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OPTIMAL ORDERING POLICY IN A DISASSEMBLY-TO-ORDER SYSTEM WITH LIMITED SUPPLY AND QUANTITY DISCOUNT

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ABSTRACT

This paper considers the disassembly-to-order (DTO) problem where a variety of returned products are disassembled in order to satisfy the demand for specified numbers of components. The main objective is to determine the optimal number of take-back end-of-life (EOL) products for the DTO system that maximizes the profit. A wide variety of products and subassemblies are considered for disassembly in order to meet the customer's demand for the different components. Several factors are considered before disassembling any product. Some of the factors include the condition of returned products, the different number of suppliers offering EOL products, and the quantity discount rate offered by each supplier. Product conditions affect the product's yield (e.g., older products tend to have a lower yield for usable components). A variety of products with different conditions and prices from a number of suppliers are considered. Finally, suppliers offer quantity discounts in order to increase their competitive edge. We solve this problem by using a model that maximizes the revenue and minimizes the total cost including the cost of acquiring the EOL products, the cost of disassembly, and the cost of disposing excess products and components. When solved, the model provides an optimal ordering policy for the DTO system. An example is considered to illustrate the use of the model.

INTRODUCTION

In recent years, consumers, manufacturing companies, and governments have become aware of various environmental issues and difficulties associated with the escalating influx of end-of-life (EOL) products. Overflowing waste sites, increasing pollution levels, diminishing natural resources, mounting governmental regulations and rising consumer desires have forced manufacturers to become more environmentally conscious [1]. However, being environmentally conscious is driven more by its business value rather than just regulations because manufacturers welcome high profits together with the potential of projecting a good image in the community [2].

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. This is the result of consumers demanding newer products with higher technologies. Because manufacturing technologies are rapidly changing, and consumers tend to upgrade their products to newer models, premature disposition of old products occurs even though they are still in very good operating conditions. Consequently, this leads to shorter lives for the products and added harmful waste. Therefore, it is essential to properly manage this problem in order to minimize the negative impact on the environment [3].

Because raw materials are depleting fast, harmful waste is constantly increasing, and landfills are filling up rapidly; manufacturers have thought of different ways to deal with this growing problem. Nowadays, manufacturers have many choices to manage EOL products. For example EOL products can be remanufactured, reused, recycled or disposed of. Remanufacturing, reusing and recycling products can help decrease the rate of depletion of virgin resources. Disposal, on the other hand, should be used as a last resort as it is harmful to the environment, increases pollution, and reduces the number of landfills. Consequently, several environmental regulations have been established which aim to restrict the number of disposed products, components and materials. This helps in conserving the environment and reducing the amount of raw materials used [4].

Disassembly is often the first crucial step in remanufacturing, recycling, and disposing. Disassembly is defined as the process in which products are separated into their components and materials using non-destructive, semi-destructive, or destructive operations. The main objective of this process is to minimize manufacturers' dependency on natural resources which in return reduces their high rate of depletion. Disassembly also allows us to use a retuned product more than once before it is discarded. This reduces the wastes sent to landfills. Additionally, the cost of reusing the materials is much less than the cost of new materials.

In recent years, the field of disassembly has gained a lot of interest. Few researchers have focused on the area of disassembly process and how it affects the environment, while others have focused on financial aspects of the field. For example, Gungor and Gupta [1] provide a comprehensive survey of issues in environmentally conscious manufacturing, and product recovery. Srivastava [2] presented a comprehensive integrated view of the published literature on all aspects and facts on Green Supply Chain Management taking a reverse logistics angle so as to facilitate further study, practice and research. The recent book by Lambert and Gupta [5] gives a good understanding of the general area of disassembly. Gupta and Kongar [6] present a disassembly-to-order algorithm that incorporates the disassembly and recovery of used products to satisfy a certain demand for products while achieving various financial and "environmentally benign" goals.

