Value Recovery of End of Life Products Using Game Theory Approach

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Abstract— Uncertainty in end-of-life (EOL) product quality, quantity, and timing is a consequence of product supply origins. In today’s market, consumers control the EOL product supply through their decisions to return or not return a specific product. As such, a value recovery enterprise’s efficiency depends on the ability to control and reduce uncertainty in EOL product returns. Strict quality and on-time delivery requirements do not directly translate from traditional, forward supply chains to value recovery enterprises. The electrical and electronic waste (e-waste) is one of the fastest growing waste streams in the world. E-waste comprises of wastes generated from used electronic devices and house hold appliances which are not fit for their original intended use and are destined for recovery, recycling or disposal. Such wastes encompasses wide range of electrical and electronic devices such as computers, hand held cellular phones, personal stereos, including large household appliances such as refrigerators, air conditioners etc. E-wastes contain over 1000 different substances many of which are toxic and potentially hazardous to environment and human health, if these are not handled in an environmentally sound manner. In this study particularly Computers to be taken into consideration as end of life product. Operational models for waste recycle is established based on the theory of closed loop supply chains. And an analysis was centralized on to decentralize decision making in the process of waste recycle with game theory adopted. 

Keywords — Value Recovery, End of Life Products, Electronic Waste, Game Theory.

I. INTRODUCTION

When a product or material reaches its end-of-life, there are several options for recovering some or all of its initial value. Through various recovery strategies, additional value can be found in a product’s original form, its material content, or its embodied energy. There are three primary methods of end of life recovery. In general terms these strategies are material reuse, material recycling, and energy recovery arranged in the typical order of decreasing recovery value. However, which method of recovery is appropriate may ultimately depend upon many additional factors including the condition of the product, the nature of its materials, and the recovery infrastructure available. The best recovery opportunity for any particular product will likely involve a combination of the above strategies.[4]

Collection, reprocessing, and redistribution activities heavily influence the success of end-of-life (EOL) product value recovery (remanufacture, recycle, reuse). EOL product collection is controlled by the consumers’ decision to return, keep, or dispose a product. A lack of control in collection methods can lead to a high level of uncertainty in EOL products and inefficient value recovery enterprises.

A potential control solution is to use incentive- based acquisition schemes. In this paper, three schemes are discussed, and the consumers’ decision to return an EOL product is analysed with one of these schemes. Operational efficiency and improve control. In turn, suppliers comply at the risk of losing profitable contracts. Critical value recovery challenges are EOL product control and reducing uncertainty in EOL product quantity, quality, and timing. This can be explained in part, because it is difficult to apply forward production control principles. The cause of high levels of uncertainty in value recovery enterprises is best illustrated by comparing traditional manufacturing supplier networks to value recovery networks. Traditional manufacturing operations retain a set of suppliers that deliver products on-time and to specifications. However, in value recovery operations, consumers, C, are individual suppliers and they decide when, or if, to return a product and at what quality level. As a product reaches its EOL a consumer analyzes the tradeoffs between available return incentives, potential remaining value, and disposal. Three deciding factors for the consumer are durability, age, and remaining value.[12]

Many items discarded 50 years ago are still in the landfill in which they were disposed. Seeking alternatives in all areas from cradle to cradle will ensure that sustainability is promoted throughout our industry and that future generations benefit. Instead of disposing of furniture when you are through with it, there are some simple alternatives.

• Donate the items to a charity
• Donate the items to a school or other learning institution
• Look for community exchange websites
• Repair, refinish or reupholster existing product
• Habitat for Humanity, Salvation Army
• Home Staging companies (Real Estate)
II. ELECTRONIC WASTE RECOVERY

The global demand for consumer electric and electronic products has been phenomenal in the last two decades. Consumer electric and electronic equipment (EEE) are of particular concern due to high production volumes and characteristically short time scales of technological or stylistic obsolescence leading to the generation of large quantities of obsolete and discarded products otherwise referred to as waste electrical electronic equipment (WEEE) or electronic waste (e-waste). The negative environmental effects of the growing consumption of electronic hardware are most visible in the end-of-life (EoL) stage. The escalating growth in consumer waste in recent years has started to threaten the environment and is posing significant challenge to waste management experts. Product recovery is mainly driven by the escalating deterioration of the environment and aims to minimize the amount of waste sent to landfills by recovering materials and parts from products at their EoL. Product recovery options include remanufacturing, material recovery (recycling), and energy recovery through waste-to-energy facilities. Product recovery reduces the requirement of virgin materials, energy consumption, landfill space and environmental pollution. The recovery of products can lead to profitable business opportunities.

