Rethinking the Utility of Waste

A look into a waste utility network model of circular-economic enterprise(s)

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Abstract

With the growth of the world's population and continued phasing of technology, waste will correspondingly increase significantly. Future companies must leverage this as a resource and invest in technologies that enable the disassembly and breakdown of these used products into useful raw materials. Characteristic of this realization will be a new model of supply chain involving a complex network of distribution of used products amongst multiple enterprises. Major challenges include optimizing this network and assigning utility (relative to an enterprise) to used products. Thus necessitating research in areas of game theory optimization, reinforcement learning, network theory, utility analysis, and much more. The motivation and discussion behind a waste utility network model in 2035, its research challenges, necessary technology, and partnerships are discussed in this work.

1 Introduction

The world's population is expected to reach 8.8 billion by 2035, according to a United Nations Department of Economic and Social Affairs report [1]. While this will result in significant increases in demand of products and provisions, what population increase also entails is an exponential increase in waste produced as a result of most current linear-economic models. Such models are characterized by a "take-make-dispose" resource model [2].

Current methodologies of mitigating waste (especially hazardous) are driven by environmental regulations and social consciousness, with some cases of monetary incentives such as pay-as-you-throw programs [3]. However, in the future as natural resources diminish and waste accumulates – there will be increasing economic incentives and benefits to mitigating waste and exploring new ways to repurpose waste into a larger variety of valuable, renewable products. Often, municipalities especially in the western states of the US will export their recycling to China for processing (accounting for one-third of all US recyclables), resulting in significant unnecessary shipping costs. Furthermore, aspirational recycling and consideration of outsourced processing as "foreign garbage" results in much of this useful material being discarded [4].

Predicted waste is evident simply from current statistics amongst many services and products, but particularly concerning highlights in 2035 will include the widespread electrification of vehicles and the continued pattern of upgrading of technology versions or transitions. Multiple countries already have set bans on fossil fuel vehicles: China, France, and the United Kingdom by 2040, and countries such as India, Ireland, Israel, Netherlands, and Sweden even earlier by 2030 [5]; when fossil-fuel vehicles become obsolete, this will pose a massive waste problem – but also a significant opportunity for the breakdown, repurposement, and recycling of product materials. Likewise, a particularly important example of a transitional stage that can be seen in the near future involves the upgrade of devices to 5^{th} generation communication networks [6]. Because of technology companies "speeding the pace of obsolescence," of products, old products are often designed to be incompatible with new technology [7] – while this nets revenue with each upgrade, a great deal of capital loss is occurring in waste; this waste should be leveraged to produce new and useful products, perhaps even finding demand for material in different sectors than the original products categorization.

A trend in a successful enterprise towards easier processing of product waste to useful material will be driven by product redesign with the assistance of research in materials science. This product redesign will require the reinvention of design heuristics by incorporating new materials and design practices that incorporate consumer waste and consider ease of product breakdown. Enterprise will have to incorporate waste not only produced by the enterprise's own products, but also from others.

In the following section

we look at the characteristics for a successful enterprise in 2035. In section 3 we present the proposed mode of operation. Section 4 addresses some of the current research challenges for our model. Section 5 details the necessary technology to support this enterprise. Section 6 outlines necessary partnerships the enterprise must maintain to be successful.

2 Characteristics

Companies in 2035 need new approaches to design by incorporating new measures of product life cycle analysis and new design heuristics that account for the resource potential of product waste (from other enterprise) as well as the rise in cost of raw materials. Thus, the assumptions for the implementation and success of this model include an increase in amount of products that can be broken down into useful material, an increase in the utility of waste and an increase in the cost of raw materials in 2035.

Research challenges will include the redesign of products without radical loss in other metrics such as performance. Challenges will include the enhanced processing of used product to useful material(s). Enhancement in the supply-chain delivery and communication of the enterprise with consumers (especially complexities of distant consumers and waste sites such as rural or internationally) will need exploration. Finally, developing a business model that considers consumer and government incentive – which may naturally arise from capitalism in the heightening of cost to produce with raw extracted material versus harnessing new potential utility in product waste must be explored. More specific research challenges are introduced in Section 4.

