Flexibility trade off in a service part supply system

Department of Operations Planning and Control -- Working Paper Series

FLEXIBILITY TRADE OFF IN A SERVICE PART SUPPLY SYSTEM

Jos H.C.M. Verrijdt*

Research Report TUE/TM/LBS/95-08
September, 1995

* Eindhoven University of Technology
Faculty of Technology Management, Paviljoen F12,
P.O. Box 513, NL-5600 MB Eindhoven, The Netherlands
Phone: +31.40.2472681/2247
Fax: +31.40.2464596
E-mail: J.H.C.M.VERRIJDT@TM.TUE.NL

This research is sponsored by the Netherlands Organization for Scientific Research (NWO).

Flexibility trade off in a service part supply system

0. Abstract

In this paper we present a framework for a service part supply system (SPSS) that is used for the control of service parts in an organization. The objective is to assure a high availability of service parts to customers in the field, such that downtime of failed equipment is minimized. At the same time the incurred costs are to be minimized. An SPSS consists of a repair structure (return flow of failed parts and the repair facility) and a distribution structure (divergent multi-echelon network). In an SPSS six flexibility trade off options are proposed that can be used to increase the flexibility of the system and hence improve the service performance. A distinction is made between capacity flexibility for the repair structure and inventory flexibility for the distribution structure of the SPSS. Two cases are discussed in which inventory flexibility is applied.

1. Introduction

In recent years an important shift towards customer service has taken place in the industries. Especially in highly competitive industries (e.g. automobiles, information systems, copiers), companies realize that offering extensive service to the customer can make a difference. The relation between supplier and buyer does often not end at the time of sale. After sales service has become a competitive weapon. Long running service contracts with the customer force the supplier to react quickly whenever a product fails at a customer site. Defective parts must be swapped quickly with good parts, in order to minimize the customers downtime. In order to respond adequately to customer calls, these companies often use a service part supply system (SPSS). An efficient and effective service mechanism is vital for attracting new customers and keeping present customers at rebuy moments. Next to this tendency of focusing on customer service, economic developments force companies to reduce costs. Therefore, the main goal for many companies in the nineties is to improve the service performance and at the same time reduce the associated costs. To realize this goal, increasing attention is paid to the logistic structure of the service part supply system. This paper discusses the various flexibility trade offs that occur in such a system.

In section 2 we present a brief literature review about the control of service parts from an operational research point of view. In section 3 we present a framework for an SPSS in which the different trade offs are discussed. In the framework we distinguish between capacity flexibility and inventory flexibility. In section 4 we present two cases in which some of the trade offs discussed in section 3 are considered. The two cases concern a manufacturer of CAD/CAM computer systems and a manufacturer of wafer steppers (used for the production of integrated circuits). Finally, in section 5 we present some conclusions and give topics for further research.

2. Literature review

The literature on multi-echelon supply systems for service parts covers over 25 years of research in this area. The METRIC-model (Multi-Echelon Technique for Recoverable Item Control, Sherbrooke (1968)) is widely considered to be the first model that captures the most important features of the problem of determining inventory levels for service parts in a multi-echelon environment. It was successfully implemented at the US Air Force. METRIC is a mathematical model that consists of a central depot supplying a number of bases (i.e. military airports) with various types of repairable parts for the maintenance of military aircraft. The demand for service parts is generated at the bases and is assumed to be (compound) Poisson. A defective part that is returned at a base is immediately replaced by a service part from stock on hand at the base (or backordered when no stock is available). The defective part is repaired either at the base or at the depot. When the part is sent to the depot for repair, an immediate resupply order is generated for that part at the depot (i.e. one-for-one replenishment). When the depot has serviceable stock on hand, a service part is shipped to the base. Otherwise, a service part is backordered and will be shipped as soon as it becomes available from the repair process. METRIC determines inventory levels for all service parts at all stocking locations (depot and bases) that minimize the sum of the expected backorders of all parts in all bases at a random point in time, subject to an investment constraint.

