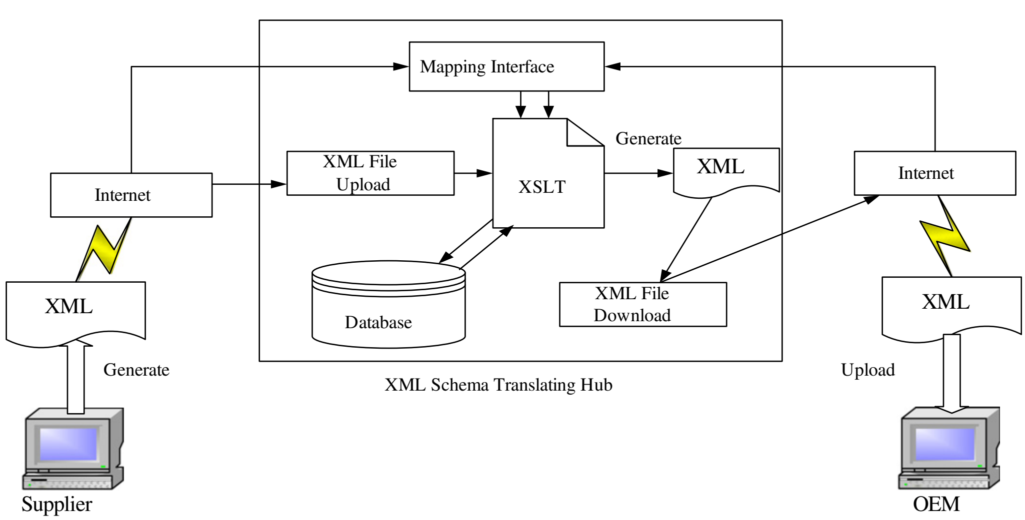

Fig. 2. The architecture of XML schema and translation hub.

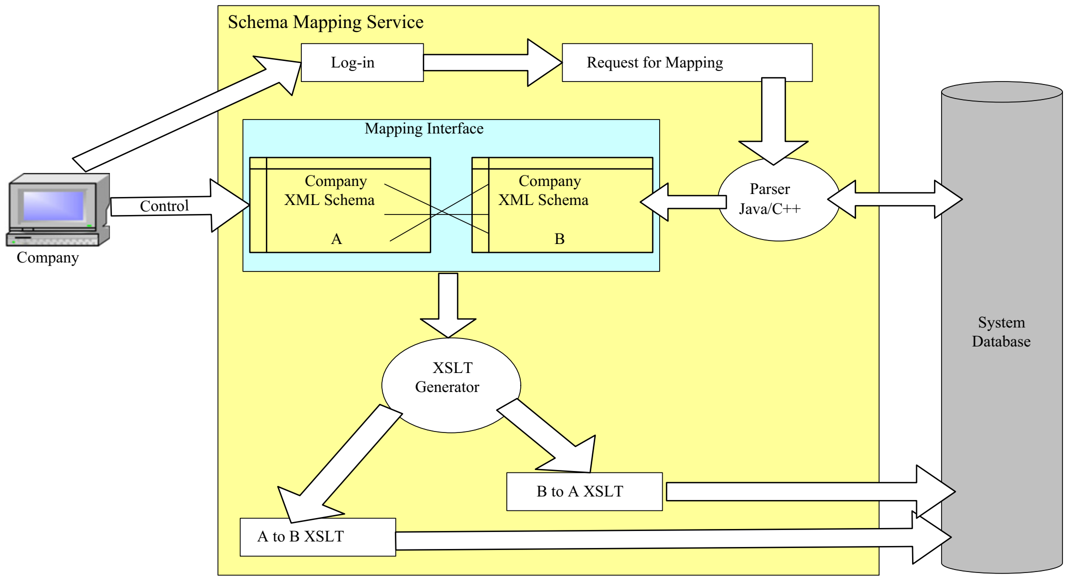

Fig. 3. The schema mapping and XSLT generating services architecture.

Table 4
The Mapping service functions.

Functions	Descriptions
Schema parser	Reads schemata' definitions, structures a presentation, and then sends the data to the Mapper
Mapper	Provides several methods for users to map their business documents. Mapper stores the mapping definitions created by the users, and finally sends it to XSLT generator
XSLT generator	Generates XSLT documents following the formulation of mapping definitions

the XML document. The tree helps members understand the structure of XML documents and enables the analysis of the element details. When mapping is completed, the schemas are sent to an XSLT generator which generates XSLT files and stores them in the database.

