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► **To cite this version:**

Thitiya Manakitsirisuthi, Yacine Ouzrout, Abdelaziz Bouras. A PLM/KMS integration for Sustainable Reverse Logistics. 8th IFIP International Conference Product Lifecycle Management PLM 11, Jul 2011, Eindhoven, Netherlands. pp.1-11. hal-01550197

**HAL Id: hal-01550197**

**<https://hal.science/hal-01550197>**

Submitted on 6 Nov 2018

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# A PLM/KMS integration for Sustainable Reverse Logistics

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**Abstract:** The international competitive market causes the increasing of shorten product life cycle and product development process with the improvement in term of time, cost and quality while increasing the waste generation. To reduce the waste generation, companies follow the environmental legislation and focus more and more on the product lifecycle sustainability. Sustainability on product lifecycle encourages in reducing wastes, saving resources and energy, reusing product and its component and avoiding of usage hazardous substances as well. Therefore, this research work is aimed to establish a Knowledge Management System (KMS) based on a multi-agent system in order to manage sustainability knowledge related to environmental security and performance through the link between Agents' knowledge base and Product Lifecycle Management (PLM) system. It will help the decision makers in each stage of the lifecycle and make them take into account the environmental impacts of their decisions. The proposed architecture will be illustrated on an industrial case study.

**Keyword:** Reverse logistics, Product lifecycle sustainability, Multi-Agents System, Knowledge management, Decision making

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## 1 INTRODUCTION

In present business competitive, time is valuable; the quicker products are introduced into the market, the more the profits are for the organization. The Product Lifecycle Management (PLM) is a key solution to manage information and product knowledge; it utilizes the advantage of information sharing to decrease timeline for product development and production process, in order to accelerate the speed to market. Because of that, since few years, a huge amount of products have been introduced into the market. So, what will happen to the environment when these products will reach to their end-of-life? If these products are dump into environment, our environment will be affected unavoidable.

The degree of environmental impacts is determined by materials and energy used in the products and in the production processes, including the outputs generated at all stages of product's lifecycle. For example, components of electronic products could contain several hazardous materials (e.g. mercury, lead, cadmium, etc.) which are dangerous for human health and environment. The higher is the number of products introduced into the market, the more waste of products are generated. So, environmental regulations and legislations have been established in order to require the organizations to take responsibility of their products when they come to end-of-life or end-of-usage, to limit and control waste generations and to dispose them in a proper manner.

Taking into account the sustainability, customers are increasing their purchasing decisions on environmental impacts generated from products, or buying products made of recycling materials. These challenges make many companies pay attention on reverse logistics as a key strategy to handling and disposition of product returned from customer. Reverse logistics is a process to recycle resources or deal with the waste materials, with a reason cost, from consumer to production point [1]. Managing the returned product efficiently not only reduces the amount of waste generation but also encourages the company in the design processes to avoid the use of hazardous substances in products.

Besides, in order to produce the products that are sustainable and less harmful to environment, rules, regulations and knowledge related to all activities of organization, together with environmental performance which occurred during the production process and the recovery process, should be captured, evaluated and stored for further useful. Considering environmental issues and regulation can help users on their decision making during the design, the production and particularly the recovery process. Consequently, it will help organization, on not only, minimizing their waste generation but also improving their environmental performances.

This research proposes to develop a Knowledge Management System (KMS) based on a Multi-Agent System (MAS) in order to manage the knowledge related to environmental regulation. The proposed system will facilitate the efficient decision making by constructing the link between the Agent's knowledge concerning sustainability and the PLM system. With this architecture, the environmental impacts will be considered in each stage of the decision making process and for the whole lifecycle of the product.

## **2 LITERATURE REVIEW**

In the past, although organizations have been developed a better quality of products continuously, the environmental effects still have been ignored during the product development. The products end-of-life and their substances were discarded in the inappropriate ways which could damage to the environment.

Now, by concerning to environmental impacts, organizations are increasing the improvement to satisfy customer requirements through sustainability of their product by using efficiently of raw materials. To success of using raw materials efficiently, organizations should reuse components and materials from the returned product which will result in reducing costs of production and waste generation [2]. Then, the organization can create their profitability from the returned product [3]. Accordingly,

reverse logistics are increasingly utilized as a competitive advantage of organization in managing the returned products [4].