Several extensions to METRIC have been developed in the course of time. Complex products such as plane engines usually consist of different modules which in their turn consist of different components. Muckstadt (1973) extended the METRIC model to take account of such a hierarchical product structure. This model is called MOD-METRIC. Another extension to the METRIC model, called VARI-METRIC, applies a two-moment approximation instead of a one-moment approximation as used in METRIC (see Graves (1985)). Finally, Hausman and Erkip (1994) adjust the METRIC model such that emergency shipments are allowed in case of a stockout situation at the bases. An excellent overview of the general METRIC approach can be found in Sherbrooke (1992).

An important assumption that is made in METRIC is that repair times for all parts are independent; that is the repair shop is modelled as an infinite server queue. Several papers have discussed this assumption. Gross (1982) analyzes an $M|M|c$ queue and compares its performance with that of an $M|M|\infty$ queue. Scudder and Hausman (1982) use simulation to evaluate the performance of different priority rules in a repair shop with limited repair capacity and compare the results with MOD-METRIC. Both papers conclude that the infinite capacity assumption made in METRIC is in general a good approximation of the repair process.

Finally, a series of papers by Cohen *et al.* (1986, 1990, 1992) discuss the control of non-repairable service parts in a multi-echelon network under a periodic review inventory policy. Some practical aspects such as emergency transshipments and pooling are taken into account. Implementation at the after sales organization of IBM in the United States was very successful (Cohen *et al.* (1990)).

A more extensive overview of the literature on the control of service part supply systems can be found in Nahmias (1981), Mabini and Gelders (1990), Cho and Parlar (1991), and Verrijdt (1994).

3. The Service Part Supply System

A service part supply system (see figure 1) is a logistical structure used for the control of service parts. The goal of the system is to maximize customer satisfaction at minimum cost. Customer satisfaction reflects the responsiveness of the SPSS to failures at customer sites. When a technical system at a customer is down, service parts are needed to replace the failed parts. The consequences of downtime for the customer can be quite severe. Especially if it concerns machinery for continuous production (24 hours per day, 7 days per week), production downtime can have serious financial consequences. Therefore, the instant availability of service parts is a measure for the performance of an SPSS. This is often expressed as the expected fill rate: the fraction of customer demand (for service parts) satisfied from stock on hand. Another service measure often seen in practice is the availability of service parts within a certain time limit. Service contracts with customers often include the guarantee to provide service parts within e.g. 4 hours.

The costs associated with the performance of an SPSS include inventory holding cost, material handling, transportation, and risk of obsolescence. Especially the risk of obsolescence is very significant since service parts generally show a very low demand frequency. A service part with a demand of five

units per year is considered a fastmoving item in the world of the parts business whereas slowmoving items are demanded e.g. only once every five years. Another cost factor to be considered is the cost of emergency procedures. The cost of emergency transshipments or emergency repair is an important factor to consider when dealing with trade offs.
Because of the high price of many service parts combined with the low frequency of demand, many service parts are economically repairable. Upon failure the defective parts are replaced by service parts and the failed parts are send to some kind of repair facility. After repair the parts can be used again as service parts. These parts are called repairables and constitute a closed loop structure: they circulate through the SPSS. However, sometimes parts are technically not repairable any longer (because of e.g. wear out) and outside replenishment is necessary. Note that because of this closed loop structure the system inventory of repairables is fixed and inventory reduction is only possible by scrap actions. Parts that are not repairable (either technically or economically) are called consumables.

