e-RL: The Internet of Things Supported Reverse Logistics for Remanufacture-to-Order

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***Abstract*—With the increasing globalization, there are many sources of uncertainty across the entire reverse logistics for end-of-life product recovery. Information sharing is a key ingredient in this respect because it helps to eradicate potential uncertainties related to various corporate behaviors, especially in remanufacture-to-order aspect. However traditional reverse logistics does not fully address itself to this issue. As a result, the progressive loss of product information as it moves through its lifecycle becomes inevitable which leads to a difficulty in implementing remanufacture-to-order strategy. Motivated by this fact, this study presents an ongoing design of novel reverse logistics (i.e., e-reverse logistics). The Internet of things technology is introduced into this framework for the purpose of keeping product life cycle information integrity. Furthermore, the cooperation and collaboration between actors involved in proposed architecture are treated in multi-agent system philosophy. The design characteristics and working principles of e-reverse logistics are detailed in this paper and it serves as a start point for further implementation.**

Keywords-RL (Reverse Logistic); IoT (Internet of Things); MAS (Multi-Agent System)

I. INTRODUCTION

The focus of this study will be on issues pertaining to IoT (Internet of Things) and RL (Reverse Logistics). Both fields are intended to be joined into research which will investigate the following key research question:

How IoT facilitated e-RL (e-Reverse Logistics) can reduce the blind spots during the EoL (End-of-Life) product recovery process?

End users, collectors, remanufacturers, redistributors and retailers are typically interconnected within networks and it is for this reason that the relationships among all of them are represented as reverse logistic networks. Having enough information about EoL products in which they are involved can be useful in RMTO (Remanufacture-to-Order) planning strategies or in assuring EoL products quality.

Built on intelligent products, the IoT, as a stimulating idea, is fast emerging in the wireless scenario. One of the main challenges faced in this area was the integrity of data as well as using a standard data format for sharing information among different RL participants. Nowadays, several approaches are used to implement information management systems architectures, such as the EPCglobal Network [1] developed by the Auto-ID consortium, the Dialog System [2] developed at the Helsinki University of Technology, the WWAI (World Wide Article Information) system proposed by Trackway, and the ID@URI approach [3]. The EPCglobal Network stands out among the rest because in 2003 it was authorized as a GS1 (Global Standards I) [4]. The GS1 system of standards is the most widely-used supply-network standards system in the world.

Motivated by these facts, in this research, e-RL is introduced, standing for the traditional RL plan with the addition of “e” element. It aims at improving the bridge between information networks and EoL product flows to form a seamless, synchronous network functioning, so that to support RL process.

Briefly, the rest of this article is structured as follows: In Section II, the fundamental of RMTO is briefly introduced; the background of the study is outlined in Section III; Section IV identifies several key backbone of e-RL proposal; Section V details the proposed e-RL strategy; research expectations are concluded in Section VI; finally, the conclusion and future work are drawn in Section VII.

II. REMANUFACTURE-TO-ORDER

The RL/remanufacture has many similarities to its traditional forward logistics/manufacturing counterpart. At the most basic level, both involve supply, production and distribution. The major difference between the two involves the supply side [5], especially in used products (refer to as core) acquisition process [6].

To avoid the uncontrolled accumulation of core inventory, the issue for the RMTO strategy would put remanufacturing industry in the spotlight. This strategy provides an interface of high variety products in relatively low volumes. Often the volumes are low even at the component production stage as there is little scope for common components because cores are remanufactured to customer design and specification. Meanwhile, basis on RMTO strategy can reduce lead time achieved when implementing new manufacturing principles such as lean production [7].

 ISBN: 978-1-61208-172-4

III. BACKGROUND OF THE STUDY

A. Traditional Reverse Logistics

There are many aspects covered by TRL (Traditional Reverse Logistics) research such as network design, vehicle routing problem, and inventory management. Interested readers please refer to [8][9][10] (a three parts comprehensive survey dedicated to TRL) for more details. However, Rogers, *et al*. [11] argued that in practice the lack of information systems infrastructure was one of the largest barriers confronting the RL executives. For example, Ranasinghe, *et al*. [12] reported that it was evident that acceptability and widespread use of product unique identity (such as electronic product code) was visible in many aspects of RL in general and in the field of remanufacture in particular. In the TRL literatures, little research work has been carried out in the context of information technology and more studies are needed to conduct in this direction so that sharing information can become a possible during RL process. Thus a major contribution of this paper lies in that introducing advanced IoT technology into RL area.