The purpose of a reverse logistics process is to make benefits from the value of returned materials or to find the proper way to dispose returned product [5]. Many researchers have classified reverse logistics process in different ways. De Brito and Dekker [6] have separated reverse logistics processes into 4 processes: Collection, Inspection/ sorting, Re-processing or direct recovery and Redistribution while Thierry et al. [7] demonstrated their options on product recovery into repair, refurbishing, remanufacturing, cannibalization and recycling. All these options of recovery processes in reverse logistics mainly concern in a way to effect to environmental and economic efficiency.

Since the environmental protection is more concerned, knowledge about environmental regulations such WEEE [8], RoHS [9], Battery directive [10] and other environmental legislations should be taken into account and shared by all users in the PLM process in order to support users making their decisions properly. These regulations guide the organizations in reducing the consumption of non-renewable resources, decreasing the amount of waste materials generation and towards the sustainability at the end.

The environmental regulations and policies from governments encourage organizations to innovate and develop their product in term of sustainability. Environmentally Conscious Manufacturing and Product Recovery (ECMPRO) is one approach of integrating the environmental issues for a new product development in the process of design, material selection, and manufacturing and managing end-of-life product [11].

For examples, (1) Cisco introduced a take back and recycling program to collect and dispose their end-of-life product. This program complies with the EU WEEE directive. With this program, Cisco helps reducing the impacts on the environment through recycling, reusing and the properly disposing of its end-of-life product [12]. (2) Hewlett-Packard [13] has designed their products, e.g. printer and laptop, to be friendly with the environment by reducing energy used in production process and during product life span, reducing the use of hazardous materials and designing products that are recyclability.

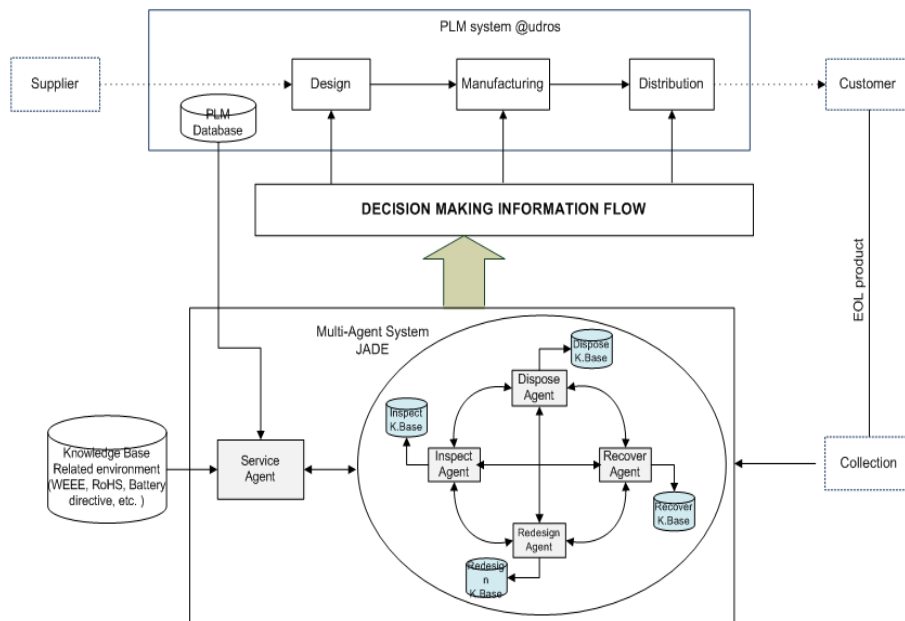
Managing the returned product has faced on how to use technologies to develop information system to deal with the returned product. The new technologies have been used for information sharing in the chain logistics such as the agent-based technology [14, and 15], RFID technology [16, and 17] or web services [18, 19]. Although, some of these technologies are applied on the return product management [20, 21], they still have a limitation.

Due to the lacking of information sharing on environmental regulations and performance between users in product lifecycle management, in the next section, we will propose a knowledge management architecture, which is based on a multi-agent system, to manage the knowledge related to environmental performance. This system will make the link between agent's knowledge base and the PLM information system and support users in their decision making, considering the environmental impacts from their products.