4. Prototype demonstration

A prototype was developed to test the proposed Integrated Green Parts Information Platform (IGPIP) and additional technical details of the system are included in Appendix A. Consistent with the proposed system described above, the system provides three basic services: registry, mapping, and exchange services. As the first step, the suppliers register their green parts' XML schemas. As the second step, the supplier members use the system functions to map their schemas with the schema of the system. As the third step, the definitions are checked, the XSLT files are previewed and the mapping services are completed. Fig. 4 shows the main process flow.

4.1. The registry services

Before requesting mapping services, supplier and OEM members register and upload their XML schema and XML documents. Fig. 5 is a screen capture of the interface showing that members select the document type to be registered and then upload the document from their computer. Members file the version and description of this document before submitting.

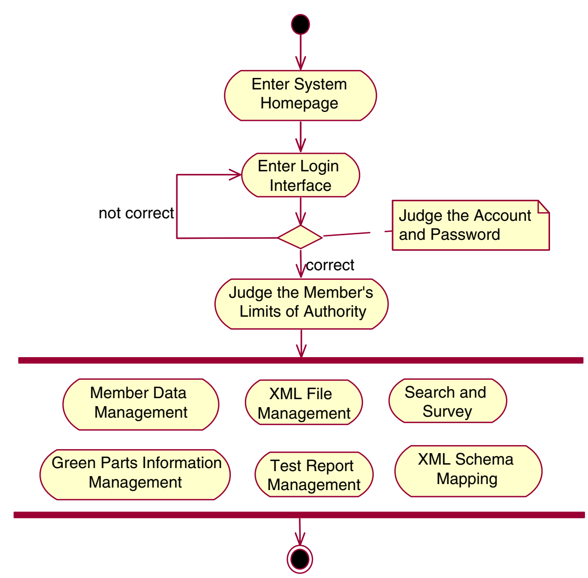

Fig. 4. The IGPIP main process flows.

As discussed in Section 3.2, the member's registration depends on their roles. The users enter the registration page and fill in the blanks with data relevant for the system administrator's management tasks. Fig. 6 depicts the information flow general members and Fig. 7 depicts the information flow for manufacturers and suppliers.

Suppliers are enabled to add green parts information and to allow other members to access this information. The process flow for adding a green part is shown in Fig. 8. This function is limited to the suppliers. The suppliers provide XML files from their systems and upload. The system translates the XML file and saves the green part information into the database. If the supplier cannot generate an XML file of their green parts, they can add parts information using the web-based interface.

Suppliers can also upload the test reports for green parts. These test reports are generated by the verification organization and certify that the green part follows environmental regulations. The

