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THE EFFECT OF DISASSEMBLY PROCESS ON SPARE PARTS INVENTORY MANAGEMENT IN POST PRODUCT LIFE CYCLE

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ABSTRACT

Timely and cost-effective acquisition of spare parts at post product life cycle (PPLC) is a challenging task due to limited supply of new spare parts. The most commonly used solution to this problem is the placement of a final order in the beginning of PPLC. Another alternative is the use of disassembled parts from End of Life (EOL) products. In this study, we consider both alternatives at the same time. First, a detailed discrete event simulation (DES) model of a disassembly line is developed. Then, a Genetic Algorithm (GA) is integrated with the DES model for the optimization of Final Order Quantities (FOQs) for critical spare parts.

1. INTRODUCTION

The after sale service involves the provision of spare parts together with necessary service personnel to customers following the sale of the original product. The effective management of after sale service activities is an important means used by manufacturers to differentiate themselves from their competitors in today's highly competitive and global markets. According to Poole [1], 40 to 50% of the profits and 25% of the annual revenues derived by manufacturers come from after sale service activities. Alexander et al. [2] estimate that the annual revenue of only four US industries—consumer electronics, personal computers, power tools, and vacuum cleaners— from after-sales service, parts, and ancillary products is somewhere between $6 billion to $8 billion. These numbers emphasize the importance of providing fast and high quality after sale service in achieving a competitive advantage over the competitors. Thus, the after sale service provides a long-term and continuous revenue opportunity [1]. Timely and cost effective supply of spare parts is a vital issue in after sales service. Seven billion dollars are expended by aircraft industry each year just for the spare parts required for the maintenance of Boeing aircrafts. For every dollar of spare parts inventory, airlines spend an additional holding and managerial cost of $0.35 [3]. Considering these numbers together with the $700 billion annual US spending on spare parts [1], it is clear that cost effective management of spare part logistics has a big potential for increasing revenues and profits.

The acquisition of spare parts can be an extremely challenging task especially at the PPLC point in time since the source of new spare parts is limited. Placing a final order for spare parts at the end of product life cycle is a common approach to this problem. However, accurate determination of the FOQ is complicated since it requires the prediction of spare parts demands for the PPLC. Prediction of demand is very difficult even when the failure rates are available and the number of installed bases is known, because a long term forecast over several years is needed

and a number of intangible factors such as fashion and obsolescence must be considered. If the demand is overestimated during the PPLC, excess parts have to be scrapped. Underestimation of demand results in opportunity cost and lost goodwill of the customers [4]. Another approach to the spare parts acquisition problem during PPLC is the use of recovered parts as a source of spare parts supply. However, the disassembly system is fraught with high degree of uncertainties in timing, quantity and quality of product returns [5]. Thus a satisfactory decision model for the determination of FOQs for spare parts during parts recovery and disassembly must have the ability of coping with many stochastic variables simultaneously.

In the literature, the most commonly used approaches to deal with the spare parts inventory management problem in PPLC are mathematical programming and simulation. Fortuin [6] presents a mathematical approach for solving the FOQ problem. Teunter and Fortuin [7], [8] improve this approach and validate it on a spare parts inventory problem of an electronic equipment manufacturer. Cattani and Souza [9] investigate the potential benefits of delaying the point of time when the final order is set up. Inderfurth and Mukherjee [10] propose an integrated approach by considering various spare part acquisition alternatives. First they use a decision tree for structuring the underlying decision problem and demonstrating the interdependences of different alternatives to choose. Then stochastic dynamic programming is employed for developing simple decision rules and a heuristic solution procedure for determining the FOQ.

The use of simulation in modeling the spare parts inventory management in PPLC represents a popular alternative to mathematical programming since simulation has the ability of describing multivariate non-linear relationships which can be difficult to put in an explicit analytical form. Spengler and Schroter [11] and Schroter and Spengler [4] model various spare part acquisition alternatives using a system dynamics simulation modeling approach. Among the other issues, they also determine the FOQ. Fleischmann et al. [12] consider the use of disassembly as a source of spare parts in a case study conducted at IBM. They use their DES model to compare alternative policies based on alternative channel designs and alternative coordination mechanisms. However, they do not consider the FOQ problem. Ilgin and Gupta [13] propose a GA based simulation optimization methodology for the determination of optimal FOQs for a number of spare parts. They assume that each spare part order requires the provision of only one spare part type. However, in real life, some spare part orders may require the provision of more than one type of spare parts at the same time. They also model the whole disassembly line as a single resource and use a uniform distribution to generate a disassembly time for each product.