### 3 KNOWLEDGE MANAGEMENT ARCHITECTURE

The developing of a knowledge management system is intended to support users sharing and communicating all information related to product and also related to the environmental regulations and performance. Figure1 is the description of the conceptual model of the proposed architecture.

**Figure 1** The proposed KMS/Multi-Agent architecture



The multi-agent system is connected to the PLM database where the product information is stored. It is also connected to the environmental knowledge base. This environmental knowledge base is shared by the agents and also by the users in each stage of the PLM process. Each agent has its own knowledge base which contains the knowledge related to environmental impacts and performance. In the following section, we describe this Multi-Agent System/

#### 3.1 The Multi-Agent System

The proposed multi-agent system includes five agents: Service agent, Inspect Agent, Recover agent, Dispose agent and Redesign agent. Each agent works independently from the others. However, they communicate and interact to share knowledge and information. Each agent communicates with the others through Agent Communication Language (ACL) which is complied with FIPA specification (The Foundation for Intelligent Physical Agents) [22]. ACL is a language, which provides agents with a means of exchanging information and knowledge and defines the types of messages.

The role and the decision making process of each agent is described briefly in the following section:

**Service agent:** This agent handles tasks and provides information (extract from PLM database) when requested by other agents.

**Inspect agent:** Its role is to inspect the returned product using the information provided from Service agent, from its knowledge base. It communicates to other agents asking for supporting information during its inspection process.

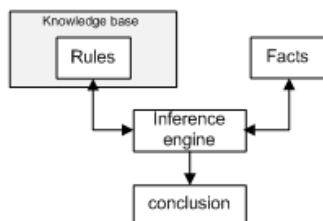
**Recover agent:** The agent analyses and offers the solution on recovery the returned product and its components using its rule based and information from Service agent and environmental knowledge base.

**Dispose agent:** The agent offers solution in the process of recycling the returned product. The solution is derived from its rule-based and environmental knowledge base. This solution encourages users in stages of PLM reducing the hazardous waste which effect on human and health and environmental performance.

**Redesign agent:** There are rules of environmental knowledge base which concerns in the environmental performance. The solution derived from the agent will help user keep in mind the integration environmental constraint in the redesign/design process.

Figure2 presents the rule-base structure in knowledge base of each agent. The information related to the environmental performance of each agent will be extracted when agents execute their inference engine during their processes.

**Figure 2** The structure of rule-base



We define our system specifications by using AUML diagrams (Use case diagram, Activity diagram, class diagram and etc.) to describe the way of our agents communicate to each other during processes for their decision making.

Figure2 illustrates the communication between Service agent and other agents during the inspection process. The RequestToPerformTask() of Service agent is to send the message to agents depend on the status of the returned product. For example, if the status of the returned product is “register”, it means that the returned product is needed to inspect. To inspect the returned product, Inspect agent requests product information from PLM database, SendMessage(), by sending message to Service agent. After receiving information from Service agent and other agents, ExecutingEngine() will be executed to find the solution/destination of the returned product from its rule-based and environmental knowledge base. Then ConfirmTask() will be sent to Service agent to confirm that the inspection process is done.

Figure3 illustrates class diagram communicating between Service agent and Inspect agent during the inspection process.

