e-Reverse Logistics for Remanufacture-to-Order: An Online Auction-based and Multi-Agent System Supported Solution

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Abstract—**Due to the rapid obsolescent nature of consumer products, the remanufacture-to-stock strategy, in which remanufacturers tend to collect certain amount of end-of-life products, remanufacturing them as many as they can and keep these remanufactured products in stock waiting for customers come to buy, is not always an optimal solution. Under this circumstance, remanufacture-to-order policy, as an effective complement, provides a good trade-off for remanufacturers between meeting consumers' demand and, in the meantime, keeping the inventory cost at a lower level. To remanufacture the used items, the manufacturer must retrieve them from the market where they are dispersed among consumers. This is accomplished by means of a reverse logistics chain that is comparable to the new product distribution system in reverse. However, the current reverse logistics do not respond to remanufacture-to-order at an efficient level. Therefore it is a necessity to develop a novel infrastructure, which can deal with these issues. This paper presents a framework called e-reverse logistics that aims at filling this gap. The major features and architecture of the proposed e-reverse logistics are detailed in this work.**

Keywords-EoL (End-of-Life) product recovery; RMTO (Remanufacture-to-Order); RL (Reverse Logistics); auction; MAS (Multi-Agent System)

I. INTRODUCTION

The EoL (End-of-Life) product recovery field has grown considerably during the past decades, due to its economical benefits and environmental requirements. Among various recovery options, remanufacture is an industrial process where EoL products are restored to like-new condition.

As remanufacturers strive to gain a competitive advantage by shortening their quote-to-delivery cycles; driving out operational costs and non-value add processes; keep lower inventories and better customer service etc., many remanufacture companies consider to employ the strategies associated with "RMTO (Remanufacture-to-Order)", where used products are acquired and available as needed to meet needs of remanufacture. RL (Reverse Logistics) plays a key role in achieving this goal. In the literature, the research of RL involves many aspects such as network design and inventory management. Various methods have also been applied to deal with RL; see [1] for a recent survey. It can be seen from this review that the problems encountered in RL always require multi-objective optimization. Therefore, artificial intelligence seems to be a

promising and most widely used tool to deal with these issues.

In [2], an attempt was made to design the structure of e-RL (e-Reverse Logistics) to cope with RMTO. Consequent to the previous study, in this research, a novel solution based on auction theory and agent technology is posed to realize e-RL in the context of RMTO. Present study focuses on the implementation of integrated decision-making processes of various actors within an e-RL process.

The rest of the paper is organized as follows: Section II identifies several key challenges of employing RMTO strategy; the proposed e-RL architecture is detailed in Section III; Section IV describes auction based and multi-agent system supported solution for realizing e-RL; finally, the conclusion and future work of the current research are drawn in Section V.

II. CHALLENGES FOR REMANUFACTURE-TO-ORDER

Remanufacturing has been considered as the transformation of used units, consisting of components and parts, into units that satisfy exactly the same quality and other standards as new units. As seen from Figure 1, the general activities involved in EoL product remanufacturing are as follows:
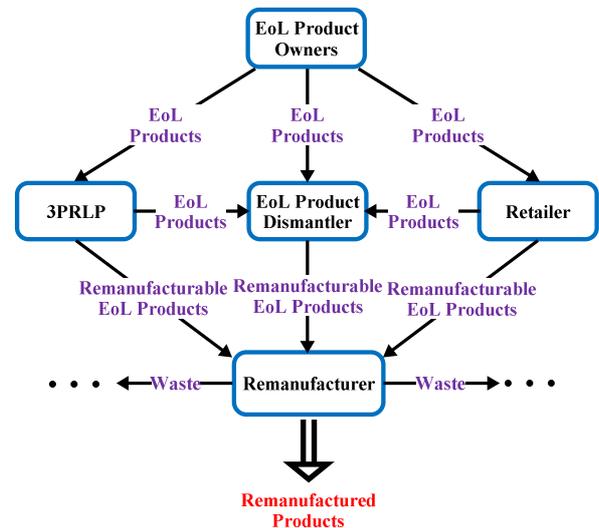

Figure 1. RL process for EoL product remanufacturing.

- Normally, the initial actor group can be identified as the EoL product owners. They are regarded to be the

source of the EoL products emergence. In order to obtain a remanufactured product, an EoL product has to be first collected from its last owners.

