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A Review of Issues in Environmentally Conscious Manufacturing and Product Recovery

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Abstract: *Environmentally Conscious Manufacturing and Product Recovery (ECMPRO) has become an obligation to the environment and to the society itself, enforced primarily by governmental regulations and customer perspective on environmental issues. This is mainly driven by the escalating deterioration of the environment, e.g. diminishing raw material resources, over owing waste sites and increasing levels of pollution. ECMPRO involves integrating environmental thinking into new product development including design, material selection, manufacturing processes and delivery of the product to the consumers, plus the end-of-life management of the product after its useful life. ECMPRO related issues have found a large following in industry and academia who aim to find solutions to the problems that arise in this newly emerged research area. Problems are widespread including the ones related to life cycle of products, disassembly, material recovery, and remanufacturing and pollution prevention.*

Keywords: *Environmentally conscious manufacturing; Product recovery; Recycling; Reuse.*

I. Introduction

During the industrial revolution, environmental issues were not addressed when designing and manufacturing products. However, in the last decade or so, Environmentally Conscious Manufacturing and Product Recovery (ECMPRO) has become an obligation to the environment and to the society itself, enforced primarily by governmental regulations and customer perspective on environmental issues. Environmentally conscious manufacturing (ECM) is concerned with developing methods for manufacturing new products from conceptual design to final delivery and ultimately to the end-of-life (EOL) disposal such that the environmental standards and requirements are satisfied ECMPRO is mainly driven by the escalating deterioration of the environment. Today's high-tech society requires thousands of different products which ultimately result in billions of tons of materials discarded, most of which end up in landfills. According to the US Environmental Protection Agency (EPA), in 1990 the amount of waste generated in the USA reached a whopping 196 million ton up from 88 million ton in the 1960s [1]. As a consequence of both fast depletion of the raw materials and an increasing amount of different forms of waste (solid waste, air and water pollution etc.), two commonly accepted primary objectives have been gaining momentum: (1) create environmentally friendly products, (i.e. green products); and (2) develop techniques for product recovery and waste management.

In order to design a product which is environmentally benign, the life cycle of the product should be well understood [2]. Life cycle analysis (LCA) spans over the development, manufacturing, use and disposal stages of the product. These have prompted campaigns such as design for recycling (DFR), design for environment (DFE) and design for disassembly (DFD). Even though LCA may seem to be the most important solution to environmental problems, its immediate e effect is in the early stages of new product development. However, the biggest damage to the environment occurs when the product completes its useful life. Thus, understanding and developing techniques for end-of-life management of the products by means of product/material recovery are extremely crucial considering the millions of products that have already been developed without incorporating their undesired effects on the environment. Recoveries of products are usually performed in two ways: recycling and remanufacturing. Recycling aims to recover the material content of retired products by performing the necessary disassembly, sorting and chemical operations. On the other hand, remanufacturing preserves the product's (or the part's) identity and performs the required disassembly, sorting, refurbishing and assembly operations in order to bring the product to a desired level of quality. Disassembly has proven its role in material and product recovery by allowing selective separation of desired parts and materials. Besides being able to recover valuable precious materials by material recovery, good component removal via disassembly could provide parts for discontinued products and reduce the lead times in the assembly of new products [3, 4].

The above raised issues have captured the attention of industries, governments and academia.

II. Background

Our environment has limited resources, i.e. the materials we convert into products, energy, water and air supply and the places where we dispose of old products, are limited. Our society uses these resources to improve the living standard. However, we also need to provide for a sustainable environment for the next generation. To this end, we need to identify the extent of the problem and take corrective action. Many researchers have been doing just that.

2.1. Decreasing earth's resources and increasing environmental problems

Ever since the industrial revolution, the number of manufactured products has increased dramatically. The current state of manufacturing processes requires the use of trillions of tons of different forms of natural resources (raw materials, energy, water, etc.). Wann [5] reports that an average American consumes 20 tons of materials every year. Energy consumption is also at dramatic levels: every day the average American uses the equivalent of twenty-seven years of stored solar energy in the form of fossil fuels [5]. The products originating from renewable and non-renewable natural resources evolve into waste after their useful lives. Waste can be defined as redundant goods, by-products or residues that have no value and must be disposed of at a cost. Different forms of waste (hazardous and non-hazardous) have been generated by both manufacturers and consumers for decades [6].

