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YENİDEN ÜRETİM SİSTEMİ İÇİN ÇOK AMAÇLI OPTİMİZASYON MODELİ

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ÖZET

Geri kazanım yönetimi kullanılmış ürünlerin son kullanıcılardan toplanması ve bunlardan sağlanan kullanılabilir parçaların yeniden imalatı, bileşenlerin yeniden kullanımı veya malzemelerin geri dönüştürülmesi olanaklarının araştırılması ile ilgilenmektedir. Çok Amaçlı Karar Verme (ÇAKV) yöntemleri çevresel kaygılar ile bunlara bağlı kapalı döngü tedarik zincirinin ekonomik olarak sürdürebilirliği ve mevcut ileri tedarik zincirine birleştirilmesi problemlerine uygulanabilir. Bu makalede önerilen matematiksel model iki temel amaca bağlı olarak kurulmuştur, şöyle ki yeniden üretim işlemleri sonucu elde edilen toplam karın maksimize edilmesi ve atık miktarının minimize edilmesi, bu amaç aynı zamanda geri kazanım oranının maksimize edilmesi anlamına gelmektedir. Bu çalışmada çelişen amaç fonksiyonları üzerinde yeniden imal edilebilir bir ürünün yaşam döngüsünde çeşitli geri kazanım oranları ve atık oranlarının etkileri incelenmiştir.

Anahtar Kelimeler: Çok kriterli karar verme, Geri kazanım, Yeniden üretim, Tersine tedarik zinciri

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A MULTI-OBJECTIVE MODEL FOR REMANUFACTURING SYSTEM

ABSTRACT

A product recovery management deals with the collection of post consumed and discarded products and explores the possibilities to remanufacture the items, reuse the components or recycle the materials from end of life items. Multi-Objective Decision Making (MODM) methods can be applied to analyze the trade-offs between environmental concerns and associated economic sustainability of closed loop supply chain integration into the existing forward supply chain infrastructure. In this paper, the proposed mathematical model based on two objectives, namely maximization of the total profit through remanufacturing operation and minimization of the dumping waste of post consumed products which amount to maximization of the recycling rate. We have analyzed the effect of reusable ratio and disposal ratio effect on the contrasting objectives of the model under various scenarios of product life cycle of the remanufacturable products.

Keywords: Multi-criteria decision making, Product recovery, Remanufacturing, Reverse supply chain

1. INTRODUCTION

Lately, governments and businesses are working on to establish a feasible used product recovery infrastructure. A vast amount of natural resources is used up for manufacturing to enrich our current lives and as a result a huge amount of consumed products, wastes are dumped into the environment (Hoshino et al., 1995). As an effective solution for the existing problems, recycling of the used products either in a part level or component level has been considered. Scarcity of the raw materials is another reason for reuse activity. Actually, it is not a new concept, recycling of cans and bottles have been operated for a long time.

Reducing waste associated with recycling, reusing and refurbishing activities. For a manufacturing firm reducing waste is a direct way to avoid the high disposal costs which is also reduce the consumption of raw materials. Collection of reusable or reproducible post consumed product is the first and one of the most important stages of the recycling activity. Disassembly plan of the collected products provides information for the material requirement planning of the remanufacturing activity.

Many authors have discussed the requirements to enhance recycling activity such as ease of disassembly, modularity, material selection and compatibility, material identification and efficient cross-industrial reuse of common parts/materials. In changing industry attitudes, a company couldn't carry on its profit and reputation without considering the environmental factors. This situation addresses new concept, Design For Environment (DFE) which is defined as "systematic consideration during new product and process development of design issues associated with environmental safety and health over the full product life cycle" (Fiksel J. and Wapman K., 1994). Kirby and Pitts (1994) stated that there are four major issues should be taken into account to build a product end-of-life disposition industry. Firstly, a convenient used product collection system should be established. Secondly, to apply as a solution for the existing problems remanufacturing activity should be continued economically. Third issue is the serviceability of these products. Fourth issue is the calculation of the environmental burden of dumping wastes. In this respect, Hoshino et al. (1995) proposed "recycle-oriented manufacturing system" to reuse the materials for manufacturing after the product's end of life which results in decreasing not only natural resources extracted but also dumping wastes. Wang et al. (2011) studied the trade-off between the environmental impact and the total cost for supply chain design problems and authors developed a multi-objective mixed-integer programming model for this purpose. Ozkır and Basligil (2013) extended this idea and proposed a fuzzy multi-objective optimization model for establishing a closed-loop supply chain network. Authors investigated that optimal number of facilities to conduct the closed-loop supply chain network operations and their locations and also control the return and purchasing amounts. Samanlioglu (2013) developed a multi-objective location-routing model and the proposed model applied in the Marmara region of Turkey. Author considered three objectives minimizing total system cost, minimizing transportation costs which are associated with the hazardous materials and minimizing risk factor of the nearby people around disposal stations. Ilgin et. al. (2015) review the literature in the area of environmentally conscious manufacturing and product recovery which are utilized multi criteria decision making (MCDM) techniques so as to assess the economic and environmental index.