- The second group is represented by a set of EoL collectors such as 3PRLP (Third Party Reverse Logistics Provider), authorized EoL product dismantler, and retailer. Though the functionalities of these three types of collectors are slightly different, they act the common role of collecting as many of EoL products as possible from end consumers.

- Remanufacturer is often treated as the third acting group in the practice of EoL product remanufacturing. It is mainly responsible for EoL product disassembly, cleaning, testing, and reassembly. In real world, 100% recovery rate of EoL product is not always achievable, so the remanufacturer not only has to procure new components to finish a remanufactured product, but generating certain amount of product waste and residue as well.

A. The Importance of RMTO

Due to the fact that high uncertainty involved in remanufacturing process such as the problem of imperfect correlation between supply of cores and demand for remanufactured units, the part matching problem and the uncertainties in the quantity and timing of returned products, etc., RMTO is often a practice in industry. Typically an RMTO remanufacturer deals with a customer's enquiry through the following stages:

- First, remanufacturer will receive an order from customer through its ordering system.

- The first stage is an initial evaluation to determine whether the remanufacturer wishes to make a bid for the order. The outcomes of this stage are the decisions to prepare or refuse a bid, and possibly to seek further clarification on the request if it accepts the bid. The availability of cores is one of the reasons that influence remanufacturer's decision.

- In the second stage, the remanufacturer decides how the cost estimates will be prepared. This means specifying how much time should be spent in the estimation process.

- The third stage is the process of preparing the cost estimates themselves. This includes specifying and configuring in detail how the job will be made and also deciding upon material and process plan of the job.

- The final stage is to set the price and lead time to bid. Here the question is to decide the margin of profit to attach to the cost estimates.

After these four stages, the proposal is put to the customer, who may accept it, reject it, or may ask for further negotiations. A further negotiation may just be a request for a lower price or could be a joint exploration of ways to change the specification to reduce the cost. Another possibility on behalf of the customer is to ask the remanufacturer for a new price for a specific delivery date, different to the one proposed by the RMTO remanufacturer [3].

B. The Role of Reverse Logistics

In order to shorten the lead time of a required remanufactured product, it is essential to have, at any time, the parts needed to assembly a new product, which has been ordered. It is made possible if there is on the shelf an exhaustive and comprehensive stock of spare parts (both new and reusable ones). This solution results obviously in a significant cost for any remanufacturer and is not always technically achievable in practice. The alternative strategy is to be able to create an effective required parts supply system to proceed to the remanufacturing process [4]. Under these circumstances, RL, in recent years, have emerged as an important research area due to a tendency towards stricter environmental regulations in industry and an awakening to the economic attraction of recovering products rather than taking the disposal alternative [1]. There are several definitions of RL available in the literature. In this research, the following definition provided by [5] is accepted: RL "*is a process in which a manufacturer systematically accepts previously shipped products or parts from the point for consumption for possible recycling, remanufacturing, or disposal.*"

However, TRL (Traditional Reverse Logistics) process suffers many disadvantages such as core collection speed slow, core delivery delays, and core delivery mistake. Among them, one major challenge faced by the RMTO industry is how to achieve satisfying dearth of good information system while dealing with the inherent variability in TRL. The variability might be caused by a variety of reasons, for example: fluctuating demands, uncertainty of job arrivals, product variety or technological changes. Facing various constraints, the next questions which would probably be asked are: what is the best way to get effective information? How would it be possible to control information to minimize the variability? Meanwhile, there is lacking of system architecture that actually realizes RL.

III. PROPOSED E-REVERSE LOGISTICS ARCHITECTURE

In this section, a brief overview of proposed e-RL is provided. As shown in Figure 2, the realization of e-RL relies on an in-depth understanding of TRL activities together with computer support and communication technologies, namely EPC (Electronic Product Code), NFC (Near Field Communication), and cloud computing.
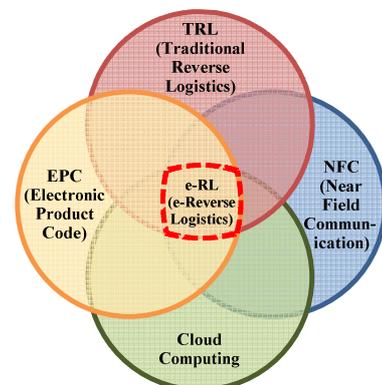
Figure 2. What is e-RL?