Successful enterprise will be defined by an adjustment of current manufacturing models such as continuous or process, intermittent or process batch and most easily through flexible manufacturing systems and common design models such as sequential and more common concurrent design practice, specifically to include the intake and outtake of used product and useful materials; the optimization and best practice of this intake and outtake will be highly complex. Current related models to this field include the heuristic design for recycling, as well as a closed-loop supply chain or circular supply chain [8,9]. While these models propose similar ideology within a single company's scope, what is proposed here is the interlinking of these types of enterprise models by increasing the utility of consumer waste and then trading constituent product materials (currently just product waste) in an optimal fashion for a given enterprise.

This model will additionally include monetary incentive to the consumer to reallocate waste (which now has utility in our assumption of developments in waste processing technologies and materials science) to various enterprise, enhancing likelihood of consumers redistributing waste from landfills and disposal to private materials processing plants under the umbrella of successful future enterprise. This concept is visualized in the following section.

3 Mode of Operation

To highlight the significant changes and ideal mode of operation, first introduced is a common current state of operations. Figure 1 shows this current mode of product material distribution.

In relation to the figures below:

$$P_{i,j} \text{ is a product of type } j, \text{consisting of materials } i$$
$$P'_{i,j} \text{ is a used product}$$
$$E_j \text{ is an enterprise that produces product of type } j$$
$$C_{k,j} \text{ is a consumer } k, \text{purchasing product } j$$

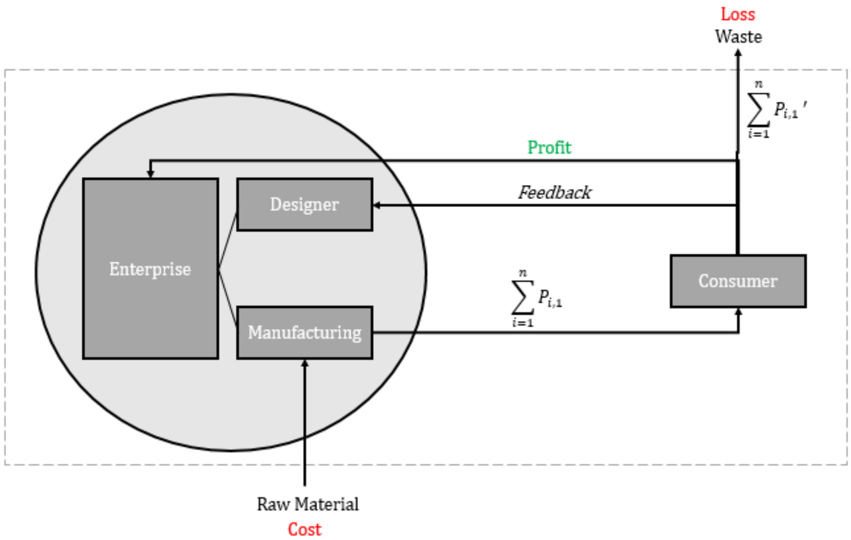

Figure 1: Current Common Model

Figure 1 simply shows an entire product P of type *j* = 1, consisting of all materials in the summation of *i* = 1 to *n* number of materials being sent to a consumer, and that consumer throwing away the used product, denoted by a prime, at the end of its life. Looking forward, Figure 2 shows a transitional state a company could consider in moving towards a waste utility model.

