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DYNAMIC PROGRAMMING FOR SOLVING DISASSEMBLY-TO-ORDER SYSTEM UNDER STOCHASTIC YIELDS, LIMITED SUPPLY, AND QUANTITY DISCOUNT

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ABSTRACT

In this paper, we consider the disassembly-to-order (DTO) problem where a variety of returned end-of-life (EOL) products are disassembled in order to satisfy the demand for specified numbers of components. However, a lot of uncertainties exist in the disassembly process that further complicates the process. A DTO model has been developed that takes into consideration the different system uncertainties and variability. The DTO model was solved in multiple periods using dynamic programming (DP). The main objective was to determine optimal number of take-back EOL products in every period from each supplier to fulfill the demand of components while maximizing total profit of the system. A numerical example is considered to illustrate the model approach.

INTRODUCTION

In recent years, waste generated from end-of-life (EOL) electronic products has grown incredibly large. Every year, millions of tons of fully functional electronic products such as cell phones, televisions, and personal computers are dumped into landfills. Recent studies and data from the US Environmental Protection Agency (EPA) show an increase in the amount of waste generated by residents, businesses, and institutions. In 2005, the amount of Municipal Solid Waste (MSW) generated in the US was more than 245 million tons which translates into 4.5 pounds of waste per person per day.

Nowadays, new technologies are evolving rapidly and consumers are demanding newer products with higher technologies. This surge in demand for electronic products has motivated manufacturers to develop newer products with higher technologies. Because consumers tend to upgrade their older products to acquire newer ones, older products with lower technologies are no longer desirable even though they are still in good operating conditions. Consequently, this leads to the premature disposal and shorter lives for these older products in addition to harmful waste to the environment. Therefore, it is essential to properly manage this waste in order to minimize the negative impact on the environment.

Governments have introduced new regulations that aim to restrict the amount of waste sent to landfills. Additionally, manufacturers have realized that they have several choices when it comes to managing EOL products. Returned EOL products can be remanufactured, reused, recycled, or disposed of. By remanufacturing, reusing, and recycling EOL products, manufacturers reduce their dependency on virgin resources, help decrease the rate of depletion of these virgin resources, and reduce the amount of harmful waste sent to landfills. Therefore, the disposal of

these EOL products is used as a last resort because it increases pollution, harms the environment, and reduces the number of landfills.

Disassembly is often the first crucial step in remanufacturing, reusing, and recycling. Disassembly is defined as the process in which products are separated into their components and materials using non-destructive, semi-destructive, or destructive operations. Disassembly allows us to break down retuned products into subassemblies and components and reuse them more than once before they are discarded. This reduces the wastes sent to landfills. Moreover, the cost of reusing EOL products and materials is much less than the cost of new products and materials.

Before EOL products can be disassembled and remanufactured, reused, and/or recycled; manufacturing companies need to first estimate the number of EOL products needed for disassembly and obtain them through the disassembly process. However, there are a number of uncertainties in the disassembly process that complicate the process. Models and techniques were proposed in the literature to address some of these uncertainties. Nonetheless, they suffered from some limitations. Previous models and techniques only considered one uncertainty in the process which was the condition of returned EOL products. EOL products are received in a variety of conditions and the yield rates of components from each product are unknown. Furthermore, the age of the products has an influence on the yield rates of the components. Older EOL products tend to have lower yield rates than newer products. Thus, heuristic procedures were used to transform the stochastic yields to their equivalent deterministic yields. Other variability that exist in the disassembly process include the limited supply of EOL products offered by a supplier, the number of suppliers offering EOL products, the quantity discounts offered by each supplier, and inventory control policy of the manufacturer. First, EOL products are supplied from a number of suppliers and each supplier can supply a wide range of products with different prices and various conditions. Second, there are capacity constraints which limit the number and variety of products that each supplier offers. Third, based on inventory limits, excess disassembled components could be carried in inventory for use in subsequent period. However, any excess disassembled components exceeding the inventory limit are disposed of. Finally, suppliers offer quantity discounts to increase their competitive edge.