DISASSEMBLY-TO-ORDER SYSTEM

In a disassembly-to-order (DTO) system, a wide variety of products and subassemblies are purchased. Inventories are only kept at the product and subassembly levels. These 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. However, there are a lot of uncertainties in the disassembly process that complicate the process. Some of the problems include the conditions of the retuned EOL products, demand uncertainty, limited supply of products from each supplier, quantity discount rates offered by the suppliers, manufacturer inventory control policies, system lead times, and components due dates.

PROBLEM DEFINITION

In this paper, we consider the disassembly-to-order (DTO) system where a variety of returned products are disassembled in order to fulfill the demand for specified numbers of components. However, there are several factors that we need to consider before disassembling the products. First, EOL products in the disassembly process are received in a variety of conditions and this leads to a lot of uncertainties in the process. For example, the yield of components from each product is unknown and this complicates the problem. Older products tend to have lower yields than newer products. Therefore, we do not know in advance how many products we need to disassemble in order to fulfill the demand for components. Second, EOL products are supplied by a number of suppliers and each supplier can supply a wide range of products with different prices and in various conditions. Additionally, there are capacity constraints which limit the number and variety of products that each supplier can offer. Finally, suppliers offer quantity discounts to increase their competitive edge. To solve this problem, we develop a model that maximizes the revenue and minimizes the total cost including the cost of acquiring the EOL products, the cost of disassembly and the cost of disposing excess products and components. When solved, the model provides an optimal ordering policy for the DTO system.

Formulation

The following notations are used in this paper:

i = Index donating the Product, $i = 1, 2, 3, \dots, x$

j = Index donating the Supplier, $j = 1, 2, 3, \dots, y$

k = Index donating the Component, $k = 1, 2, 3, \dots, z$

π = Total profit of selling components k

TP_j = Total purchase from supplier j

x_{ij} = Number of products i purchased from supplier j

p_{ij} = Price of buying product i from supplier j

s_k = Price of selling component k

DR_j = Discount rate of supplier j

DC_k = Disposal cost of 1 unit of component k

Num_{kij} = Number of components k in product i from supplier j

DAC_{kij} = Cost of disassembling component k in product i from supplier j

$TDAC_k$ = Total disassembly cost of component k

Yld_{kij} = Yield of component k in product i from supplier j

D_k = Demand of component k

Cap_{ij} = Capacity of supplier j for product i

Q_k = Total quantity of component k

Objective Function:

$$\text{Max } \pi = \sum_k (s_k * D_k) - \left[\sum_j (1 - DR_j) * TP_j + \sum_k DC_k * (Q_k - D_k) + \sum_k TDAC_k \right]$$

Subject to:

$$x_{ij} \leq Cap_{ij} \quad (1)$$

$$TP_j = \sum_j \sum_i (p_{ij} * x_{ij}) \quad (2)$$

$$Q_k = \sum_k \sum_j \sum_i (Yld_{kij} * x_{ij}) \quad (3)$$

$$\sum_k Q_k \geq D_k \quad (4)$$

$$TDAC_k = \sum_k \sum_j \sum_i (DAC_{kij} * Num_{kij} * x_{ij}) \quad (5)$$

NUMERICAL EXAMPLE

We consider a case example to illustrate the application of the disassembly-to-order model. The objective of our case example is to maximize profit. We have 4 suppliers, 6 products, and 4 components. Each supplier offers 6 different types of products, each being a combination of 2 different components. The products from each supplier are priced differently and the conditions of the products differ from one supplier to another. This difference in product conditions will result in different yields for different components. Each supplier offers a different discount schedule which is based on the total dollar amount of products purchased from that supplier. Tables 1 through 5 summarize the input data used in the model to calculate the optimal purchase quantity of each product from each supplier. This information includes the demand of each component and the discount schedule of each supplier.

Table 6 is a summary of information regarding the 6 products from each supplier including the yield of components, the purchase price, the capacity, and the optimal purchase quantity. The model gives an optimal solution with a total profit of \$1,968.57 and discount rate of 10% from supplier 1, discount rate of 7.5% from supplier 2, discount rate of 18% from supplier 3, discount rate of 20% from supplier 4.