Electronic devices contain up to 60 different elements, many of which are valuable, such as precious and special metals, and some of which are hazardous. Land filling electronics is undesirable for many reasons, including the fact that trace amounts of precious metals including gold, silver and palladium, and larger quantities of metals and alloys including copper, aluminum, and steel used in electronics are not recovered. Recycling electronics reduces the environmental impact of manufacturing products from raw materials, reduces cost and waste, and also lessens the United States (U.S.) dependence on foreign supplies or minerals and other valuable materials found in electronic devices. However, there are many obstacles to recycling electronic waste, including uncertainty surrounding the end-of-life management of electronic devices, lack of recycling infrastructure, lack of regulatory infrastructure, etc.

A. Composition of E Waste

E-waste consists of all waste from electronic and electrical appliances which have reached their end-of-life period or are no longer fit for their original intended use and are destined for recovery, recycling or disposal. It includes computer and its accessories—monitors, printers, keyboards, central processing units; typewriters, mobile phones and chargers, remotes, compact discs, headphones, batteries, LCD/Plasma TVs, air conditioners, refrigerators and other household appliances. The composition of e-waste is diverse and falls under ‘hazardous’ and ‘non-

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It contains over 1000 different substances, many of which are toxic, and creates serious pollution upon disposal. Obsolete computers pose the most significant environmental and health hazard among the e-wastes.

Fig. 2 Typical waste composition by weight (Widmer et al., 2005)

Reuse and recovery of electronics reduces the environmental impact of these products, as well as the impact from primary production of metals and fractions found in electronics. Public Health Factors

Discarded electronics contain a variety of toxic metals, including lead, cadmium, mercury, chromium, and polyvinyl chlorides, and thus the disposal of electronics poses a significant environmental and health risk when not properly handled. Although e-waste represents less than 2% of landfill mass, it contains 70% of the hazardous waste in heavy metals (Jiang et al). The following hazardous components can be found in e-waste (see Table 2).
### Table 1
Concentration of metals in common electronic products

<table>
<thead>
<tr>
<th>Appliances</th>
<th>Average weight (kg)</th>
<th>Fe % weight</th>
<th>Non Fe-metal % weight</th>
<th>Glass % weight</th>
<th>Plastic % weight</th>
<th>Electronic components</th>
<th>Others % weight</th>
</tr>
</thead>
<tbody>
<tr>
<td>Refrigerators and freezers</td>
<td>48</td>
<td>64.4</td>
<td>6</td>
<td>1.4</td>
<td>13</td>
<td>-</td>
<td>15.1</td>
</tr>
<tr>
<td>Personal Computer</td>
<td>29.6</td>
<td>53.3</td>
<td>6.4</td>
<td>15</td>
<td>23.3</td>
<td>17.3</td>
<td>0.7</td>
</tr>
<tr>
<td>TV Sets</td>
<td>36.2</td>
<td>5.3</td>
<td>5.4</td>
<td>62</td>
<td>22.9</td>
<td>0.9</td>
<td>3.5</td>
</tr>
</tbody>
</table>

End-of-Life Options for E-waste
End-of life management options for electronic waste include: (1) Reuse of functional electronics (2) Refurbishment and repair of electronics (3) Reuse and recovery of electronic components (4) End-processing for recovering metals (5) Disposal. Reuse, refurbishment, or repair of electronic products is most desirable since this option increases the lifespan of the electronic product in order to achieve greater resource efficiency. However, in order to reuse electronics, the equipment must be functional and working. The minimum requirements for donation vary depending on the organization receiving the electronics.

Recycling of electronics allows for precious and special metals to be recovered, reduces the environmental impact associated with electronic manufacturing from raw materials, and ensures that hazardous substances in electronics are handled correctly. It should be noted that reuse and recycling are not alternative options; reused products need to be recycled properly and efficiently at the end of their useful life.

#### III. The Indian Scenario

In India, e-waste is becoming an important waste stream in terms of both quantity and toxicity, as typical of any developing economy in transit. During the past two decades, the Indian economy has reported significant changes, as typical of an economy in transit. The Indian electronics industry has emerged as a fast growing sector in terms of production, internal consumption and export (Dimitrakakis et al., 2006). The growth of PC ownership per capita between 1993 and 2000 was 604 per cent as against the world average of 181 per cent during the same period (Sinha-Ketriwal et al., 2005). Contrary to the world average of 27 computers per 1000 people and over 500 computers per 1000 people in the US, India in the year 2004 had one of the lowest PC penetration rate at just 9 computers per 1000 people (Moskalyuk, 2004). However, the size of India’s market in absolute terms is larger than most of the high income countries (Sinha-Ketriwal et al., 2005). The increase in consumption rates of electronic products and higher obsolescence rates are leading to growing problems of e-waste.