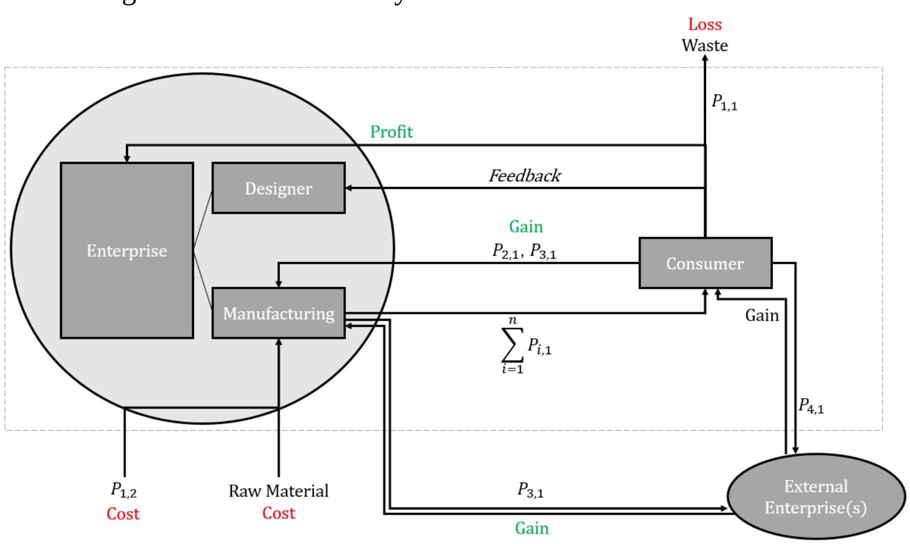

Figure 2: Transitional Model

In Figure 2, an enterprise begins to incorporate used product material from a separate enterprise, denoted by j = 2, consisting of material i = 1. It additionally intakes material from its own product j =1, materials i = 2, and i = 3. The manufacturer has the option to sell off this refined used product material i = 3 to the external enterprise. Furthermore, the model takes into account the consumer's potential of selling a different used product material i = 4 to an external enterprise. A potential mode of operation for an ideal enterprise in 2035 is shown in Figure 3 below, outlining the complexities in resource allocation and communication between nodes of enterprises and consumers.