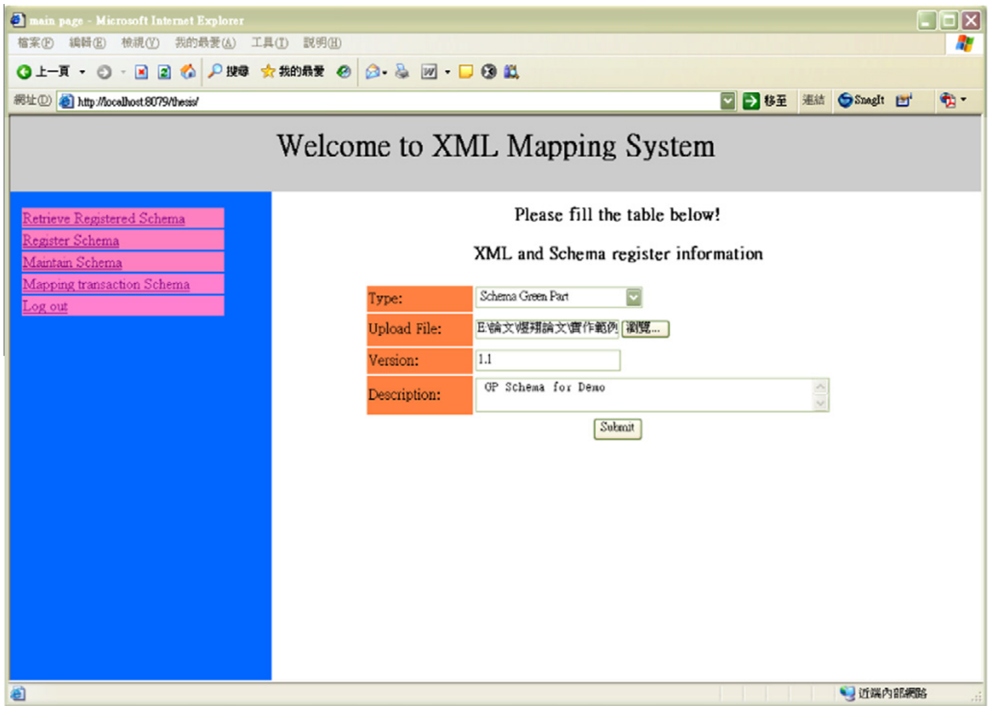

Fig. 5. The interface of registering and uploading.

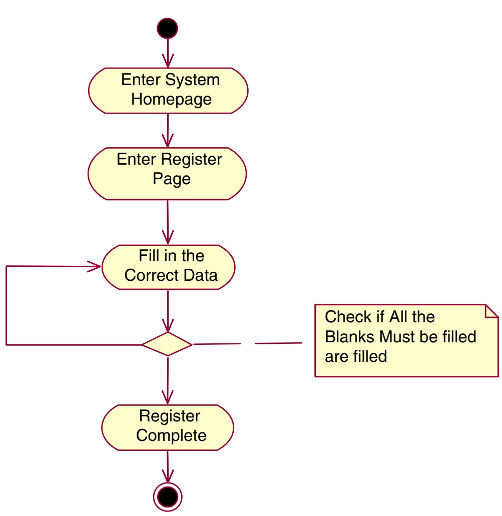

Fig. 6. General member registration process flow.

process flow for uploading test reports is illustrated in Fig. 9. The system provides a search interface for manufacturers. Fig. 10 shows the search process flow. OEM members log in, enter the search interface, and input the supplier's name, green part name, and the restrictions. The system then lists all green parts that fit the search.

4.2. The mapping interface

A major obstacle in information exchange is the differences in taxonomies used by various members of a supply chain (Jung, 2008). This service will allow for data interoperability among heterogeneous platforms among the organizations. As members request mapping services, the system automatically loads the source and target XML schema into the schema parser. The task of the schema parser is to analyze the definition inside the schema that regulates the content and structure shown in XML documents. The schema mapping service is used by suppliers and manufacturers. Members log into the system, then enter the schema mapping interface. From the interface, the users upload an XML schema and the system parses the document and displays a structure tree. Members check the rules and save the XSLT document. In order to exchange green part information, the different XML schemas must be translated. A schema mapping service enables the members to define the rules for translating schemas. After the schema parser records the properties of the tags and the data of the tags, the tree constructor uses the data to build a tree for representing the XML document. The tree helps members understand the structure of XML documents and enables the analysis of element details. The system lists the member's schema tree on the left side and the system's schema tree on the right side of the interface (Fig. 11). When members click on an element listed in the tree, the system uses the information to define the mapping rules. Fig. 11 also shows the source element's information and the rules used for mapping.

The prototype system provides six rules for mapping: mapping the source content to the target, mapping the calculated source content to the target, separating the content into target tags, merging the content of source tags to one target tag, defining constant values to fill in the target tags, and setting conditions. As members define the mapping rules, the system records the information so that it can be used for editing and review. Users can define, edit, and review the XSLT content. The system also provides examples of common business documents for reference. Once the user click the "finish" button, the system will generate the XSLTs for automatic mapping of green product data from one XML format to another XML format when requested. The mapping service provides six main functions. The following explanations describe how the main functions work. All six functions have been implemented in the web-based IGPIP prototype.

1. *Direct mapping:* The direct mapping function enables the direct mapping of source content to the target elements.