B. Remanufacture-to-Order

One of the challenge associated with RMTO is the EoL product information to which the remanufacturer has embraced core acquisition appears equivocal. In a remanufacture system, core acquisition is largely exogenous, and the timing, quantity, and quality of core are much more uncertain than in traditional production distribution systems. Parlikad, *et al*. [13] argue that a fundamental obstacle in achieving more acceptable cores acquisition levels lies in that information related to the cores is often irrecoverably lost after the point of sale. Moreover, a great variety in offered products and the complexities involved in RMTO environment makes it a difficult task to collect a wide range of information. Thus the information sharing, collaboration, and coordination in an effort to improve channel efficiency is a necessity in RMTO area [14][15]. Therefore, by introducing a novel RL structure, this research can be treated as an initial attempt to solve these issues.

IV. BACKBONE OF e-REVERSE LOGISTICS PROPOSAL

e-RL is concerned with the applications of the IoT in RL area. Triggered by advanced computing techniques, one can witness that IoT has far-reaching impacts on citizens, businesses, and society as a whole. Therefore the purpose of this section is to give reader a quick overview of this disruptive idea.

A. What is Internet of Things?

In general, the IoT can be defined as: "*A global network infrastructure, linking physical and virtual objects through the exploitation of data capture and communication capabilities. This infrastructure includes existing and evolving Internet and network developments. It will offer specific object-identification, sensor, actuator and connection capability as the basis for the development of independent federated services and applications. These will be characterized by a high degree of autonomous data capture, event transfer, network connectivity and interoperability* [15]."

Under the term of "IoT", electronic systems can be, in principle, integrated into all conceivable objects around us. This ubiquity of information technology can thus be applied in many fields ranging from industrial production up to individual, daily life. In a word, no human endeavor or thought would be unchanged by IoT.

B. Enabling Technologies

Currently many techniques are driving the progress of IoT at different levels and they can be classified into the following categories.

1) *Context Information Identification Techniques:* The context information identification is the essence of IoT. Currently the technique like PEID (Produt Embeded Information Device) [16] is a potential way of providing real-world entities with certain degree of "intelligence" so that the required level of context awareness can be achieved.

2) *Context Information Resolution Techniques:* Apart from the representation object identification technology, spontaneous interoperation is also a necessary which means after obtaining the complex context information of a physical object provided by a PEID, a database-like infrastructure is required to solve any potential queries. The most important use of context information resolution is to find an information service associated with objects. In practice, EPCglobal network [1] is an industry driven, product centric data management architecture to provide product's traceability based on PEID technology.

V. DESCRIPTION OF PROPOSED E-REVERSE LOGISTICS STRATEGY

A. Key Players of e-Reverse Logistics Strategy

Several actors are involved in proposed e-RL strategy and their characteristics are laid out as follows:

1) *End User:* The roles of end user are twofold: on one hand, anyone who owns an EoL product can be referred to as an end user; on the other hand, end user also means a customer who purchases a remanufactured product directly from remanufacturer's online ordering system. Both groups of end users are coexisted in the marketplace and keep switching roles with each other.

2) *EoL Product Collector:* In the proposed framework, an EoL product collector refers to any business entity that has been authorized for participating EoL product collection activities.

3) *RMTO Firm:* A RMTO firm means a remanufacturer who actually carries out EoL product

remanufacture activities and in the meantime employs RMTO policy. There are several types of RMTO firms in practice such as OEM (Original Equipment Manufacturer) and independent remanufacturers. But in this research they are treated as same since e-RL strategy is engineered to fit them all.

B. Brief Summary of e-Reverse Logistics Strategy Working Principles

The working principles of e-RL strategy is summarized and mapped in Figure 1. The red dashed lines represent the interacting information flows between different players, while the green solid lines show the physical product transportation process.

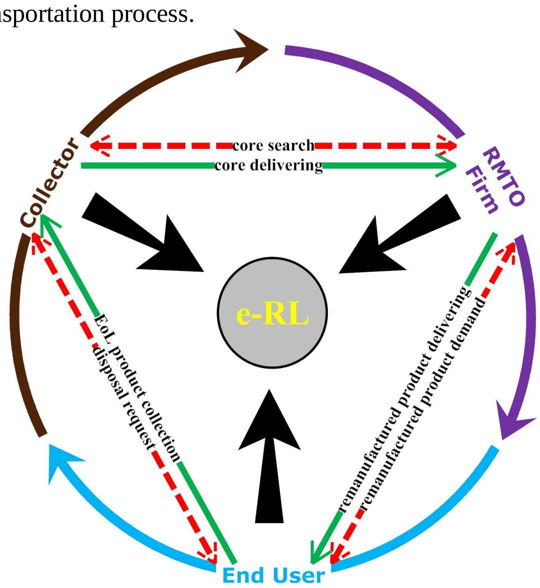

Figure 1. Processes mapping of e-RL strategy.

