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Reverse Logistics Information Management Using Ontological Approach

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***Abstract*—**Reverse Logistics (RL) Network is considered as complex and dynamic network that involves many stakeholders such as: suppliers, manufactures, warehouse, retails and costumers, this complexity is inherent in such process due to lack of perfect knowledge or conflicting information. Ontologies on the other hand can be considered as an approach to overcome the problem of sharing knowledge and communication among the various reverse logistics partners. In this paper we propose a semantic representation based on hybrid architecture for building the Ontologies in ascendant way, this method facilitates the semantic reconciliation between the heterogeneous information systems that support reverse logistics processes and product data.

***Keywords*—**Reverse Logistics, information management, heterogeneity, Ontologies, semantic web.

I. Introduction

NOWADAYS more attention is given to reverse logistics, due to the growing environmental legislation, as a process of planning, implementing and controlling the efficient cost effective flow of raw material, in process inventory, finished goods and related information from the point of consumption to the point of origin for the purpose of recapturing value, or proper disposal [1]. The reverse logistics (RL) is the management of any type of returns from any customer with lower costs and greatest profits even if it is very complicated and quite difficult to manage.

One of the most serious problems facing enterprise in the execution of the operation of reverse logistics is uncertainty. This uncertainty arises from the fact that a decision maker does not dispose about information which quantitatively or qualitative is appropriate to describe, prescribe or predict, deterministically and numerically the object system, its behavior or other characteristics [2].

Reference [3] elaborate four main reasons that cause uncertainty in such process: (1) lack of information, (2) abundance of information, (3) conflict evidence, and (4) ambiguity. Indeed to cope with these problems enterprises have invested enormously in reverse logistics information management technology, these systems include data base, information and communication systems such as product data Management PDM, Product Lifecycle Management PLM, enterprise resource planning ERP etc…., however this variety of ICT systems that support reverse logistics network increase the semantic conflicts in information.

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To deal with these semantic conflicts and ensure the interoperability between various data sources involved in reverse logistics network we propose an ontological approach based on hybrid architecture for building the Ontologies in ascendant way starting from local ones. Then we use these Ontologies to build manually the global ontology and define mapping between global and local Ontologies.

The structure of this paper is as follows: Section II describes the information management problem in Reverse logistics network. Some background information and communication systems which support the reverse logistics Processes/Product ontology are stated in section III. The method used for constructing the reverse logistics ontology will be described in Section IV *E*. Section V discusses the resulting structure for reverse logistics Ontologies. Finally, we conclude the paper with some remarks and perspectives.

II. Reverse Logistics Problem and Issues

Information and knowledge management in Reverse Logistics Network integrates information from external and internal elements of the management process of returned product, and aid to allies in Reverse Logistics to take appropriate decision. The decision making performance in each step of reverse logistics process requires specific knowledge or information to be available collectively for a specific application. Due to several factors as: (technology, interoperability, uncertainty sharing modes and others…), sharing and collecting this knowledge and information in real time became the reverse logistics processes issues.

In fact over these past decades companies have invest enormously in Information and communication technologies (ICT) to deal with problem of uncertainty of incoming returns. To achieve this, the reverse logistics to share real time information on the product design for disassembly information, local information and information lifecycle.

Most of information systems adopted for reverse logistics network vary in scale, usage and level of technology these systems including Product data management (PDM), Product lifecycle (PLM) and Enterprise resource planning (ERP), or any other legacy system. Indeed most of product or process information are stored and managed in different ways by these heterogeneous ICT applications, therefore there is the need to identify the existing enterprise application systems and standards, identify the information required for planning of reverse logistics operations, and determine which application these knowledge and information resides in and in which format and tables.

III. Background

A. Reverse Logistic Network

In the literature, most of the authors including [1], [4], [5] have defined a reverse logistics with four main steps: Gate keeping (entry), collection, sorting and disposal. The first step is the recognition of product return, this is very critical to succeed in managing the system. Reference [1] defines it as deciding which products are allowed to enter the system. The second step is the collection permits the retrieval of products from internal or external customers; here the collection may be made in several ways. Detailed sorting (or the third step) decides the fate of each returned item. At that moment, the company may decide what to do with the product, be it subject to inspection, tests, or other manipulations. The last step involves the choice of disposal, the destination of the product. These reverse logistics activities need two other important elements to be integrated as is mentioned by [4] which are shown in Fig. 1: An integrated information system to keep track of what's happening, and coordinating system which is responsible of the overall performance and management of the RL system. Regarding the information in reverse logistics network we must bear in mind that communication and sharing information in real time among different partners play a key role in the successful implementation of these steps.

