PRODUCTION PLANNING BASED ON RELIABILITY MODELS FOR PART REUSE

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Abstract: This paper describes a production planning procedure addressing the issue that the timings and quantities of returned products and reusable components included in them is unknown. This procedure first predicts the quantities of returned products and reusable components at each time period by using reliability models. Using the predicted results, the procedure performs production planning based on Material Requirement Planning (MRP). This procedure enables us to plan at each time period: the quantity of the products to be disassembled; the quantity of the reusable components to be used; and the quantity of the new components to be produced.
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1 intrODUction

Product recovery is one of the effective ways of preventing waste products, and there are some strategies for the product recovery: material recycling, reuse, remanufacture, and thermal recycling. The reuse and remanufacture of used products or components are more effective and generally more economic than the other strategies. In this paper, we deal with production planning in the case that components included in returned products are reused for a different purpose: for example, CPUs of computers are reused as those of toys or refrigerators. In such a case, the following issues make production planning difficult [1,2]:

1. The timings and quantities of returned products and reusable components are unknown.
2. The condition of returned products is unknown until they are disassembled and inspected.

In this paper, we propose a production planning procedure that addresses the first issue. This procedure first predicts the quantities of returned products and reusable components at each time period by using reliability models. Using the predicted results, the procedure performs production planning based on Material Requirement Planning (MRP).

Some approaches to the production planning for reuse or remanufacture have been developed. Gupta et al. developed an MRP-based algorithm to plan disassembly operations [3, 4]. Uzoy et al. presented a linear programming model to plan the cost optimal quantities to be overhauled, disassembled, and disposed in each period [5, 6]. However, these works don't consider the issues mentioned above.

In this paper, we illustrate our approach with simple products and present some sample calculations to demonstrate the effectiveness of our approach.

2 Reliability Models for Prediction

In this section, we illustrate our prediction method with the product shown in Figure 1, which includes a parallel sub-system composed of the components P2 and P3. This product can work even if either P2 or P3 has failed, provided that P1 is working.

2. 1 Assumptions

Our prediction method is based on the following assumptions:

A1. products are used until fail

A2. products are returned as soon as they fail.
A3. a component can be reused if its residual life is over a certain time.
A4. components are neither repaired nor refurbished. Therefore the residual lives of components cannot be lengthened.
A5. the failure of each component occurs independently of other components' failures.

2.2 Reliability model for predicting the quantity of returned products

The probability that a product purchased at time *t* fails in the interval between *ta* and *tb* is described by:

(1)

where *F(t)*: probability of failure before *t*,
tu: mean time from the time when a product is purchased to the time when the product starts to be used.
Figure 2 shows the relationship among *t*, *tu*, *ta*, and *tb*.
A function *F(t)* differs from one product structure to another. For the example shown in Figure 1, *F(t)* is described by:

(2)

where, $f_i(t)$ (i=1, 2, 3) is the failure probability density function of component Pi.

If the demand of the product at each time period is given (i.e., the past demand is known and/or the future demand is forecasted) as shown in Figure 3, the quantity of returned products that fail in the interval between *ta* and *tb* is described by:

(3)

where *d(t)* is the density function of the demand, which satisfies the following equation.

(4)

where D_i is the demand of the product in time period *i* and *r* is a length of one time period such as one week.

Figure 3: Demand of the product shown in Figure 1.

2.3 Reliability model for predicting the quantity of reusable components

First, we enumerate the cases that a product fails in the interval between *tz* and *tz+dtz* but some components included in it can be reused, where *dtz* is an infinitesimal time. For the example shown in Figure 1, the following cases can be enumerated:

Case1: component P3 has failed before *tz*, and component P2 fails in the interval between *tz* and *tz+dtz,* but component P1 can be reused.
Case2: component P2 has failed before *tz*, and component P3 fails in the interval between *tz* and *tz+dtz,* but component P1 can be reused.
Case3: components P2 and P3 fail in the interval between *tz* and *tz+dtz,* but component P1 can be reused.
Case4: component P1 fails in the interval between *tz* and *tz+dtz,* but component P2 can be reused. In this case, a product fails in the interval between *tz* and *tz+dtz* but P2 can be reused, regardless of whether P3 has failed or not.
Case5: component P1 fails in the interval between *tz* and *tz+dtz,* but component P3 can be reused. In this case, a product fails in the interval between *tz* and *tz+dtz* but P3 can be reused, regardless of whether P2 has failed or not.