In the "e-RL" circle, research is focused on Internet-based decision making models with various distributed sources and human interaction, which would allow the decision structures to be adaptive and more responsive. Additionally, information exchange is required to influence other parties' local decisions, to act coherently and to achieve better results for the entire system. Briefly, the e-RL framework works as follows:

- **Step 1**: The EoL product owners use their NFC enabled mobile device to publish pieces of used product information online, by simply scanning the ready-to-discard products' integrated EPC tag.
- **Step 2**: When a remanufacturer lodges a core request to a 4PLP (Forth Party Logistics Provider), she will search online to look for appropriate EoL product information (i.e., an event been published by used product's last owner). Once 4PLP captures pieces of information, she will immediately forward them to the remanufacturer for further confirmation.
- **Step 3**: Supported by cloud computing, remanufacturer can verify the EoL product information through EPCglobal network, and this will in turn help remanufacturer to evaluate the residue value of a certain used product. Once the remanufacturer decides which core is suitable for his needs, he will send the feedback to 4PLP.
- **Step 4**: When a 4PLP receives a confirmation message, she will distribute the collection orders among a set of other companies with actual transport capacity such as 3PRLP, EoL product dismantler, and retailer.
- **Step 5**: Once a collector successfully gets the order from 4PLP, she will handle any return from the customer to remanufacturer including the physical movement of the goods and so on.

The purpose of establishing e-RL is to achieve lower core acquisition costs for remanufacturer, lower barriers for new suppliers to enter the market of remanufacture, more convenient and environmental conscious ways of discarding EoL products for end customers, and consequently better EoL products remanufacture market efficiency which will in turn make RMTO possible.

Though e-RL is theoretically promising, it still faces some challenges in the real-life implementation: first, the core information provided by 4PLP is multiple and the remanufacturer needs a way to determine which one is the best; second, in order to acquire the collection order from 4PLP, the EoL product collectors such as retailer, 3PRLP and dismantler need an environment that they could negotiate with 4PLP and end customers simultaneously so that a optimal collection solution can be achieved; third, in stead of being passively join the EoL product recovery, which in some degree may decrease the efficiency of whole e-RL process, the end customers also need an environment to support them actively choosing the best option to discard an EoL product; last but not the least, the e-RL process involves many dynamic factors, information and communication technologies do cease these problems to certain degree, but still a more advanced method should be proposed to cope with these dynamic influences.

IV. ONLINE AUCTION BASED AND MULTI-AGENT SYSTEM SUPPORTED SOLUTION FOR e-REVERSE LOGISTICS

In this work, the e-RL process is treated as a cooperative distributed system that integrates participating business entities in RMTO, including various EoL product owners, several EoL product collectors, one or more 4PLPs and remanufacturers. This architecture enables and facilitates common economic services and commerce transactions between the consumers and suppliers, such as brokering, pricing, and negotiation, as well as cross-enterprise integration and cooperation in whole reverse logistics. In the conceptual architecture, the e-RL exists as a collection of economically motivated software agents.
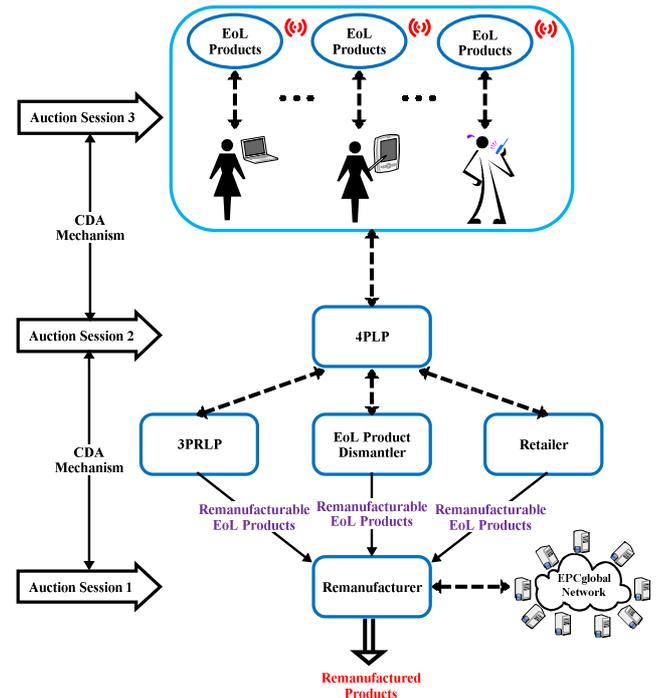

Figure 3. e-RL for RMTO and Auction Sessions.

