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GENERATING A DISASSEMBLY-TO-ORDER PLAN

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ABSTRACT

The main objective of this research is to effectively solve a disassembly-to-order (DTO) problem. DTO is a system where a variety of returned products are disassembled to fulfill the demand for specified numbers of components and materials. Therefore, the optimal DTO plan must be generated in order to satisfy all demands, as well as to maximize profit and minimize costs of the system. Techniques implemented to solve the problem are Genetic Algorithm (GA), Linear Physical Programming (LPP) and refining algorithm. In this paper, we describe how GA and LPP techniques together with a refining algorithm can be combined to solve for the optimal numbers of take-back products. A numerical example is considered to illustrate the methodology.

INTRODUCTION

In recent years, wastes generated at the end-of-life (EOL) of electronic products have grown incredibly large. Due to the customers' desire to acquire products with latest technologies, millions of tons of electronic products, from cell phones to computers, are forced to be prematurely outdated and are dumped in landfills each year. The majority of the products discarded are otherwise in good functioning conditions. Therefore, an appropriate waste management is indispensable in order to prevent and diminish electronics wastes which cause negative impact on the environment.

There are several ways to manage EOL products. The most common choices are remanufacturing, reusing, recycling and disposing. Among these, disposal is the least desirable option as it causes reduction in the number of landfills and is harmful to the environment. Remanufacturing, reusing and recycling, on the other hand, can help decrease the rate of depletion of natural resources and help manufacturers save on disposal cost. Governments, manufacturers and consumers are aware of such problems. This has led to the implementation of several environmental regulations.

For remanufacturing, reusing and recycling, the components and materials must be obtained from EOL products through the disassembly process. In this paper, we focus on solving the disassembly-to-order (DTO) problem where EOL products are taken back from last users to be disassembled to fulfill the demands of components and materials. The objective is to generate the DTO plan, which includes the optimal numbers of take-back products, the numbers of products to be sent through each disassembly process and how to disassemble them. The solution must be generated in a way that it can satisfy all the demands while trying to achieve aspiration levels on profit and costs of the system, as well as to minimize the environmental impact.

This paper is organized as follows. In the next section, we provide a brief review of the relevant literature. Then we describe the DTO system and state the problem. After that, we introduce techniques implemented to solve the problem, which are followed by a case example. Finally we provide some conclusions of our work.

LITERATURE REVIEW

Disassembly has recently been studied by many researches. A recent book by Lambert and Gupta [9] is helpful in understanding the general area of disassembly. We briefly summarize some of the relevant literature that is useful for this paper.

Boon, Isaacs and Gupta [2] provided a net profit function for recyclers to investigate and report the factors that most influence the profit, and to assess the effect of changes in different variables on recycler's profits. Jung and Bartel [7] presented an economic analysis for used equipments in computer take-back and recycling process. Inderfurth and Langella [6] introduced an approach for solving the disassembly-to-order problems under stochastic yields. Yano and Lee [14] presented a review of lot sizing strategies with random yields. Linton [10] proposed options and obstacles on managing electronic products at their end-of-life. Moyer and Gupta [13] presented a survey of works related to environmentally conscious manufacturing, recycling and complexity of disassembly in the electronics industry. Ellis [3] presented a review based on environmental issues in electronics manufacturing.

Literatures related to the techniques presented in this research are as follows. Messac, Gupta and Akbulut [12] introduced a new approach (viz., linear physical programming) to solve multiple objectives optimization problem. Altiparmak, Gen and Lin [1] proposed a Genetic Algorithm to design multi-product multi-stage supply chain networks and investigate its effectiveness and efficiency on different size problems. Kongar and Gupta [8] applied Genetic Algorithm to solve disassembly sequencing problem. McGovern and Gupta [11] presented Genetic Algorithm for obtaining optimal or near-optimal solutions for disassembly line balancing problems.

