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# A Knowledge Management System for a Sustainable PLM

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**Abstract:** Today, the trend of doing business concerns not only the efficiency but also the sustainability of product and the health of environment. In order to reduce waste generation and improve product or product development process in term of time, cost and quality, organization focuses more and more on Product lifecycle sustainability. It helps reducing waste, conserving resources, using recycling materials, designing product for easy disassembly and avoiding using hazardous material. This paper proposes a knowledge management architecture, based on a multi-agent system, which focuses on the “sustainability” in order to manage knowledge in each stage of the product lifecycle, and particularly in the recovery process.

The aim of this research work is to distribute the environmental knowledge about sustainability (e.g. environmental regulations, rules, norms...) by using multi agent system architecture. The proposed system will make the link between the agent’s knowledge base and PLM (Product Lifecycle Management) systems. It will help the decision makers in each stage of the lifecycle and make them take into account the environmental impact of their decisions. The proposed architecture will be illustrated on an industrial case study.

**Keywords:** Knowledge management, Multi-Agents System, Product Lifecycle Systems, Sustainability, Reverse logistics.

## 1. Introduction

Due to the increasing of international competition and competitive pressure in market, various products have been introduced to serve the customers' requirements. Customers increase their purchasing decisions on environmental impacts generated from products. The worldwide environmental concerns lead to the development of environmental legislations and regulations. These require companies to take responsibility on their production processes and take back their end-of-life products.

The degree of environmental impacts is determined by materials and energy used in the production processes and by outputs generated at each stage of

product's lifecycle. These challenges make many companies pay attention on reverse logistics as one of a strategy. Reverse logistics is not just reusing pallets or recycling bottles but it is also concerned by the redesign process of using less materials or avoided the use of hazardous substances in products. Reverse logistics is much concerning in environmental consciousness, therefore managing the returned product efficiently can reduce the amount of waste generation into the environment.

Environmental legislations and regulations have been established in order to require companies taking responsibility to collect the used products, to disassemble these products into components and parts and further for reusing in

manufacturing process and disposing for preventing environmental damage. For company, in order to generate products that are more on sustainable and less adverse to environment, knowledge related to all activities of organization and knowledge related to environmental performance should be captured, evaluated and stored for further useful during those processes.

Environmental issues and legislations can help decision maker to take the proper decision during the design, production and recovery processes. So, this research proposes a knowledge management architecture based on multi-agents system in order to capture, store and manipulate knowledge related to environmental security and performance through the link between agent's knowledge and

PLM systems. The proposed system will help the decision maker to make the efficient decision making related to environmental impacts.

## **2. Literature Review**

In general, the current PLM systems are designed to support user from the beginning at the design stage up to the point of delivery to customers [1, 2] The concept of Closed-loop PLM allows all the users to access and manage the information throughout the whole product lifecycle including the product information at its end-of-life [3]. However, they are not designed to manage the information in reverse logistics. In the past, organizations have been asked to develop products and services for a better quality, less expensive within a timely manner and the environmental effects have been ignored during the design and production process.

Hazardous materials were discarded in the inappropriate way which could damage the environment.

Since customers are aware of environmental impacts, organizations are increasing the improvement of customer satisfactions through product sustainability, by using efficiently of raw materials in production process; which include reusing materials from the used product and at the same time reducing costs of production and waste generation[4]. That means that the organizations can create their profitability from returning products [5]. Therefore, reverse logistics has been increasingly used by organizations as a competitive advantage [6].

Reverse logistics covered the product returns, including recycling, remanufacturing, disassembling and reusing materials from the used products

[7]. Fig-1 shows the flow of reverse logistics in the product's lifecycle; the used products can return to organizations with many reasons such as customer dissatisfaction or product reaches to their end of useful life. In early stage of reverse logistics, knowledge will be used to identify where the returned products should go for recycling, disposal, repairing, refurbishing, remanufacturing or reusing. Recovery process can help organization to use less of materials by reusing materials, components or parts of the returned product for a second life in another product. Thus, reverse logistics can be considered as part of sustainable development, and organization can make profit from reverse logistics as additional sources of revenue [5].