2. PROBLEM STATEMENT

Many authors proposed quantitative models for the remanufacturing process but these approaches still ineffective to find a robust solution for current problems of the industry. On the other hand, considerable amounts invested, the Organization of Economic Cooperation and Development (OECD) and the Environmental Protection Agency (EPA) published that the estimated worldwide environmental technology industry put at $200 billion a year and expect the amount to reach between $300 and $600 billion by 2000 (Dillon, 1994). Gupta and Taleb (1994) presented an algorithm for scheduling the disassembly of discrete parts products which determines the order quantity and the disassembly schedule for the parent item to satisfy the deterministic demand on time. Main assumptions of the algorithm are similar to the assumptions of Material Requirements Planning (MRP), i.e. all the parameters are deterministic. Also, it assumes that all the parts (leaf items) which are disassembled from the parent items (root items) can be remanufactured, so it ignores the defective parts and dumping wastes. Guide and Srivastava (1997) pointed out the main complicating factors of the remanufacturing process. These factors include: probabilistic routing files, stochastic material replacement, and highly variable processing times needed to perform required remanufacturing operations. Also, they proposed rough cut capacity planning techniques and buffering from material recovery in a uncertainty situation in a recoverable manufacturing environment as an alternative to MRP. Gupta and Taleb (1996) and Taleb et al. (1997) presented an algorithm for the disassembly scheme of the products which have common parts/materials. Algorithm gives a priority to cheapest procurement option of the same part among the existing products.

Low inventory costs, low unit costs, and the alternative use of parts/materials across several end products are the benefits of commonality. Reverse MRP approach may not be an effective tool for planning parts/materials to be remanufactured. Because of the dynamic nature of the remanufacturing process, i.e. variance in collected amount of used products, variance in disassembly time. Keeping high level safety stocks may be the only solution for these problems but it will increase the inventory costs.