DISASSEMBLY-TO-ORDER SYSTEM

Disassembly is the process of systematic removal of the desired components or materials from the original assembly so that the components or materials are obtained in the desired form. In a DTO system, varieties of EOL products are taken back from the last users to the disassembly facility and are disassembled to satisfy the demands for components and materials. In this paper, we consider several types of disassembly which are selective (only selected items are disassembled), complete (all items are disassembled), non-destructive (focusing on items rather than materials) and destructive (focusing on materials rather than items) disassembly.

The DTO process starts with the retrieval of take-back EOL products from collectors. Depending on the condition of the EOL products, some of them are sent to disposal. The rest (majority) of them are disassembled, using either destructive or non-destructive disassembly. The components yield from non-destructive disassembly is stochastic. The components obtained are in either good working condition or broken. Good components are used to satisfy the demands for used components. Additional components may be supplemented from outside suppliers to satisfy the demands. Bad components, together with materials from destructive disassembly, are sent to the recycling process, either in-plant or out of plant, to satisfy the demands for materials used for recycling. In-plant recycling is limited to the available in-plant capacity. Since it is difficult to recover all the materials from all the components recycled, the yields are stochastic. Components that exceed the demands are sent to disposal along with the waste materials from the recycling process.

In the next section, we present techniques and discuss how they can be applied to solve the DTO problem. First, to generate the optimal numbers of take-back products, we introduce a technique which is a combination of Genetic Algorithm (GA) and Linear Physical Programming (LPP). This technique

combines the advantage of GA which greatly reduces complexities of solving high-level complex problems and the advantage of LPP which efficiently manages multi-objective problems with vagueness. After that, we present a refining algorithm which rearranges the flow of the products and then generates a DTO plan which includes the optimal number of products to be sent to each disassembly station, the number of products to be completely disassembled and selectively disassembled, and also how to selectively disassemble them. This helps ensure the maximum benefit of the disassembly process by reducing the number of procured and disposal components, thus leads to a higher profit.

PROPOSED TECHNIQUES

Phase 1: Generating the optimal numbers of take-back products

As stated in the previous section, we implement a combination of GA and LPP techniques to generate the optimal numbers of take-back products. GA is an adaptive heuristic search algorithm based on the evolutionary ideas of natural selection and genetics. Initially Genetic Algorithm starts with a set of randomly generated feasible solutions (in this case, the number of take-back products) which form the initial population. Each member of the population (each solution) is encoded as an artificial chromosome. Chromosomes are normally represented by a combination of numbers, alphabets and/or other characters, which contain information about the solution mapping. Each chromosome is then assigned a score based on a predefined fitness function. Basically chromosomes with better scores are chosen as parents to create the next generation of population by the hope of achieving a chromosome with the best score. For more information on GA and how GA can be applied to solve the DTO problem, see Imtanavanich and Gupta [4].

Since the chromosomes' scores are used to determine the parent chromosomes, fitness function has to be formulated in such a way that it accurately represents the objective of the problem. Generally the DTO problem is multi-objective and contains vagueness in aspiration levels of the goals. LPP, which is basically an optimization technique that has capability to represent the decision maker's preferences by implementing class functions and to efficiently manage multi-objective problem, is a very appropriate technique implemented as a fitness function. For more information on LPP, including the LPP model and how to implement LPP to the DTO problem, see Imtanavanich and Gupta [5].

In order to calculate score for each chromosome by using LPP, we basically plug in each chromosome (numbers of take-back products) to the LPP model, and then calculate the objective value (the summation of class functions of all goals) which will be used as the chromosome's score. According to LPP model, the best objective value is zero. Therefore, chromosomes which have scores closer to zero will be selected as parent chromosomes.

Phase 2: Refining the solution and generating the DTO plan

After we obtain the optimal numbers of take-back products, we apply the refining algorithm. First, we add a selective disassembly process and a mixed (non-destructive and destructive) disassembly station, which are excluded in the first model in order to reduce the significant amount of complexities in solving the problem. Then we rearrange the flow and generate the number of products to be sent through complete non-destructive, complete destructive and selective mixed disassembly stations, as well as the details on how to selectively disassemble the products. This algorithm prevents over-disassembled components caused by a complete disassembly process, thus greatly reduces the number of procured and disposal components and consequently leads to a higher profit.