Bylinsky [7] reports that according to the National Academy of Sciences, 94% of the substance that is pulled out of the earth, enters the waste stream within months. According to the Environmental Protection Agency (EPA), about 12 billion ton of industrial waste is generated annually in the United States and the scary part is, over a third of this amount is hazardous waste. Another estimated figure shows that by the year 2005, every family in the USA will own a computer [7]. That suggests that used computers will enter the waste stream as fast as we produce them. Europe is facing similar problems. The number of landfill sites where we can bury the non-hazardous solid waste is going down with the increasing amount of waste. Since old recycling methods, such as dumping, burying and burning in the open field, are no longer desirable due to tough new environmental laws and increasing consumer concerns [8], new methods have to be explored. For example, the importance of removing hazardous materials from refrigerators, such as Freon (which is a type of gas that has been proven to be destroying the ozone layer of the atmosphere), ABS (Acrylonitrile-Butadiene-Styrene), PVC (Polyvinyl Chloride), BS (Bile Salts) and PUR (Polyurethane) foam, cannot be ignored. Similarly, making responsible end-of-life choices for conventional military munitions is very crucial.

2.2. Response to negative environmental developments the good thing about us as a society is that we learn from our mistakes and experiences.

Wann [5] perfectly emphasizes the interactions between the environmental problems and the future of the society. The society as a whole has developed a heightened environmental awareness in response to numerous environment related problems that have recently surfaced. However, it is crucial to minimize the response time for corrective action to environmental problems as long delays could lead to irreversible damage. The governments, the industries [9] and the public have been very receptive and responsive to the environmental problems. The common goal is to integrate environmentally friendly thinking into daily practices.

One of the reasons for rapid developments in the material recovery and the ECM practices is the changing consumer perspective. Recently, consumers have become aware of their environment and the potential problems that can be created by neglecting it. Therefore, they have started to show more interest in buying products that are environmentally friendly and which will be taken back by their manufacturers at the end of their useful lives for recycling etc. This has become an incentive for the manufacturers to design and market environmentally friendly products (or `green products') to gain advantage in the marketing platform against their competitors. Therefore, companies have started to analyze the product life cycle in order to insert the environmental component into the product design to produce a product that has a low production cost and is environmentally friendly. The manufacturers and consumers are also forced by many environmental laws and legislation to pay more attention to the environmental issues. In many countries, the environmental protection laws, regulations and tax implications are already in place or in the works [10]. Frosch [11] describes the development of environmental regulations in the USA which has been applied in three stages since Earth Day 1970. The first stage is the `end-of-pipe regulation' which defines restrictions on the types of materials that can be discarded, as well as where and how they can be discarded. Some of the well-known laws under this stage are the clean Air Act, the Clean Water Act and the Resource Conservation Act. The second stage started with the Pollution Prevention Act of 1990, which focused on reducing pollution within the industrial processes. Finally, in the third stage, the aim is to encourage `clean production' with the coordination of industry and the Environmental Protection Agency (EPA). The European Community has passed laws prohibiting the disposal of more than 15% of an automotive product by the year 2002 and this percentage drops to 5% in the year 2015 [1]. In Europe, government initiatives to make both manufacturer and user responsible for disposing of the wastes associated with a product are commonly being practiced. Material recycling goals proposed in the law stated that by 1995, steel, non-ferrous metals, tires, glass and plastics must be recycled to the level of 100, 85, 40, 30 and 20%, respectively. Other European countries have similar measures on their agenda. In addition to making laws that enforce ECMPRO practices, taxation has been used as another weapon in fighting pollution problems. Crognale [10] sees the environmental regulations and laws as the basis for environmental management.