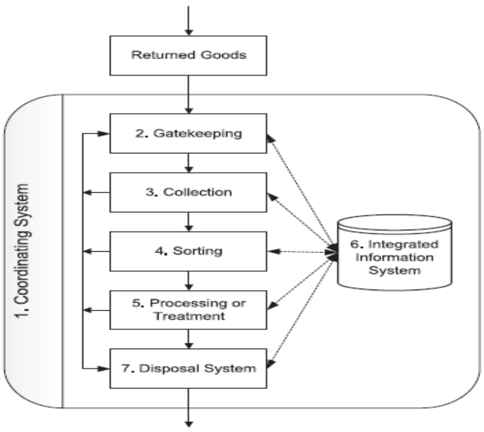

Fig. 1 Reverse logistics system elements [4]

Going back to the essentials of reverse logistics where the recurring theme regarding reverse logistics is that they include Processes related to the recovery of Products with the objective to facilitate re-introduction of return into Marketplaces, so based on these three themes and According to [2] they have developed a three dimensional space with axes of references: Products, Processes and Marketplaces where they place the existing ICT that support reverse logistics network as shown in Fig. 2. The major function of these information systems are listed with more details in the next subsection.

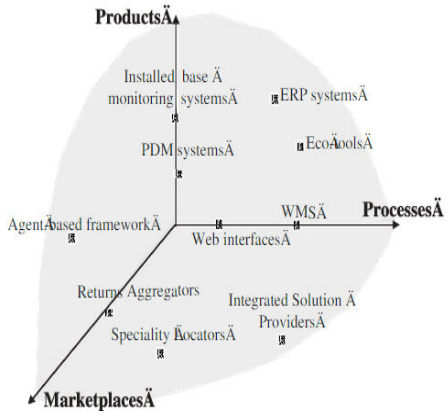

Fig. 2 ICT Systems in Reverse Logistics classification [2]

B. Information and Communication Systems

1) ICT systems that support reverse logistics Product data: Product data Management (PDM) systems are focused on capturing and maintaining information on products and or process through its development entire lifecycle, typical information managed in the PDM module include: Bill of materials, engineering change orders and possible order processing. PDM system is a subset of larger concept of product lifecycle Management PLM system. PLM encompasses the processes needed to launch new products, manage changes to existing products and retire products at the end of their life. According to [2] the main contribution of PDM system is their potential to provide an in informational backbone to integrate Eco-Tools, MRP/ERP systems for returns, warehouse Management (WMS) for returns and thus to support consistent and updated product data through its entire lifecycle. Table I introduces the systems that interact with PDM system and their main functional requirements.

TABLE I
Information Systems for Returns Management [2]

Information Systems	Functional requirements
Eco-Tools	Product design for optimal end of life recovery
MRP/ERP systems	Support different recovery options of returns
WMS systems	Control handling costs of returns

2) ICT systems that support reverse logistics processes: To support the return process, either special purpose reverse logistics ICT have been developed or WMS were extended with proprietary systems to control returns. Warehouse management systems can provide decision making for further recovery options and communication this information to other actors involved in reverse logistics network; also it collects product information to optimize the processing of information.
3) ICT systems that support product data and reverse logistics processes: Here we find the enterprise resource planning ERP systems for product recovery; it is successfully used to support manufacturing and recovery processes. In the other hand we find Eco-Tools system are analytical tools that provide estimations of the

environmental effect of production process, recovery options and the end of life disposal effects of products.

This categorization doesn't include all reverse logistics information systems necessary to efficiently manage Reverse logistics, regarding the literature we must bear in mind that it falls short in defining the reverse logistics ICT systems, their characteristics and their interdependence.

Indeed to improve the use of these ICT systems mentioned above and to enhance the communication between different stakeholders involved in reverse logistics we need to develop new capabilities to ensure semantic interoperability between these heterogeneous systems in order to deal with ambiguous and abundance of information.