The online auction based and MAS supported e-RL solution incorporates three auction sessions (see Figure 3) and each of which is viewed as a separate market environment. Different auction mechanisms are employed in every auction session and each participant agent (consumer or supplier) in certain auction session acts independently and contracts to buy or sell at a price agreed upon privately.

A. Auction Sessions

The three auction sessions are detailed in the following subsections:

1) Auction Session 1_Reverse Vickrey Auction: In this session, a remanufacturer will publish the core request information, and a 4PLP will look for a suitable core. The underlying auction mechanism of this session is reverse Vickrey auction. In practice, the reverse auction is often used to refer to purchasing auctions (i.e., the roles of the buyer and the seller are swapped). The reason that Vickrey mechanism is chosen lies in that this auction has shown that

bidding one's true evaluation is the dominant strategy. As such, the Vickrey auction eliminates the need for strategizing. Since there is an easy dominant strategy the bidders do not have to think about what they should do. They just play their dominant strategy and bid their true valuation. Thus makes it a very attractive auction in terms of its efficiency compared with other auction types.

Basically, there are three sets of agents in this session as shown below:

- **Core_Request_Agent**: Representing the role of remanufacturer to ask for cores via Internet.
- **Search_Agent**: It works for 4PLP to look for core information online.
- **Auctioneer_Agent**: It has the capability to carry out the buying task in this session.

In general, Auction Session 1 works as follows: the core_request_agent formulates a purchase-order and assigns it to an auctioneer_agent in Session 1. The auctioneer_agent receives a request from the core_request_agent to process the purchase-order. Consequently, the auctioneer_agent formulates an "announcement" including all the auction parameters supplied by the core_request_agent such as the required item details, quantity, minimum price and desired required deadline. This "announcement" is encapsulated in side a "call-for-bid" message that is sent out to all potential bidder agents registered with the current auction session. At a certain time, the auctioneer_agent send "propose" messages to all search_agents indicating the start of the bidding process. Search_agents express their preferences in the format of universal bidding language and send "bid" message back to the auctioneer_agent. When the purchase deadline reaches, the auctioneer_agent ceases to accept any messages and send a "reject" message for late arriving messages. Immediately after this, the bid evaluation process commences by comparing the structure of aggregated bids against certain classes of bids that indicate an optimal allocation of winners and calculation of payments is ultimately guaranteed. Otherwise, the auctioneer_agent runs a heuristic algorithm in order to arrive at a computationally feasible approximate winner allocation. Finally, the auctioneer_agent sends "inform" messages to all search_agents as well as the core_request_agent to notify them of the auction result. Then each agent is responsible for notifying its representative human player of the auction outcome at the end of this auction session.

2) Auction Session 2_Reverse Combinatorial Auction: In this session, 4PLP will publish the EoL product collection information, and different collectors will bid for packages of various EoL products. Reverse combinatorial auction mechanism will be employed in Auction Session 2. In combinatorial auction setting, the bidders can place bids for sets of items instead of just placing one bid for each item for sale. This is arguably a more attractive option compared with other auction types in the context of this session.

Thus, apart from auctioneer_agent (see Auction Session 1), there are four sets of agents involved in this session:

- **Advertise_Agent**: Working for 4PLP to redistribute the EoL product collection order confirmed by remanufacturer.

- **3PRLP_Agent**: On behalf of 3PRLP to bid EoL products collection.
- **Dismantler_Agent**: Representing EoL products dismantler to bid the collection order.
- **Retailer_Agent**: It stands for retailer to participate in auction.
- **Auctioneer_Agent**: It has the capability to carry out the buying task in session 2.