Normally, in each round of iteration, the e-RL strategy will perform as follows:

- First, the sales department receives an order from a customer through the company's online ordering system.
- In order to perform an evaluation of whether the company should make a bid or not for such order, decision makers must take into account various factors. Among them, the existence of cores is the most influential one. Therefore, the sales department will immediately forward the core existence enquiry to the supply department.
- After receiving such enquiry from the sales department, the supply department will at once set out to search cores through the EPCglobal network.
- The outcome of this lookup stage will be the required cores cannot or can be found. If the answer is no, the supply department will notify the sales department and the latter will reject this particular customer's order; otherwise if the answer is yes, the supply department will receive a list of candidate cores' specifications (i.e., EPC information, it is required to send a query to the EPC information system of all sites until a whole lifecycle data is located.) and such information will be promptly forwarded to production department.
- When candidate cores' EPC information reach the production department, several sub-departments within it (e.g., disassembly, remanufacturing, and inventory departments) will be further consulted to help with the issues like remanufacturability evaluation, remanufacturing cost pre-calculation, and lead time estimation.
- After this stage, the sales department will finally receive a report-like feedback from production department in which all the useful results are outlined. Based on this feedback, the sales department will negotiate with the customer about the price, due date, payment methods, and so on.
- Once a purchasing order has been actually made, the sales department will send a copy to supply department and the latter will start buying cores from collectors.
- As soon as the production department receives physical cores, a designated remanufacturing process will be carried out.
- When a remanufactured product passes the prescribed testing procedure at the production department, it will be finally delivered to the corresponding customer.
- The product will stay in the marketplace until it reaches the end of its current life cycle. By that time, the end user will send a disposal request to EoL product collectors via his mobile device which embedded the NFC (Near Field Communication) tags and later on the allocated collector will sort out the collection issue.

Both the upstream and downstream flows (and the interactions between them) are considered within the concept of e-RL.

VI. Research Expectations

A. Expected Outcomes

- Establishing an architecture of e-RL, which is built on MAS (Multi-Agent System).
- e-RL strategy provides RL participants with a self-developed EPCglobal network to support EoL products' lifecycle information sharing and more effective communication amongst the e-RL participants. With such feature, each RL participant can track and trace the EoL products anywhere and anytime in a timely manner.
- Modeling and simulation of the proposed idea in NetLogo [17] and open source environment.

 ISBN: 978-1-61208-172-4

B. *Expected Contributions*

- Improving the collaborative efficiency and effectiveness in RL.
- Obtaining a better understanding of the value of information in the field of EoL product remanufacture.
- With improved visibility of the e-RL process, companies can respond to customer demand more promptly and efficiently by identifying the scattered cores in the marketplace that need to be acquired for RMTO purpose.
- It should be noted that the system is not limited to RMTO process, it can also integrate such information with other applications to support decision making and communication.

VII. Conclusion and Future Work

The paper presented an idea of e-RL, which is built on IoT and MAS approaches. Main features and working principles were discussed as well. This architecture design of e-RL is the first step towards a successful RMTO policy employment.

As a future work, validating the feasibility and effectiveness of proposed e-RL will be the focus. On one hand, the following work will be carried out to prove the new idea's feasibility: (1) open source solution for RFID event generation and searching and (2) agent-based modeling and simulation. On the other hand, in order to demonstrate the e-RL's effectiveness, the comparison with TRL will be made from the following perspectives: (1) customer's willingness-to-return; (2) processing speed of EoL products collection and (3) robustness of RMTO practitioners responding to market demand.

This position paper treats RL in the context of RMTO from a novel viewpoint. Its architecture characteristics and design features are different with TRL from many aspects. It is expected, by completing the future work plan, the e-RL would serve as a solid basis for employing RMTO strategy in practice which, on a higher level, will make the sustainable development become possible.

Acknowledgment

This work is partially supported by National Research Foundation (NRF), South Africa and Dean's Office, Faculty of Engineering and the Built Environment, University of Johannesburg, South Africa. The authors also gratefully acknowledge the helpful comments and suggestions of the reviewers, which have improved the presentation.

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