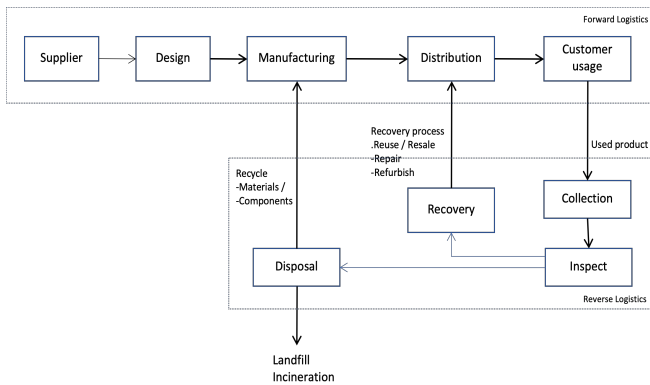


Fig-1. Product lifecycle stage in forward and reverse logistics

The numbers of environmental legislations and regulations are increasing from last decades. They are established in order to protect and control materials and outputs which have an effect on our environment. These legislations vary by each country, in European Union, directives have been introduced such as Waste from Electrical, Electronic Equipment (WEEE) [8] was introduced to prevent, to reuse, to recycle and to dispose the waste of EEE; Restriction of Hazardous Substances (RoHS) [9] was developed to consider the possibility of hazardous

materials/substances in waste products may have bad affects during the processing; Registration, Evaluation, Authorisation and Restriction of CHemicals (REACH) [10] has been forced in June 2007 to protect human health and environment from the risk that can be posed by chemicals. In United State, there are many laws and regulations issued by U.S. Environmental Protection Agency (EPA) [11] to respond to the recycling and waste generation. International Organization for Standardization (ISO provides standard solutions and benefits for many sectors such as business, industry and technology such as ISO14000 family and ISO9000 family which have been introduced to minimize harmful effects on the environment caused by organization's activities [12].

Environmental laws and regulations encourage organization continually to develop their products in sustainability point of view by increasing the efficiency of reusing or substitution of materials, recycling parts or components and recovery returned product. In the recovery process, the effective of reusing and recycling of the returned product can help decreasing environmental impacts and conserving resources and energy. Environmentally Conscious Manufacturing and Product Recovery (ECMPRO) supports the organization to integrate environmental issues into a new product development in term of design, material selection, manufacturing process and managing end-of-life product [13].

Different programs to reduce the environmental impact

through the intelligent design are developed. For example, the design for environment of Hewlett-Packard's products (e.g. printer, laptop, and monitor) helps improving environmental performance by reducing energy used in production and during product life span, reducing the use of materials or use materials less impact to environment and designing product that are easier to recycle or upgrade [14]. Therefore, having a higher degree of knowledge on environmental aspects could balance the organization's operating costs, environmental impact and product quality as an example of Coors brewing company, Dell [15] and SC-Johnson [16].

In the next section we will propose the concept of multi-agent system to manage the knowledge with an environmentally friendly point of

view. The proposed system makes the link between agents who contain the knowledge related to environmental legislations and PLM information systems. This architecture will help the decision makers to consider the environmental impacts of their products.

### **3. The proposed Sustainable Reverse Logistics system**

The proposed system uses concept of agents for developing the knowledge management system. In each stage of the product lifecycle, particularly in the recovery process, users do not know where to search, or do not have time to search, for the knowledge related to environmental impacts; agents can help them to manage those knowledge for decision making. Agents are proactive, and can make the system more efficient by learning from their preceding experience both failures and

successes. Each agent works independently from others, it can use different technique to solve problems. Moreover, it can communicate or interact with other agents sharing its knowledge and information.

The proposed architecture is composed of four agents: *Inspect agent*, *Recover agent*, *Dispose agent* and *Redesign agent*. Each agent can connect to a PLM system called @udros (see Fig-2). All of them have their own knowledge base related to environmental impacts such as environmental laws, standards or rules which are classified in term of Environment, Health and Safety. Each agent communicates with the others using Agent Communication Language (ACL) which is complied with FIPA specification (Foundation for Intelligent Physical Agents) [17]. ACL is a language with specifically



defined syntax and semantics; it is a collection of standard, and represents the basic of communication between agents in multi-agent system.