In this study, we extend Ilgin and Gupta's [13] research in two ways. First, we consider spare part orders requiring simultaneous provision of more than one spare part types. Second, our DES model allows for the detailed modeling of the disassembly line. Similar to Ilgin and Gupta [13], reordering of spare parts during PPLC is not possible in the system considered. In other words, the only source of spare parts during this period is the parts harvested from the discarded and EOL products. Hence, the determination of the optimal FOQs for critical spare parts requires the simultaneous consideration of the demand for spare parts during PPLC and timing and quantity of product returns. In order to cope with these highly uncertain components of the problem, firstly, a detailed DES model describing the manufacturing system with its spare parts inventory and remanufacturing related aspects is developed. Uncertainty in demand during PPLC, uncertain product returns and part recovery is included in the DES model. Then, a GA is

integrated with the DES model for the optimization of FOQs for critical spare parts. The details of the study and experimental results are presented. Finally, directions and suggestions for further research are presented.

2. SYSTEM DESCRIPTION AND SIMULATION MODEL DEVELOPMENT

The firm considered in this study is a producer of a seven-part product. Since the product has reached its end of production phase, the firm tries to determine the FOQs for three parts (A, D, E) of the product which are demanded by the customers most frequently. In addition to FOQ, the administration is planning to use disassembled parts from EOL products which arrive exponentially at a rate of 30 products per hour. Table 1 depicts different parts disassembled at each station together with the mean disassembly times. Disassembly times for components are distributed exponentially. The order inter-arrival time is exponentially distributed with a mean of 5 minutes. There are 7 order types. Some order types require the provision of more than one spare part types at the same time. The probability of occurrence of each order type and demand quantities for spare parts in each order type are depicted in Table 2. If the parts required by an order type could not be supplied using FOQ or disassembled parts, the order is lost.

According to the disassembly line control mechanism of the firm, if FOQ for each part is greater than 10 (*minimum inventory level*), the incoming EOL products are not disassembled. They are stocked for disposal. Whenever the FOQ for a part reduces to *minimum inventory level*, disassembly of this part is carried out. Disassembly of a part is stopped when the number of disassembled parts becomes equal to the difference between the *total expected demand during the PPLC* and the FOQ of this part. Following the disassembly, the resulting subassembly is sent to the station which disassembles a part whose FOQ is less than or equal to *minimum inventory level*. If there is no station in that condition, the subassembly is stocked for disposal. Whenever the total volume of the excess product and subassembly inventories become equal to the volume of a small truck (425 cft), the truck loaded with excess inventory is sent to a recycling facility. Any product or subassembly inventory which is greater than 10 *(maximum inventory level)* is assumed to be excess. Parts are disposed at the end of the PPLC period. Part volumes are given in Table 1. The volume of a product is taken as 2.128 cft. In order to calculate the disposal cost of a product, subassembly or part, the weight in pounds is multiplied by the *disposal cost per pound* ($0.4). Disposal costs of products and subassemblies are increased by a factor called *disposal cost increase factor* (0.20). In the calculation of transportation cost, the operating cost associated with each trip of the truck is assumed to be $50. The disassembly cost is $2 per minute. For each EOL product, the facility demands a $30 collection fee.

DES model of the system was developed using Arena 11. An animation of the DES model was built for the verification of the model. In addition, model output results were checked for reasonableness. Dynamic plots and counters providing dynamic visual feedback were used to validate the DES model. Each DES experiment has been carried out for 362880 minutes, the equivalent of three years with one eight hour shift per day.

In order to determine the *total expected demand during PPLC* for each part, five replications of the simulation model were carried out. The maximum total demand from these five replications was taken as the *total expected demand during PPLC* value for the respective part.

Table 1 Part Characteristics

Part	Unit Production Cost (Final Order)	Unit Sales Price (Final Order)	Unit Sales Price (Disassembly)	Weight (lbs)	Volume (cft)	Station	Mean Disassembly Time (min.)
A	10	20	16	0.3	0.008	1	1
B	-	-	-	0.8	0.015	-	-
C	-	-	-	2	0.056	-	-
D	25	50	40	2	0.016	2	2
E	50	100	80	4	0.263	3	2
F	-	-	-	4	0.081	-	-
G	-	-	-	20	2.128	-	-

Table 2 Order Types

Order Type	Probability	Spare Part Code	Demand Quantity	Probability
1	0.20	A	1	0.60
			2	0.40
2	0.20	D	1	0.50
			2	0.50
3	0.20	E	1	0.80
			2	0.20
4	0.10	A	1	1
		D	1	1
5	0.10	A	1	0.35
			2	0.65
		E	1	0.40
			2	0.60
6	0.10	D	1	1
		E	1	1
7	0.10	A	1	1
		D	1	1
		E	1	1

3. GA OPTIMIZATION PROCESS

Each GA chromosome represents a possible configuration of the FOQs of critical spare parts based on the specified upper and lower bounds. The GA performs tournament selection. The GA also uses elitism to save and copy the fittest chromosomes into the next generation. For each pair of selected parents, crossover and mutation operations are applied to generate a new pair of offspring. Two-point crossover is performed, and the crossover points are selected randomly.