C. Ontology

The word ontology first appeared in Aristotle's philosophical essays, where it used to describe the nature and Organization of being. Artificial Intelligence (AI) practitioners are currently using the word ontology to formally represent domains of knowledge.

Ontology as semantic primitive is simply hierarchal description of the important concepts in a domain, coupled with a description of each of these concepts. Ontologies consist of various concepts that include: class, subclass, class hierarchy, instance, slot, value, defaults value, facet, type, cardinality, inheritance, variable and relation [6].

Ontology models support several useful features, main of which are: To share common understanding of the structure of information among human or/and software agents, to enable reuse of domain knowledge, to make domain assumptions explicit, to create a semantic interoperability between the various data sources, to provide formal analysis of terms [7]. The aim of this work is to implement these advantages to establish semantic interoperability between heterogeneous information systems involved in reverse logistics network.

IV. Approach

Faced with the complexity of information management in RL system, and with uncertainty in making decision in reverse network, we have proposed a novel approach which combines between semantic-web technologies and multi-agents paradigm to design a collaborative information management system. It would be a way to communicate and coordinate between the different stakeholders and a way to improve decision making process.

The proposed system consists of four layers. Which are decision-making layer, coordinating system layer, Ontology (semantic web) layer and Database layer, the relation among the four layers are shown in Fig. 3. The major functions of these layers are listed as follows:

A. Decision Making Layer

Decision making is quite difficult process in reverse logistics network leading to the analysis of several variables which are characterized by uncertainty, for this reason, the brain of agent is composed of a Bayesian decision network (BDN) see Fig. 4, this option allows the agent to take the best decision, estimating benefits in cost and time, analyzing and managing uncertain information about return.

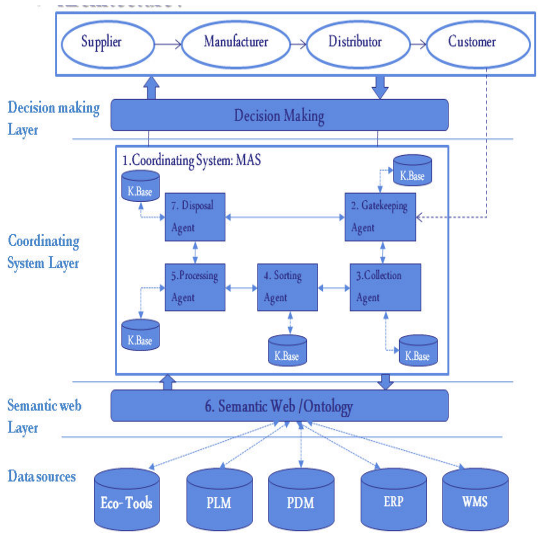

Fig. 3 Proposed Architecture [8]

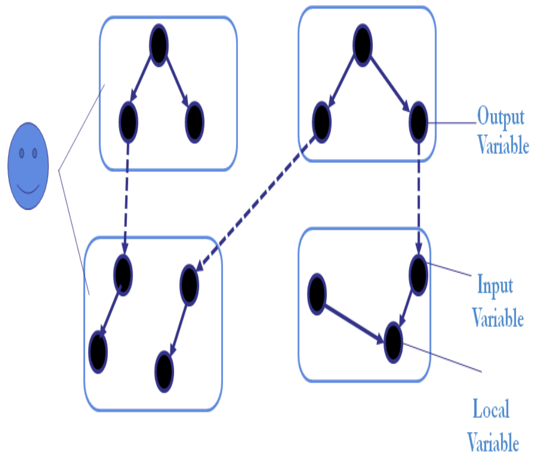

Fig. 4 Multi-agents System Probabilistic Reasoning

B. Coordinating System Layer

It is a multi-agents System composed of 5 agents who act respectively during the 5 steps of reverse process: Gate keeping Agent, Collection Agent, Sorting Agent, Processing Agent and Disposal Agent, each agent has its own knowledge base that contains knowledge about the system environment (as is shown in Fig. 3). Furthermore, each of those is characterized by learning capability to improve its own behavior. These agents communicate with internal resources (local databases) and external (partners of the supply chain).The role of each agent is described in the following section:

1) Gate keeping Agent: Receives request from the customer, to authorize the returned products, based on its knowledge base it takes decision, the fact that his brain is composed of Bayesian decision network allows it to take the best choices.

