Chapter 1

Introduction and summary

1.1 Motivation

Consider a service (and repair) center that provides service for complex equipment. Some examples are as follows.

Example 1.1 Logistics Operations Philips Consumer Service (LOPCS), which is situated in Eindhoven in The Netherlands, is the logistic service provider for all the Philips products. They serve the Service Groups within the Philips National Organizations as well as third parties that have entrusted their service logistic operations to LOPCS. Philips is a company that produces electronic equipment, ranging from relatively inexpensive products like hair dryers and kitchen appliances to expensive ones like television sets and videorecorders or even more expensive medical equipment.

Example 1.2 Service organization Dutch Railways (NS, division NS Materieel), which is situated in The Netherlands, and is responsible for the repair and overhaul of trains.

A difference between these two service centers is that the first provides service to outside customers, whereas the second is responsible for keeping its own equipment operational. This affects the service period, being the period during which service is required for some piece of equipment. For Example 1.1, the length of the service period is the time period during which Philips promises to
repair any failure that might occur. This is determined by the European Association of Consumer Electronic Manufacturers (EACEM), of which Philips is a member. All members of the EACEM have agreed on the length of the service period for any type of product. The length of this service period depends on the type of product involved. Television sets for instance have a service period of 8 years, while medical equipment can have service periods of more than 10 years. For Example 1.2, the length of the service period is the time period during which NS plans to use the trains.

To be able to provide service, a service center must be able to supply service parts throughout the service period. As long as the product is still in production, service parts can easily be attained. However, the duration of the service period is typically much larger than the production period. In Example 1.1, the production period is mostly less than a year, whereas the service period is, for instance, about 3 years for hair dryers, 8 years for televisions and more than 10 years for medical equipment. Hence, due to the fast technological changes at Philips, the service period is much longer than the production period. In Example 1.2, the situation is even more extreme. Since trains are highly specialized (no two different countries use the same type of trains), the production period stops immediately after the last train of some order is delivered to NS.

In order to distinguish the period after the production has stopped from the period before that time, we divide the service period, i.e., the life cycle of service parts, into the following three phases, as is done in Fortuin [20] and Verrijdt [68].

- **Initial phase:** A new appliance is introduced to the market and service parts are needed to support it. For a successful introduction, it is necessary to provide a high service performance right from the start. Hence, stockpoints have to be filled with sufficient numbers of parts. However, since the appliance has just been introduced to the market, no historical demand data are available. As a result, inventory locations are usually overstocked in the initial phase.

- **Normal phase:** This phase begins when enough data on realized demands are available to forecast future demand with some accuracy. These forecasts can be used to determine (nearly) optimal stock levels. Clearly, the boundary between the initial and the normal phase, i.e., the time at which the initial phase ends and the normal phase starts, is fuzzy. The normal phase ends when the production of the appliance is stopped.
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- **Final phase:** The final phase begins when the normal phase ends, i.e., when the production of the appliance is stopped. It ends when the ‘last’ service contract expires.

As mentioned before, the service period might reduce to only the final phase for highly specialized equipment. With respect to inventory control, the final phase has some specific characteristics, which are:

- Since it is the last phase, there is a large risk of obsolescence associated with ordering parts in the final phase, especially near the end of that phase. All remaining stock will have to be disposed of at the end of the final phase.
- The opportunity for ordering parts is not guaranteed in the final phase. As long as an appliance is being produced, i.e., during the initial and the normal phase, service parts can easily be attained. After these phases, the production of the appliance is stopped, and sometimes the production of the corresponding service parts is also discontinued. In other situations, it is possible to order parts during the final phase also, but the price is much higher than in the previous phases. For instance in the NS case, the price after the beginning of the final phase is generally 3 to 5 times the price at the beginning of that phase. In both types of situation, it seems sensible to order a large number of parts at the beginning of the final phase, that is, at the last time that either parts can be ordered, or parts can be ordered at a low price, depending on the type of situation. In calculating this large order, however, one has to keep in mind that there is a risk of obsolescence, since parts that remain unused at the end of the final phase become useless, and have to be disposed of at that time.