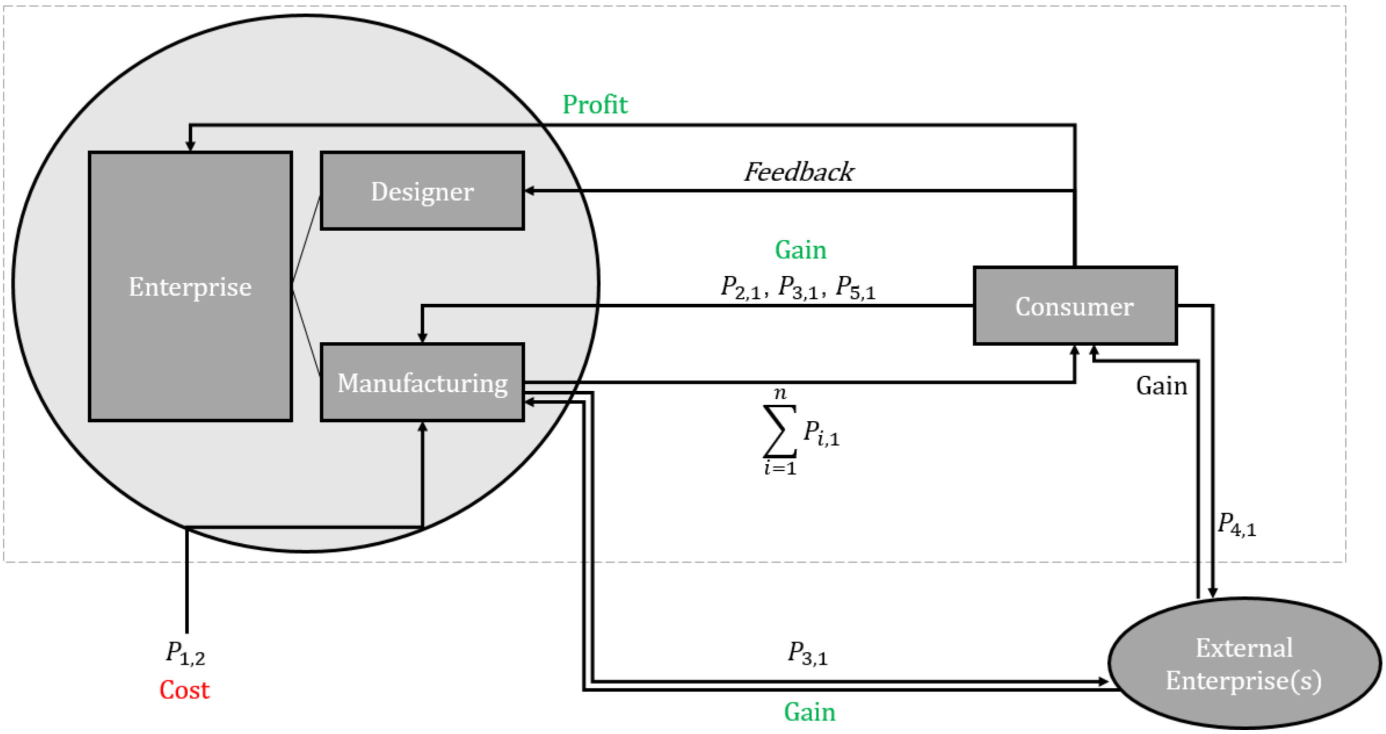

Figure 3: Ideal Waste Utility Enterprise Model

Figure 3 shows an ideal company model in 2035 that incorporates intake of materials i of used products j from various enterprise(s), as well as the selling of material from the enterprise's own product, received from the consumer. It also proposes a direct distribution of some materials from the consumer to other enterprise, highlighting a potential area of competition in the future.

In a theoretical case, Figure 3 consists of the following materials:

$$P_{i,1} = [Copper, Aluminum, Steel, Polyethylene, Polypropylene]$$

$$j = 1 == [Car], \qquad j = 2 == [Stereo]$$

The model in general shows a product, P, that consists of i materials, labeled as j = 1 for product 1. This enterprise produces product type j = 1. The consumer then sends back to the manufacturer portions of this used product that consist of material i = 2, 3, and 5; these could correspond to aluminum, steel, and polypropylene. The consumer also is able to send the external enterprise a part of the used product consistent of material i = 4, which could correspond to polyethylene.

The manufacturer is also able to intake material from a different type of used product j = 2, of material type i = 1, which in our case represents copper; thus the manufacturer has two sources of material intake. Furthermore, the manufacturer could sell portions of the used product from the consumer that are in surplus to another enterprise. In this case, the manufacturer is selling a surplus of its own used product j = 1 consisting of material i = 3, or steel, to an external enterprise.

