An Expert System for Sustainable Product Lifecycle Management

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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 and an Expert 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, Expert system, Decision Making

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) and an Expert System in order to manage the knowledge related to environmental regulation (directives, norms, regulations…). 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 PLM and Artificial Intelligence

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.

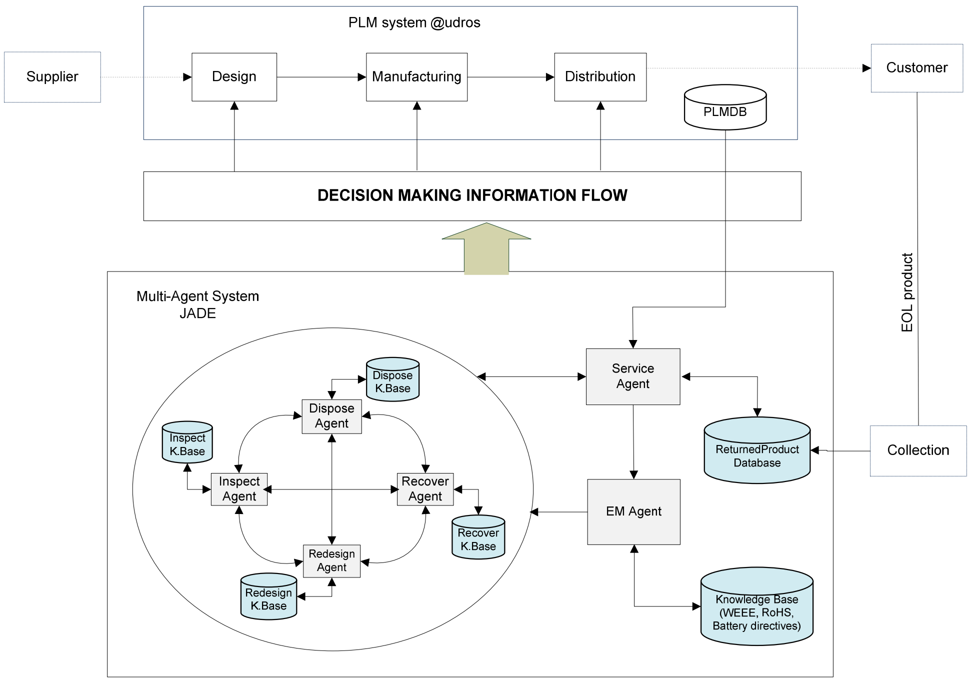
Managing the returned product has faced on how to use technologies to develop information system to deal with the returned product. The new technologies have been used for information sharing in the chain logistics such as the agent-based technology [14, and 15], RFID technology [16, and 17] or web services [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 THE KNOWLEDGE MANAGEMENT ARCHITECTURE

We propose a knowledge management system using multi-agent architecture to enable the communication and cooperation among the agents. The proposed architecture composes of 6 agents: Service agent, Inspect Agent, Recover agent, Dispose agent, Redesign agent and EM agent. Figure1 describes the conceptual model of the system 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.

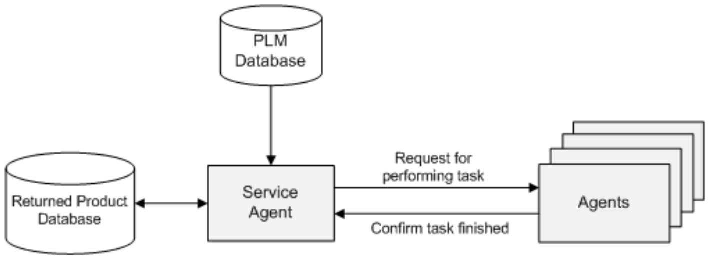
3.1 The Multi-Agent System

The proposed multi-agent system includes six agents: Service agent, Inspect Agent, Recover agent, Dispose agent, Redesign agent and EM Agent. Each agent is autonomous and work independently from the others. However, they communicate and interact to share knowledge and information, 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 reasoning process of each agent are described in the following section:

***Service agent*:** This agent handles tasks which concern the interface with the PLM system; it receives requests from the involved agents and provides them the requested information after extracting it from the product technical database of the PLM system (see Figure2).

