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PLANNING COMPONENTS RECOVERY FROM MULTIPLE PRODUCTS

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ABSTRACT

This paper presents a two-stage model that provides a unique solution for planning components recovery from products with components commonality. The objective of the model is to determine the number and type of products to disassemble, to fulfill the demand of various components, in order to minimize disassembly and disposal costs.

INTRODUCTION

With an alarming increase in the stream of consumer goods discarded today, the focus these days is on developing new operational techniques on planning for components recovery. Products made with recovered components are sometimes not only cheaper but also better. For example, the reuse of computer chips in the production of toys can prove to be more reliable than the freshly produced chips because the reused chips would have survived the “burn-in” period. In addition, because retrieved parts are often classified as scrap, manufacturers may be able to obtain them at a below-market cost.

One particular requirement of a component recovery system is the need for disassembly prior to their retrieval. Since disassembly is sometimes motivated by the profit from retrieving only a few particular components from the product, a widespread retrieval of all components has not been achieved. As a consequence, when only the components in demand are retrieved, major subassemblies that need proper disposal are left behind in a disassembly facility. Most often the remaining components must be disposed of at a cost: such cost constituting the hidden costs of the process.

The decision to determine the number of various products needed to fulfill the demand of components can no longer be based on the profit making objective alone but also on the cost of waste disposal, especially when unused components, that are potentially hazardous, are dumped in public landfills. The focus of this research is on the systematic decision making approach used to determine the aggregate number of a variety of products to disassemble in order to fulfill the demand of a variety of components, and yet have an environmentally benign policy of minimizing waste generation.

LITERATURE REVIEW

Literature in the area of planning for components recovery can be classified based on the technique that is applied to solve the problem. The various techniques include disassembly scheduling, disassembly process planning and mathematical programming.

In the area of disassembly scheduling, Gupta and Taleb [1] presented an algorithm for scheduling the disassembly of a discrete, well-defined product structure. The algorithm determines the disassembly sequence of the components such that the demand for those components are satisfied. In their subsequent paper, Taleb and Gupta [4] improved the methodology to include the disassembly of multiple product structures with parts/materials commonality.

Veerakamolmal et al. [5] applied planning and sequencing techniques to create an efficient disassembly plan, that minimizes the total processing time and, thus, the cost of disassembly. The technique stresses the significance of the product structure representation, the clustering of component modules, and the sequencing of disassembly process. The result is the optimal makespan schedule for the disassembly process plan.

In another area that takes a mathematical programming approach to solve the problem of disassembly, Isaacs and Gupta [3] investigated the impact of automobile design on disposal strategies by using goal programming. The paper explains the increasing interests of automobile manufacturers in designing light automobiles and their effectiveness on recycling and reuse. Hoshino et al. [2] used goal programming to analyze the profitability and recycling rate for recycle oriented manufacturing systems. The result shows that there is a trade-off relationship between the total profit achieved and the recycling rate.

MODEL FORMULATION

In every product, there are precedence relationships that dictate the order in which the components can be retrieved. A unique characteristic of the disassembly problem is the association of operational costs with the complexity of the disassembling stages that are determined by the product structure. Although there are alternatives in which the sequence may proceed, each one bears a unique time

signature reflecting the number of operations required to reach different components within a product.

The model considers a set of demand constraints that must be satisfied. Suppose that there are n different products (A_1, A_2, \dots, A_n) to be disassembled to fulfill the demand of m components (C_1, C_2, \dots, C_m). A set of dependent supply constraints is assigned to account for components availability in the product. Furthermore, the products may have components commonality and the sequence to disassemble the products may depend on the way they are structured. The precedence relationships of subassembly modules in a product structure play an important role in finding the strategy of sequencing components for removal. For example, a sequence in which to disassemble a product could be $\{C_1 \rightarrow C_2 \rightarrow C_3\}$ while the sequence to disassemble another product could be $\{C_1 \rightarrow C_3 \rightarrow C_2 \rightarrow C_4\}$. To reach component C_3 in the first product, a disassembler must first remove components C_1 and C_2 while in the second product the disassembler simply needs to remove component C_1 . The result is that it may take less time (and hence less cost) to retrieve C_3 from the second product than the first.

The methodology uses a two-stage heuristic approach to obtain the solution. First, the most efficient sequence is determined to get to the desired parts. Second, a mathematical programming based procedure is applied to solve an aggregate planning problem where the objective is to find the best combination of products to disassemble in order to fulfill the demand for different types of parts. This model accounts for such major costs as: i) cost of transportation, ii) cost of labor, and iii) cost of unwanted components disposal.

We assume that the supply of products, that have been disposed of at the end of their lives, is infinite. The component recovery facility must pay a fee to transport the products to the facility and to dispose of the leftover subassemblies. It is also assumed that the quality of each part is consistent throughout the product line and the planning cycle is one period.

The First Stage: At this stage a methodology is used to determine the minimum makespan schedule for each component such that the precedence constraints are not violated. The procedure consists of disassembly tree representation of the product, implementation of the modularity assignment rule and execution of the disassembly sequencing heuristic (for details, please refer to Veerakamolmal et al. [5]).

The Second Stage: In the second stage, the solution approach focuses on resolving the possible discrepancies

in the product structures because the number of components in different products may not be equal. The components are retrieved from various products in order to efficiently fulfill the demand.

The following goal programming (GP) formulation can be used to solve the problem of components discrepancy.