Due to these special characteristics it seems sensible to develop a special class of ordering policies for service parts in the final phase, instead of applying policies that have been developed for the normal phase. Verrijdt [68] provides an excellent overview of inventory control in the normal phase. In fact, most studies on service part logistics focus on the normal phase.

In this thesis we focus on the inventory control of service parts in the final phase. We will discuss both the situation with a price increase after the beginning of the final phase, and the situation where it is impossible to order parts after the beginning of the final phase. We refer to the second type as a final order situation. We remark that some practitioners refer to it as an all-time-buy situation. Special attention in this thesis is given to parts with a small demand.
rate, i.e., to slow-moving parts, since service parts are typically slow-moving. Indeed, most service parts are very slow-moving. Consider for example the boundary demand rate between slow-moving parts and fast-moving parts of 10 parts per year, as suggested by Peterson and Silver [56]. We encountered examples in practice where more than 80% of the service parts were demanded less than 4 times over the past year.

To the best of our knowledge, Fortuin [20] [21] and Geurts and Moonen [24] are the only authors that also focus on final phase service parts logistics. Fortuin [20] [21] discusses situations where it is impossible to order parts after the beginning of the final phase. Geurts and Moonen [24] discuss an inventory problem with a finite planning horizon after which remaining parts become obsolete and with an increase in the setup cost for ordering (the price of an item remains unchanged) for parts that are not ordered immediately. Besides these authors, many others have studied one of these two aspects that characterize the final phase of a service part. We summarize the most important results at the beginning of each following chapter.

Before discussing the specific situations that we study, how those were modelled, and to what type of inventory control policies we restrict ourselves, we discuss the general objective of this thesis.

## 1.2 Research objective

The objective is to develop ordering policies, i.e., inventory control policies, for service parts in the final phase. We seek policies that minimize the total service cost, being that part of the cost in the end phase that can be influenced by the inventory control decisions in the end phase. Service cost minimization means balancing the revenues of providing a better service by increasing the stock of service parts against the investment cost associated with such an increase.

In order to understand why it is important to develop ordering policies that minimize cost, one has to realize that the number of different types of service parts that are stocked by service organizations is, in general, very large due to the diversity of products that most companies sell. For instance, at LOPCS (Philips) over a hundred thousand different types of service parts are stocked. Hence, applying policies that ignore the risk of obsolescence, for instance, can lead to enormous costs. In firms, until the seventies, not much attention was paid to the service cost. They were regarded as inevitable for providing service
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and staying in competition. In recent years, however, smaller profit margins have led to an increased interest in service cost minimization.

We consider the following cost factors:

- Inventory holding cost
- Replenishment cost
- Shortage penalty cost or backorder cost
- Disposal cost

The way in which the penalty cost is modelled differs from one situation to another. At LOPCS (Philips), for instance, it is not possible to order parts after the beginning of the final phase. When out-of-stock situations occur, alternatives for fulfilling demands are sought. In general, if the part under consideration is functional and no substitute for this part is available, the only alternative is to offer the customer a new currently produced comparable appliance at a reduced price, the so-called ‘commercial’ solution. Hence, a penalty is incurred every time a demand occurs for a part that is out-of-stock. In other situations, when it is possible to order parts during the entire end-phase, we do not allow lost demands and the penalty for a backorder is proportional to the length of the backorder time.