Figure 2 The interaction between *Service Agent*, the other Agents and PLM database



Inspect agent: receives requests, from the system, to inspect the returned products characteristics. Based on this and on the parameters of the problem, this agent checks if there are similar problems in its knowledge base by using the Case-Bases Reasoning approach. Then, it proposes to the end user some rules and solutions to manage this return product. Since the inspection process is the most important to classify the end-of-life product (whether to be repaired or to be recycled), to complete its task, the *Inspect agent* needs the supporting information from the *Recover agent* and the *Dispose agent*. The expertise of the different agents, and the fact that they share their information and knowledge, allow the system to find the proper solution for each returned product.

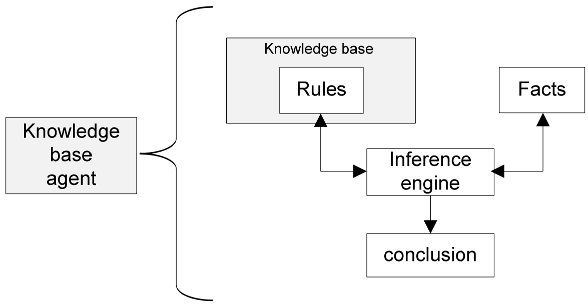
Recover agent: after receiving a message from the *Inspect agent* specifying that the returned product needs to be recovered. The *Recover agent* looks into its knowledge base which contains rules related to how repairing the products taking into account the environmental problematic by using the environmental knowledge base. For example, repainting a bicycle frame, or a part of the frame, should be performed in an environmental friendly way; and the producers should be informed that the use of organic solvents and highly toxic of compounds should be avoided.

Dispose agent: is responsible of the recycling or the reusing of the materials. Its knowledge base contains information related to how eliminate hazardous materials or reuse materials contained in the returned product. This agent will help the organization reducing the use of resources and energy by reusing materials or parts for the second life of the product. For example, in case of recycling the battery of a bicycle, the sealed lead batteries are mainly used in the electric bicycle. The *Dispose agent* may give information about the treatment so as to recover some materials such as by broken into small pieces and heated until the metal melted.

Redesign agent: once the *Inspect agent* analyzes and finds out that the returned product needs to be redesigned for environmentally friendly. The solutions will be proposed by the *Redesign agent* using its knowledge base and taking into account the environmental impacts point of view. For example, misunderstanding on the unclear instruction on gearing system could make its function shorter than it should. Then creating a clearly understandable instruction manual can reduce the amount of returned products by extending its useful life. *Redesign agent* may also suggest to the designer to create a clear manual instruction and use a recycling paper. This can also conserve the energy and resources of water, woods and other materials used in paper manufacturing and absolutely minimize the amount of waste generation in the environment.
The *Redesign agent* may also propose the change of the product design to use more modularity components or minimizing the number of parts in a product to simplify the disassembly process. These will help saving time, cost and energy in the recycling process phase.

EM agent: EM agent receives the requested messages from the *Service agent*. Its knowledge base contains facts and rules related to the environmental legislations such as WEEE, RoHS and Battery directives. After runing the inference engine, the EM agent sends information back directly to agents who request through the *Service agent*. The figure3 shows the structure of rule-based system in EM agent.