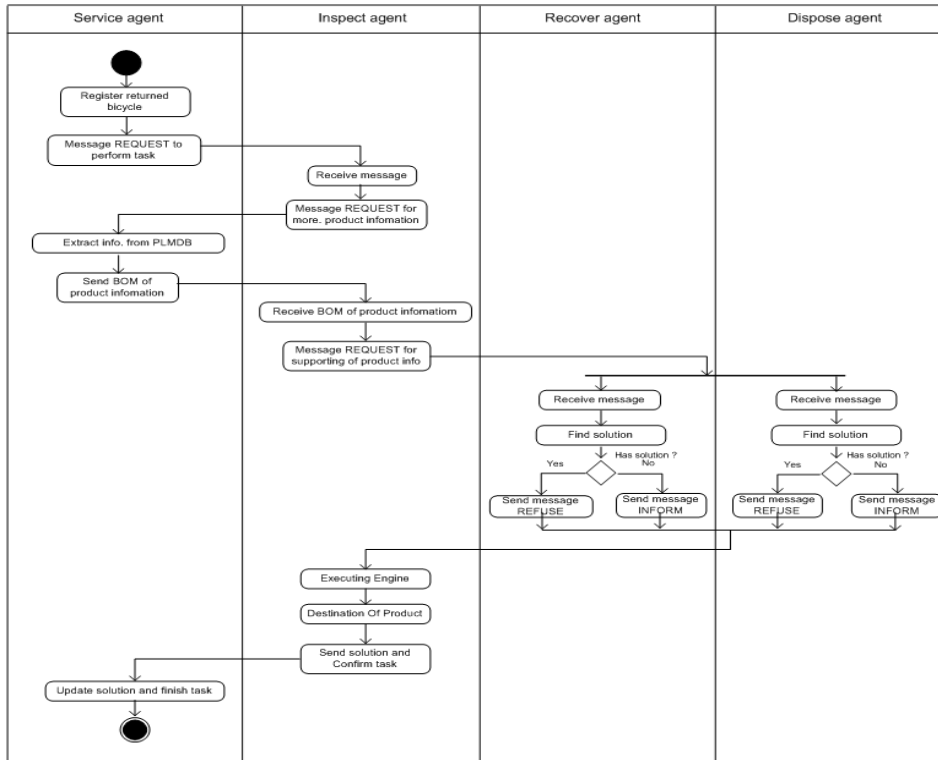
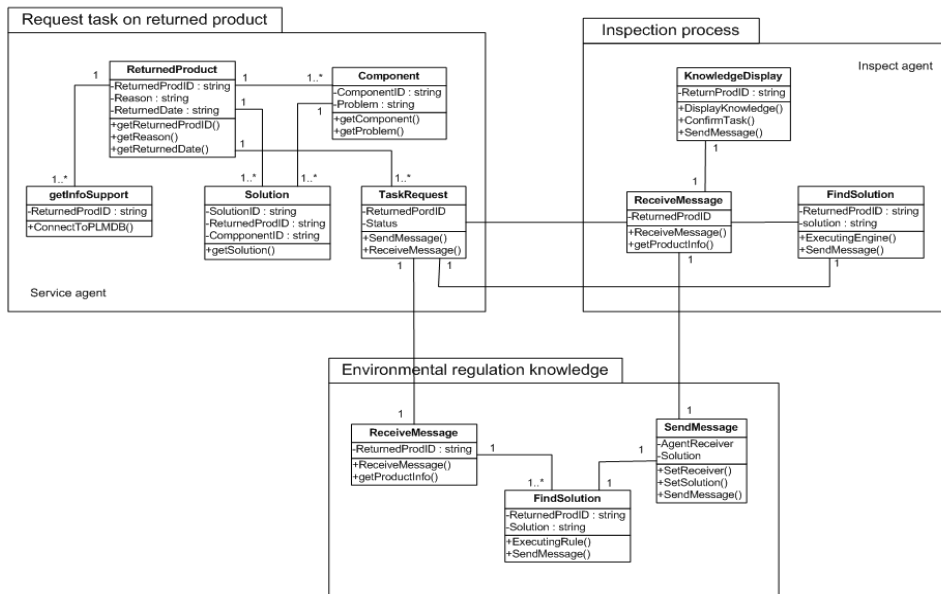


Figure 3 The interaction between *Inspect agent*, *Service Agent*, during inspection process



The prototype of this Multi-Agent architecture is in the process of development; it is based on the JADE (Java Agent Development Framework) platform [23]. JADE is an open source, implemented in java language and is in compliance with FIPA specification.

### 3.2 Knowledge representation and Decision Making Process

#### 3.2.1 Rule-based reasoning

In the rule-based approach, the knowledge is represented as a set of “IF...THEN...” rules to represent the domain knowledge. The inference engine is a system which processes the rules, and the knowledge, based on the fact of the given situation. In this work on multi-agent system, we used a rule-based reasoning approach to formalize the environmental regulations. This in order to support users in their decision making process. Figure4 illustrates an example of environmental legislation of the European directive RoHS formalized using rule-based concepts [9].