Our paper attempts to develop a disassembly-to-order (DTO) plan using dynamic programming (DP) for multiple periods. The model we develop takes into consideration the above mentioned system uncertainties and variability. The main objective of the model is to determine optimal number of take-back EOL products in every period from each supplier to fulfill the demand of components while maximizing total profit of the system. A numerical example is considered to illustrate the model approach.

LITERATURE REVIEW

Recently, the area of disassembly has been the main focus of many researchers. Some researchers focus on profit maximization while others focus on improving the disassembly process itself. Kongar and Gupta [1, 2] studied the DTO system and presented a multi-criteria optimization model which determines the best combination of each EOL product type to be taken back for disassembly in order to fulfill the demand for items and materials under a variety of physical, financial, and environmental constrains. Inderfurth and Langella [3] developed two

heuristics for solving DTO problems with stochastic yields. The heuristic procedure transformed the stochastic yields to their equivalent deterministic yields. Imtanavanich and Gupta [4] considered the DTO problem where the main objective was to determine the optimal number of returned products to be disassembled in order to fulfill the demand for a specified number of parts. Imtanavanich and Gupta [5] modeled the DTO problem with stochastic yields using a multi-criteria decision making approach. Since the conditions of returned products were unknown, the authors used a heuristic procedure to convert the stochastic yields to their deterministic equivalents. Imtanavanich and Gupta [6] developed a multi-criteria decision making approach in multiple periods for a DTO system under product deterioration and stochastic yields. Imtanavanich and Gupta [7] introduced a technique which is a combination of genetic algorithm (GA) and linear physical programming (LPP) to solve the DTO system. After solving the DTO system, a DTO plan to determine 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 was generated using a refining algorithm.

DISASSEMBLY-TO-ORDER SYSTEM

In a DTO system, a wide variety of EOL products are purchased or taken back from end users in order to be disassembled to satisfy the demand for components and/or materials. There are two types of disassembly: complete and selective disassembly. In complete disassembly, all items are disassembled; however, selective disassembly only disassembles items that are of interest and the rest items are not disassembled. Additionally, the process of disassembly can be destructive or non-destructive. In destructive disassembly, some items are allowed to be damaged during the disassembly process; however, in the non-destructive disassembly, items are not allowed to be damaged during the disassembly process. Inventories are kept at the product, subassembly, and component levels. Products and subassemblies are disassembled into individual components as customers demand for specific components. Therefore, the manager has two critical decisions to make: how many EOL products and subassemblies to purchase before the final demand arrives, and once the demand arrives, how to disassemble the EOL products and subassemblies to maximize the profit.

PROBLEM DEFINITION

Due to limit space, our nomenclatures and mathematical model are not included in this paper. Figure 1 is a graphical representation of our DTO problem. In DTO problem, a variety of returned EOL products are considered for disassembly in order to satisfy the demand for certain components. EOL products are purchased from a number of suppliers and sent to the collection facility in order to be inspected and prepared for disassembly. After that, they are sent to the disassembly process. Components are separated using both destructive and non-destructive disassembly. Components from the non-destructive disassembly process are used to satisfy the demand for reuse and for storage. On the other hand, components from the destructive disassembly process are used to satisfy the demand for recycled components.

The yield of components from non-destructive disassembly is stochastic. Components obtained from non-destructive disassembly are divided into two types: good non-destructive components

and bad non-destructive components. Good non-destructive components are used to satisfy the demand for reused components and storage. If demand cannot be satisfied from the good non-destructive components, additional components may be supplemented from an outside supplier to satisfy the demand. Bad non-destructive components consist of damaged components and components that are not in a good condition for non-destructive disassembly. Components obtained from destructive disassembly are also divided into two types: good destructive components and bad (contaminated) destructive components. Bad non-destructive components along with good destructive components are sent to the recycling process, while contaminated components are sent to the disposal process. In order to satisfy the demand for recycling, components are recycled either in-plant or out-plant. Since in-plant recycling is cheaper than out-plant recycling, components are first sent to the in-plant recycling process. However, in-plant recycling process has a capacity limit on the number that can be processed and any additional demand can be satisfied through the out-plant process. Finally, components that exceed the demand for reuse, recycle, and storage are sent to disposal along with the contaminated or waste components from the recycling process.