Figure3: The structure of the rule-based system of EM agent



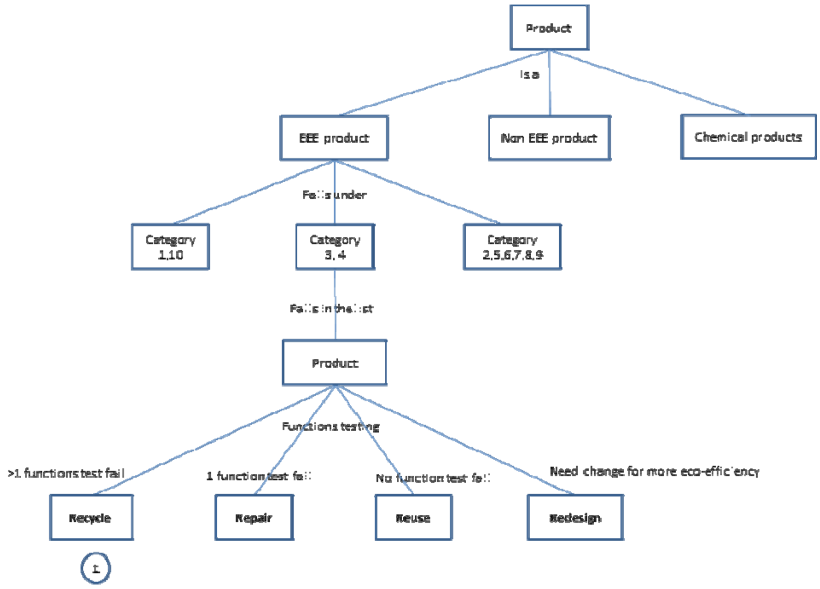
The knowledge base of the *EM agent* contains the domain knowledge useful for problem solving. In our rule-based system, the knowledge is represented as a set of rules of environmental regulations. Each rule specifies a relation, recommendation or solution and has an If/Then structure. When the conditions parts of a rule are satisfied, the rule is fired and the action part is executed. A set of facts used to match against the IF (conditions) parts of rules are stored in the knowledge base. Then, the inference engine carries out the reasoning to reach a solution. It links the rules given in the knowledge base with the facts. Other agents' knowledge base use the same architecture (rule-base structure and inference engine), the difference is the knowledge domain which depends on each agent's roles.

3.2 Knowledge representation and the Reasoning Process

We use ontology to formalize the knowledge of the product end-of-life. by defining each object and its relationship in the domain of recycling which related to environmental performance. Our framework can be represented as a common understanding about the content of recycling of electronic product and this structure can be shared between agents. To illustrate this conceptual, the environmental regulations, e.g. WEEE, RoHS and Battery directives, including the company's recycling process of electronic product will be used as instruction how to handle the end-of-life or returned product when they are recycled. Knowledge represented in the domain of electronic product is about product type which is an electronic product or not, a category of product, functions of product, or destination of product depends on its function, etc. This knowledge can be presented in form of statements, for example, EEE Product is a product which its function mainly uses of electricity. EEE Product falls under category 3. It should be recycled when more than one function testing is fail. These forms of statements can be put as rules in format of IF-THEN.

To formalize this knowledge we used a semantic network as described in an example in the figure 4

Figure 4 An example of semantic nets for product recycling



These are examples of rules based on environmental regulation and directives:

Rules from WEEE Regulations:

Rule1: IF product depends on electronic in order to work properly
THEN Product is EEE Product

Rule2: IF EEE products fall under categories 3 or 4 and EEE product is mobile phone and mobile phones' destination is recycle

THEN the rate of recovery shall be increased to a minimum of 75% by an average weight per appliance and component, material and substance reuse and recycling shall be increased to a minimum of 65% by an average weight per appliance (WEEE directive Art7. (Annex IA)).

Rules from company's recycling process:

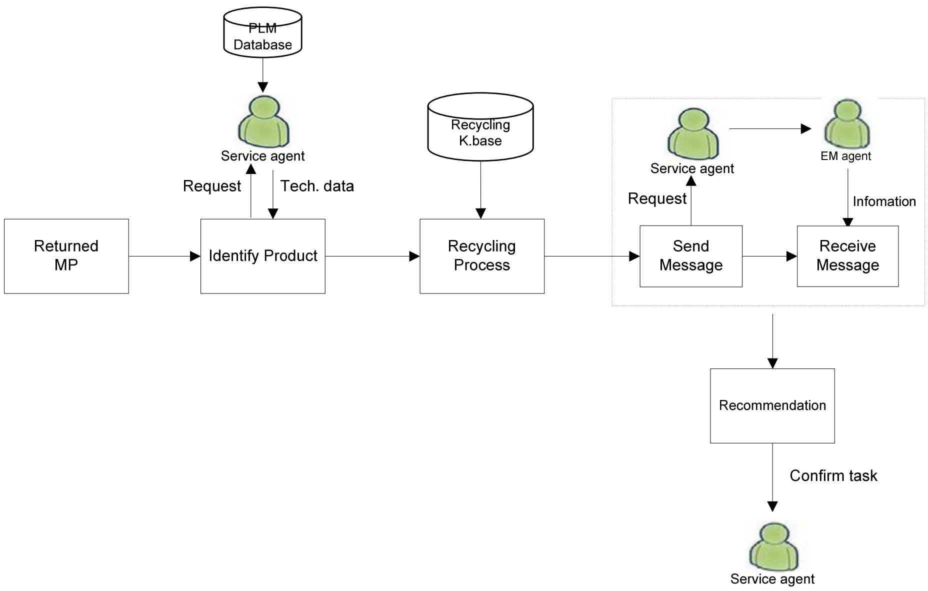
Rule1: IF calling test does not generate a service response
THEN ping testing is not function