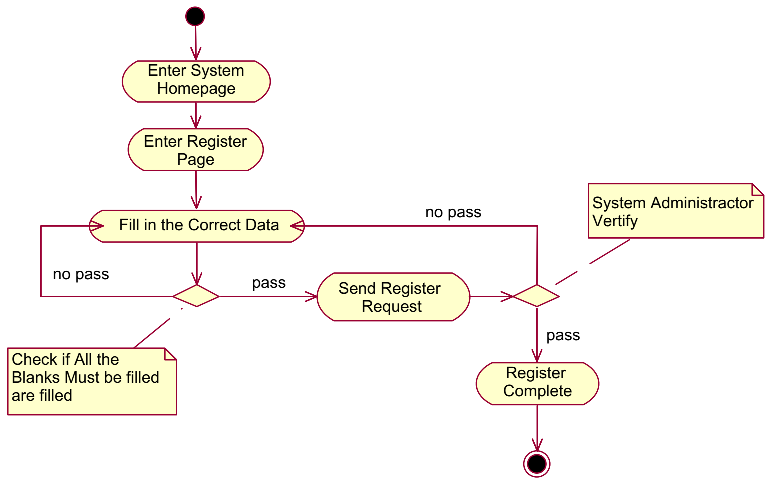

Fig. 7. Manufacturer and supplier registration.

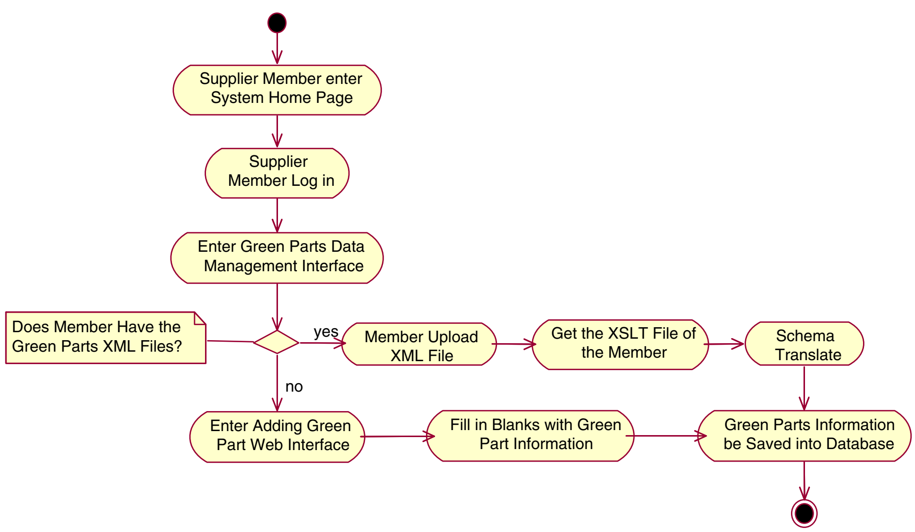

Fig. 8. Adding green parts into the IGPIP database.

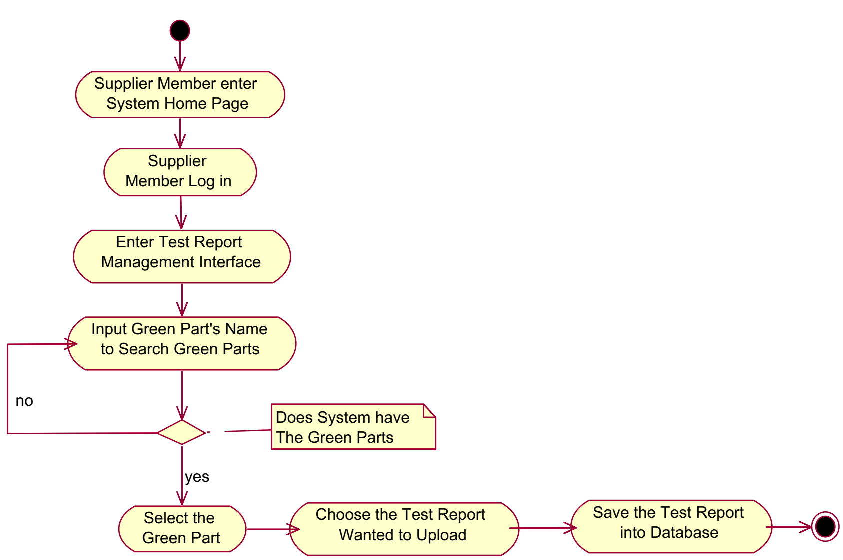

Fig. 9. Uploading test reports.