CASE EXAMPLE

In this example, we consider four types of notebooks as take-back products. The structures of the products and important input data of the components are shown in the figure and the table below.

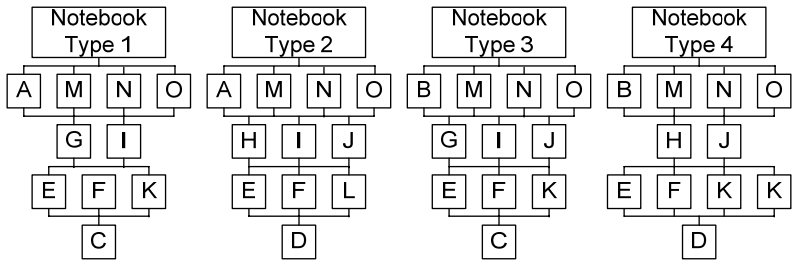

Figure 1. Product structures for case example

Table 1. Input data for the case example

Components	*Price of component*	*Dest. Diss cost*	*Non-dest diss cost*	*Disposing cost*	*Unit holding cost*	*Procurement cost*	*Disposing cost*	*Reuse Demand*	*Recycling Demand*
[A] LCD Monitor Type I	75	0.15	0.25	0.5	0.35	75.5	0.5	460	300
[B] LCD Monitor Type II	65	0.15	0.25	0.5	0.35	65.5	0.5	400	280
[C] Motherboard Type I	45	0.1	0.15	0.2	0.1	45.5	0.2	430	220
[D] Motherboard Type II	35	0.1	0.15	0.2	0.1	35.5	0.2	370	250
[E] Processor	50	0.05	0.1	0.15	0.08	50.5	0.15	730	340
[F] Memory	35	0.05	0.1	0.15	0.05	35.5	0.15	1590	350
[G] Harddrive 20Gb	40	0.1	0.15	0.25	0.15	40.5	0.25	400	200
[H] Harddrive 30Gb	50	0.1	0.15	0.25	0.15	50.5	0.25	440	250
[I] CD Drive	20	0.1	0.12	0.2	0.12	20.5	0.2	390	180
[J] Combo Drive	40	0.1	0.12	0.2	0.14	40.5	0.2	680	200
[K] Network Card	20	0.05	0.1	0.15	0.07	20.5	0.15	690	200
[L] Modem	10	0.05	0.1	0.1	0.11	10.5	0.1	650	220
[M] Keyboard	10	0.06	0.12	0.1	0.1	10.5	0.1	710	250
[N] Battery	35	0.05	0.1	0.15	0.06	35.5	0.15	710	210
[O] Power Adaptor	25	0.05	0.1	0.15	0.1	25.5	0.15	730	160

Take-back product costs for notebook type 1, 2, 3 and 4 are 300, 325, 360 and 350 respectively. More details on the input data can be seen in the similar case example in Imtanavanich and Gupta [4].

Phase 1: Optimal numbers of take-back products

First, we calculated the optimal numbers of take-back EOL products by using Genetic Algorithm (GA) and Linear Physical Programming (LPP) concept. In order to apply LPP, we defined range limits for each goal as given in the table below

Table 2. Range limits for each goal

Preference Level	Total Profit	Procurement Cost	Take-back Cost	Disposal Cost
Ideal	> 60000	< 56000	< 420000	< 350
Desirable	(58000, 60000)	(56000, 58000)	(420000, 435000)	(350, 400)
Tolerable	(56000, 58000)	(58000, 60000)	(435000, 450000)	(400, 450)
Undesirable	(54000, 56000)	(60000, 62000)	(450000, 465000)	(450, 500)
Highly Undesirable	(52000, 54000)	(62000, 64000)	(465000, 480000)	(500, 550)
Undesirable	< 52000	> 64000	> 480000	> 550

After having all the input data, the GA process started. The process was set to be terminated when it has evolved for 1000 steps or there has been no improvement for 500 steps (whichever comes first). After evolving for 559 steps, stopping condition (viz., no improvement for 500 steps) was met. The total run time was approximately 4 seconds. The optimal numbers of take-back product type 1, 2, 3 and 4 were 241, 261, 400 and 321 respectively. Profits and costs calculated are shown in table below.