The existing system of e-waste processing in India is mostly handled by a very well networked informal sector (Sinha and Mahesh, 2007; Pavan and Dasgupta, 2009) where the disposal and recycling of computer waste are very rudimentary as far as the recycling techniques employed and safe recycling practices are concerned resulting in low recovery of materials; and pose grave environmental and health hazards. The process followed by these recyclers is product reuse, conventional disposal in landfills, open burning and backyard recycling (Dixit, 2007). Most often, the discarded electronic goods finally end-up in landfills along with other municipal waste or are openly burnt releasing toxic and carcinogenic substances into the air. The major sources of e-waste in India are the...
government, public and private sectors, retailers, individual households, PC manufacturing units, the secondary markets and illegally imported scrap (Veena, 2004). According to BAN (2002), India after China is the second largest importer of e-waste from developed countries. Though new computers and peripherals can be imported into the country without any license, the import of used computers can only be made by a licensed dealer, who later can trade them with special permission from the Director General of Foreign Trade (DGFT). However, the import of used computers and other peripherals are free from any kind of duty, under the donation category. The field investigations by Toxics Link, cites large scrap dealers acquiring e-waste not only from the corporate sector and the government but also from illegal imports. These scrap dealers sort the collected units for reuse and recycling markets. Additionally, there are kabaadiwalas, who source functional units from scrap dealers and retailers and sell them to service shops and assemblers. In India, the recycling sector is primarily unorganized and the working conditions are appalling. The mechanism followed in the non-formal recycling sector is shown in Table 2. The removal of copper or aluminium is done by open burning of wires, with the least protection. This process is hazardous since burning of PVC results in the emission of carcinogenic dioxins and furans.

IV. LITERATURE REVIEW

In these states the various sectors like manufacturing, industrial, commercial, institutional, household, research and development are the major contributors for e-waste generation. Both informal and formal stakeholders are participating in e-waste treatment in the country. Presently the informal recyclers are dominating over formal and treating 90 to 95% of the total e-waste generated by environment unfriendly manner in the country [Khattar, 2007]. The EEEs are being manufactured with the composition of more than one thousand substances [MoEF, Guidelines, 2008]. The presence heavy metals like Hg, Pb, Cd, Cr (vi) etc. in the e-wasted components made them hazardous and toxic and attracted the attention of e-waste stakeholders to arrange a separate treatment place for them. Apart from hazardous contents, it has valuable and precious recoverable and recyclable metals in it. In game theory each decision maker plays the game to optimize the decision maker’s own objective, knowing that other players’ decisions affects the decision maker’s objective value and that the decision maker’s decision affects others’ payoffs and decisions. Relatively small number of agents interacting strategically in a system (Gibbons 2001). Petrosjan and Zaccour (2003) computed the characteristic function for all possible coalitions and applied the Shapley value to determine a fair distribution of total cooperative cost among players in a cooperative game of pollution reduction. Casey et al. (2007) reported the application of game theory to the life cycle of bottle packaging and presents a framework for analysis of the choice between refillable and disposable bottles. Qiao-lun et al. (2005) analyzed the efficiencies of price decisions of recycled products between the manufacturer and retailer using game theory. Liu et al. (2011) analyzed the behavior of enterprise, government, and the consumer for their joining the green supply system using game theory. Wang et al. (2010) proposed the application of game theory to create a mixed-strategy static game model of electronic manufacturers and suppliers and optimal mixed-strategy Nash equilibrium was found for developing the measures against the hazardous substances risk of suppliers for electronics manufacturers. Zhang and Jin (2011) presented the pricing model of RSC based on closed-loop supply chain and game theory. Barari et al. (2012) developed a two-player synergetic alliance with the focus on maximizing economic profits by lever-aging the product’s greenness. Gao and Jin (2011) used game theory for an RSC consisting of one manufacturer and two distributors and concluded that the maximum profit can be obtained with the three member enterprises cartelization. M S Abu Bakar* and S Rahimifard described the significant environmental cost associated with management of products at the end-of-life which resulted in the emergence of ‘producer responsibility’ legislations to encourage increase in recovery and recycling practices. The current recycling applications of electrical and electronic waste are often developed on ad hoc basis and mainly attributable to the hidden economic value within used products. However, owing to stricter regulations on end-of-life product recycling, it is now essential to evaluate the recycling costs and environmental benefits of reclaimed products and materials as well as the selection of appropriate recycling strategy. This paper describes the initial investigation in the realization of a computer-aided recycling process planner for electrical and electronic products. The assertion made was such that a systematic approach to producing bespoke eco-efficient recycling process plans for individual products will significantly improve the value recovery from recycling activities.