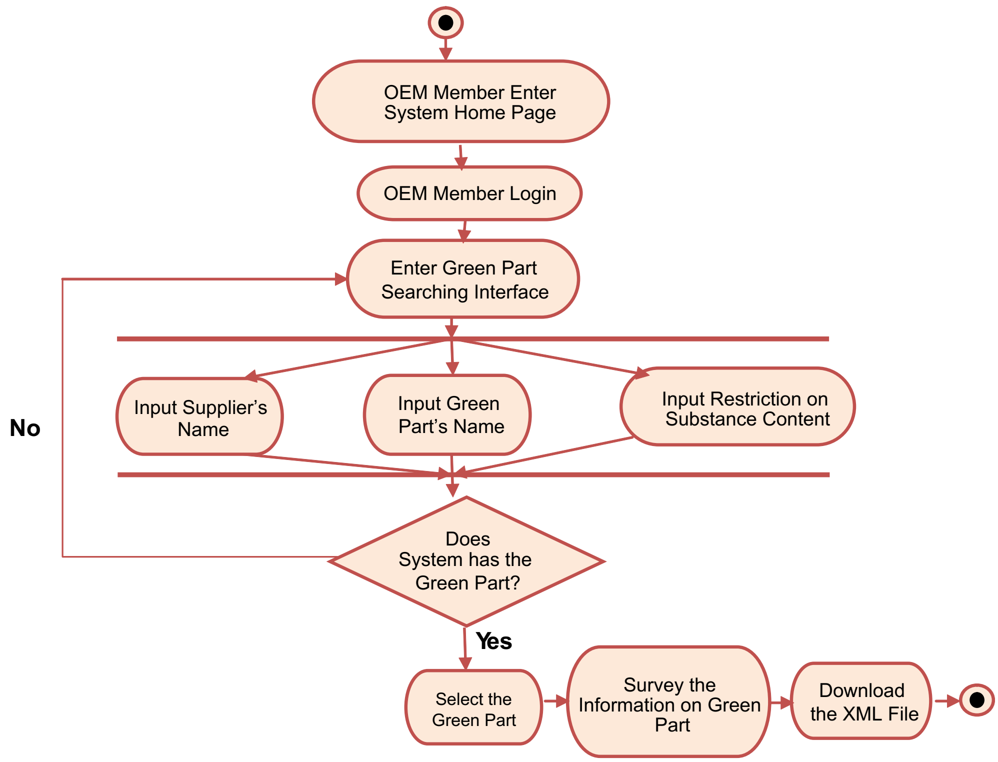

Fig. 10. The process flow and activity diagram of Search and Survey Module.