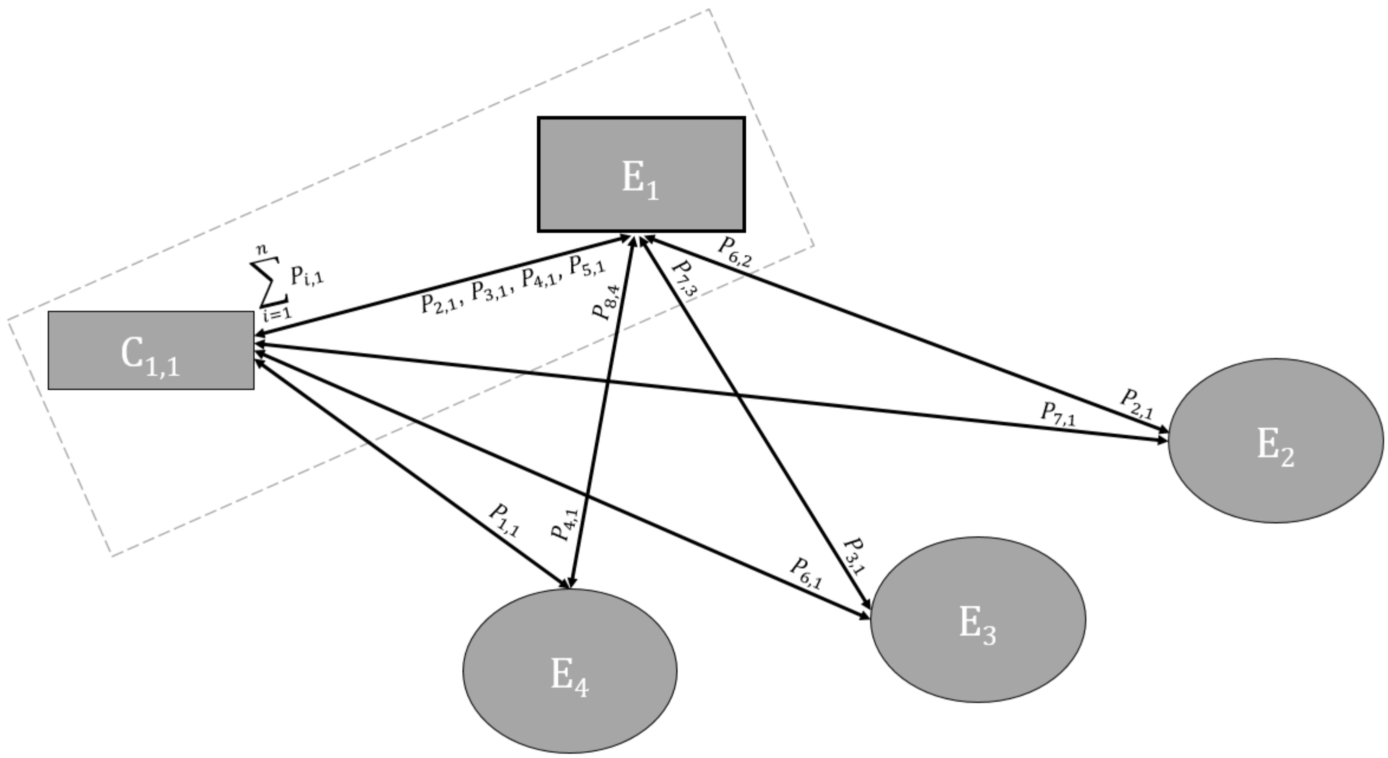

Figure 4: Network of Product and Material Distribution

Figure 4 shows a simplified network of product material distribution across various enterprises. It shows the exchange of only one product from enterprise 1, E_1 to consumer 1, C_1. Certainly, this model becomes highly complex when considering more products distributed from n enterprises to n consumers. Further complexity arises when n enterprises distributes multiple products to m consumers. This future resource allocation model, leveraging waste utility in 2035 will be challenging to optimize. Proposed methodology and challenges for optimizing material routing in the future are detailed further in the following section.

In this model, enterprise E_1 is selling product j = 1 to the consumer k = 1, who only desires product j = 1. The consumer is sending used product waste to all four enterprises, in the form of i = 1, 2 … 7 different materials; the enterprises in return would likely monetarily compensate the consumer (not shown in Figure 4). Each enterprise is also trading material from its own used product; for instance, enterprise E_2 is selling enterprise E_1 its own product j = 2, made of material i = 6. In return, or unrelated, company E_1 is selling enterprise E_2 its own used product j = 2, made of material i = 2.

4 Research Challenges

The most significant research challenges for this model (1) involve characterizing the utility of used products, and (2) optimizing resource intake and outtake for an enterprise considering this waste utility. Secondary but important research challenges less focused on in this essay include (3) product design heuristics that account for this new waste utility resource model, and (4) communication and physical transportation of resources between enterprises and consumers.

(1) Utility of the used product will likely be a function of multiple factors: ease of material discretization or separation, individual material market value, material manufacturability, and cost of resource distribution and allocation. Mathematically modeling and accounting for the temporal dynamics within each of these factors with the goal of characterizing a products waste utility will be especially challenging. Research measures will include further development of characterization techniques similar to those presented by Behdad, such as:
   a. *Mixed integer linear programming*
   b. *Multi-attribute utility analysis*

   Such techniques involve determining the decision process behind product disassembly to mine the value-added embedded in a product, and then how to best utilize the value-added once it is recovered, by using a transition matrix integrated with mixed integer linear programming [10]. In considering uncertainty of disassembly and reassembly models with factors of time and damage potential, graph-based integer linear programming combined with multi-attribute utility analysis has high potential for understanding used product utility [11].