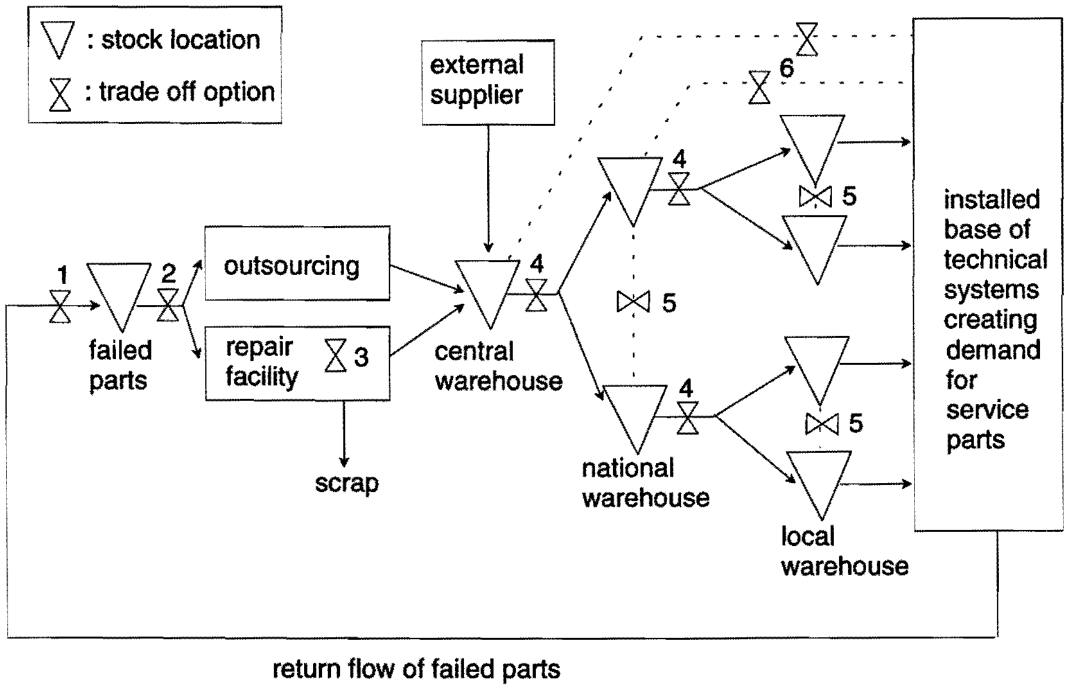

Figure 1: Service Part Supply System

The SPSS consists of two main parts: a repair structure and a distribution structure. The repair structure of the SPSS consists of an inventory location for failed parts, the repair facility itself, and possible outsourcing of repair activities. Also the return flow of failed parts from the customer field to the repair facility is part of the repair structure. The repair facility can be a complex structure of repair activity centres. Complex products (e.g. plane engines) generally consist of modules which in their turn consist of several parts or components. For each level in the product hierarchy (product-level, module-level, component-level) separate repair centres can exist. The interdependency between these centres is obvious: when repairing at product-level (resp. module-level) serviceable modules (resp. components) are necessary to replace failed modules (resp. components).
The distribution structure of the SPSS is a network of inventory locations supplying each other and the customers. Usually such a network is a multi-echelon divergent network consisting of a central company wide inventory location, national or continental inventory locations, regional inventory locations, local inventory locations, and carstocks. There is a tendency in recent years to cut down the number of echelons in the distribution network to save costs. However, to ensure a high availability of service parts to all customers 2- or 3-echelon networks are still needed.
In an SPSS there are several possibilities to increase the flexibility of the system and hence influence

the service performance. In figure 1 these flexibility options are characterized by faucets numbered 1 to 6. In the repair structure we propose three flexibility options (numbers 1, 2, and 3). These three options together are called the **capacity flexibility** because they all are directly related to the capacity of the repair process.

1) *Control of the return flow*: The return flow of failed parts can be organized in different ways. When parts are returned one-by-one to the centralized inventory location for failed parts, the cycle time for repairables is minimized and hence the system inventory is also minimal. However, in practice return shipments often consist of batches of parts because this reduces transportation costs.
2) *Workorder release for the repair process*: The release of workorders for repair jobs has to consider three aspects: (i) what type of parts to repair, (ii) how many parts of each type to repair, and (iii) where to repair (outsourcing the repair work or using your own repair facility).
3) *Repair shop flexibility*: The flexibility in the repair shop can also be increased in a number of ways. By using different priority rules and batching policies for the repair jobs, the output of the repair facility can be influenced. Another possibility is the use of overtime policies that depend on the workload of the repair facility.