Rule2: IF battery does not response with a volt meter
THEN battery testing is not function

….

Rule10: IF ping testing is not function AND loop testing is function AND screen and keypad testing is function AND battery is not function
THEN mobile phone's destination is recycling

Figure Example of interactions between agents during the recycling process



4 The MAS/KMS Implementation

According to Agent UML references [AUML, 2010], use cases have been identified during the analysis phase of the project and the functional aspects of the system developed. We used Use Case Diagram to specify our agents and to define the tasks and behaviors of these agents as shown in Figure 5.

Figure 5 The interaction between agents during the MP recycling process

The class diagram (see Figure 6) shows how to find out the solution for the returned product in the inspection process which begins from the *Service agent* to the *Inspect agent* where the inspect solution may come from the *Recover* and *Dispose agents'* knowledge base and the Environmental knowledge base.

Figure 6 UML Class Diagram: information sharing during the inspection process

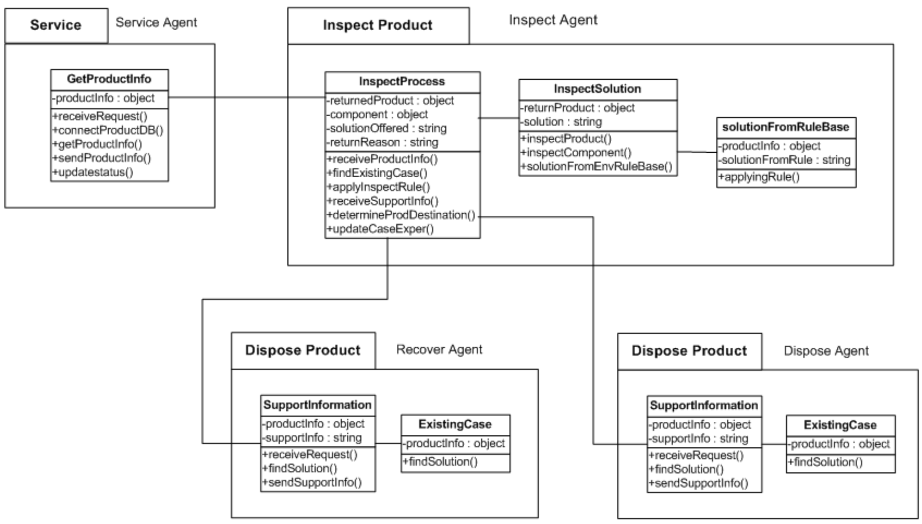
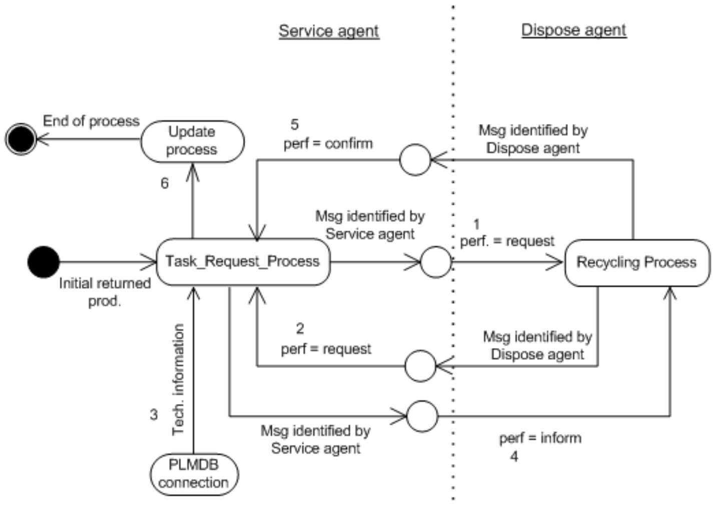