(2) Especially challenging will be a company's model for optimizing the resource allocation in response to supply and demand from different companies, as well as individual consumers; this trading of resources will have a massive system dynamic that effects all players involved in complex mannerisms. Such a network will require the further development of research in optimization and controls techniques which include but are not limited:
   a. *Game theory*
   b. *Network theory: combinatorial optimization*
   c. *Machine learning: reinforcement learning, neural networks*
   d. *Uncertainty in complex networks*

   Specific examples of current work with high applicability in modeling this buy-sell network between consumers and enterprises can be interpreted from Odonkor's and Lewis' modeling of energy-building clusters. Within this work, energy producing and consuming building networks are optimized to buy and sell energy to each other, as well as the grid; Methods utilized include Monte-Carlo Pareto Band generation to train generalized linear models as well as reinforcement learning techniques to find optimum operational strategies [12,13]. An example of a study with potential applicability to modeling the uncertainty of this waste utility network is detailed by Mashhadi et al., factoring in uncertainty in market demand, quantity, and quality of returns in regards to remanufacturing; this is accomplished by utilizing stochastic optimization with chance-constrained programming [14]. A final example which holds great applicability and potential involves various game theory optimization techniques, where in this case, the various enterprises and consumers are the players; where consumers are attempting to achieve the lowest cost and highest sell value of their used products, and enterprises are attempting to find the best balance with low used product material costs and high sell value of their new products. Significant literature on game theory approaches to optimization are presented by Rao, and can continue to be further developed upon in the future [15].

(3) Developing heuristics for product redesign that require maintaining or maximizing performance while taking into account design for recycling, utility of waste will be challenging. Most heuristic models are developed from surveys and observational studies involving preexisting design experts who have had considerable experience, and their validation is coupled with design studies often involving students in individual and team design scenarios; an example of such can be found by Fillingim et al., where design heuristics are developed from NASA's JPL architecture team [16]. It will take a great deal of time to develop the exemplified level of expertise, far past 2035 for new product design heuristics to be developed, unless new techniques for developing heuristic design while incorporating the waste utility model are researched.

(4) Communication and logistics of transportation of resources will necessitate developments in big data, and could potentially be enhanced with upcoming developments of mass collaboration. Big data will have to be communicated quickly between enterprises and customers because of the temporal nature of material market pricing and demand, it must be secure, and will involve significant reliance on intelligent sensor based product implementations for assisting the evaluation of used product utility. The potential of utilizing intelligent sensors for products is paralleled in a study by Esmaeilian et al., involving the heightened potential of waste management through "smart cities" [17].

An enterprise will need to invest in research of these four major aforementioned challenges, in order to develop a successful business model that leverages the predicted waste utility model in 2035.

5 Technology

Technology necessary for the success of this enterprise and its employees will involve the development of the internet of things, increase in computational power and communications via developments in transistor technology and higher frequency communication [18]. Embedded product sensor technology will rely on networks to communicate long distances to users and will operate efficiently through low power, self-sufficient techniques harnessing piezo-electric and thermoelectric technology [19]. Fast and reliable networks of transportation to allocate useful used products and their discretized materials to various enterprises will be necessary for this model to succeed; such technology might involve high speed railways, autonomous electrified vehicles to mitigate cost of labor, and also unmanned aerial vehicle delivery systems coupled in conjunction with other transport methods [20]. New technology and techniques in image processing and robotics will be crucial in used product breakdown and disassembly [21]. And finally, with communication networks of this scale, security through methods such as block chain will be characteristic of enterprise in 2035 [22].

6 Partnerships

Partnerships will be particularly essential in academia, industry, and in relationships with government bodies and individual consumers.