In the distribution structure we also propose three flexibility options (numbers 4, 5, and 6). These three options together are called the **inventory flexibility** because they are directly related to the availability of inventory in the distribution system.

4) *Allocation policy for the inventory locations*: An important issue in the parts business is the determination of the assortment for the various inventory locations. The large number of part types (more than 50.000 different types is no exception) combined with other characteristics such as high prices, low demand frequencies, high risk of obsolescence, and short response time requirements, necessitates the differentiation of stock assortments in the various inventory locations. Another aspect concerns the allocation policy in case of shortages: how is the available inventory to be allocated in the supply chain?
5) *Inventory pooling (lateral transshipments)*: When technical systems at customer sites are down because of a stockout situation at the supplying inventory location, checking neighbouring inventory locations for available inventory might be very rewarding. Sharing inventory between several inventory locations in the same region or country reduces the waiting time for customers significantly.
6) *Alternative sourcing*: Next to the possibility of inventory pooling, it could also be worth considering the possibility to supply the waiting customer from an upstream inventory location in the supply chain (national or central warehouse). Using alternative supply sources in case of an emergency reduces the downtime of the customer significantly.

These six flexibility options in an SPSS determine the flexibility of the SPSS as a whole and therefore determine the trade off between service performance and associated costs. Research into these separate flexibility options can result in the following trade offs: in what situations is it economically worthwhile to implement flexibility. For example, in Verrijdt (1995) the trade off between using emergency repair and investing in inventory is investigated. De Haas (1995) investigates the effectiveness of using overtime policies in complex repair facilities. In the next section we discuss two cases in which some kind of trade off is considered.

4. Practical applications

In this section we present two cases in which the control of the service part supply system at two different companies was subject of research. The cases were carried out as graduation projects and are documented in Lamers (1994) and Kanters (1994).

Case 1

The company in this case is specialized in graphical computer hard- and software for industrial and professional applications. The project was carried out at the Field Services department in Nijmegen, the Netherlands, responsible for the after sales service and service part distribution in Europe. The service part supply system of the company consists of three echelons: one central warehouse in Nijmegen, national warehouses in 24 European countries, and several local warehouses associated to each national warehouse. Field engineers pick up service parts at the local warehouses and visit customers to solve machine problems. The aim of the project was to gain insight into the parameters that determine the service performance of the service part supply system and the associated costs. The current logistical concept was evaluated and alternatives were proposed. The attention was focused on the Nijmegen - UK branch of the service part supply system. In relation to the SPSS framework presented in the previous section, the study concentrates on the sourcing policy for the different types of service parts. This corresponds to trade off option 6 in figure 1.

Two service measures are considered: the *expected fill rate* (EFR: fraction of demand for service parts satisfied from stock on hand in the local warehouses) and the *workorder completion rate* (WCR: the fraction of workorders carried out without delay). A workorder is issued when a machine failure at a customer site requires a visit of a field service engineer. Because of the difficulty of assessing the type of failure by phone, the field service engineer sometimes takes more than one service part along. It is also possible that certain parts are needed for diagnostic purposes. If all required parts are available on hand in the local warehouses, no delay is incurred when executing the workorder. However, if one of the parts is not available on hand, the execution of the workorder is delayed since overnight supply of that part is required. The service performance experienced by the customer can best be approximated by using the WCR. Whether a machine failure can not be resolved because one part is missing or all parts are missing, is irrelevant to the customer. A relation between the EFR of the individual parts and the WCR is derived as follows:

$$WCR = \sum_{i=1}^{\infty} p_i \, (EFR)^i$$

where p_i represents the fraction of the total number of workorders that requires i spare parts. A graphical example of the relation between EFR and WCR is shown in figure 2. The shape of the curve depends on the values of p_i In the example the values of p_i are chosen as follows: $p_1 = 0.6$, $p_2 = 0.3$, and $p_3 = 0.1$. For example, when the EFR for the individual parts is 60%, the WCR equals 49%. Note that the WCR is always lower than the EFR.

