Outline for a rotable control structure

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OUTLINE FOR A ROTABLE CONTROL STRUCTURE

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ABSTRACT

In general, maintenance organizations need an inventory of spare parts to carry out their activities. A subset of those parts is recoverable, the so-called rotables. Rotables are waiting for repair, under repair, waiting for use or in use. In practice different rotable flows are encountered. They are characterized in the first section of this paper. To control a rotable flow cost-effectively, various control decisions can be made. Those control decisions are either item or capacity oriented and must be integrated in a framework: the control structure. An outline of such a structure for the control of a simple rotable flow is presented in this paper.

1. INTRODUCTION

Of late decennia, much attention is called to production control problems. Well-known tools like MRP have been developed to support management in solving production control decisions. These tools commonly require stable and predictable short-term demand conditions to some extend. In practice however, short-term demand can be unpredictable, for instance corrective maintenance demand. The task of maintenance is to reduce the downtime of production equipment. For that purpose spare parts are used. A subset of the spare parts can be recoverable: the so-called "rotables". Examples of rotables are for instance airplane-engines or printed-circuit-boards. During maintenance of the production equipment failed rotables are exchanged by their recovered counterparts.

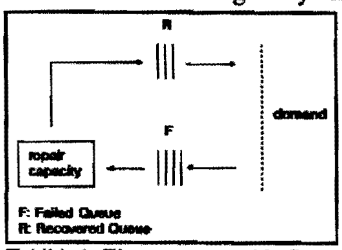

Exhibit 1: Elementary rotable flow.

Thus rotables can adopt two states; the failed and the recovered. The failed rotables queue up in front of a repair capacity. After repair the recovered rotables are available for the maintenance process, exhibit 1.The cost-effective control of rotables is the subject of the research on hand. In this paper we focus on the control structure.

Nowadays, the product assortment is widening and the production equipment is loaded increasingly irregularly. As a consequence the failure behavior of the production equipment is becoming less predictable and corrective maintenance is becoming more important. The timing of corrective maintenance cannot be adequately planned. So is the demand to recovered rotables. In general such situations are characterized by

- a fluctuating aggregate demand pattern,
- a short-term detailed demand uncertainty,
- a closed loop inventory which must be procured well ahead and
- a high operator flexibility to react on short-term demand variation.

Considering rotable flows in practice, we distinguish four different rotable types. Rotable type (11) has a simple product structure. Its purchasing costs are high in comparison to the shipment costs, but low in comparison to the stagnation costs of the production equipment. The recovered rotables are kept in a central warehouse. Rotable type (12) has a simple product structure. Its purchasing costs are low in comparison to the shipment costs and the stagnation costs of the production equipment. Consequently a rotable can be stocked economically near by the production equipment. The production equipment is distributed widely e.g. copiers. As a result the inventory will be widely distributed as well. Characteristic is a multi-stage inventory. Rotable type (21) has a complex product structure. Its purchasing costs are high in comparison to the shipment and the stagnation costs. To reduce the purchasing costs of the rotables, some cheaper rotable subassies are stocked. Two repair levels can be distinguished. The first level involves rotable repair: The second level involves subassy repair. Like the rotables, also the subassies rotate. Characteristic is a multi-level repair process. Rotable type (22) has a complex product structure. Its purchasing costs are high in comparison to the shipment costs, but low in comparison to the stagnation costs. Based on the number of repair levels and inventory stages all rotable flows are classified, table 1.

Table 1: Classification of rotable flows.

		number of inventory stages	
		single stage	multi stage
number of repair levels	single level	cell(11) tool repair	cell(12) electronic repair
	multi level	cell(21) aircraft repair	cell(22) aircraft repair

In section 2 the relevant literature on rotables is briefly reviewed. Based on the review we conclude that the majority of the papers address the item aspect of rotable control. Very little attention has been addressed to the capacity aspect. Further no control structure has been presented yet which integrates the capacity and material aspect of rotable control. In section 3 we elaborate on a control structure for the rotable flow of cell (11) in the classification. In section 4 the paper is concluded with a discussion.