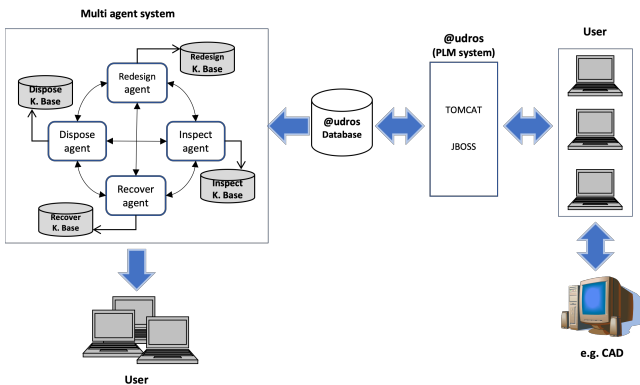


Fig-2. The link between agents and PLM system

- *Inspect agent*: This agent is responsible for analyzing the returned product. For example, the BOM (Bill Of Material) is received from the PLM system. Then, the agent looks for the solution (e.g. how to replace battery, recycle circuit board, repair LCD) in its problem solving base and its knowledge base (see Table-1) which contains rules for inspecting BOM and solutions in order to help user extending the returned

product's life or making the most benefits from parts and materials. The *Inspect agent* also send message to other agents asking for any solutions if they exist (see Fig-3). It then determines the destination of the returned product (ex, repairing, reusing, recycling, refurbishing or redesign).

Table-1.Ex. *Inspect agent* and its Knowledge Base

Agent's	Agent's Behaviors	Agent's Knowledge Base
<b>Agent name:</b> Inspect agent	AnalysisProduct() -IdentifyProduct -AnalysisBOM  CheckQualityOfProduct() -AppProbSolvingCase -AppRuleInKBase  DetermineDestination() -SolutionGivenByUser -ProposeSolution  SendingMessage()	match = MatchCase(ref.Product, existing Product) If(match==true) Get-The-Solution() Else{ For each BOM(CellPhone){ ApplyInspectingRule() Get-The-Solution() } } End-Of-Life: InspectingRule(Battery-Ni-Cd){ Case: Exhaustion & Not-Function Treatment: Dispose and recycle hazardous materials Case: Broken AND Low-Function Treatment: Repair battery or replace it from others }

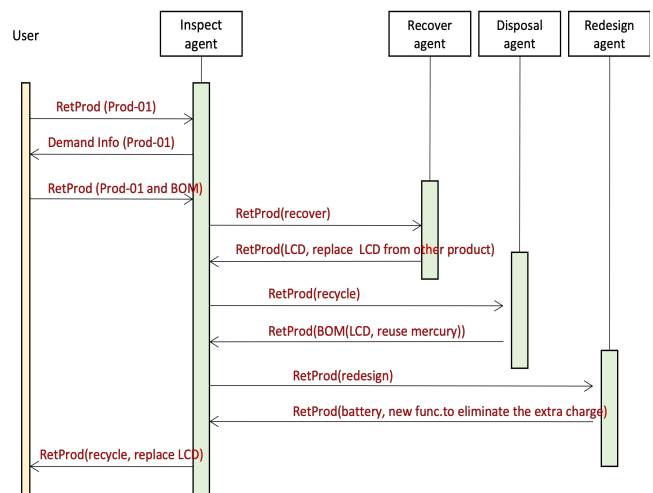


Fig-3.Ex. *Inspect agent* messages to other agents

- *Recover agent*: After receiving the message from *Inspect agent* that the returned product needs to be recovered. The *Recover agent* looks into its knowledge base (KB) for the solution. Its KB contains rules and information about standards, environmental laws and regulations. For example, bicycle's frame needs to be fixed by repainting but painting is bad for environment, waste of resource and poisonous to human's health. The information in the KB will help user on how to use less dangerous toxic chemical in painting with less effect to environment or how to protect human from hazardous gas or substance.