In principle, this session works as follows: considering a 4PLP, who manages multiple wanted EoL goods to be collected and transported to different destinations, using auctions to make short-term contracts with carriers. When 4PLP has a list transportation orders from remanufacturer, all the carriers that would like to participate in the auction observe the orders and submit their bids for various packages of orders.

3) Auction Session 3_First-Price, Sealed-Bid Auction: In this session, EoL product owners will publish the EoL product information, and the collectors will bid for them. In order to increase the customers' willingness-to-return, the first-price, sealed-bid auction is chosen in this session. Generally, in this auction, each bidder places his bid in a sealed envelope. These bids are given to the auctioneer who then picks the highest bid. The winner must pay his bid amount.

In addition to the same agents as described in Auction Session 2 like 3PRLP_agent, dismantler_agent, retailer_agent, and auctioneer_agent, Auction Session 3 has a new agent set, that is, mobile_agent and its characteristics are described as below:

- **Mobile_Agent**: mobile_agent acts as the EoL product owner. Basically a mobile_agent is capable of moving over a network, such as the Internet, while interacting with foreign hosts, gathering information on behalf of the user and returning to the user after performing its assigned duties.

In general, Auction Session 3 works is this way: when a mobile_agent publish a piece of EoL product information, different bidder agents such as retailer_agent, dismantler_agent and 3PRLP_agent will submit their bids privately and the highest bidder will eventually win the auction and pays his own bidder.

Meanwhile, in order that multiple sellers and multiple buyers can trade simultaneously, CDA (Continuous Double Auction) mechanism is selected as a connection between different auction sessions. In CDA setting, buyers and sellers can continuously update their bids and asks at any time throughout the trading period.

B. Agent Architecture

In a trading framework agents must interact with each other, selling and buying resources. Trading agents should sell for the higher proposal and vice-versa for buying. Each negotiation consists of a sequence of interactions [6] and thus each committee of agents can be viewed as a player in a game [7]. Basically, every agent consists of knowledge and capability packages, each of which is tailored according to the agent's specific role. An auction-based e-RL mainly recognizes eight sets of agents, namely, auctioneer_agent,

core_request_agent, search_agent, advertise_agent, 3PRLP_agent, dismantler_agent, retailer_agent, and mobile_agent. They belong to two types of agents respectively: auctioneer-type agent and bidder-type agent.

In an auctioneer-type agent, the knowledge package contains the information in the agent's memory about the environment and the expected world. This includes the agent self-model, other agents' model, goals that need to be satisfied, possible solutions generated to satisfy each goal, and the local history of the world that consists of all possible local views for an agent at any given time. The agent's knowledge also includes the agent's desires, commitments and intentions toward achieving each goal [8]. The capability package includes the reasoning component, the domain actions component which contains the possible set of domain actions that when executed the state of the world will be changed, and the communication component where the agent sends and receives messages to and from other agents and the outside world. The architecture of auctioneer-type agent is show in Figure 4 (a).

Figure 4.   Architecture of auctioneer-type and bidder-type agent.

When bids via agents' communication messages coming from the bidder-type agents through the communication component assigns a goal-state. The problem-solver component is responsible for the collection of bids and the winner determination process to allocate the item or bundles and their respective prices. Through the interaction component, the auctioneer-type agent sends out an "accept" message at the beginning of auction session informing the supplier-agent that the auction will be carried on its behalf. Once the auction ends, the outcome must be reported to all participants. This information is encapsulated in outgoing messages and sent to the outside world through the communication component.

The role of the bidder-type agent is to express its preferences in bid format and sends "bid" messages out to the auctioneer-type agent. The problem solver component contains a bid class that implements a cyclic behavior in order to respond to incoming messages from the auctioneer-type agent that requests bids. This class implements all the bidder-type agents' tasks such as registrations and bid valuations. Similarly, as shown in Figure 4 (b), the bidder-type agent is designed using the same agent architectural principles.

The bidder-type agent interacts with the consumer via a user-interface designed to express the atomic bids as well as constraints that signify which item/bundle is mutually exclusive. The formulated bid represents the body of the agent's communication message that will be sent to the auctioneer-type agent via the communication module.

V.   CONCLUSION AND FUTURE WORK

This paper presented an ongoing research on developing a robust architecture of e-RL for meeting RMTO requirements. By integrating advanced information technologies, this framework provides the users with a more convenient option of discarding EoL products, and in the meantime, the framework also allows RMTO practitioners to take decisions on accepting or rejecting customers' demand in a more real-time manner.