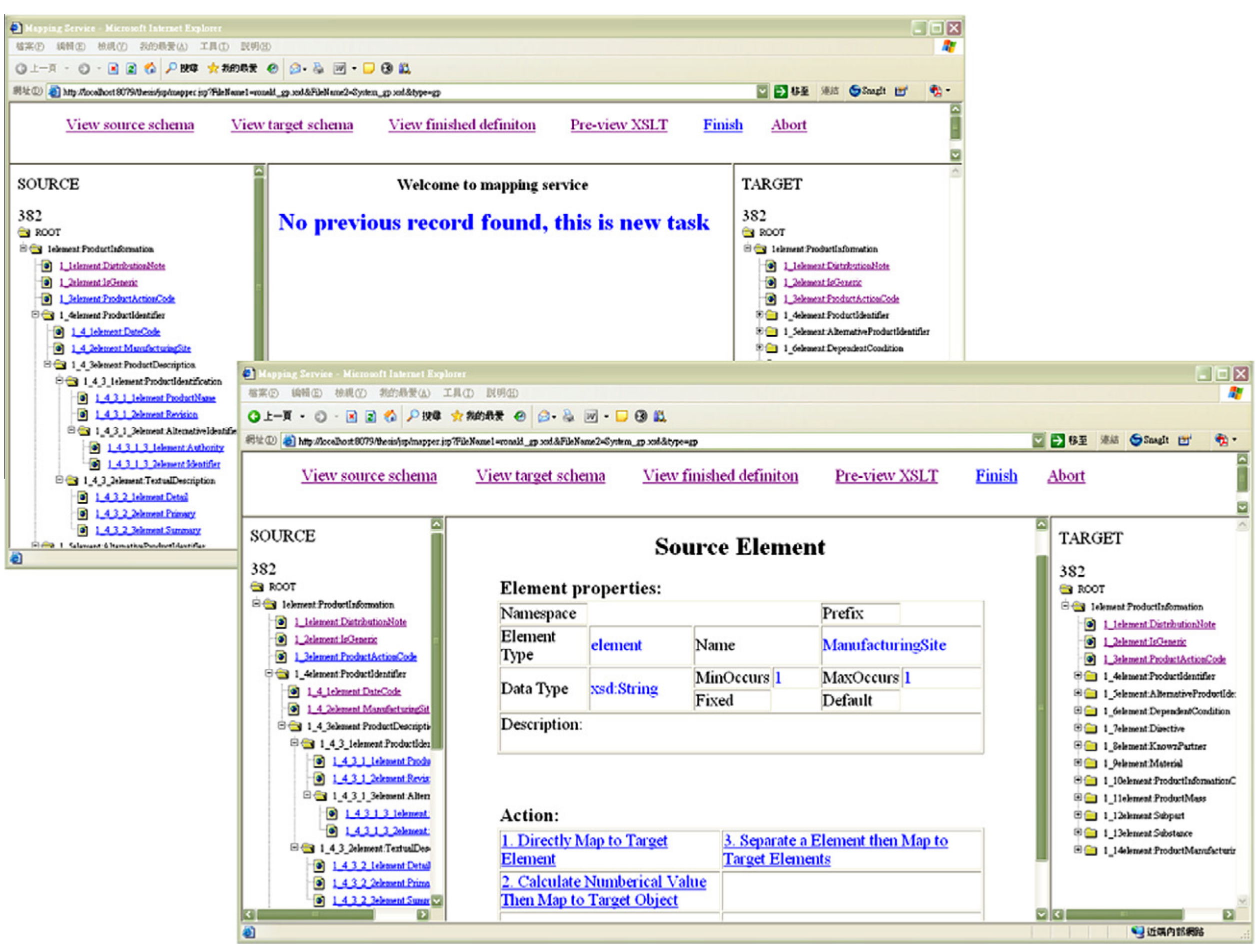

Fig. 11. The schema mapping interfaces.