- *Dispose agent*: This agent will classify the problem of parts/components in the environmental impacts point of

view. It is responsible for recycling or reusing materials as much as possible. Its knowledge base (see Table-2) contains information related to eliminate hazardous materials or reuse materials from the returned product. This agent will help organization reducing the use of resources and energy by reusing materials or parts for the second life. For example, in case of reusing bicycle's frame, it needs to be repainted, and the paint may contain lead or mercury substances. The *Dispose agent* sends message to *redesign agent* that both lead and mercury substances should be listed on the label in order to reduce time and cost of recycling

Table-2.Ex. *Dispose agent* and its KnowledgeBase

Agent's Propert	Agent's Behaviors	Agent's Knowledge Base
<b>Agent name:</b> Dispose agent	AnalysisProduct() -IdentifyProduct -AnalysisBOM  TreatMaterialPart() -AppProblemCase -AppRuleInKBase  SendingMessage()	ProblemSolvingCase -ExistingCase -Solutions  Disposal(Battery): - <b>Environment</b> -POV(cadmium): Treatment: -Shouldn't be disposed of in a landfill or Incinerator, disposal cadmium following document (WEEE-Annex II) - <b>Health</b> -POV(cadmium): Treatment: -Hazardous substances such cadmium, should be labeled to avoid risk of

Agent's Property	Agent's Behaviors	Agent's Knowledge Base
		contact (REACH-cadmium, CAS No 7440-43-9) -Safety-POV(cadmium): Treatment: -Give info/disposal to user on the risk of these substances and their effects to env. and human (RECAH) -Labeling to indicate type of materials on product (WEEE)

- *Redesign agent*: Once the *Inspect agent* analyzes and finds out that the returned product needs to be redesigned for environmental performance. The solutions from *Redesign agent's* KB will be presented taking into account the environmental impacts; for example, products can be returned because of misunderstanding or difficulty to understand the instructions. Then creating a clearly understandable instruction manual can reduce the amount of returned products by extending its useful life. *Redesign agent* may also suggest the designer to create a new instruction manual by using recycling paper. This can conserve the energy and resources such as water, woods

and other materials used in paper manufacturing and also minimize the amount of waste generation.

The Fig-4 shows an example of the interaction between agents and the decision maker. Along with the environmental regulations in ISO 14062 [18, 19] and the solutions from agents (e.g. use a few type of materials in product, use low complexity of components or substitute hazardous materials with materials less effect to environment), agents such as *Redesign agent* may propose the changes of the product design to use more modularity components or minimizing number of parts in a product for an easily removable during the disassembly process. These will help saving time, cost and energy in the recycling process.

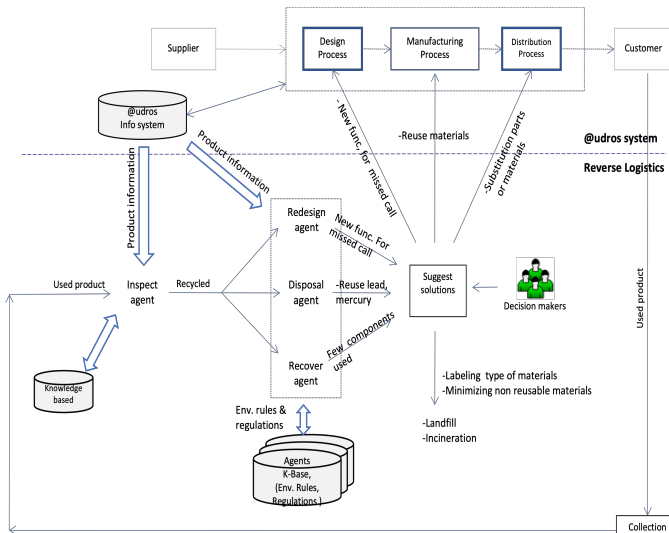


Fig-4. An example of communication between agents

Therefore, the interactions between agents and the use of environmental rules and regulations in their knowledge base encourage users in decision making focusing on environmental impacts. In this research, the prototype of this architecture is developed using JADE (Java Agent Development Framework) platform [20]. JADE is an open source, implemented in java language and is in compliance with FIPA specification.

#### 4. An illustrative of case study

In the case study, we will focus on electrical and electronic product sector. Products in this sector have the similar type of BOM and type of materials used. To validate our architecture, we propose an example of product lifecycle of cell phone. According to the proposed system, each of the returned cell phone will be inspected and checked by the *Inspect agent*. The *Inspect agent* makes the connection to PLM system and gets the information of this returned product such as family model, BOM, date of manufacturing, etc. Then the cell phone's problem (e.g. shorten battery's life, LCD no display or malfunction on circuit board) will be analyzed with information derived from the "problem solving base" by matching to the previous experiences in the *Inspect agent's* knowledge base.