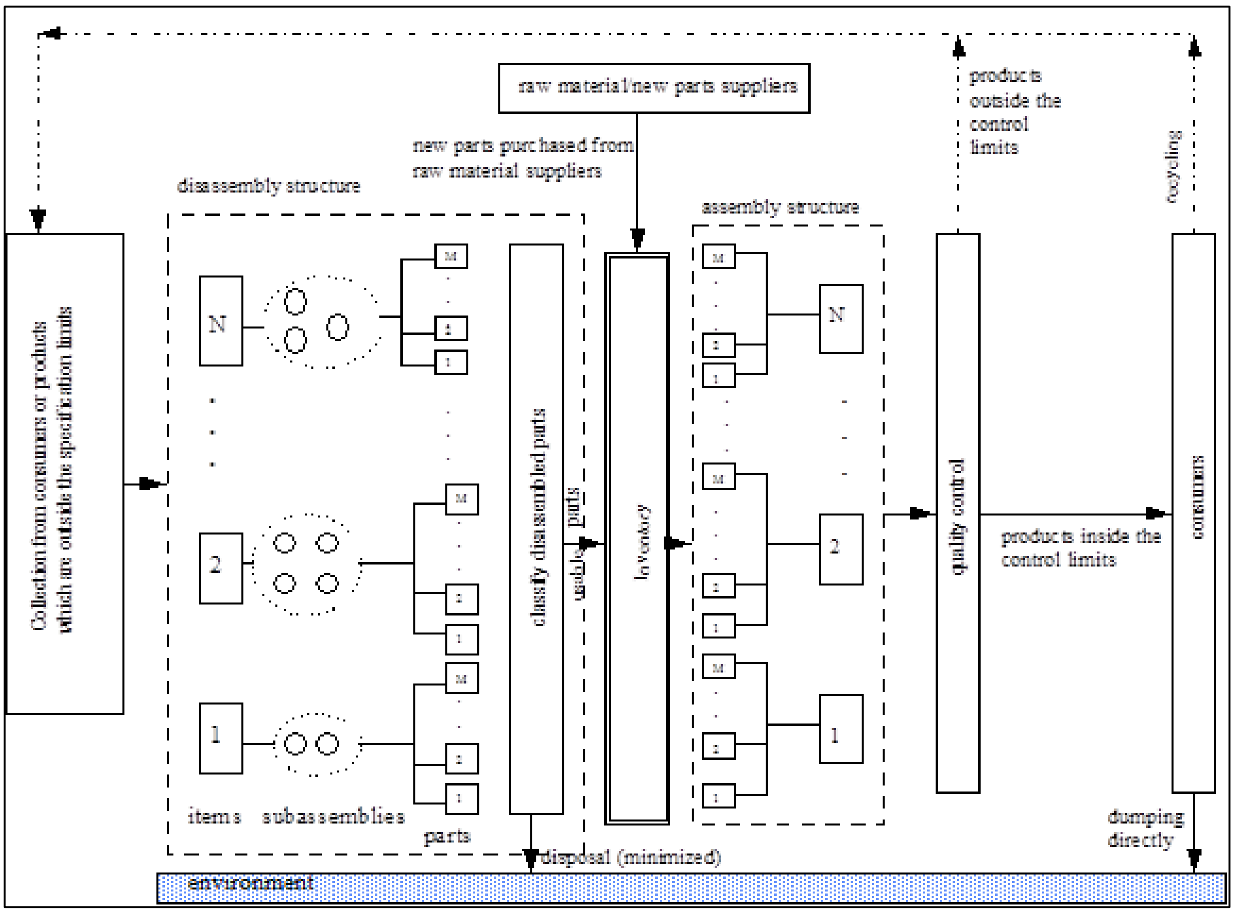

Figure 1. Integrated disassembly/assembly environment

From the figure 1, it is obvious that an effective disassembly plan should consider multiple and conflicting factors. This paper focuses on the optimization analysis of remanufacturing process. Goal programming approach is used as an optimization method for this problem. Profit maximization is permanent objective of the proposed model. Other objectives determined by the decision maker’s preference, minimization of disposal amount, minimization of disassembly lead time or minimization of the total number of disassembled root items etc. A basic structure of the proposed disassembly/assembly environment is depicted in figure 1. Deterministic demand for parts (leaf items) can be procured from either disassembled components (reuse) or from raw material/part suppliers. Disassembly and assembly structures are two main divisions of the system. Used product collection facility provides the system requirements externally and unshipped products because of the defects are returned to disassembly structure via collection facility provides the system requirements internally. All returned products directly disassembled till leaf item level, reusable parts cleaned and refurbished then directed to inventory, others disposed to the environment. Of course, it is not possible to recycle all the used products, some of them dumped to environment directly by consumers.

3. REMANUFACTURING MODEL

A model based on two objectives, namely maximization of the total profit and minimization of the dumping waste, namely maximization of the recycling rate. Graphical representation of the product structure is presented in Figure 2. In this model we do not considered the reuse of the products in a subassembly level. Following assumptions are made for the formulation of the model:

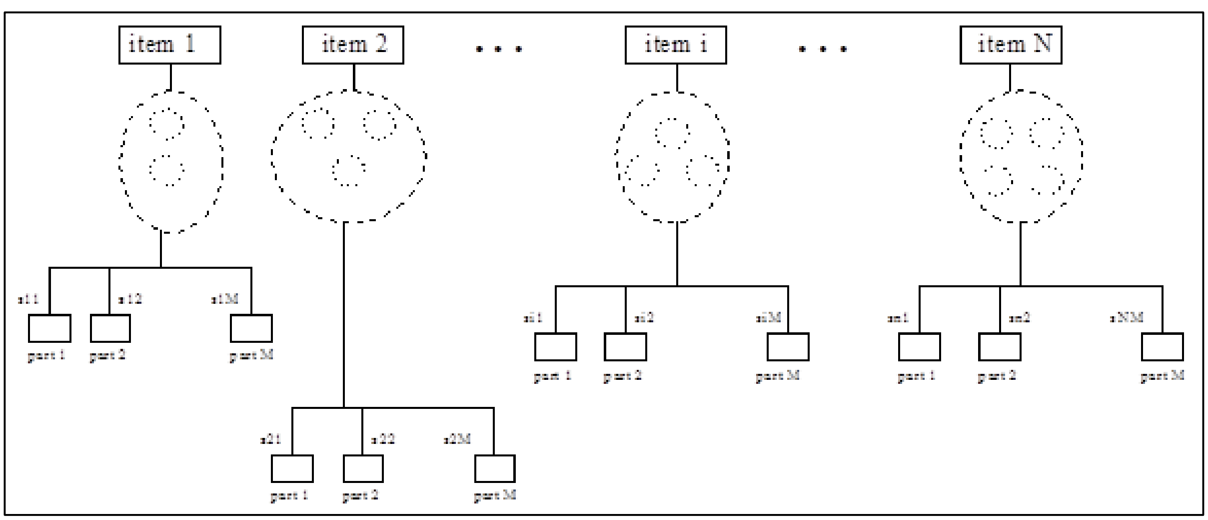

Figure 2. Products disassembly structure with parts commonality

1. Each product (root item) i (i=1,...,N) may consists of j (j=1,...,M) different parts (leaf items). Different products have different number of yields for the common parts. This situation represented by the constants S_{ij} (i=1,...,N; j=1,...,M).

2. In each period t (t=1,...,T) production quantity of each product i (i=1,...,N) is equalized with the deterministic demand of these products.

3. Same parts may have different reusable rate and disposal rate according to the disassembled products.

4. Necessary parts for production may procure from the raw material/part suppliers.

5. All the necessary costs for production activity is known.

6. Product’s disassembly and assembly lead time is ignored.

Within the remanufacturing process, the model formulation is presented with the following indices, decision variables and model parameters.

Indices

i=index for product (root item) number, i=1,...,N.
j=index for parts (leaf items), j=1,...,M.
t=index for period number, t=1,...,T.

Decision Variables

X_{it} =The number of used products to be collected (purchased) and disassembled simultaneously in period t to satisfy the known demand (i=1,...,N; t=1,...,T).

Z_{jt} =The number of new parts/materials to be purchased in period t to satisfy the known demand (j=1,...,M; t=1,...,T).

d_1^+ =The positive deviational variable for the first objective that represents a difference between the achieved total profit and target value (in dollars).

d_1^- =The negative deviational variable for the first objective that represents a difference between the achieved total profit and target value (in dollars).

$d_2^+ =$ The positive deviational variable for the second objective that represents a difference between the achieved and target disposition rate (in percentage).

$d_2^- =$ The negative deviational variable for the second objective that represents a difference between the achieved and target disposition rate (in percentage).

Model Parameters

$\alpha_j =$ Disposal ratio of part *j* (*j*=1,...,*M*), (in percentage).

$\beta_j = 1 - \alpha_j =$ Reusable ratio of part *j* (*j*=1,...,*M*), (in percentage).

$(CC)_i =$ The collection cost of product *i* (*i*=1,...,*N*), ($/product).

$(DC)_i =$ The disassembly cost of product *i* (*i*=1,...,*N*), ($/product).

$(FC)_i =$ The fixed cost for product *i* (*i*=1,...,*N*), ($/product).

$(NPC)_j =$ The cost of purchasing new part *j* (*j*=1,...,*M*), ($/pc.)

$(PC)_i =$ The production cost of product *i* (*i*=1,...,*N*), ($/product).

$(PRQ)_{it} =$ The production quantity of product *i* in period *t* which is equalized to the known demand (*i*=1,...,*N*; *t*=1,...,*T*), (product/period).

$S_{ij} =$ Indicates the number of the part (leaf item) *j* which disassembled from product (root item) *i* or the required number of part *j* to make product *i* (*i*=1,...,*N*; *j*=1,...,*M*).

$(SP)_i =$ The selling price of product *i* (*i*=1,...,*N*), ($/product).

$(WC)_j =$ The dumping cost of part *j* (*j*=1,...,*M*), ($/part).

$W_1^- =$ Weight for the deviational variable of first objective function.

$W_2^+ =$ Weight for the deviational variable of second objective function.

Model Formulation

Objective function is minimization of the deviational variables. Since over achievement of the first objective function is desirable, maximization of the total profit, it is not penalized. Similarly, under achievement of the second objective is desirable, minimization of the disposal amount, so it is not penalized as the first objective.