During the development of the online auction based and MAS supported solution for proposed e-RL model, several difficulties were faced by the authors. The first one was related with a lack of commercial available module that would be able to translate end users' RFID data into appropriate events (i.e., pieces of EoL products information). But according to the literatures, an open source solution called LogicAlloy [9] has been selected as an RFID application level event middleware. LogicAlloy collects and filters the raw data from RFID readers, generates electronic code report and then subscribes the report into other applications. Furthermore, in order to assess the EoL products (i.e., core remanufacturability evaluation), remanufacturers have to access EPCIS (EPC Information Service) database. Currently, such EPCIS repository does not exist. Therefore, another choice of open source software compliant with the EPCIS standard called Fosstrak EPCIS Repository [10] was made in this research. The third difficulty was to model and simulate the proposed solution for e-RL model. By balancing the usability and functionality, NetLogo [11] was chosen in this work. As an agent-based
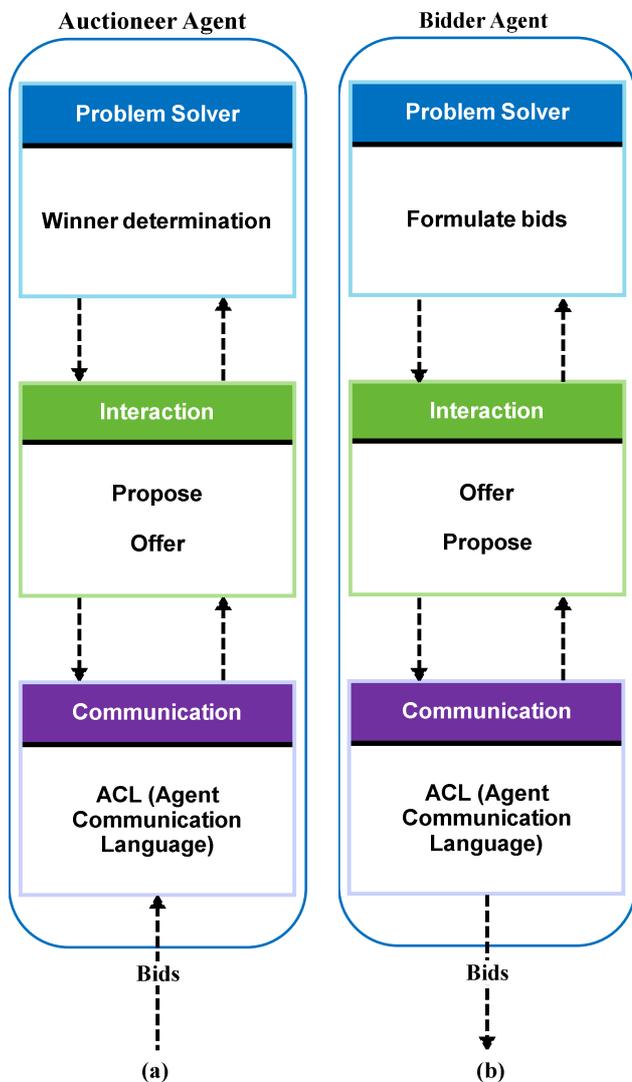
complex system modeling software environment, NetLogo offers modelers the opportunity to give hundreds or thousands of "agents" all operating independently. This makes it possible to explore the connection between the micro-level behavior of individuals and the macro-level patterns that emerge from the interaction of many individuals. It is believed that through the aforementioned steps, the feasibility of e-RL can be demonstrated.

As a future work, the authors intend to develop a comparison scheme to validate the effectiveness of e-RL in contrary to TRL. The building blocks of this scheme must be able to show that: (1) the customers' willingness-to-return rate has been improved which can be measured by consumer happiness index; (2) the response delay has been largely reduced in the context of RMTO and (3) the cooperation degree among various EoL product collectors has been increased.

The current version of this research services as an architectural description and main features' explanation of proposed e-RL. It is believed by combining aforementioned future work plan, the e-RL could permit a robust use of RMTO strategy which, in turn, will make a better contribution to EoL product recovery management.

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