Academia will be absolutely necessary for the development of new computational optimization techniques, mentioned in Section 4. The development of communication systems, and application of new heuristics to product design with consideration to a network waste utility model will require extensive and creative research; considerations of the increase in cost of raw material versus recycled waste material will be factored into product design and economic strategies. Psychological and sociological partnerships within academia must be made to understand the consumer's willingness to adapt this type of model, submitting used products for monetary gain to private disassembly and recycling facilities.

Industry must be willing to collaborate with other enterprise, or merely trade with other enterprise for sourced materials in this new fashion that adds the complexity of used product value as a resource for raw materials. Sharing and collaboration of big data on used product utility and value will likely be mutually beneficial for optimizing this model amongst multiple players.

Government will be greatly affected by the potential reduction in waste and recycling – which might now be transported to privately owned repurposement facilities that harness the new utility of waste. This changing dynamic will result in waste management job shifting, and (ideally) the purchasing of waste from dumps and recycling plants for commercial use. Furthermore, government incentive programs have potential to encourage the implementation of this waste-utility model.

Consumers might consider direct partnership with the enterprise in contractual agreements to send used or obsolete products back to their own enterprise (or others), or discount incentives upon returns. Consumers must be able to easily interact with the pick-up method for used products and coordinate scheduling accurately for maximum efficiency on both the enterprise and consumer end; an example might include a drone flying in to pick up a used product at a particular time the consumer is home. Education of consumers will furthermore be a massive component in this new waste utility model.

7 Conclusion

A waste utility model will have positive impact incentivized by cost mitigation for enterprises, monetary consumer benefits, and positive environmental impact. This model proposed is a sustainable method for product design and production, but is highly complex. Optimizing this model relative to a particular enterprise will have significant uncertainty and temporal variation in areas such as consumer demand, material market pricing, and used product utility. Potential methodologies include adapting multi-attribute utility analysis to used products, incorporating reinforcement learning and game theory to optimize resource intake and outtake, and novel heuristics for product design considering waste utility. As cost of raw materials rise with the diminishment of natural resources, and disassembly and research in the breakdown of materials progresses, used products will contain greater value and their repurposement will become economically favorable for successful enterprises in 2035.

References

[1] United Nations, Department of Economic and Social Affairs, Population Division (2015). *World Population Prospects: The 2015 Revision, Key Findings and Advance Tables*. Working Paper No. ESA/P/WP.241.

[2] Mohammed Haneef Abdul Nasir, Andrea Genovese, Adolf A. Acquaye, S.C.L. Koh, and Fred Yamoah (2017). Comparing linear and circular supply chains: a case study from the construction industry. *International Journal of Production Economics, Vol. 183,* pp. 443-457.

[3] Lisa Skumatz, David Juri Freeman, Dana D'Souza, and Dawn Bement (2011). Recycling Incentives: Part 1. *Resource Recycling*, Portland, OR.

[4] Livia Albeck-Ripka (2018). Your Recycling Gets Recycled, Right? Maybe, or Maybe Not. *New York Times.* Accessed May 31, 2019. https://www.nytimes.com/2018/05/29/climate/recycling-landfills-plastic-papers.html

[5] Harris Page (2019). 10 Countries Banning Fossil Fuel Vehicles Before 2050. *WiredBugs, Amazon Services LLC.* Accessed May 31, 2019. https://wiredbugs.com/countries-banning-fossil-fuel-vehicles/

[6] Alissa Fleck (2018). The Shift From 4G to 5G Will Change Just About Everything. *Adweek.* Accessed May 31, 2019. https://www.adweek.com/digital/the-shift-from-4g-to-5g-will-change-just-about-everything/

[7] Alana Semuels (2019). The World Has an E-Waste Problem. *Time Magazine*. Accessed May 31, 2019. http://time.com/5594380/world-electronic-waste-problem/

[8] Gabrielle Gaustad, Elsa Olivetti, and Randolph Kirchain (2010). Design for Recycling. *Journal of Industrial Ecology, Vol. 14,* pp 286-308.