Min. $D = (W_1^- \times d_1^-) + (W_2^+ \times d_2^+)$ (1)

subject to,

1. Total profit function due to remanufacturing operations can be expressed as follows;

Total profit= $\left\{TR - \left(C\&DC + P\&FC + DUMC + NPC\right)\right\}$ (2)

Constraint (2) is the first objective function of the model which should be maximized and greater than or equal to some specified aspiration level of total profit. Terms which are constitute the total profit are given below:

TR (Total Revenue)= $\sum_{t=1}^{T}\sum_{i=1}^{N}(PRQ)_{it} \times (SP)_i \quad \forall i,t$ (3)

Total revenue is obtained by selling the product *i* with selling price $(SP)_i$, in period *t*.

CC&DC (Collection Cost and Disassembly Cost): Collection and disassembly cost of post consumed product *i* in period *t*. Each collected products disassembled to their parts which could be reused in an assembly line.

$$CC\&DC = \sum_{t=1}^{T}\sum_{i=1}^{N}\left((CC)_i + (DC)_i\right) \times X_{it} \qquad \forall i,t \tag{4}$$

P&FC (Production and Fixed Cost): Production and fixed costs of product *i*.

$$P\&FC = \sum_{t=1}^{T}\sum_{i=1}^{N}(FC)_i + \left((PC)_i \times (PRQ)_{it}\right) \qquad \forall i,t \tag{5}$$

DUMC (Dumping Cost): Dumping costs of product *i*.

$$DC = \sum_{t=1}^{T}\sum_{j=1}^{M}\sum_{i=1}^{N} S_{ij} \times X_{it} \times (WC)_j \qquad \forall i,j,t \tag{6}$$

NPC (Cost of the new parts): Cost of new parts to be purchased to satisfy known demand.

$$NPC = \sum_{t=1}^{T}\sum_{j=1}^{M}(NPC)_j \times Z_{jt} \qquad \forall j,t \tag{7}$$

2. Minimizing dumping waste is the second objective function of the model. It should be less than or equal to some specified percentage.

$$\sum_{t=1}^{T}\sum_{j=1}^{M}\alpha_j \times \sum_{i=1}^{N} S_{ij} \times X_{it} \Big/ \sum_{t=1}^{T}\sum_{i=1}^{N}(PRQ)_{it} \qquad \forall i, j, t \tag{8}$$

3. Production amount in each period is balanced with known demand and necessary parts for production are supplied from either disassembled used products or raw material/parts suppliers.

$$\sum_{i=1}^{N}(PRQ)_{it} \times S_{ij} = \beta_j \times \sum_{i=1}^{N}\left(X_{it} + Z_{jt}\right) \qquad \forall i, j, t \tag{9}$$

4. Collection amount of post consumed products in period *t* cannot be exceed production amount of the product *i* in period *t*.

$$\sum_{i=1}^{N}(X)_{it} \le \sum_{i=1}^{N}(PRQ)_{it} \qquad \forall i, t \tag{10}$$

5. Necessary parts for product *i* which procured from raw materials/parts suppliers cannot be exceed production amount of the product *i* in period *t*.

$$Z_{jt} \le \sum_{i=1}^{N}(PRQ)_{it} \times S_{ij} \qquad \forall i, j, t \tag{11}$$

6. Nonnegativity conditions.

$$X_{it} \ge 0, \forall\, i,\, t.$$
$$Z_{jt} \ge 0, \forall j,\, t. \tag{12}$$
$$d_1^+,\ d_1^-,\ d_2^+,\ d_2^- \ \ge 0$$

4. NUMERICAL ANALYSIS AND RESULTS

This section presents a numerical example with a hypothetical data for the proposed model in the previous section. For illustrative purposes two products case considered which have common parts. First product consists of two units of part 1 and three units of part 2.

Second one consists of one unit of part 1 and two units of part 2, i.e. $s_{11}=2$, $s_{12}=3$ and $s_{21}=1$, $s_{22}=2$. Five production period is considered for this problem, *T*=5. The production quantity of product *i* which is equalized the demand in period *t* is given in Table 1. Part *j* requirements according to these demand in period *t* presented in Table 2. Additional data for parameters of the proposed model is given in Table 3.