Notation

$D_j =$	total number of demand for component j (unit);
$DC =$	cost of waste disposal per lb. (\$).
$LC =$	cost of labor per hour of operation time (\$);
$MS_{ij} =$	makespan of component disassembly and retrieval (min.);
$NA_i =$	number of products needed to fulfill the demands of components (unit);
$NP_{ij} =$	number of component j that consists in product i (unit);
$RMW =$	maximum generation of waste as regulated by legislation (lb.);
$TAC =$	total cost of products transportation (\$);
$TC_i =$	cost of products transportation to the facility (\$);
$TLC =$	total labor time of disassembly and retrieval (min.);
$WP_j =$	net weight of each component (lb.);
$X_{ij} =$	supply of component j from product i (unit);

The goal programming formulation is as follows:

$$\text{Minimize } S_1^{(+)} + (LC)S_2^{(+)} + (DC)S_3^{(+)} \quad (1)$$

Subject to:

$$\sum_i [(TC_i)(NA_i)] - S_1^{(+)} + S_1^{(-)} = TAC \quad (2)$$

$$\sum_{ij} [(MS_{ij})(X_{ij})] - S_2^{(+)} + S_2^{(-)} = TLC \quad (3)$$

$$\sum_{ij} [(WP_j)((NP_{ij})(NA_i) - (X_{ij}))] - S_3^{(+)} + S_3^{(-)} = RMW \quad (4)$$

$$X_{ij} = (NP_{ij})(NA_i) \quad ; \quad "_{ij} \quad (5)$$

$$\sum_j \sum_i X_{ij} = D_j \quad ; \quad "_{ij} \quad (6)$$

$$NA_i, X_{ij} = 0 \text{ (and Integer)} \quad ; \quad "_{ij} \quad (7)$$

where $S_i^{(+)}$ and $S_i^{(-)}$ represent the auxiliary variables signifying the over achievement and under achievement of the goals, respectively.

The primary objectives of the model are to minimize the costs of transportation of products, the labor time required for disassembly and retrieval, and the disposal cost of unwanted materials which are achieved in the GP formulation by minimizing the value of auxiliary variables on each of the goals, thus giving the decision maker a clear judgment to the utility measures of components recovery in terms of monetary units. That is, limiting $S_1^{(+)}$, $S_2^{(+)}$, and $S_3^{(+)}$, with the upper limit of (TAC , TLC , RMW), while allowing the values to fall below the limit without penalty.

The constraints in equations (2, 3, and 4) limits the number of the set of values that binds the final solution to a feasible set of figures. The figures are the positive auxiliary variables $S_1^{(+)}$, $S_2^{(+)}$, and $S_3^{(+)}$ that poses as upper bounds for each objective, and vice versa for the negative auxiliary variables $S_1^{(-)}$, $S_2^{(-)}$, and $S_3^{(-)}$. Equation (5) represents the dependent supply constraint that limits the number of supplying components not to exceed the limit available in one product. The demand requirement constraint in equation (6) specifies that the demand for every type of components must be fulfilled. No backlog is allowed. The final equation (7) is the non-negativity constraint which also limits the resulting component variables to be integer.

EXAMPLE

Consider the example of components recovery from multiple products given in tables 1 and 2. The tables exhibit the operation time needed to disassemble and retrieve the components and the number of components present in the products. Note that there are three different products each made up of various combinations of a maximum of four different components.

Table 1. Makespan (MS_{ij}).

MS_{ij}	Component (j)			
	C_1	C_2	C_3	C_4
Product (i)				
A_1	15	9	9	9
A_2	15	17	10	-
A_3	14	-	13	-

Table 2. Number of Components in each Product (NP_{ij}).

NP_{ij}	Component (j)			
	C_1	C_2	C_3	C_4
Product (i)				
A_1	3	2	3	5
A_2	2	5	3	-
A_3	2	-	2	-

Let the demand for each component (D_1, D_2, D_3, D_4) be (15, 15, 25, 20). Assuming that the cost of hauling products (TC_1, TC_2, TC_3) to the facility is (15, 9, 8), the cost of labor per hour of operation time (LC) is \$15, and the cost of waste disposal per lb. (DC) is \$0.50.

The optimal solution obtained by using the GP model is $(NA_1, NA_2, NA_3) = (4, 3, 2)$ with surpluses $(S_1^{(+)}, S_2^{(+)}, S_3^{(+)})$ equal to (\$3, 362 minutes, 10 lb.). The optimal number of components ($X_{11}, X_{12}, X_{13}, X_{14}, X_{21}, X_{22}, X_{23}, X_{31}, X_{33}$) to retrieve from each product are (5, 8, 12, 20, 6, 7, 9, 4, 4), thus fulfilling the exact demands for every part.

To analyze the effect of an increase in the cost of labor (LC), should the decision maker intend to decrease the amount of workload that exceeds the upper limit (TLC), for example, the labor cost parameter (LC) can be increased from \$15 to \$30. The result shows a decrease in $S_2^{(+)}$ from 362 to 324 (min.). However, there is a tradeoff that resulted in an additional cost contributed by an increase in $S_1^{(+)}$ from 3 to 15 (\$) and in $S_2^{(+)}$ from 10 to 22 (lb.). The result illustrates that to compensate for a reduction in the labor time by 38 minutes, an additional cost of \$12 and an additional 12 lb. of waste is generated. Various alternatives for component retrieval and disposal can be explored by the decision maker to optimize the tradeoffs between economic feasibility and the degree of environmental detriment.

CONCLUSIONS

The main functions of a components recovery model include disassembly and retrieval of components to fulfill the market demands. The mechanism to configure the disassembly and retrieval of components is a two-stage system that takes into consideration the supply of products, their product structures and the demands of each component, in order to specify the number of product required.

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