[9] Saeed Rahimpour Golroudbary and Seyed Mojib Zahraee (2015). System dynamics model for optimizing the recycling and collection of waste material in a closed-loop supply chain. *Simulation Modeling Practice and Theory, Vol. 53,* pp. 88-102.

[10] Sara Behdad, Minjung Kwak, Harrison Kim, and Deborah Thurston (2010). Simultaneous Selective Disassembly an End-of-Life Decision Making for Multiple Products That Share Disassembly Operations. ASME. *Journal of Mechanical Design, vol. 132(4).* DOI: 10.1115/1.4001207.

[11] Sara Behdad and Deborah Thurston (2012). Disassembly and Reassembly Sequence Planning Tradeoffs Under Uncertainty for Product Maintenance. ASME. *Journal of Mechanical Design, vol. 134(4).* DOI: 10.1115/1.4006262.

[12] Phillip Odonkor and Kemper Lewis (2016). Optimization of energy use strategies in building clusters using pareto bands. ASME. *42nd Design Automation Conference,* Charlotte, NC. DETC2016-59963.

[13] Phillip Odonkor and Kemper Lewis (2019). Automated Design of Energy Efficient Control Strategies for Building Clusters Using Reinforcement Learning. ASME. *Journal of Mechanical Design, vol. 141(2).* DOI: 10.1115/1.4041629.

[14] Ardeshir Raihanian Mashhadi, Behzad Esmaeilian, and Sara Behdad (2015). Uncertainty Management in Remanufacturing Decisions: A Consideration of Uncertainties in Market Demand, Quantity, and Quality of Returns. ASME. *Journal of Risk and Uncertainty in Engineering Systems, vol. 1(2).* DOI: 10.1115/1.4029759.

[15] Singiresu S. Rao and Theodor I. Freiheit (1991). A Modified Game Theory Approach to Multiobjective Optimization. ASME. *Journal of Mechanical Design, vol. 113(3).* DOI: 10.1115/1.2912781.

[16] Kenton B. Fillingim, Richard Ossie Nwaeri, Felipe Borja, Katherine Fu, and Christiaan J. J. Paredis (2018). Design Heuristics: Analysis and Synthesis from Jet Propulsion Laboratory's Architecture Team. ASME. *30th International Conference on Design Theory and Methodology,* Quebec City, Quebec. DETC2018-85584.

[17] Behzad Esmaeilian, Ben Wang, Kemper Lewis, Fabio Duarte, Carlo Ratti, and Sara Behdad (2018). The future of waste management in smart and sustainable cities: a review and concept paper. Elsevier. *Waste Management, vol. 81,* pp. 177-195.

[18] Masataka Nakazawa, Kazuro Kikuchi, and Tetsuya Miyazaki (2010). High Spectral Density Optical Communication Technologies. *Springer*. DOI: 10.1007/978-3-642-10419-0.

[19] Henry A. Sodano, Daniel J. Inman, and Gyuhae Park (2005). Comparison of piezoelectric energy harvesting devices for recharging batteries. *Journal of Intelligent Material Systems and Structures, vol. 16(10),* pp. 799-807. DOI: 10.1177/1045389X05056681.

[20] Ke Zhang, Wei Zhang, and Jai-Zhi Zeng (2008). Preliminary study of routing and date integrity in mobile ad hoc UAV network. IEEE. *2008 International Conference on Apperceiving Computing and Intelligence Analysis*. ISBN: 978-1-4244-3425-1.

[21] Miko M. L. Chang, Soh K. Ong, and Andrew Y. C. Nee (2017). Approaches and challenges in product disassembly planning for sustainability. Elsevier. *Procedia CIRP, vol. 60,* pp. 506-511. DOI: 10.1016/j.procir.2017.01.013.

[22] Paul J. Taylor, Tooska Dargahi, Ali Dehghantanha, Reza M. Parizi, and Kim-Kwang Raymond Choo (2019). A systematic literature review of blockchain cyber security. *Digital Communications and Networks*. DOI: 10.1016/j.dcan.2019.01.005.