We can describe the probability of occurring each of the cases, by using the failure probability density functions of the components. For example, the probability of occurring Case1, $PT^{Case1}_{tz,}$ is the product of the following probabilities:

λ The probability that component P3 has failed before *tz*:

(5)

λ The probability that component P2 fails in the interval between *tz* and *tz+dtz*:

(6)

λ The probability that component P1 can be reused:

(7)

where *tr* is a threshold of residual life. If the residual life of a component is over this threshold, this component can be reused.

From these probabilities, the probability of occurring Case1, $PT^{Case1}_{tz,}$ is described by:

… (8)

In the same way, the probabilities of occurring Case2, 3, 4 and 5 are described by:

… (9)

… (10)

(11)

(12)

From these equations, we can describe the probability that a product purchased at time *t* fails in the interval between *ta* and *tb* but component Pi (i=1,2,3) included in it can be reused, , as follows:

… (13)

… (14)

… (15)

It is to be noted that component P1 can be reused in Case 1, 2, and 3, however Case 3 is not considered in equation (13) because the probability of occurring Case 3 is very small.

We can describe the quantity of reusable component Pi (i=1, 2, 3) included in the products that fail in the interval between *ta* and *tb*, as follows:

, i=1,2,3 (16)

2.4 Computational example

Using the equations, we computed the quantity of products that fail in each time period but include reusable components. In this computation, we assume that the failures of components are based on exponential distributions in which the failure rates of P1, P2 and P3 are 0.0000055(1/min), 0.0000065(1/min), and 0.000013(1/min) respectively. We also assume that *tu, tr;* and one time period are 1,250(min), 60,000(min), and 2,500(min) respectively. Taking the product demand shown in Figure 3 as input, we predicted the quantities of returned products and reusable components, as shown in Figure 4.

Figure 4: The quantities of returned products and reusable components in each time period.

3 PRODUCTION PLANNING BASED ON THE PREDICTION

We perform production planning using the predicted quantities of returned products and reusable components. MRP enables us to plan for each time period: (1) the quantity of the returned products to be disassembled; (2) the quantity of the returned products to be material-recycled; (3) the quantity of the reusable components to be used; (4) the quantity of the new components to be produced; and (5) the stocks of the returned products, reusable components, and new components.

3.1 Assumptions and procedure

This method is based on the following assumptions:

An assembly factory orders appropriate lots of reusable components from a disassembly factory. Then the reusable components are removed from returned products at the disassembly factory and transported to the assembly factory. The assembly factory also orders appropriate lots of new components from a part manufacturer.

If the stock of returned products carried forward at the disassembly factory is over an upper limit, a surplus of the stock over the upper limit is transported to a recycler for material recycling.

The safety stock of new components is used for compensating a difference between predicted and actual quantities of reusable components.

Disassembly Lead Time(DLT), which is the time needed to obtain a reusable component from a returned product, is a multiple of a time period.

Ordering Lead Time(OLT), which is the time elapsed between placing an order of new components and receiving them, is also a multiple of the time period.

The gross requirement of a component at each time period is given, which can be calculated from Master Production Schedule(MPS) and Bill of Material(BOM) of a product.

Based on these assumptions, this procedure determines the lot number of reusable components to be ordered at each time period according to the gross requirements of the components, on the following condition:

- The reusable components that are planned to be ordered need to be less than the predicted quantity of reusable components.
- Reusable components are ordered as much as possible.