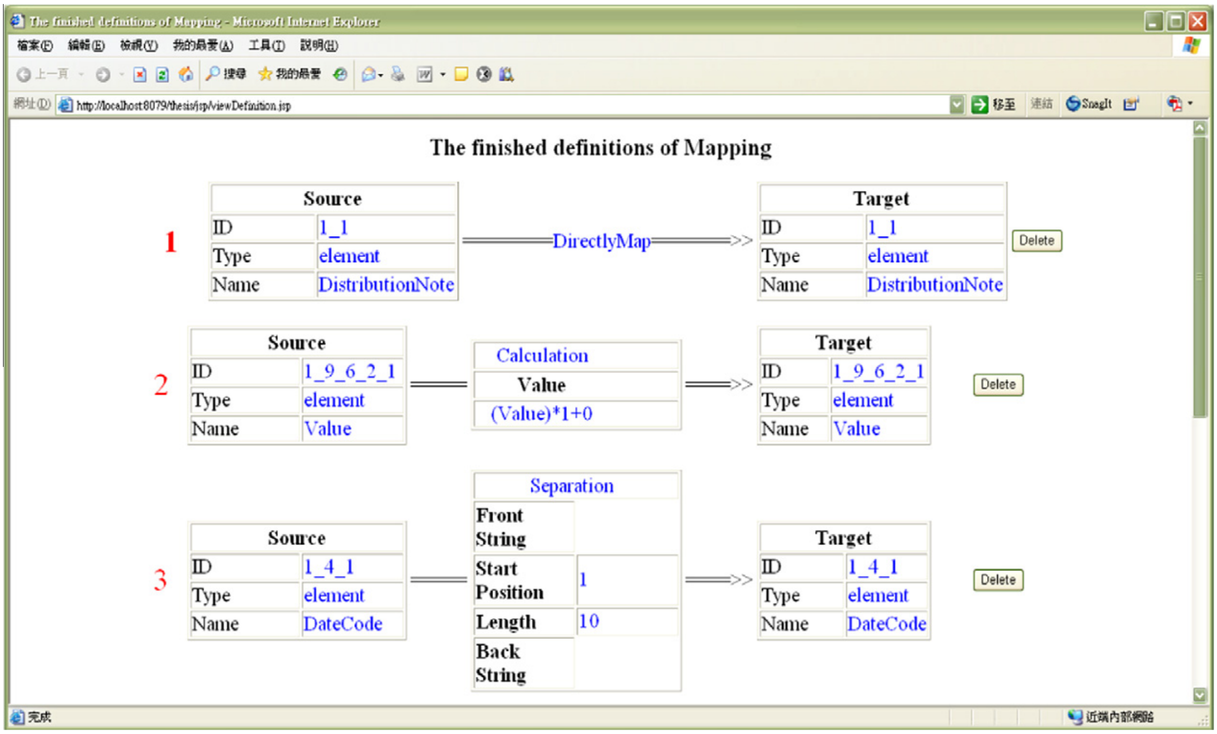

Fig. 12. The rule definition interface for mapping services.

2. *Calculation function:* This function enables the mapping of source elements with additional calculation and conversion to target elements.
3. *Separation function:* The Separation function places separate content into seperate target tags. For example, an element representing a complete date (specify year, month and day in one 8-digit element) can be separated into three elements (one 4-digit and two 2-digit) representing year, month and day.
4. *Constantvalue function:* This function enables users to place constant values into the target tags.
5. *Combination function:* This function enables the merging of content from several source tags into one target tag, i.e., the reverse of Separation Function.
6. *Set the "For-Each" condition function:* This function enables members to put a "for-each" rule into a specific target tag with a specific value. If the value of a source tag matches the condition, the rule for the target tag is executed. In general, the XSLT generator can set the "for-each" loop automatically. This function serves as a condition filter.

In addition to the above defined functions, the user can review, revise, and delete the mapping rules. Fig. 12 is a screen capture of the rule definition interface.

5. Conclusion

This paper prototypes an information exchange platform to enable manufacturers and designers to increase the usage of green parts to satisfy the requirements for environmentally regulated products with minimized effort. To achieve this goal and to include all members of the supply chain with enterprise resource planning systems, the platform is built on an XML-based hub with a web-based interface. The prototype was designed and implemented to demonstrate the viability of the platform to a electrical equipment manufacturers association. The XML Hub is based on the RosettaNet 2A13 standard and it enables suppliers and manufacturers to translate their part data for efficient Internet-based data exchange. The proposed platform provides the ability to integrate, exchange, and manage all product-related data and procedures across heterogeneous platforms and organizational boundaries. The proposed design of this platform eliminates the need for members to use different data standards than what is used internally within each company. The requisite advantage of the prototype data exchange system is the ability to accommodate differing resource planning platforms. The platform satisfied the participating companies (members) goal to reduce overall green product development cost by shortening lead time in product design and manufacture as well as minimizing human data entry. Additionally, a public information platform better enabled members to find and select green parts for manufacturing. The web-based platform system described and developed in this research provided a tool for members that satisfied both the design goals and the system implementation budget. Finally, as a public information platform, the hub facilitates the sourcing of suitable green alternatives and provides more choices to OEM members. Increased part choices impact cost effectiveness, facilitate the creation of products, and minimize negative environmental impact of products.

Acknowledgement

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Appendix A

The technical details of the Integrated Green Parts Information Platform (IGPIP) Prototype.

The technical specification of the prototype developed in this research:

- *Operation System:* Microsoft Windows XP Professional Version 2002 Service Pack2.
- *Web Server:* JSP Server Tomcat 5.0.
- *Java Platform:* J2SDK1.4.2.
- *Database:* Oracle 9i.
- *Java Server Page:* The subset of java language used for developing web-based thin-client applications.
- *Jdom:* The java package for XML application development.
- *XML schema 1.0:* The definition language for specifying the format of XML documents. It follows the XML specification and is more flexible than DTD.
- *XSLT:* A kind of XML language used to translate the format of XML documents to other formats.
- *XML Spy 2006 SP2:* It provides an easy compile interface to edit the XML Schema and DTD.
- RosettaNet 2A13 Standard is used for the implemented system.

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