III. Environmentally Conscious Manufacturing (ECM)

ECM involves producing products such that their overall negative environmental effects are minimized [12]. ECM consists of the following two key issues:

1. Understanding the life cycle of the product and its impact on the environment at each of its life stages and
2. Making better decisions during product design and manufacturing so that the environmental attributes of the product and manufacturing process are kept at a desired level.

The first issue is necessary for drawing lines to determine how the product will evolve from the drawing board and how it will affect the environment throughout its life stages. If we fully understand the life cycle of the product, we can then transfer this information onto the actual development of the product (which addresses the second issue of ECM). In addition, understanding the end-of-life stage of the product is critical since one of the largest impact on the environment occurs at that stage.

During the design stage of the product, there are different objectives that the designers may focus on. Depending on the end-of-life strategy of the product, the design of the product can be realized to increase recyclability, manufacturability, disassemblability and to minimize the effect on the environment. When designing a product with environmental features, material selection should also be considered as a key element.
Once the design decisions of a product are complete and the materials for its production are identified, the product's environmental attributes are pretty much set. However, in addition to design and materials decisions, issues involving selection of energy source, cooling systems and handling of hazardous byproducts etc. must be controlled during the manufacturing process to achieve a complete ECM concept.

3.1. Environmentally Conscious Design (ECD)

ECD aims to design products with certain environmental considerations. In the literature, both the life cycle analysis (LCA) of the product and the design for environment (DFE) are emphasized.

3.1.1. Life Cycle Analysis or Assessment (LCA)

LCA is a process for assessing and evaluating the environmental, occupational health and resource consequences of a product through all phases of its life, i.e. extracting and processing raw materials, production, transportation and distribution, use, remanufacturing, recycling and final disposal. LCA examines and quantifies the energy and materials used and wasted and assess the impact of the product on the environment. LCA usually facilitates the systematic collection, analysis and presentation of environmentally related data.
The steps involved in LCA, are as follows:

- Identification of the goals and boundaries of LCA,
- Analysis of inventory to achieve a balance between material and energy in the system,
- Evaluation of the system's impact on the environment,
- Assessment of the most promising system improvements to reduce the negative environmental impact.

LCA has applications in many areas. The results of an LCA may provide the basis for the development of environmental laws, taxes and regulations. Industries may use LCA to support product development so that the overall environmental impact of the product is minimized. Qualitative and quantitative characteristics of the product life cycle are taken into account by means of LCA during the conceptual design of each new product. This enables designers to estimate the costs and benefits associated with the design attributes of the product, energy consumption, materials requirement and after-life choices of the product. Many companies make use of LCA to support their public claim of environmental responsibility.

The scope of LCA involves tracking all the materials and energy flows of a product from the retrieval of its raw materials out of the environment to the disposal of the product back into the environment. The complexity of the LCA problem grows when the product structure is large and complex and the number of factors to be considered increases. Utilizing the power of computers for collection, organization and analysis of necessary data can help shorten the time it takes to conclude the LCA related decision process. In practice, however, such a process could be extremely involved if the limits of the system are not clearly defined. Therefore, prior to the execution of LCA, the associated goals and boundaries of the Life Cycle must be defined. Although the goals of LCA are system dependent, the economic issues are valid for all systems.
LCA can be treated as an optimization problem by maximizing the added value and minimizing the resource consumption and waste dispersion activities.

Ishii et al. [13] and Ishii [14] developed software called LINKER (which has been developed using Tool Book under Microsoft Windows) by concentrating on advanced planning for product retirement and addressing the level to which a product should be disassembled. LINKER allows the user to evaluate a design at various stages of the life cycle. After entering the required data into the software's input stream, LINKER displays the disassembly times for components and fasteners, the compatibility index and the retirement cost breakdown for each clump, including the reprocessing and disassembly cost. These results are used to create better designs to satisfy the measures of the designer. Other computer supported LCA tools have also been developed. Some researchers concentrate on the development of a knowledge-base that can provide understanding of the connections among various elements of life cycle design.