The quantity of the products to be disassembled at each time period is determined according to the lot number of the reusable components that are ordered. If the predicted quantity of reusable components is not enough to satisfy the gross requirements, this procedure determines the lot number of new components to be ordered.

3.2 Computational example

We performed production planning for the case that component P1 of the product shown in Figure 1 is reused as component P4 of the product shown in Figure 5. The quantities of the returned original products and reusable P1s are shown in Figure 4, and the MPS of the product reusing P1s is shown in Figure 6. We assume that both DLT and OLT are one time period. Figure 7 shows one of the results of production planning. As shown in Figure 7, at the early stage the reusable components are not ordered because there are not enough returned products to obtain one lot of the reusable components. However, after 20th period, the reusable components are ordered instead of new components. The proper quantity of returned products is disassembled to obtain the lot number of reusable components. The fluctuations of the planned orders and the products to be disassembled result from the lot size.

We also examine the effect of parameters (lot size of components and the stock limit of returned products at the disassembly factory), by performing production planning with various parameter values. Figure 8 shows the comparison of production plans from the viewpoint of net profits. As shown in this figure, the parameters affect the net profits, and in this case the maximum net profit is obtained in the case that the stock limit is 40 and the lot size of components is 20. Table 1 shows the factors we considered here to calculate the net profits.

Table 1 Costs and benefits we consider to calculate net profits

Benefit by selling products to consumers
Benefit by selling returned products to a recycler
Cost of purchasing new P4s from a part manufacturer
Cost of purchasing new P5s from a part manufacturer
Cost of obtaining reusable P1s by disassembling returned products at the disassembly factory
Cost of assembling products at the assembly factory
Inventory cost for new P4s
Inventory cost for new P5s
Inventory cost for reusable P1s
Inventory cost for returned products
Cost of transporting new P4s
Cost of transporting new P5s
Cost of transporting reusable P1s
Cost of transporting returned products

4 CONCLUSIONS

We proposed a production planning procedure addressing the issue that the timings and quantities of returned products and reusable components are unknown. This procedure first predicts the quantities of the returned products and reusable components at each time period by using the reliability models. Using the predicted results, the procedure performs production planning based on MRP. This procedure enables us to plan at each time period: the quantity of the returned products to be disassembled; the quantity of the reusable components to be used; and the quantity of the new components to be produced. We illustrated our approach and presented some sample calculations to demonstrate the effectiveness of our approach. We are going to compare our approach and other cases that don't carry out the prediction. We are also expanding our approach for taking account of the following issues:

(1) In Section 3.2, we assume that only one type of component(P1) is reused. However, in practical cases, some components that are obtained simultaneously from one returned product may be reused.
(2) One type of reusable components may be obtained from different types of products.
(3) One type of components may be reused to different types of products.

References

[1] Fleischmann, M., et al., 1997, Quantitative models for reverse logistics: A review, European Journal of Operational Research, 103, pp.1-17.

[2] Guide Jr., V.D.R., Jayaraman, V. and Srivastava, R., 1999, Production planning and control for remanufacturing: a state-of-the-art survey, Robotics and Computer-Integrated Manufacturing 15, pp. 221-230.

[3]Gupta, S.M. and Taleb, K.N., 1994, Scheduling disassembly, International Journal of Production Research 32, pp. 1857-1866.

[4] Taleb, K.N., Gupta, S.M. and Brennan, L., 1997, Disassembly of complex product structures with parts and materials commonality, Production Planning and Control 8, pp. 255-269.

[5]Clegg, A., Williams, W. and Uzoy, R., 1995, Production planning and control for companies with remanufacturing capability, Proceedings of the 1995 IEEE International Symposium on Electronics and the Environment. IEEE, pp. 186-191.

[6] Uzoy, R., 1997, Production planning for companies with product recovery and remanufacturing capability, Proceedings of the 1997 IEEE International Symposium on Electronics and the Environment. IEEE, pp. 285-290.