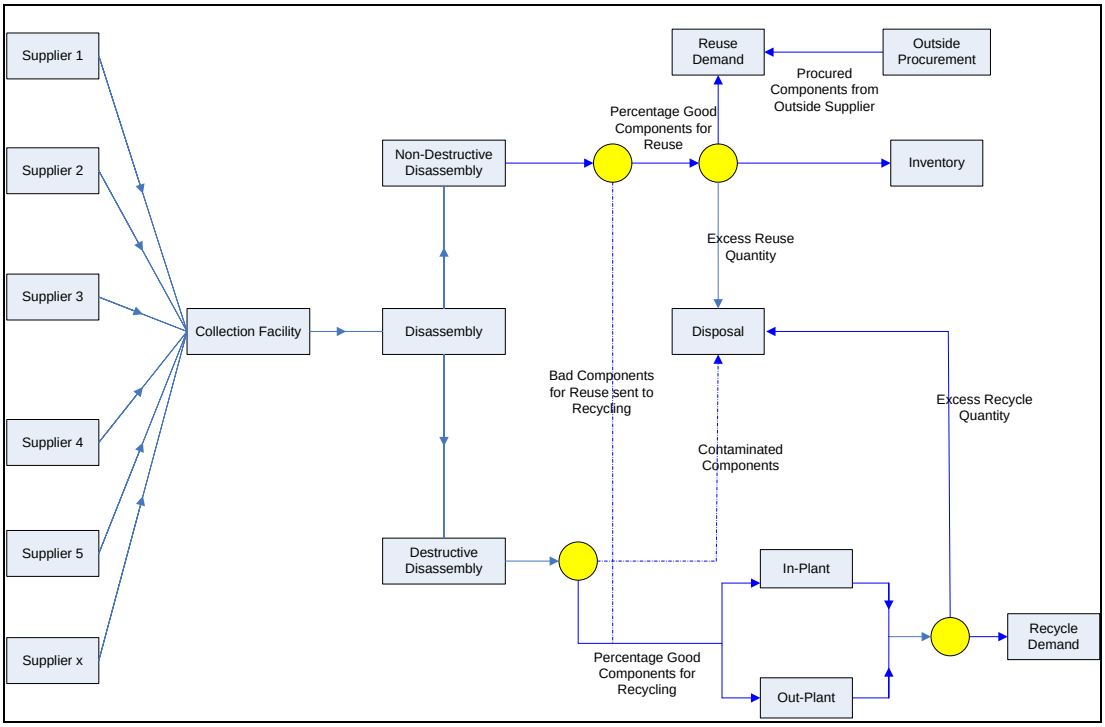

Figure 1: DTO System

NUMERICAL EXAMPLE

We consider a case example to illustrate the application of the DTO model. The objective of the model is to determine the best combination of EOL products to be purchased from each supplier in every period that maximizes total profit. There are 2 suppliers, 3 products, 10 components, and 3 periods. Each supplier offers 3 different types of products, each being a combination of 8 different components. The products from each supplier are priced differently and the conditions of the products differ from one supplier to another. This disparity in product conditions result in

different yields for different components. Each supplier offers a different discount schedule based on the total dollar amount of products purchased from that supplier.

Again due to limited space, only data from period 1 are provided in this paper. Tables 1 though 5 summarize the input data used in the model. The main objective of the DTO model is to find the best combination of EOL products to be purchased from each supplier in every period which maximizes the total profit. We used Lingo 11.0 to solve the DTO model using DP. The output of our model is summarized in Tables 6 & 7. Table 6 gives the quantity of procured components (Q^{PR}), quantity of disposed components (Q^{DP}), quantity of stored components (Q^{EInv}), and inventory capacity (Cap^{Inv}) in period 1. Tables 7 presents the optimal quantity of each EOL products (Q_i^{EOL}) purchased from every supplier in periods 1, 2, and 3. The systems final total profit is $158,478.70.