2. RELEVANT LITERATURE

The majority of the relevant literature addresses, for all rotable flows of the classification, the calculation of the closed loop inventory, subject to a budget restriction. To reduce mathematical complexity many authors assume: (compound) independent Poisson failures, stationary demand, a fixed number of rotables, no lateral resupply, no subcontracting and ample capacity (until recently). An overview is presented [1].

In the early literature, solutions methods for the closed loop rotable inventory problem have been published under the collective noun METRIC [2] [3] [4] [5].

METRIC solves the problem assuming ample capacity. More recently the ample capacity restriction is relaxed and the inventory problem is solved by means of a closed loop queuing approach [6] [7] [8] [9]. The queuing approach is more accurate than METRIC in solving the problem, however more intricate too. Therefore, lately, attention is directed to METRIC again. The gap between both approaches has recently been closed by means of approximations [10].

The control problem can be decomposed in a long term planning problem and a short term shopfloor decision problem [11]. On the planning level the most economical rotable inventory is determined. Like in METRIC the result of the marginal analysis will be an expected shortage of high cost rotables. On the shopfloor level the individual service levels must be balanced, taking into account the actual state of the repair process.

So far the literature deals with the item aspect of rotable repair control alone. In the characteristics however we signalize the importance of operator flexibility, a capacity aspect of rotable control. The literature that addresses the capacity aspect of rotable control is scarce. Some introductory research to overtime policies has been carried out for a multi-level rotable repair flow, table 1 cell (21) [12]. The effects of proactive and reactive overtime on the stock out risk of the recovered inventory is analyzed. The results indicate that overtime affects the stockout risk most effectively when reactive final assy overtime is paired with proactive component overtime.

3. ROTABLE CONTROL STRUCTURE

Unlike the literature on rotable control, in the production literature much attention is directed to production inventory control structures which integrate the capacity and the item aspect, for instance Bertrand, Wijngaard and Wortmann (BWW) [13]. BWW have developed a design approach which, for various production inventory control situations including make-to-stock, is applied for structuring the control. Rotable repair can be seen as make-to- recovered stock and thus the make-to-stock control situations is used as a starting point. In this section, the BWW approach is briefly explained and fit to the rotable flow of cell (11) in table 1.

BWW use the decomposition technique. They assume, among others, that the control of the flow within production units (PUs) can be separated from the control of the flow between PUs. The flow between PUs is controlled by means of the intermediate inventories. We focus on the control between PUs. The framework co-ordinating the tasks that affect this flow is referred to as "the goodsflow control structure (GFCS)". and is briefly explained in this section. For the interested reader we refer to the literature.

The authors propose to decompose the GFCS into two hierarchical levels of control: aggregate production planning (APP) and material co-ordination (MC). In the APP, the higher control level, the various control aspects of the organization (sales, logistics, etc.) are integrated. In the make-to-stock situation with standard items, the outputs of the aggregate planning process are: (i) The aggregate delivery plan, which for families of items, the APP-items, states the planned deliveries over a number of future periods. (ii) The capacity use plan, which for selected capacity types (often one per PU), states the required effective use in terms of hours per period over a number of future period. (iii) The capacity adjustment plan, which for the selected capacity types states the adjustment of the available hours per period over a number of future periods. (iv) The aggregate inventory plan, which specifies the planned inventory for the various production stages, for a number of future periods. The inventory is planned in terms of the number of APP-items and simultaneously in terms of "stored capacity" of the selected capacity types. The four plans are the driving force for the short-term capacity control and material co-ordination.

In MC the work-order release priorities are established, based on the aggregate delivery plan, the detailed demand information and the expected work-order throughput times. At a work-order release moment the priorities are combined with an aggregate release pattern. The pattern is the outcome of a workload control process, which is a tuning of the capacity use plan and the actual workload of the PU. The actual work-order release is a fine tuning between the workload control and the material co-ordination. So far BWW. We intend to fit the GFCS on rotable repair.