2) Collection Agent: After receiving a message from the gate keeping agent, the collection agent check its knowledge base which contains rules and information related to transportation mode and cost.
3) Sorting Agent: It receives the returned product, and then it should decide how to treat it based on the information stored in its knowledge base. The next task is to undertake across-verification of the returned product with the return authorization given by gate keeping agent.
4) Processing Agent: Its knowledge base contains information about treatment options such as repair recycle, remanufacturing, upgrade and repackaging of returned products. The Bayesian network allows this agent to take the best decision about every option cited above and respecting certain criteria. After that the product may be subjected to the chosen treatment (recycling, reusing…)
5) Disposal Agent: At the exit of reverse logistics system as is shown in Fig. 2 and after recapturing the product value, this agent is allowed to take decision about shipping cost and also using its knowledge base and its belief should think about how to minimize the redistribution process in cost and time.

C. Ontology Layer

It uses semantics-web technology to improve the flexibility of access in different terms; different system may have their own terms, this layer used to resolve the semantic conflicts arising from the cooperation between different and heterogeneous systems used in reverse logistics network.

D. Data Sources Layer

Many information systems exist in this layer, for example we found respectively for reverse logistics Processes and Product data PDM and PLM systems, ERP, Step standardization, and among others. These systems are mainly used for query, maintenance, and communication; they can effectively utilized by the different actors (human /software agent) through the ontology layer.

Going back to the ontology layer, the aim of this Approach is to formulate all technical data and concepts contributing to definition of reverse logistics ontology, and to enhance the interoperability between different ICT involved in reverse logistics network.

E. Method for Building Ontology Layer

In this section we present the approach of Ontologies construction using the hybrid architecture which proposes an ascending Method for building Ontologies starting from local ones. Then we use these Ontologies to build manually the global ontology and define mapping between global and local Ontologies. We use OWL (Ontology Web Language) to define Ontologies and their mappings.

As depicted in Fig. 5, the Ontology development consists in three phases:

The first phase: Consists in building the local Ontologies, first of all we must analysis the various data sources related to reverse logistics process, this first step consist to analysis each source independently. After that the ontology concepts are defined, their relations and their constraints on their use.

The second phase: Consists in extracting the global ontology starting from various concepts defined in local Ontologies and it contains two steps: firstly analysis of local Ontologies, and as second step: selection of all concepts and solving semantic conflicts to determine the global ontology concepts.

The third phase: This consists in defining mapping between the global and local Ontologies. The global ontology is built from local Ontologies using OWL annotations.

In this paper we treat only the first phase, which concerns the building of the local Ontologies.

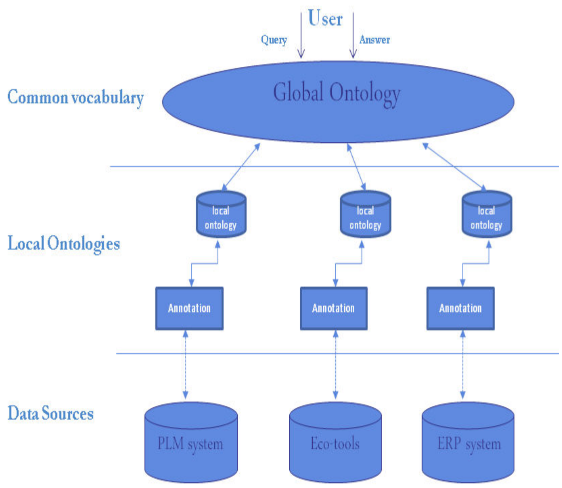

Fig. 5 Approach for constructing the Reverse logistic Ontology

V. Implementation

Reverse Logistics Ontology captures from ERP, PLM, and PDM systems the various concepts and their relationships among each other.

A snapshot of the constructed local Ontologies which are illustrated in Figs. 6-8 these parts focus on modeling the Product and Process concepts, and which are defined differently in each system for example the concept *Physical_product* defined in PLM ontology is equivalent to Product in ERP and PDM Ontologies, also analyzing the Concept *Non_human_Resource* is equivalent to *Physical_resource* and equivalent to *Material_Resource* union *Equipement_Resource* defined in PLM_local Ontology.