3.1.2. Design for Environment (DFE)

Knowledge gained during LCA needs to be transferred into the initial design of a new product. It is actually possible to focus on a specific stage of the product's life such that the environmental impact is minimized in that stage as well as emphasizing the entire life of the product. Researchers have analyzed different stages of a product's life and developed techniques and logistics to improve the design of the product from an environmental perspective. These techniques, all together, are referred as the design for environment (DFE). Fiksel [15] presents an excellent overview of DFE concepts and practices. Fiksel defines DFE as: a systematic consideration of design performance with respect to environmental, health and safety objectives over the full product and process life cycle." According to the author, DFE can be broken down into many stages, including, manufacturing, consumer use and the end-of-life of the product. Throughout these stages, different forms of design strategies can be envisioned as the pieces of DFE. For example, in order to minimize the effect of the product on the environment at the manufacturing stage, design objectives may include design for energy conservation to reduce the energy use in production and to be able to use renewable forms of energy and design for minimizing the discharge of hazardous byproduct during production. Similar concerns are also valid during the distribution of the product. Finally, during the end-of-life stage of the product, there are design objectives to increase the output of the product recovery. These include design for material and product recovery, design for disassembly, design for waste minimization, design under legislation and regulations, etc.

Design for Recycling (DFR) suggests making better choices for material selection such that the processes of material separation and material recovery become more efficient. Some general characteristics of DFR are as follows:

- Long product life with the minimized use of raw materials (source reduction),
- Fewer number of different materials in a single product while maintaining compatibility with the existing manufacturing infrastructure,
- Fewer components within a given material in an engineered system,
- Increased awareness of life cycle balances and reprocessing expenses,
- Increased number of parts or subsystems those are easily disassembled and reused without refurbishing,
- More adaptable materials for multiple product applications and
- Fewer `secondary operations' reducing the amount of scrap and simplifying the recovery process.

On the other hand, design for remanufacturing (or part recovery) suggests the use of reusable parts and packaging. Disassembly is used both in recycling and remanufacturing to increase the recovery rate by allowing selective separation of parts and materials. Thus, designing for disassembly (DFD) is important and therefore it has been given special attention. DFD initiatives lead to the correct identification of design specifications to minimize the complexity of the structure of the product by minimizing the number of parts, increasing the use of common materials and choosing the fastener and joint types which are easily removable. DFD is often carried out using software due to the complexity of the problem. Kroll et al. [16] propose a rating scheme that allows the designers to translate properties of a design into quantitative scores and thus provide a means of identifying weaknesses in the design and comparing alternatives.

DFD is just one of the aspects of DFE. However, DFE comes with more than one task. Glantschnig [17] identifies three components of DFE, viz., the challenges faced by product designers and environment specialists, the green design challenges from a company's point of view and the external factors and forces that affect the design decisions. The ultimate goal of green design is to reduce the overall environmental damage when producing goods and providing services. To achieve this goal, in addition to this cooperative work, availability of guidelines, checklists and software-based DFE tools also play a key role. The authors utilize a modified version of the AHP (Analytic Hierarchy Process) model to compare alternative decisions by evaluating the change in the environmental features and the economical performance of the design. According to the authors, the AHP model is the most effective model among multicriteria decision making approaches for comparing different `green' product development alternatives. The authors note that such a model (1) integrates all the criteria into a single overall score for ranking decision options and (2) particularly appeals to decision makers involved in the evaluation of very complex programs."

Besides DFE approaches, the environmental effect of a product can also be reduced by designing the product for a longer life. The following design considerations may take place in the manufacturing and recovery stage: design for repair, design for assembly, design for minimum tool requirement for disassembly and so on. Some researchers refer to product design improvement efforts as design for `X' (DFX) where X stands for a design under consideration such as Manufacturability, Testability, Install ability, Compliance, Reliability, Disassembly etc. DFX is an integrated approach to designing products and processes for cost-effective, high quality downstream operations from manufacture through service and maintenance. DFX aims to reduce time to market, lower cost and increase quality of the product.