Figure 7 illustrates the activities of the *Dispose agent* from one activity to another, including the communication with the other agents. After the *Dispose agent* receives the information needed, it analyzes the returned product. To find out the solution for dismantling product, it sends the message requesting for supporting information to other agents, then applies the fact of product information with dismantling rules and environmental regulation knowledge base. The agent tries to find out the appropriate solution of unusable components and disposal of waste. In order to reduce the environment impacts, the recycling rules and disposal rules have been applied. Finally, the *Dispose agent* sends a message to confirm that the task has been finished to the *Service agent*.

Figure 7 UML Activity Diagram: Inspection product between Service agent and Inspect agent



The Multi-Agent System is developed using the JADE (Java Agent Development Framework) platform [23]. JADE is an open source, implemented in java language and is in compliance with FIPA specification.

5 The Mobile Phone Lifecycle Case Study

To validate the proposed architecture, we introduce an example of recycling process for a mobile phone (MP). When the mobile phone reaches to its end-of-life, it will be sent back to manufacture and register into the PLM database system. Once the returned MP is ready to inspect, the *Service agent* sends a message to the *Inspect agent* who needs some information about this returned product and send request to the *Service agent*. This agent connects to the PLM database and searches information that matched to the returned MP and sends back this information to the *Inspect agent*. The *Inspect agent* uses this MP's information as facts in order to match against rules in its knowledge base.

In the inspecting process, these facts will be used to find out which rules to be fired. IF Rule1-Rule4 in Table1 (inspecting rules of the *Inspect agent*) are matched, the action will be used as facts to find which rules to be fired again. In this case Rule10 will be fired. The *Inspect agent* also sends a message with these facts to the *Service agent* if there are any complementary rules related to environmental regulations which matched with facts they have during the inspecting process.

Table 1 An example of rules in Inspect agent's knowledge base

Rules	Inspecting rules
Rule1	**IF** calling test does not generate a service response **THEN** ping testing is not function
Rule2	**IF** speaking to mobile phone during on a call is not function **THEN** loop back testing is not function
Rule3	**IF** mobile phone cannot switch on and presses each key does not appears on LCD screen **THEN** screen and keypad testing is not function
Rule4	**IF** battery does not response with a volt meter **THEN** battery testing is not function
…	…
Rule10	**IF** ping testing is not function **AND** loop testing is not function **AND** screen and keypad testing is not function **AND** battery is not function **THEN** mobile phone's destination is recycle

The *Service agent* will then forward this request to the *EM agent*. If the facts are matched then rules in environmental regulation knowledge base (Table2: Environmental rules applied during the inspecting process) will be fired. Finally, the results will be sent back to the *Inspect agent*. Therefore, the results will be collected and send to the end-user for helping him in the decision making process. In this example, the *Inspect agent* sends a message to the *Service agent* with the information that the returned MP's destination should be recycled.

Table 2 Environmental rules applied during inspecting process

Rules	Environmental regulation knowledge base
Rule1	**IF** EEE products fall under categories 3 or 4 and EEE product is mobile phone and mobile phones' destination is recycling **THEN** the rate of recovery shall be increased to a minimum of 75% by an average weight per appliance and component, material and substance reuse and recycling shall be increased to a minimum of 65% by an average weight per appliance. (**WEEE directive Art7 (Annex IA)**)
Rule2	**IF** product type is mobile phone **THEN** the 1^{st} priority should give to reuse, the 2^{nd} should give to recovery and the last should give to recycle (**WEEE directive para.(18)**)

After returned MP is inspected and its destination is set to recycle, Service agent sends a message to the *Dispose agent* for recycling the returned MP. Figur8 shows the recycling process.

With this supporting information from EM agent, users can use this information for making a better decision on recycling mobile phone in the environmental point of view.

6 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 and RoHS directive 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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