We consider the output of the APP and MC again. (i) The aggregate delivery plan: In a rotable situation, the failing production equipment is the customer that must be satisfied. Thus an aggregate delivery plan should be derived from the forecast of corrective maintenance occurrences and the rotables which are necessary for that purpose. Both parameters cannot be predicted adequately and consequently the delivery plan will be hardly predictable too. Thus, in controlling rotable repair, an aggregate delivery plan is not suitable as a driving force. (ii) The capacity use plan: This plan anticipates on the future average aggregate demand. The average demand depends on the failure behavior of the different rotable types and is predictable. Therefore we expect that a repair capacity use plan can be formulated similar to a production capacity use plan. (iii) The capacity adjustment plan: The capacity adjustment plan anticipates on future aggregate demand. As we mentioned already in section 1, the aggregate demand fluctuates in time. Its average can be predicted, even its variations, alas often not the variation occurrences. Trends cannot easily be predicted and as a consequence the value of the capacity adjustment plan is limited. However, as we mentioned in section 1, essential is the operator flexibility to react on demand uncertainty. If controllable, e.g. operator overtime, this flexibility is a temporary excess capacity which could be integrated in the capacity adjustment plan. We notice a shift from a structural capacity adjustment in production situations to a more flexible capacity adjustment in rotable situations. (iv) The aggregate inventory plan: In a rotable situation, the aggregate inventory consists of all failed and recovered rotables. The task of the inventory is to counter both demand and repair time variations. Repair time variations are caused by temporarily capacity overloads. These occur when the demand exceeds temporary the available repair capacity. We can anticipate on such events by "storing" capacity: Stocking an additional number of fast moving items. Pointing at the essentialities of rotable repair in section 1, we conclude that the aggregate inventory plan accomplishes an important task in rotable situations.

In rotable situations, MC consists of rotables. The rotable work-order release is dependent on the workload control and the established priorities between rotables. The workload control is again a tuning process between the capacity use plan and the actual workload in the PU. The priorities on the other hand cannot be based on the aggregate delivery plan like in production situations, because such a plan is hardly predictable in rotable situations. However, using the actual demand information and the knowledge that the rotable inventory is a closed loop, priorities can be established. We balance for instance on every release moment the individual fill rates of the recovered inventory. This task is carried out by the rotable co-ordination process. Also in rotable situations we need a fine tuning in the work-order release process and thus a work-order release process.

We conclude that, in structuring the rotable control problem, we need a different arrangement of the APP-plans. The aggregate delivery plan is not useful and moreover the function of the capacity adjustment plan is limited. This loss in controllability can be compensated by means of setting repair capacity levels, inventory levels and using operator flexibility. All interact and therefore must be weighted together in the APP in order to achieve a certain performance criterion e.g. the probability that, during maintenance, a recovered rotable is available for exchange. We elaborate on the APP process which is explained stap by stap.

Consider the most elementary rotable flow, table 1 cell (11), single-item. To control this flow we search for an optimal tuning between the capacity use plan and the inventory plan. The optimal tuning is found by regarding the problem as a queue with restricted queue length [14]. The cumulation of all steady states where the number of recovered rotables at least equals the number of production equipment yields the service level. Thus given a certain repair capacity and a required service level, we vary the repair capacity utilization rate, calculate the rotable inventory and fill in both the repair capacity and the rotable inventory in a cost function. For different values for the repair capacity, different cost functions are obtained. In accomplishing our performance criterion we are interested in the minimal cost function.

Lets assume that in the example the rotable inventory consists of four rotables. Now consider a similar rotable flow with two rotable types r1 and r2 that share the same repair capacity. The rotables r1 and r2 have similar failure and repair characteristics. The capacity - inventory trade off involves the determination of the steady states of a multi-item queue, which is not straight forward. If we translate a rotable in hours work, we can define some states, attach average inventory costs, and solve the problem as a single-item queue. In this manner we reduce the complexity a lot, but also introduce an error because of recovered inventory imbalance. If this error can be estimated, then the total inventory can be determined. The total inventory can be divided among the different rotable types on the basis of the failure and repair characteristics.