3.2. Environmentally Conscious Production (ECP)

In addition to environmentally friendly product designs resulting from DFE initiatives, issues involving production must also be addressed to have a complete concept of environmentally conscious manufacturing [15]. These issues include selecting energy sources necessary for production, designing cooling systems and handling hazardous byproducts. Currently, numerous production techniques, material handling systems and energy sources are available. Utilizing some sort of an assessment tool to select among them may be valuable financially as well as improve the environmental features of the production system. Bock [18] develops a tool to come up with a good material and process combination. Similar models have been developed to analyze how the selection of different manufacturing processes effect the environment.

Many companies monitor their waste generation as a result of their manufacturing processes. Several techniques have been proposed for such a monitoring process. For example, weighting methods were proposed to measure the chemical and toxic discharges of different manufacturing methods used. Rupp and Graham [19] evaluate a printed circuit board (PCB) production plant from an environmentally consciousness point of view.

3.3. Industry Examples

The automotive industry leads in research and development activities in response to the negative environmental developments. For example, Chrysler, Ford and GM researchers are trying to improve disassemblability features of their automobiles to take `ease of destruction `together with `ease of construction' into consideration. The new European Ford model, Mondeo, is claimed to be 85% recyclable. Another example is the efforts of Mercedes-Benz to implement a total vehicle recycling program with two main elements: vehicle design and vehicle recycling. Billatos and Nevrekar [20] highlight the Benz design efforts which include choosing environmentally compatible and recyclable materials for components, reducing the volume and variety of plastics used, making plastics parts with logos and avoiding composite materials as much as possible. Mercedes Benz started taking scrap cars back in 1991 and has been performing the material recovery process as part of their environmentally friendly production program. The information gathered from the recycling process is transferred as DFE and DFR initiatives to the new product design stage. Mercedes and Swatch have jointly designed a prototype car entirely realized in vegetable fibers (at the expense of metals) and valuable special materials. Another German car company, BMW, recently announced a pilot program in North America to test the feasibility of recycling BMW automobiles; because of the strict German laws the company already recycles cars in Europe. Targeting three US cities, BMW will give owners a $500 credit towards the purchase of a new or used BMW for turning in a car to a dismantling center. BMW has been using color coding for differing plastic materials for the past 15 yr. The color coding scheme allows development of efficient dismantling and disassembly techniques. BMW transfers the knowledge gained from dismantling and disassembly processes into new product development. Using DFD principles and more recyclable components in the original design, BMW hopes to increase the percentage of recycled car weight from the present 75 to 90% in the future [20]. BMW targets to produce a car out of 100% recycled parts by the year 2000.

Similar efforts are being made by the German manufacturing arm of General Motors (GM), Adam Opel AG, Volkswagen, Nissan Motor Company and Volvo Car Corporation. Volvo has been trying to increase the efficiency of its recycling methods by giving grants to universities and research institutions. The grants have been awarded to projects on life-cycle analysis, dismantling methods, materials recycling, energy recovery, and disposal of environmentally hazardous materials and transportation of materials to/from recycling centers. Consumer electronics and computer industries are also involved in the environmental movement. There are a lot of small and big companies investing into these causes. Digital, Proctor & Gamble and Canon are working to improve the recycleability of their products [21]. Digital uses the 6R approach on their used products (6R means Recycle, Reclaim, Refurbish, Remanufacture, Resell and Reuse).

Xerox Corporation strongly believes that environmentally conscious practices will become a customer requirement in the near future and is taking appropriate actions to prepare by applying life cycle design and DFE on its products. The company's goal is to achieve 0% end-of-pipe parts headed for landfills.

The number of transistors in a Pentium chip is 3.1 million. Increasing the number of transistors in a single chip will result in fewer chips to build and fewer chips to dispose, lowering the resource consumption as well as lowering the generation of waste. Intel has also developed a chip level technology to put PCs in a `sleep' mode in which the power consumption is reduced 6±10 fold. One of the world's biggest computer market share holders, IBM, has had a pollution prevention program since 1971. The goal is to achieve continuous improvement in the reduction of hazardous waste generated from IBM's manufacturing processes and its used products. IBM also develops design specifications for its new products to improve product's end-of-life material recovery. Household goods manufacturers are also encouraged by the current environmentally-driven green manufacturing efforts [20].