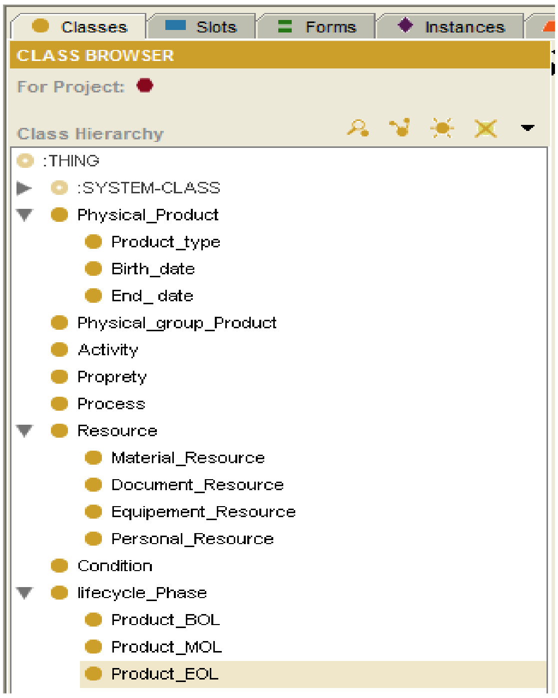

Fig. 6 Fragment of PLM_ local Ontology

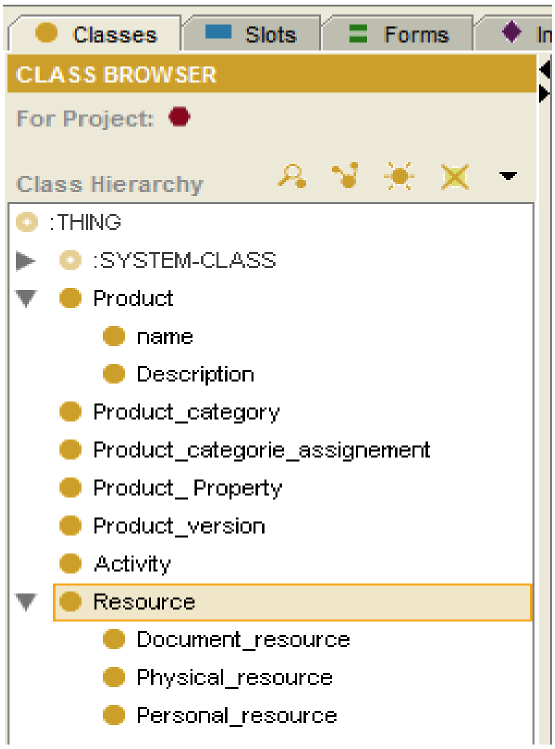

Fig. 7 Fragment of PDM_ local Ontology

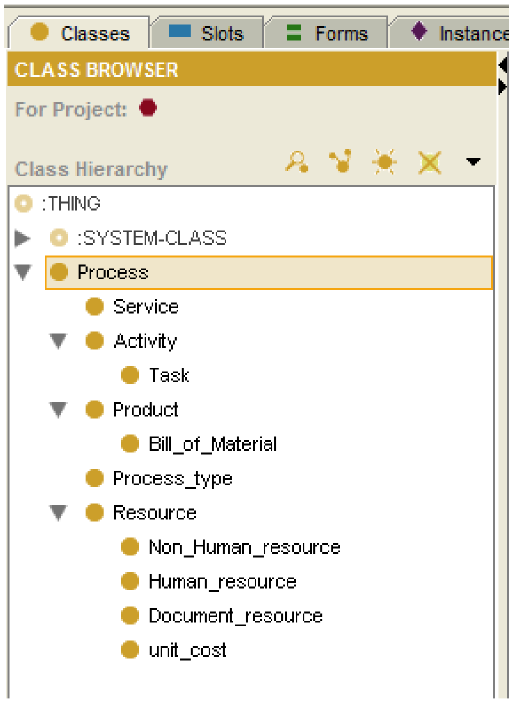

Fig. 8 Fragment of ERP_ local Ontology

VI. Conclusion

In this paper we have treated only the first phase, which concerns the extraction of the local Ontologies. The next step is to use these Ontologies to build manually the global ontology and define mapping between global and local Ontologies. We use OWL (Ontology Web Language) the mappings. In order to enhance the interoperability between ICT systems involved in reverse logistics network.

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