Yen Ting, Ng a *, Wen Feng, Lu b , Bin, Song proposed concept to decide end-of-life (EoL) product recovery option, followed by methods to quantify product condition. A case study was presented using refrigerator crankshaft to illustrate the implication of product condition on product recovery decision making. The product condition comprises wear-out life of the product, change of dimension and cleanliness level. With thorough understanding of EoL product condition, it enables original equipment manufacturers (OEMs) to make quick and informed decision. Vi Kie Soo *, Matthew Doolan. According to the author Electronic waste (e-waste) is one of the fastest growing waste streams in the world due to the rapid pace of
technology enhancement and development. The exponential growth of e-waste contributes to a rapid increase in the rate of contaminants and waste entering landfills. This paper assessed the waste produced from the recycling of mobile phones in different countries highlighting the material flows and the amount of waste released to the environment. A comparison of mobile phone Printed Circuit Boards (PCBs) recycling through the formal recycling facilities in Malaysia and Australia were used as case studies. The results presented highlight the toxicity of waste and the impact to the environment. This study identifies that the demand for recycled materials, law enforcement, and the e-waste recycling system are significant drivers to reduce the environmental impact of mobile phone recycling.)

Soo-cheol Lee 1, * and Sung-in Na: The main purpose of this paper is to review and compare E-waste management systems operating in East Asian countries in efforts to identify future challenges facing the circulatory economies in the region. The first topic of this paper is cost sharing (physical and financial) as applied to the various stakeholders, including producers, consumers, local governments and recyclers, in the E-waste management systems. The authors’ preliminary result is that the E-waste management systems operating in these East Asian countries have contributed to extended producer responsibility and DfE to some extent, but many challenges remain in their improvement through proper cost sharing among the stakeholders.

S. Chatterjee and Krishna Kumar studied about Electronics waste which is becoming a crisis for the society. Huge accumulation of e-waste and their recycling through primitive means for extraction of precious metals is real concern in the developing countries as e-waste contains hazardous materials. Recycling of e-waste through proper technologies is, however, considered to be a profitable business in developed countries due to the presence of precious metals (including gold, silver etc.) in printed circuit boards (PCBs). The present recycling cost is, however, not viable and thereby huge volume of e-waste is being exported to the developing countries like India, China, Brazil etc., where manpower is inexpensive and enforcement of environmental laws is not so stringent. This article is proposing an outsourcing model where equal participation of the formal and non-formal sector is ensured to make the e-waste management business a profitable one.

Zhang Qian 1, Shen Zhongming: Operational models for waste recycle is established based on the theory of closed loop supply chains and an analysis cast on centralized and decentralized decision making in the process of waste recycle with game theory adopted. The present situation and existing problems are subsequently discussed before an accumulate data process of the data of 9 experimental provinces and 19 other provinces built on which an empirical study is performed on the effects that selling price and recycling price respectively have on sales volume and recycle volume. Economics of Electronic Waste Disposal Regulations The components of municipal solid waste are rapidly changing. Obsolete computers, cellular phones, televisions, and many other outdated electronics, all known as electronic waste, are becoming a greater proportion of the global municipal waste stream million tons of electronic waste per year. Sirajuddin Ahmed studied the increase in sales of electronic goods and their rapid obsolescence which has resulted in generation of electronic waste, which is popularly known as e-waste. Changing trends and exponential growth of electronics industry, increase of electrical and electronic products, consumption rates and higher obsolescence rate leads to higher generation of e-waste. This paper presented a study of the amount of e-waste generated by different sectors and devices during the last few years and the trend it follows. It included the prediction of amount of E-waste trend.