Another important area related to green production is packaging, since better packaging methods can significantly decrease the use of materials. For example, Colgate [7] has created a very smart design for the packaging of toothpaste. The toothpaste comes in a plastic tube which can stand on its own top. Thus, it does not require a carton box unlike other similar products.

IV. Recovery Of Materials And Products

A recent paper by Fleischmann et al. [22] categorizes recovery simply into material recovery and added value recovery. We also categorize the recovery process into material recovery (recycling) and product recovery (remanufacturing). Material and product recovery are carried out mainly due to three reasons: (1) hidden economic value of solid waste, (2) market requirements and (3) governmental regulations. Material recovery mostly includes disassembly for separation and processing of materials (e.g. carrying out necessary chemical operations) of used products. The main purpose is to minimize the amount of disposal and maximize the amount of the materials returned back into the production cycle. Product recovery includes disassembly, cleaning, sorting, replacing or repairing bad components, reconditioning, testing, reassembling and inspecting. The recovered parts/products are used in repair, remanufacturing of other products and components and for sale to an outsider.

Various forms of the material/product recovery have been around for a long time. Automobile (metal scrap brokers), electronic and paper recycling are the most common examples [22]. Among these, the automobile recycling is most advanced. In the USA, while just 20% of glass, 30% of paper products and 61% of aluminum cans are recycled, 95% of the 10 million cars and trucks that are retired each year go to the recycler and for each of those cars, 75% by weight is recovered for reuse. In Europe, according to the 1994 figures, the recovery rate (in percentage of total consumption) of paper products is relatively higher, about 43% [22]. The recovery rate of electronic consumer products (mostly computer products) is also fast developing.

In order to perform product recovery profitably and according to applicable laws and regulations, collection of retired products must be planned. Collection decisions involve location selection of collection centers (where retired products are collected and stored prior to distribution to recycling or remanufacturing facilities); layout design of collection centers (including material handling and storage); and transportation (designing the transportation networks to bring used products from many origins to a single collection center). The biggest challenge in collection related problems is the level of uncertainty involved in the quality and quantity of products collected.

4.1. Material Recovery or Recycling

Recycling is performed to retrieve the material content of the used and non-functioning products. As previously mentioned it is mainly driven by economic and regulatory factors. The economic value of used products is the reason for several recovery infrastructures. One of the best examples is the US automobile recycling infrastructure [23]. In the USA, for more than half a century, some very well developed automobile recycling centers provided hundreds of jobs and brought millions of tons of materials back into the production cycle. Automobiles arrive at the dismantling facility directly from the end-user or from the auto dealers. The dismantler removes reusable components and particularly valuable materials fractions (e.g. large castings, batteries, etc.). Tires and fluids are also removed to allow the remaining hulk (which is the remaining body and the chassis) to be accepted by the shredding processor downstream. The hulk is flattened for ease of transport to the hulk shredder who buys the hulk from the dismantler. The shredder reduces the hulk into small pieces. Separation into ferrous, nonferrous and non-metallic automobile shredder residue fractions is achieved by the magnetic and density separation techniques. Then the materials are sorted to be sent to the demand points. As a result of this infrastructure, metal recyclers (or scrap `processors') supply nearly half the USA's iron, steel and copper, 55% of the lead, a third of the aluminum, plus assorted titanium, zinc, molybdenum from over 60 million tons of scrap gathered from an intricate web of suppliers. Encouraged by the success of the automobile and electronic goods recycling in the USA, European companies are also developing ways to increase profitability in their recycling programs.