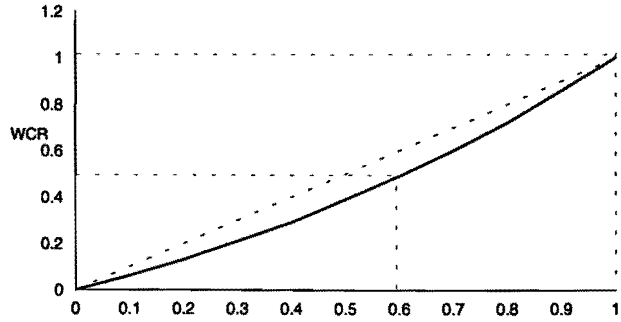

Figure 2: WCR as a function of EFR

Analysis of the situation showed that reducing replenishment lead times for service parts put on stock in the UK has a negligible impact on the service performance. The low demand frequency in combination with short replenishment lead times (approximately one week) does not leave much room for increasing the service performance significantly. Improving the availability of service parts put on stock in the local warehouses even further has a negligible effect on the service performance of the local warehouse as a whole and on the WCR.
Another important conclusion was that the most important factor determining the service performance of the SPSS is the decision *what* parts to put on stock in the regional warehouses. In the current situation all parts were stocked in the UK. About 20% of the part types were responsible for 80% of the total demand and were therefore stocked at the local warehouses. The remaining 80% of the part types were stocked in the national warehouse in the UK. However, overnight supply is required when these centrally stocked parts are needed at customer sites somewhere in the UK. Supplying these parts from the central warehouse in Nijmegen also requires overnight supply. Quantitative analysis showed that considerable savings are possible when moving slowmoving parts from the national warehouse in the UK to Nijmegen, realizing the same service performance. The reduction in inventory cost (approximately two million dollars) outweighs the extra costs incurred by special overnight deliveries from Nijmegen to the UK.
A decomposition approach was followed when evaluating the different stocking policies. First, it was determined what parts to stock in the UK (as a whole) and what parts to stock centrally in Nijmegen. A trade off analysis is used, taking into account the inventory costs in the UK, transportation costs from Nijmegen to the UK, and inventory costs at Nijmegen. Second, the parts that are stocked in the UK should be allocated as good as possible to the different local warehouses in order to maximize the service performance.

Case 2
The company in this case is a high tech company developing, assembling, selling, and servicing wafer steppers, which are used for the production of IC's. The company is one of the three major producers of wafer steppers in the world and its main market is the USA. The service department is responsible for the preventive and corrective maintenance activities. Corrective maintenance is performed according to the repair-by-replacement principle for which service parts are needed. The Logistics department is responsible for the world wide supply of the required service parts. The SPSS consists of three echelons: a centralized worldwide stock in the Netherlands, a continental stock in the USA, and local stocks in Europe, Asia, and the USA, located near customers. The aim of the project was to develop a model for stock decisions for the different categories of service parts at the various locations in the supply system, taking into account customer requirements and expectations. This corresponds to trade off option 4 in figure 1.
The service part assortment and the required stock levels at the local warehouses are calculated using a technique called marginal analysis: service parts with the highest contribution in decreasing backorders per invested guilder are added to the local inventory, until a desired operational availability of the wafer steppers is realized. The operational availability depends on the downtime due to maintenance activities and due to lack of service parts. The assortment and stock levels at the continental warehouse are also calculated using the marginal analysis technique. When evaluating the inventory policy of the worldwide stock, four categories of service parts are distinguished: non-repairable fastmovers (policy: demand forecasting as input to MRP), non-repairable slowmovers (policy: (s,S)), non-repairable ultra slowmovers (policy: periodic evaluation), and repairables (policy: system inventory based on scrap probability, repair time, and supplier lead time).