IV. RESEARCH METHODOLOGY

A. Game Theory

In order to discuss game theory, it is first necessary to define a game. Ken Binmore states: "A game is being played by a group of individuals whenever the fate of an individual in the group depends not only on his own actions but also on the actions of the rest of the individuals in the group" (1990, 1). The essence is dependent interactions between two or more persons; the implication is a framework for the analysis of these strategic (dependent) decisions. The use of the word "game" does not limit its application to the trivial or merely entertaining; rather, "game" is used in the sense of rules, strategies, and preferences of outcome, also when each player knows each other’s options and preferences (Schelling 1988). Clearly, many social situations fit into this description of "game."

Dependent decisions resemble crystals which must be reduced to their simplest pattern to be fully understood and amenable to manipulation. The first step towards understanding is to rid dependent social situations of all but detail relevant to the decision at hand. "[Game theorists] are simply attempting to separate those features of a problem that are susceptible to uncontroversial rational analysis from those that are not" (Binmore 1992, 4). By focusing only on those aspects of the problem which factor into the decision process, one may avoid many of the emotional and moral questions which "muddy the water." Sidestepping these questions is appropriate since the analysis is of the situation and not of the individuals (Schelling 1988).

A different question of what criteria individuals use in the decision process is a rationality assumption question. Game theorists assume that players optimize or maximize their outcomes. Implicit assumptions of player rationality and perfect knowledge of all options round out the self-interested
economic man. Such an assumption does not restrict one from varying the goals of the economic man, and therefore his rationality. As discussed earlier, attitudes and preferences are part of the situation and "game theory takes them as data". The game model employed is based on the player's strategy choice. Strategies embody all decisions necessary for one player to finish a game.

Thus, the games are presented in normal, bi matrix form, that is, in matrix form where each cell contains two payoff entries. The strategy choices for each player define the rows or columns. Within each cell of the resulting matrix are the payoffs for that strategy combination. It is these payoffs which the players seek to maximize.

In game theory there are a few things which must be explicit before beginning. These "rules of the game" include defining the players, the rules of the game, information available to each player, and the consequences of that action for all (Harsanyi 1977, 88). These plus the rationality assumptions combine to form the game theory model.

Nash equilibrium

A strategy game is a model of interacting decision makers. Here each player has a set of possible actions. The model captures the interaction between the players by allowing each player to be affected not only by his/her actions but also by the actions of all players. More precisely, a strategic game is defined as:

A strategic game (with ordinal preferences) consists of:

- A set of players
- For each player, there is a unique set of actions (or pure strategies)
- For each player, preferences over the set of action profile (pay-off or utility function)
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In a strategic game, it is frequently convenient to specify the player's preferences through a pay-off function. Here the payoffs have only ordinal significance. For example, if a player's payoffs to the action profiles a, b and c are 1, 2 and 10, then the only conclusion that can be made is that the player prefers c to b and b to a; the numbers do not imply that the preferences between c and b is stronger than her preference between a and b. Time is completely absent from the model. The idea is that each player chooses her action once and for all, while all the players choose their actions simultaneously, in the sense that no player is informed, when he chooses his action and of the action chosen by any other player. Each player chooses the best available action and this best available action depends in general, on the other player's actions. Therefore, each player must form a belief about the other player's actions and such belief is derived from his/her past experience playing the game, and that this experience is sufficiently extensive that he/she knows how his/her opponents will behave.

V CONCLUSION

When a product or material reaches its end-of-life, there are several options for recovering some or all of its initial value. Through various recovery strategies, additional value can be found in a product's original form, its material content, or its embodied energy. There are three primary methods of end of life recovery. In general terms these strategies are material reuse, material recycling, and energy recovery arranged in the typical order of decreasing recovery value. However, which method of recovery is appropriate may ultimately depend upon many additional factors including the condition of the product, the nature of its materials, and the recovery infrastructure available. The best recovery opportunity for any particular product will likely involve a combination of the above strategies. The e-waste recycling is becoming non-viable business in western countries due to high cost of labour, transportation, electric power etc. The volume of e-waste is, however, enhancing alarmingly in the world. Due to presence of the toxic elements, it is all the more dangerous for the society to stock them without carrying out appropriate disposal. It is also observed that the growth of consumption of the electronics products and subsequent disposal are increasing in the developing countries, whereas, the consumption rate in the developed countries are getting saturated. Computer is used as the product in this case study to illustrate the implication of product condition on recovery cost and environmental impact. In conclusion, the proposed concept is able to stimulate and support value recovery is economically efficient to reduce overall waste generation over land filling. Game theory modelling helps to prove value recovery is the dominant strategy to avoid excess generation of end of life products to prevent environmental pollution.

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