The *Inspect agent* will also apply its problems with its knowledge base to extend this cell phone's useful life as long as possible in order to reduce cost, resources and energy and mainly to reduce the environmental impacts. For example, a cell phone is returned when it reached to its End-Of-Life, the *Inspect agent* analyzes this returned product and its components and determines if they will be reused or recycled, for example, LCD and battery need to be discarded.

After receiving the message from the *Inspect agent* that this returned product needs to be recycled, the *Dispose agent* looks for the technical data of this cell phone such as what are the type of materials made of each component (circuit board, LCD, battery, etc.), numbers of component composed of or any toxic substances (mercury, lead, cadmium, etc.) are used in cell

phone. This product information can be retrieved from the PLM @udros Database.

The *Dispose agent's* knowledge base contains environmental rules and regulations of RoHS, WEEE, REACH and other directives that give information to user during the decision making process. Therefore, the case of recycling or discarding a cell phone's battery which contains materials such as nickel and cadmium or a LCD that composed of glass or plastic which contains mercury, the *Dispose agent* may propose the solutions managing the risks posed by chemicals and provide the appropriate safety information for the user such as the disposal information on how to discards or eliminate these hazardous substances, what are the negative environmental effects and how to discard them safety to human and

environment. And also to give the information of what are the recycled materials should be

reused again in cell phone manufacturing. (see Table-3).

Table-3.Example of solutions and environmental impacts

Agent	Decision making	Environmental impacts
Inspect	Cell phone's destination = recycle	Extend component's life
Disposal (recycle)	Listing type of materials composed of LCD on label (lead, mercury, copper, etc.) (ISO 14062 or the EU Eco-label)	Reduce energy used by save operation time virgin raw material usage
	Information of how to disposal lead, mercury, copper, etc. List of reusable parts/materials (speaker, microphone, lead, copper, aluminum, etc.)	Less emission hazardous gas to environment because of the disposal instruction (REACH and RoHS)
	List of substitution materials List of type of battery on its label	Reduce recycling time and safety repair (ISO 14062 and REACH)
	Reduce disassembly time	Reduce resources and energy used during disassemble phase (ISO 14062)

The *Redesign agent* considers a group of returned cell phone having the same kind of problem. *Redesign agent* introduces solutions that help the designer in product design. For example, customers may return back their cell phones earlier because of a shorten life time of battery due to the extra charge. The additional time, after it has already successfully charge up, causes the cell phone's life time battery depletion. This will increase the amount of the returned cell phones back to organization even they do not reach their end of life. The

*Redesign agent* may suggest a new idea to the designer by designing the cell phone to properly charge and eliminate any extra charging or by developing a new function to record any missed calls while the cell phone is off. With the concept and the practice of ISO14062 related to the integration of environmental aspects into product design and development, the *Redesign agent's* solutions will help in effective use of resource, reducing the use of virgin of raw materials, and decreasing number of the returned cell

phone returned back to organization when they do not reach to their end life. The effective use of resource means that less material and energy is consumed while the amount of product is increased and waste generation is reduced. Consequently, it will extend the cell phone's useful life, reduce the manipulating cost of the returned cell phone, conserving resources and energy while decreasing the waste from cell phone. Thus, environmental performance will be improved.

## **5. Conclusion and Future works**

Environmental legislations and regulations influence the use and reuse of materials, substances and chemicals in products and production processes. The customer awareness of environmental issues is increasing which may change customer's behaviors of

purchasing products and returning of used products. These will result to the improvement of the organization on their products in terms of time, cost and quality and towards the sustainability. This paper proposes a knowledge management system based on multi agent system by making the link between agents' knowledge base and PLM system (@udros system). Each agent shares its knowledge related to environmental issues, regulations or standards in order to help user in decision making particularly in reverse logistics towards the sustainability. The proposed system will encourage organization on reducing the cost of waste dispose, increasing the reuse of materials/parts of product, helping user designing product and reusing efficiently materials in term of sustainability and enhancing the

environmental performance. The concept of ontology will be applied to knowledge management in order to combine different kinds of knowledge about environmental impacts in the recovery process. It will help organization and their users sharing and learning this environmental knowledge across the stage of product lifecycle.

The prototype of the research work is in the process of development and will be validated on a real industrial case study.

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