Economically-driven recovery process finds its application in the consumer electronics industry as well. A typical computer contains gold, silver, palladium and platinum. The amount of precious materials is much higher in earlier manufactured electronics products. Recovery of precious materials from consumer electronic products requires proper equipment and is generally completed in mass. Moyer and Gupta [4] report that a company in Canada with a specialized copper smelter processed more than 100,000 ton of recyclable materials (one quarter of which consisted of electronics products) in 1993. From this material, the company recovered 34 ton of copper, 123 ton of silver, 7 ton of gold and 5 ton of platinum and palladium.

Besides the recovery of highly valuable materials, other materials such as plastics [10] are being recovered due to environmental concerns. Regulatory electronics recycling is also practiced.

In order to find a balance between the resources invested in a recycling process (i.e. time and money) and value gained from the recovered materials, economic analysis of recycling process is sometimes carried out. The objective, of course, is to continue the recovery process as long as the profitability is maintained.

Johnson and Wang [24] discuss a methodology for carrying out material recovery in an efficient way. The methodology incorporates an initial study to determine the percentage of product which is recoverable, the initial cost/benefit estimates of recovery and the initial goals of material recovery options, identifying the disassembly level which generates a preferred sequence of disassembly which will maximize the value gained from recovery and the implementation stage of strategies developed in the previous levels.

The authors consider design and process attributes as well as the uncertainties that are likely to arise in a recycling system. In order to incorporate these attributes into the proposed approach, the authors utilize fuzzy-set theory and group technology.

4.2. Product Recovery or Remanufacturing

Lund [25] describes remanufacturing as an industrial process in which worn-out products are restored to like-new condition. Through a series of industrial processes in a factory environment, a discarded product is completely disassembled. Usable parts are cleaned, refurbished and put into inventory. Then the product is reassembled from old parts (and where necessary new parts) to produce a unit fully equivalent or sometimes superior in performance and expected lifetime to the original new product." Fleischmann et al. [22] define remanufacturing as a process of bringing the used products back to `as new' condition by performing the necessary operations such as disassembly, overhaul and replacement. Remanufacturing is also referred as recycling-integrated manufacturing. Industries that apply remanufacturing typically include automobile industry, electronics industry and tire manufacturers. Similar to the conventional production systems, in remanufacturing systems, there are operational, manufacturing, inventory, distribution and marketing related decisions to be made [26,27]. In general, the existing methods for conventional production systems cannot be used for the remanufacturing systems.

V. Conclusion

- Environmental issues are gaining justifiable popularity among society, governments and industry due to negative environmental developments.
- Research shows that the manufacturing of environmentally friendly products is crucial in order to minimize the use of virgin resources. This can be achieved by studying the life cycle of the product from its design stage to its retirement stage and incorporating this information into engineering design and production.
- Reclamation of materials and parts from outdated products is equally crucial in fighting against the environmental degradation. The recovery process reverses the one-way production and helps us move closer to a sustainable system.
- Disassembly is an important component of remanufacturing which is currently labor intensive and expensive. Thus, it is very important to develop automated disassembly systems which may eliminate the drawbacks of manual disassembly, i.e. lengthy disassembly completion time, human exposure to possible hazardous materials and byproducts, expensive labor use, etc.
- For successful implementation of ECM and recovery processes, it is necessary to develop qualitative and quantitative decision tools. The applicability of traditional tools is limited because the objectives, constraints and other characteristics of the traditional systems are different from those for the ECMPRO systems.
- Effort must be made for ECMPRO systems to be profitable so that the incentive for development and planning of these systems continues.
- National environmental laws and regulations must be globalized because our environment is a global issue rather than an individual nation's problem.
- Although the current development in ECMPRO research is encouraging, it is being conducted in clusters. It is, therefore, necessary that interactions between these research efforts be studied in order to develop interrelationships and determine the global effect of this field.
- The ECMPRO research should take advantage of the powerful tools available in Industrial Engineering and Operations Research.