5. Conclusions and further research

In this paper we discussed the flexibility trade off options in an SPSS. These flexibility trade offs are divided into capacity flexibility for the repair structure and inventory flexibility for the distribution structure. For every trade off separately the increase in service performance has to be balanced against the incurred cost of applying flexibility. More research is needed to investigate the effect of the different trade off options. The objective is to find criteria for every flexibility trade off: When is it worthwhile to consider a certain trade off and what are the associated benefits and costs?

References

Cho, D.I., and Parlar, M. (1991), "A survey of maintenance models for multi-unit systems", *European Journal of Operational Research* 51, 1-23.

Cohen, M.A., Kleindorfer, P.R., and Lee, H.L. (1986), "Optimal stocking policies for low usage items in multi-echelon inventory systems", *Naval Research Logistics Quarterly* 33, 17-38.

Cohen, M.A., Kamesan, P.V., Kleindorfer, P.R., Lee, H.L., and Tekerian, A. (1990),"Optimizer: IBM's multi-echelon inventory system for managing service logistics", *Interfaces* 20, 65-82.

Cohen, M.A., Kleindorfer, P.R., Lee, H.L., and Pyke, D.F. (1992), "Multi-item service constrained (s,S) policies for spare parts logistics systems", *Naval Research Logistics* 39, 561-577.

Graves, S.C. (1985), "A multi-echelon inventory model for a repairable item with one-for-one replenishment", *Management Science* 31, 1247-1256.

Gross, D. (1982), "On the ample service assumption of Palm's theorem inventory modelling", *Management Science* 28, 1065-1079.

Haas, H.F.M. De (1995), *The coordination of initial stock and flexible manpower in repairable item systems*, Ph.D. dissertation, Graduate School of Industrial Engineering and Management Science, Eindhoven University of Technology.

Hausman, W.H., and Erkip, N.K. (1994), "Multi-echelon vs. single-echelon inventory control policies for low-demand items", *Management Science* 40, 597-602.

Kanters, M.M.M. (1994), "To spare or not to spare? That's the (key) question!", graduation report 2601, Faculty of Industrial Engineering and Management Science, Eindhoven University of Technology.

Lamers, J. (1994), "Field Service Spare Part Logistics at Intergraph", graduation report 2443, Faculty of Industrial Engineering and Management Science, Eindhoven University of Technology.

Mabini, M.C., and Gelders, L.F. (1990), "Repairable item inventory systems: a literature review", *Belgian Journal of Operations Research* 30, 57-69.

Muckstadt, J.A. (1973), "A model for multi-item, multi-echelon, multi-indenture inventory system", *Management Science* 20, 472-481.

Nahmias, S. (1981), "Managing repairable item inventory systems: a review", in: L.B. Schwarz (ed.), *Multi-level Production/Inventory Control Systems: Theory and Practice*, TIMS Studies in the Management Sciences, 16, Elsevier, 253-278.

Scudder, G.D., and Hausman W.H. (1982), "Spares stocking policies for repairable items with dependent repair times", *Naval Research Logistics Quarterly* 29, 303-322.

Sherbrooke, C.C. (1968), "METRIC: a multi-echelon technique for recoverable item control", *Operations Research* 16, 122-141.

Sherbrooke, C.C. (1992), *Optimal inventory modelling of systems: multi-echelon techniques*, John Wiley & sons inc., New York.

Verrijdt, J.H.C.M. (1994), "Repairable item and inventory control, a research proposal", research report TUE/BDK/LBS/94-13, Graduate School of Industrial Engineering and Management Science, Eindhoven University of Technology.

Verrijdt, J.H.C.M., Adan, I.J.B.F., and Kok, A.G. de (1995), "A trade off between emergency repair and inventory investment", research report TUE/BDK/LBS/95-05, Graduate School of Industrial Engineering and Management Science, Eindhoven University of Technology.