Since real-valued encoding is used in the GA, the mutation operator is implemented by random replacement. If a gene is to be mutated, a new FOQ is randomly picked and assigned to the gene. The following *Profit* function is employed to evaluate the fitness of each alternative solution:

$$Profit = (SR+CR) - (HC+DC+DPC+TC+FC) \quad (1)$$

The different cost and revenue components in equation 1 can be defined as follows. *SR* is the revenue generated by the component sales during the simulated time period (STP). *CR* is the revenue generated by the collection of EOL products during the STP. *HC* is the holding cost of parts, products and subassemblies during the STP. *DC* is the disassembly cost during the STP. *DPC* is the disposal cost of parts, products and subassemblies during the STP. *TC* is the transportation cost during the STP. *FC* is the total cost of final orders placed for three parts at the beginning of the PPLC.

The initial population is constructed by randomly creating a set of chromosomes. Each chromosome of the initial population is then evaluated by the DES model. The GA code automatically gets the fitness value of each alternative solution from the DES model to create a new generation using genetic operators. When the maximum number of generations is reached, the solution is accepted as optimal.

4. RESULTS

GA uses a population size of 20, and 100 generations of evolution. The probability of crossover is set as 0.90. Mutation is performed immediately after the crossover with probability 0.10. For all parts, the lower bound is 0. Upper bound for each part is equal to the *total expected demand during PPLC*, i.e. 47303, 43964, 43934 for part A, D, E, respectively. For each chromosome, five simulation replications were carried out.

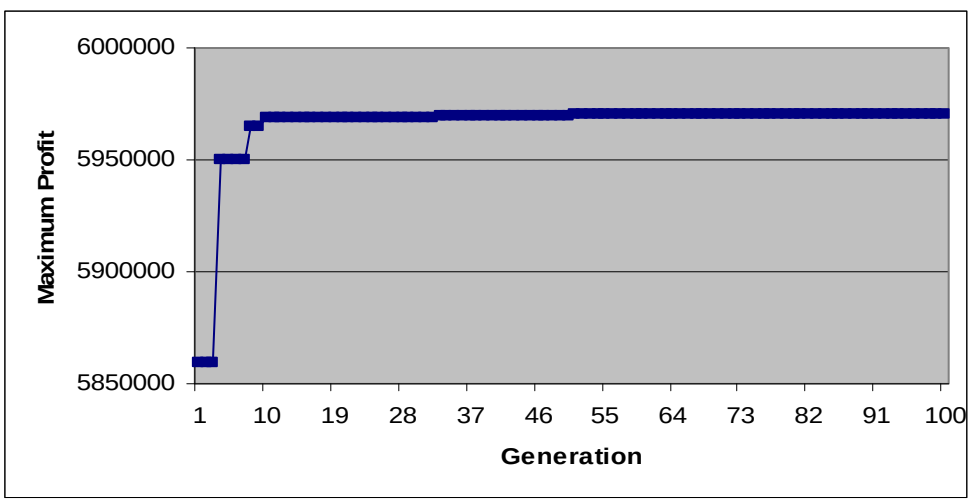

Figure 1 Convergence Graph of the GA

The convergence graph of the GA is presented in Figure 1. According to this figure, the GA converges to a solution at the 51st iteration. The proposed FOQs for part A, D, E are 7247, 5828, 3753, respectively. This solution results in an average profit of $5,970,125.

5. CONCLUSIONS

Placing a final order is a common approach to deal with the spare part acquisition problem at the PPLC. Another approach is the use of recovered parts as a source of spare parts supply. In this study, we considered both of these approaches at the same time and determined the optimal FOQs for critical spare parts. First, a detailed DES model of a disassembly line was developed by considering spare part orders requiring simultaneous provision of more than one spare part types. Then, the FOQs were optimized by integrating a GA with the DES model. The study can be extended by analyzing the effect of different factors on FOQs.

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