Suppose that as a result of this procedure we are advised to stock three rotables r1 and three rotables r2. If the rotables r1 and r2 have different purchasing costs, respectively c1 and c2 and $c1 > c2$, it can be considered to stock only two rotables r1 and four rotables r2. In that case c1 minus c2 is gained. However, rotable type r1 will be out of recovered stock frequently if no work order release priority is attached. Thus an economical division of the rotables among the rotable types, the so-called rotable composition, depends on the restrictions of the material co-ordination. On the other hand the same inventory composition affects the average cost of an hour of inventory which in turn affects the capacity - inventory trade off. If the latter effect can be neglected, the detailed inventory (in rotables) can be decomposed from the aggregate inventory (in hours capacity). The detailed inventory affects the material co-ordination. Only the aggregate inventory decision is included in the capacity - inventory trade off.

Now we include the adjustment plan in the trade off. The adjustment plan encloses all measures that increase the volume of the capacity on the short term e.g. operator overtime. Such measures affect the workload norms and consequently the release patterns on the short term. However it can be shown that those measures also have a favorable effect on the rotable inventory [15]. The inventory purchasing decision affects the long term. We decompose the actual short term capacity adjustment decision from the capacity adjustment measures. Only the adjustment measures together with their costs and restrictions are included in the trade off.

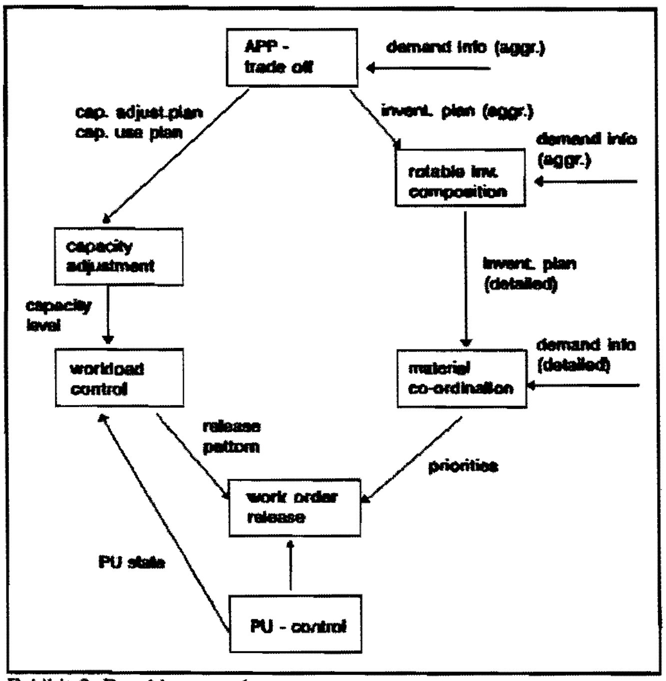

Exhibit 2: Rotabla control structure.

The above results in the repair inventory control structure of exhibit 2. The structure integrates four processes: (1) the long term APP-trade off, (2) the short term capacity adjustment process, (3) the long term rotable composition process, (4) the short term workload control process, (5) the short term rotable co-ordination process and (6) the short term work-order release process.

4. DISCUSSION

In section 3 a rotable control structure is presented which integrates capacity, capacity adjustment measures and aggregate rotable inventory on a long term. The capacity adjustment measures are decomposed from the actual capacity adjustment. The capacity adjustment is attached to the workload control process. The aggregate inventory is decomposed from the detailed inventory. During this decomposition stage the complexity of the APP process is reduced considerably. With the help of computer simulation we are proving whether those decomposition stages are legitimate.

Since the beginning of 1993 the research is executed in co-operation with a dutch aircraft engine maintainer, cell (21). We are analyzing if the control structure presented in this paper supports the management in structuring the rotable repair control. We focus on the contribution of various capacity adjustment measures.

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