**Figure 4** An example of Rule-Based Knowledge representation for RoHS regulation

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Rule1:
IF product falls under category 3
THEN product is mobile phone
AND reference is WEEE directive Annex IB

Rule2:
IF component = printed circuit board AND printed circuit board contains lead
THEN The maximum concentration value of 0.1% by weight in homogeneous materials for lead
AND reference is amending RoHS directive Art.(1), decision applying from 1 July 2006 Art. 2

Rule3:
IF component = printed circuit board AND printed circuit board contains mercury
THEN The maximum concentration value of 0.1% by weight in homogeneous materials for
mercury
AND reference is amending RoHS directive Art.(1), decision applying from 1 July 2006 Art. 2

Rule4:
IF component = printed circuit board AND printed circuit board contains hexavalent chromium
THEN The maximum concentration value of 0.1% by weight in homogeneous materials for
hexavalent chromium
AND reference is amending RoHS directive Art.(1), decision applying from 1 July 2006 Art. 2

Rule5:
IF component = printed circuit board AND printed circuit board contains polybrominated
biphenyls (PBB)
THEN The maximum concentration value of 0.1% by weight in homogeneous materials for
polybrominated biphenyls (PBB)
AND reference is amending RoHS directive Art.(1), decision applying from 1 July 2006 Art. 2
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#### 3.2.2 Previous Cases experience

The previous experiences including the solutions are stored in the database of all the agents. Each agent checks in its database for solutions to solve the problems that occurs. A solution in the agent's case base system will be first matched and then sent to user. User will decide whether the solution retrieved is applicable or not to its problem. Our system is developed to manage experts' knowledge by exploring the best practices. Figure5 shows an example of existing case problem which concerns a bicycle.



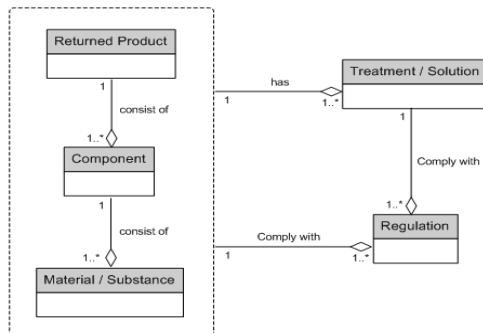
**Figure 5** Previous case problem of bicycle in the *inspect agent's* knowledge base

<b>Problem description:</b> ProductID: Bike-01 Problem Area: Frame Problem Desc1: Small cracked on Head tube Problem Desc2: Down tube bended like curve
<b>Solution:</b> IF Head tube small cracked THEN Welding  IF Down tube bended like curve THEN Using tools to make it straighten  IF small cracked on Head tube AND Down tube bended like curve THEN Fix can be done but not well functioning on the use
<b>Output:</b> 1. After welding, a short period of using and need more frequency checking 2. Fix cannot be done then replacing with the new one

### 3.2.3 Ontology

To make agents understand each other, the agents must speak the same language and also have a common understanding on the semantic of the knowledge (ontology). So, the ontology is a part of the agent's knowledge base which describes what type of things agent is dealing with and how they are related to each other. We have defined our returned product ontology for sharing information and knowledge through agent communications. Figure 6 illustrates an example of the end-of-life returned product ontology, which has been shared between agents in the proposed system.