Table 1. Demand for product 1 and 2 (units/period)

Period	1	2	3	4	5
Product 1	2	0	1	1	2
Product 2	1	3	3	1	3

Table 2. Required number of part 1 and 2 for known demand (units/period)

Period	1	2	3	4	5
Part 1	5	3	5	3	7
Part 2	8	6	9	5	12

Table 3. Products and parts values for model parameters

	Product/part 1	Product/part 2
$(CC)_i$ = collection cost of product *i* ($/pc.)	$0.5	$0.5
$(DC)_i$ =disassembly cost of product *i* ($/pc.)	$1.0	$1.0
$(FC)_i$ =fixed cost of production for product *i* ($/period)	$4.0	$5.0
$(NPC)_j$ =cost of purchasing new part *j* ($/pc.)	$2.0	$3.0
$(PC)_i$ = production cost for product *i* ($/pc.)	$2.0	$3.0
$(WC)_j$ =dumping cost of part *j* ($/pc.)	$0.25	$0.30
α_j =disposal ratio of part *j* (in percentage)	vary according to the problem	
β_j =reuse ratio of part *j* (in percentage)	vary according to the problem	

According to these hypothetical data, the proposed model is solved and results for a required amount of new part 1 and part 2 in period t (t=1,...,5) is presented in Figures 3 to 6. $500 is chosen a total profit for the aspiration level of the first objective function and 25% disposal ratio is chosen as the aspiration level of the second objective function. Also it is assumed that underachievement of the first objective function and over achievement of the second objective function have equal weight.

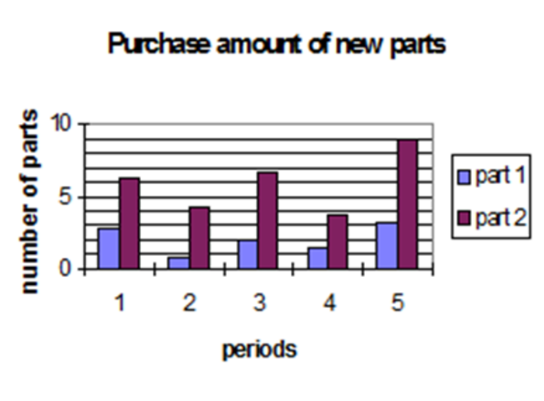

Figure 3. α_1=0.75 and α_2= 0.60

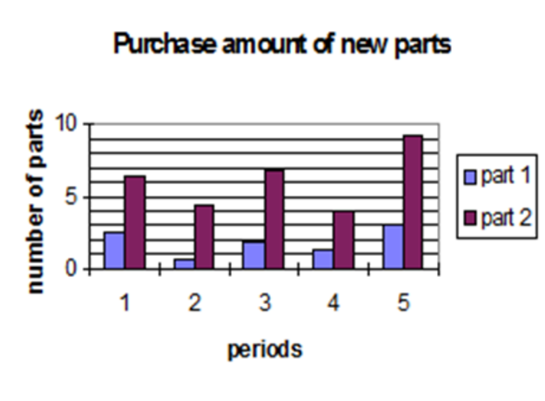

Figure 4. α_1= 0.80 and α_2= 0.55

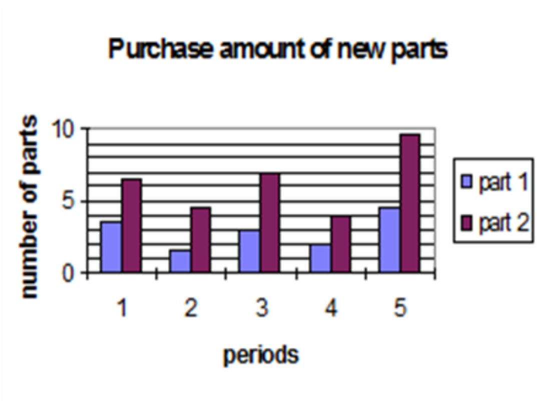

Figure 5. α_1= 0.50 and α_2= 0.50

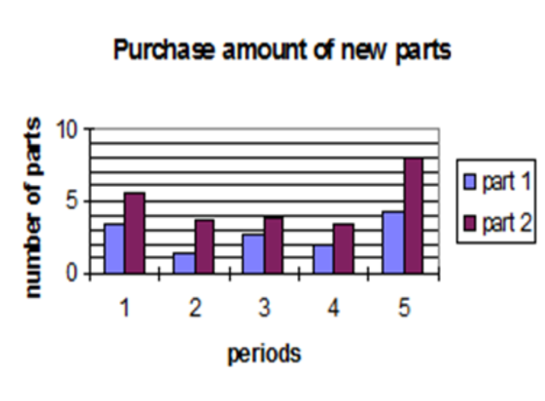

Figure 6. α_1= 0.55 and α_2= 0.80

5. CONCLUSION

In this paper, a multi-objective model proposed for an integrated disassembly/assembly manufacturing environment. An optimization model of the system has two objective functions, maximization of the total profit and minimization of the disposal rate. Goal programming approach is used as an optimization tool for the proposed model.