Table 1: Product Purchase Price & Capacity

Product	Supplier 1		Supplier 2	
	Purchase Price	Capacity	Purchase Price	Capacity
1	$30	250	$39	286
2	$32	252	$30	259
3	$34	381	$32	268

Table 2: Component Input Data

	Reuse Demand	Reuse Sell Price	Recycle Demand	Recycle Sell Price	Holding Cost	Disposal Cost	Non-Dest. Cost	Dest. Cost
A	400	$23	980	$3	$5.45	$0.60	$12	$0.55
B	400	$23	300	$16	$5.40	$0.40	$11	$0.50
C	350	$22	250	$18	$5.35	$0.70	$10	$0.45
D	450	$18	930	$3	$5.35	$0.70	$9	$0.50
E	350	$22	280	$15	$5.45	$0.80	$12	$0.60
F	300	$21	260	$18	$5.40	$0.50	$10	$0.65
G	400	$22	240	$17	$5.55	$0.90	$13	$0.60
H	300	$20	550	$5	$5.25	$0.40	$12	$0.55
I	450	$21	720	$4	$5.35	$0.55	$10	$0.50
J	300	$23	230	$15	$5.40	$0.65	$11	$0.45

Table 3: Discount Schedule Supplier 1

Discount Schedules	Discount Rate
0 < 5,000	0.0%
5,000 < 15,000	3.0%
15,000 < 20,000	5.0%

Table 4: Discount Schedule Supplier 2

Discount Schedules	Discount Rate
0 < 5,000	0.0%
5,000 < 15,000	2.5%
15,000 < 20,000	6.0%

Table 5: Component Yields for each Product from Both Suppliers

		A	B	C	D	E	F	G	H	I	J
Supplier 1	Produc 1	0.44	0.66	0.00	0.51	0.58	0.67	0.00	0.45	0.34	0.54
	Produc 2	0.45	0.00	0.62	0.50	0.56	0.00	0.71	0.34	0.63	0.50
	Produc 3	0.41	0.61	0.59	0.49	0.00	0.51	0.70	0.33	0.60	0.00
Supplier 2	Produc 1	0.39	0.62	0.00	0.46	0.55	0.63	0.00	0.40	0.29	0.50
	Produc 2	0.49	0.00	0.60	0.54	0.64	0.00	0.69	0.37	0.66	0.57
	Produc 3	0.44	0.70	0.58	0.53	0.00	0.58	0.68	0.36	0.62	0.00

Table 6: Quantity Procured, Disposed, and Ending Inventory

	A	B	C	D	E	F	G	H	I	J
Q^{PR}	0	0	27	0	28	0	0	0	0	6
Q^{EInv}	50	31	0	50	0	50	0	43	50	0
Cap^{Inv}	50	50	50	50	50	50	50	50	50	50
Q^{DP}	453	0	45	474	0	85	1	72	367	76

Table 7: Product Purchase Quantity in Periods 1, 2, & 3

	Period 1			Period 2			Period 3		
	Q_1^{EOL}	Q_2^{EOL}	Q_3^{EOL}	Q_1^{EOL}	Q_2^{EOL}	Q_3^{EOL}	Q_1^{EOL}	Q_2^{EOL}	Q_3^{EOL}
Supplier 1	249	252	378	18	237	39	251	1	263
Supplier 2	110	19	22	386	0	251	286	229	308

CONCLUSION

In this paper, we evaluated the disassembly-to-order (DTO) problem where a variety of returned end-of-life (EOL) products were disassembled in order to satisfy the demand for specified numbers of components. The main objective was to determine the optimal number of take-back EOL products to be purchased from every supplier that maximizes the total profit. The model had to take into consideration several factors including the condition of returned products, the variety of products from different suppliers, and quantity discounts offered by suppliers. Dynamic Programming (DP) was used to solve the multi-period DTO problem and determine the best combination of the EOL products to be taken back from each supplier.

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