Table 1: Component Demand

Component	Demand
A	364
B	516
C	843
D	468

Table 2: Supplier 1 Discount Rate

Discount Schedules Supplier 1	Discount Rate (DR1)
0 < 400	0.0%
400 < 800	3.0%
800 < 1200	5.0%
1200 < 1500	8.0%
1500 < 1800	10.0%
1800 < 2500	13.0%
>= 2500	20.0%

Table 3: Supplier 2 Discount Rate

Discount Schedules Supplier 2	Discount Rate (DR2)
0 < 500	0.0%
500 < 1000	2.5%
1000 < 1500	6.0%
1500 < 2000	7.5%
2000 < 2500	11.0%
2500 < 3000	15.0%
>= 3000	21.5%

Table 4: Supplier 3 Discount Rate

Discount Schedules Supplier 3	Discount Rate (DR3)
0 < 200	0.0%
200 < 400	2.5%
400 < 600	4.5%
600 < 800	7.0%
800 < 1000	9.5%
1000 < 1500	13.0%
>= 1500	18.0%

Table 5: Supplier 4 Discount Rate

Discount Schedules Supplier 4	Discount Rate (DR4)
0 < 200	0.0%
200 < 400	2.5%
400 < 600	6.0%
600 < 800	7.5%
800 < 1000	11.0%
1000 < 1500	15.0%
>= 1500	20.0%

Table 6: Model Results for Product Purchase Quantity from each Supplier

		Yield of Component				Purchasing Price	Capacity	Purchase Quantity
		A	B	C	D			
Supplier 1	Product 1	0.289	0.959	0.000	0.000	\$4.50	100	97
	Product 2	0.000	0.000	0.801	0.331	\$3.50	152	151
	Product 3	0.570	0.000	0.000	0.732	\$5.00	352	1
	Product 4	0.000	0.487	0.000	0.755	\$4.25	332	4
	Product 5	0.471	0.000	0.733	0.000	\$3.75	132	49
	Product 6	0.000	0.320	0.600	0.000	\$3.25	112	112
Supplier 2	Product 1	0.225	0.817	0.000	0.000	\$3.50	100	97
	Product 2	0.000	0.000	0.798	0.326	\$3.00	87	87
	Product 3	0.529	0.000	0.000	0.750	\$4.25	128	127
	Product 4	0.000	0.507	0.000	0.793	\$5.00	175	0
	Product 5	0.443	0.000	0.769	0.000	\$3.50	72	72
	Product 6	0.000	0.416	0.797	0.000	\$3.75	122	122
Supplier 3	Product 1	0.185	0.731	0.000	0.000	\$3.00	225	142
	Product 2	0.000	0.000	0.849	0.272	\$2.75	101	101
	Product 3	0.508	0.000	0.000	0.686	\$3.00	203	129
	Product 4	0.000	0.570	0.000	0.778	\$5.00	82	79
	Product 5	0.432	0.000	0.910	0.000	\$4.00	52	52
	Product 6	0.000	0.395	0.844	0.000	\$4.75	87	87
Supplier 4	Product 1	0.191	0.915	0.000	0.000	\$5.00	254	8
	Product 2	0.000	0.000	0.907	0.309	\$3.75	65	65
	Product 3	0.515	0.000	0.000	0.719	\$4.00	103	103
	Product 4	0.000	0.525	0.000	0.613	\$3.25	100	32
	Product 5	0.367	0.000	0.751	0.000	\$2.50	62	62
	Product 6	0.000	0.483	0.827	0.000	\$5.50	103	103

CONCLUSION

In this paper, we evaluated the disassembly-to-order (DTO) problem where a variety of returned products are to be disassembled in order to satisfy the demand for specified numbers of components. The main objective was to determine the optimal number of take-back end-of-life (EOL) products for the DTO system that maximizes the profit. Our 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. As a result, the model was able to determine the best combination of the EOL products to be taken back from each supplier for disassembly in order to satisfy the demand of each component and maximize the profit.

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