**Figure 6** The concept of returned product ontology

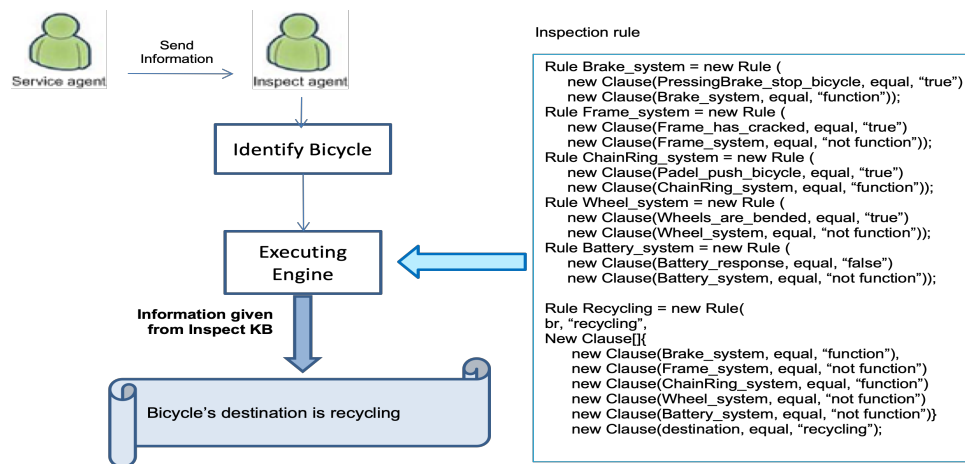


## 4 VALIDATION OF THE SYSTEM : THE BICYCLE CASE STUDY

To validate the proposed architecture, we used an industrial case study about the lifecycle of a bicycle. According to our system, each of the returned bicycles will be inspected and checked by the *Inspect agent*. The *Inspect agent* receives the references information such as bicycle model (family), bill of material (BOM) or date of manufacturing from the *Service agent*. Then it analyzes the returned bicycle's problems through previous experience cases in its knowledge base. For example, a returned bicycle is returned with

the reason “End-Of-Life”, wheel and frame are broken and not functioning. The *Inspect agent* examines and checks its quality then analyzes and sets its destination to “recycling”. Wheel, frame and battery are determined to discard (Figure7).

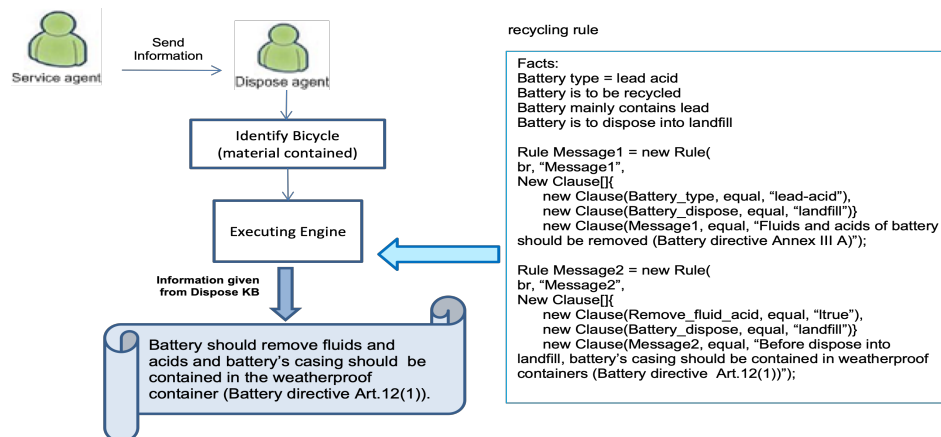
**Figure 7** Executing inspection rule of *Inspect agent*



After that, the *Dispose agent* receives the message from the *Service agent* that there is a returned bicycle which needs to be recycled. It asks for some technical data such as: types of material of each component/part, number of components/parts... and sends messages to the agents about, for example, the disposal information of wheel, frame and battery.

The *Disposal agent*'s Knowledge base contains the rules or regulations on how to operate reusable, and non-reusable, substances/materials taking into account the improvement of the environmental performance. In our example, to recycle a lead-acid battery of bicycle that contains large amounts of lead. With the structure of rule-based of *Dispose agent*, it proposes solutions such as: the recommendation on how to discard lead-acid battery based on the information of the EU Battery directives. These solutions are significant information for the decision making of the users in order to save time and cost of operation process, as well as reduce the environmental impacts (see Figure8).

**Figure 8** Message from *Dispose agent* after executing rule



In the case of returned bicycle to be redesigned, for example, a group of used bicycles returns to the organization having the same kind of problem: *customers did not understand how to use the shift gear when they were riding*, the *Dispose agent* will propose that the instruction guide should be reviewed to make sure that the customer clearly understand how to use the gear shifting efficiency. This solution will help in reducing the number of returned bicycle, and consequently, it will result the conservation of resources and energy and the reduction of waste generation; which improve the environmental performance.

## 5 CONCLUSION

A KMS/PLM architecture, based on a Multi-Agent system, has been proposed to share the product's knowledge and environmental legislations among reverse logistics activities. The environmental restrictions such as WEEE, RoHS and Battery directives encourage organizations to take responsibility by producing sustainable products. Sharing this environmental knowledge between users in every stages of product lifecycle process will improve the efficiency on managing of the end-of-life products in organization.

The proposed system will encourage organization on reducing the cost of waste disposal, increasing the reuse of materials/parts of product, helping user designing product and reusing efficiently materials and enhancing the environmental performance. We are now working on the ontology for the Environmental Knowledge base, and trying to validate the prototype on a real industrial case study.

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