We have analyzed the effect of various disposal ratios of part 1 and 2 for five periods in the numerical analysis section and summarized the results through Figure 3. to Figure 6. As shown in Figure 3. for 0.75 and 0.6 disposal rate for part 1 and 2 respectively. Purchase amount of new parts of part 2 significantly more than part 1 and the difference more specifically observed in the last period. Similar results are also obtained for 0.8 and 0.55 disposal rates of part 1 and 2 respectively Figure 4. In Figure 5. We have examined balanced scenario for 0.5 disposal rate for part 1 and 2 and it’s also observed that the necessity of new parts part 2 considerably more than part 1.

Because of the complicating nature of the inventory and holding costs for the recycling activity or material return flows, these costs are ignored in the first objective function. A major reason is the growing uncertainty within the system. Collection amount of the post used materials and disassembly time for the used products highly variable. Another issue is reuse of the subassembly modules is not considered which could be a more economical approach of the recovery of the components. Consequently, the proposed model should be extended to cover all the necessary costs into account. Also other conflicting objectives which have an effect on the process should be included in the model.

REFERENCES

Chany, Ni-Bin and Wang, S. F. (1997), Integrated Analysis of recycling and Incineration programs by goal programming techniques, *Waste Management & Research*, 15, 121-136.

Dillon, P. S. (1994), Mandated electronics equipment recycling in Europe: implications for companies and U.S. public policy, *International symposium on Electronics & the Environment*, 15-20.

Fiksel, J. and Wapman, K. (1994), How to design for environment and minimize Life cycle cost, *IEEE Symposium on Electronics and the Environment*, San Francisco, CA.

Guide, Jr., V. D. R. and Srivastava, R. (1997), Buffering from material recovery uncertainty in a recoverable manufacturing environment, *Journal of the Operational Research Society*, 48, 519-529

Guide, Jr., V. D. R. and Srivastava, R. and Spencer, M.S. (1996), Are production systems ready for the green revolution?, *Production and Inventory Management Journal*, Fourth quarter, 70-76.

Gupta, S. M. and Taleb, K. N. (1994), Scheduling disassembly, *International Journal of Production Research*, 32 (8), 1857-1866

Gupta, S. M. and Taleb, K. N. (1996), An algorithm to disassemble multiple product structures with multiple occurrence of parts, *Proceedings of the International Seminar on Reuse*, Eindhoven, The Netherlands, November 11-13, 153-162

Hoshino, T., Yura, K. and Hitomi, K. (1995), Optimization analysis for recycle-oriented manufacturing systems, *International Journal of Production Research*, 33(8), 2069-2078

Ignizio, J. P. (1976), *Goal Programming and Extensions*. Lexington, USA: Lexington Books.

Ilgin, M.A., Gupta, S. M. and Battaia, O. (2015), Use of MCDM techniques in environmentally conscious manufacturing and product recovery: State of the art, *Journal of Manufacturing Systems*, 746-758.

Kirby, J. R. and Pitts, D. (1994), Resource recovery strategies for end-of-life business machines, *International symposium on Electronics & the Environment*, 167-170.

Ozkır V. and Basligil H. (2013), Multi-objective optimization of closed-loop supply chains in uncertain environment, *Journal of Cleaner Production*, 41, 114–125.

Samanlioglu F. (2013), A multi-objective mathematical model for the industrial haz-ardous waste location-routing problem, *European Journal of Operations Research*, 226 (2), 332–340.

Taleb, K. N., Gupta, S. M., and Brennan, L. (1997), Disassembly of complex products with parts and materials commonality, *Production Planning and Control*, 8 (3), 255-269.

Wang F., Lai X. and Shi. N. (2011), A multi-objective optimization for green supply chain network design, *Decision Support Systems*, 51 (2), 262-269.