Table 3. Profit and costs achieved from the optimal solution

Goals	Aspiration level	Actual Value
Total Profit	**>≈ 60000**	61580.16
Procurement cost	**<≈ 56000**	55667
Take-back Cost	**<≈ 420000**	413825
Disposing cost	**<≈ 350**	133.7

Phase 2: Generating a DTO plan

After we included selective disassembly process and mixed disassembly station, and then rearranged the flow of the products and generated the DTO plan. The results are as follows.

Table 4. The number of products sent to each process

Product	**Type 1**	**Type 2**	**Type 3**	**Type 4**
Number of take-back products	241	261	400	321
Number of good-for-disassembled products	236	253	396	315
Send to				
Complete Non-Destructive Disassembly	236	68	186	165
Complete Destructive Disassembly	0	0	5	0
Selective Mixed Disassembly	0	185	205	150

For products sent to selective mixed disassembly station. The details are summarized in the table below.

Table 5. The details on how to selectively disassemble the products

Product 2 (From 185 Units)	Non-Destructive	Destructive	Ignore
110 Units	A,D,F,H,L,N	E,I,J,M,O	-
25 Units	A,D,F,H,I,L,N	J,M,O	E
19 Units	A,D,F,H,I,L,N	J,M,O	E
19 Units	A,D,F,H,L,N	E,J,M,O	I
12 Units	A,D,F,H,I,L,N	E,J,M,O	-
Product 3 (From 205 Units)	Non-Destructive	Destructive	Ignore
107 Units	E,F,J,K,O	B,C,G,M	I,N
19 Units	E,F,J,K,O	B,C,G,I,M	N
18 Units	C,F,G,J,K	B,I,N	E,M,O
15 Units	C,F,G,J,K	B,I	E,M,N,O
14 Units	F,G,J,K,O	B,C,I	E,M,N
13 Units	E,F,J,K,O	B,C,G,I	M,N
10 Units	F,J,K,O	B,C,G,I	E,M,N
9 Units	C,F,G,J,K,O	B	E,I,M,N
Product 4 (From 150 Units)	Non-Destructive	Destructive	Ignore
105 Units	B,F,J,L,M	D,E,H,K,N	O
14 Units	B,J,K,L,N	D,E,H,M	F,O
14 Units	B,J,L,M	D,E,H,K,N	F,O
12 Units	B,J,L	D,E,H,K,M,N	F,O
5 Units	B,J,L,N	D,E,H,K,M	F,O

Profit and costs achieved after refining the solution are as follows.

Table 6. Profit and costs after refining the solution

Goals	Before	After
Total Profit	61580.16	65098.39
Procurement cost	55667	52236.47
Take-back Cost	413825	413825
Disposing cost	133.7	46

CONCLUSIONS

In this research, we presented techniques to solve a disassembly-to-order problem. Since the objective is to satisfy all demands, as well as to maximize profit and minimize costs of the system, the numbers of take-back products are the most important and have to be optimally generated. Implementing a combination technique of Genetic Algorithm and Linear Physical Programming helps reduce the complexities of solving high-level decision making problem and helps manage multiple objectives problem with vagueness. In addition, refining the solution by considering selective disassembly and mixed disassembly station makes the problem more realistic and eliminates over-disassembled components caused by a complete disassembly process, thus resulting in a higher profit. The case example proves that the optimal solution is effectively achieved in a short time.

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