REFERENCES

[1.] Nasr N. Environmentally conscious manufacturing. In: Careers and the Engineer, 1997. p. 26±7.
[2.] Steinhilper R. Design for recycling and remanufacturing of mechatronic electronic products: challenges, sol-utions and practical examples from the European viewpoint. In: ASME Design for Manufacturability Conference, Chicago, IL, 14±17 March 1994, 1994. p. 65±7.
[3.] Brennan L, Gupta SM, Taleb KN. Operations planning issues in an assembly/disassembly environment. International Journal of Operations and Production Management 1994;14(9):57±67.
[4.] Moyer LK, Gupta SM. Environmental concerns and recycling/disassembly e orts in the electronics industry. Journal of Electronics Manufacturing 1997;7(1):1±22.
[5.] Wann D. Deep design: pathways to a livable future. Washington: Island Press, 1996.
[6.] Raleigh LH, Knox RC, Canter LW. Proposed nonhazardous-industrial-waste classification scheme. Journal of Environmental Engineering 1995;121(5):402±10.
[7.] Bylinsky G. Manufacturing for reuse. In: Fortune, 1995. p. 102±12.
[8.] Benson A. Engineering cars for recycling. In: Assembly, 1996. p. 42±5.
[9.] Shrivastava P. The role of corporations in achieving ecologically sustainability. Academy of Management Journal 1995;20(4):936±60.
[10.] Crognale G. The next generation of environmental management. In: Proceedings of the IEEE International Symposium on Electronics and the Environment, Dallas, TX, 6±8 May 1996, 1996. p. 323±7.
[11.] Frosch RA. Industrial ecology: adapting technology for a sustainable world. Environment 1995;37(10):16±37.
[12.] Sarkis J. Supply chain management and environmentally conscious design and manufacturing. International Journal of Environmentally Conscious Design and Manufacturing 1995;4(2):43±52.
[13.] Ishii K, Eubanks CF, Di Marco P. Design for product retirement and material life cycle. Materials & Design 1994;15(4):225±33.
[14.] Ishii K. Life-cycle engineering design. Journal of Mechanical Design 1995;117B:42±7.
[15.] Fiksel J. Design for environment: creating eco-e•cient products and processes. McGraw-Hill, 1996.
[16.] Kroll E, Beardsley B, Parulian A. A methodology to evaluate ease of disassembly for product recycling. IIE Transactions 1996;28(10):837±45.
[17.] Glantschnig WJ. Green design: an introduction to issues and challenges. IEEE Transactions on Components, Packaging and Manufacturing Technology-Part A 1994;17(4):508±13.
[18.] Bock L. Material-process selection methodology: design for manufacturing and cost using logic programming. Cost Engineering 1991;33(5):9±14.
[19.] Rupp G, Graham S. Process design and optimization for environmentally conscious printed circuit board assemblies. In: Proceedings of the IEEE International Symposium on Electronics & the Environment, Orlando, FL, 1±3 May 1995, 1995. p. 95±9.
[20.] Billatos SB, Nevrekar VV. Challenges and practical solutions to designing for the environment. In: ASME Design for Manufacturability Conference, Chicago, IL, 14±17 March 1994, 1994. p. 49±64.
[21.] Anonymous. The green designers. In: Enterprise, 1994. p. 14±20.
[22.] Fleischmann M, Boemhof-Ruwaard JM, Dekker R, van der Laan E, van Nunen JAEE, Van Wassenhove LN. Quantitative models for reverse logistics: a review. European Journal of Operational Research 1997;103:1±17.
[23.] Hendrix J, Massey KA, Whitham E, Russel M, Bras BA. Technologies for the identification, separation and recycling of automotive recycling. International Journal of Environmentally Conscious Design and Manufacturing 1997;6(2):37±50.
[24.] Johnson MR, Wang MH. Planning product disassembly for material recovery opportunities. International Journal of Production Research 1995;33(11):3119±42.
[25.] Lund R. The remanufacturing industry: hidden giant. Boston, MA: Boston University, 1996.
[26.] Kopicky RJ, Berg MJ, Legg L, Dasappa V, Maggioni C. Reuse and recycling: reverse logistics opportunities. Oak Brook, IL: Council of Logistics Management, 1993.
[27.] Stock JR. Reverse Logistics. Oak Brook, IL: Council of Logistics Management, 1992.

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