We consider both a discounted and an undiscounted cost criterion. Since, as aforementioned, the final phase is typically very long, sometimes more than 10 years, we consider the discounted cost criterion to be the most appropriate one. However, in some of the situations that we consider (Chapters 2 and 4) we have not been able to derive the presented results under a discounted cost criterion, and hence we resorted to the undiscounted cost criterion. We remark that in those situations, a discount factor can be incorporated into the analysis, although not theoretically entirely correct, by changing some of the cost components in the model. In the well-known EOQ-formula, for instance, a discount factor multiplied by the price of the part is added to the ‘true’ holding cost factor resulting from renting warehouse space, lighting and heating the warehouse, order handling, etc. References about how to set the holding cost factor and the discounting factor in a discounted cost model are Aucamp [1], Christensen and Fryman [12], Singhal and Raturi [57] [58] and Corbey and Jansen [14]. Many authors have used this approach of adding the interest cost to the holding cost factor, see for instance Naddor [48], Peterson and Silver [56], and Tersine [63]. We remark that these authors also suggest to model the obsolescence cost in the same manner, that is, by adding a fixed obsolescence
factor multiplied by the price of a part to the holding cost factor of that part.
We strongly oppose that approach of incorporating obsolescence cost into the
model. The interest cost is distributed ‘fairly’ among all parts in stock, by us-
ing the above described approach, since the opportunity loss associated with
ordering a part is proportional to the price of that part. In order to distribute
obsolescence cost fairly, however, a distinction between slow-movers and fast-
movers has to be made, and the remaining planning horizon until obsolescence
has to be taken into account. Clearly, slow-moving parts with small planning
horizons should be ‘punished’ more than other parts with comparable prices.
That is, modelling obsolescence cost should result in stocking (relatively) more
fast movers with large planning horizons and less slow movers with small plan-
ing horizons. This will certainly not be accomplished by adding a fixed cost
factor times the replenishment cost of any component to the holding cost fac-
tor. We model obsolescence ‘correctly’ by considering finite planning horizons
and modelling the disposal cost as a separate factor.

We assume that there is a deterministic finite planning horizon, correspond-
ing to the length of the final phase. In the main part of this thesis, demand
during this final phase is assumed to be driven by a Poisson process with a
fixed rate. In Chapter 5 we consider more general demand processes.

1.2.1 Closed-form or graphical
As explained above, the goal is to determine ordering policies that minimize,
at least approximately, the total expected cost. Out of practical considerations,
we also want these developed policies to be both easy to understand/implement
and easy to calculate. Preferably it should be possible to either represent the
(nearly) optimal policy graphically or to characterize its parameters by closed-
form formulas. The advantages of a policy that satisfies one of these criteria
is that it is very easy to recalculate the optimal policy if one or more model
parameters change, either using the graphical representation or a calculator,
respectively. It is also easy to perform a ‘What if’ (sensitivity) analysis, using
either the graphical presentation or a spread-sheet software package (present
in almost any firm), respectively.

Our desire to derive simple policies, represented either graphically or by
closed-form formulas, does not mean that the analysis leading to these results
has to be simple. Indeed, just turning over the leaves of this thesis, one notices
that the analysis is sometimes fairly complicated. In our opinion the com-
plexity of the analysis used does not necessarily effect the probability that a
1.3 Summary

The remainder of this thesis consists of two parts. Chapters 2, 3 and 4 form the first part. Chapters 5 and 6 form the second part. For readers that are interested in one specific part or chapter of this thesis, we remark that all the parts and chapters are self-contained.

Before discussing the contents of Chapters 2 to 6, we first indicate the global contents of the parts. In Part I, we study the problem of controlling the stock of service parts in the final phase, if parts can be ordered during the entire final phase, but the price of these parts is lower at the beginning of the final phase than after that time. In Part II, we study the problem of controlling the stock of service parts in the final phase, if it is impossible to order parts after the beginning of the final phase. That is, we study final order situations. Next, we discuss the problems studied in Chapters 2 to 6 in more detail.

In Chapter 2, we study the situation where parts can be ordered at any time during the final phase, but are less expensive at its beginning. There is no setup cost for ordering and demands occur one at a time. There is a single (central) depot. We assume full backorder and a deterministic replenishment lead time $L$. We propose an ordering policy that consists of two parts: an initial order-up-to level effective at time 0, and a base-stock ordering policy during the planning horizon. We restrict ourselves to policies where the base-stock level is nonincreasing with time, which seems sensible since the obsolescence risk associated with stocking parts increases with time. We develop a method for calculating the optimal policy in this class of remaining time base-stock ordering policies.

In Chapter 3, we study the same problem as in Chapter 2, restricted to slow moving parts with small lead times. For these parts, we develop an ordering strategy that overcomes the computational complexity of the optimal policy developed in Chapter 2. As in Chapter 2, this ordering strategy consists of an initial provisioning and a base-stock ordering policy during the planning horizon. However, the base-stock level is restricted to be at most one. We propose a nearly optimal ordering policy of this type that is represented by simple
closed-form formulas. It is shown by numerical calculations that this policy is close to the optimal policy for most slow moving parts with small lead times if the planning horizon is large.

In Chapter 4, we extend the single depot situation of Chapters 2 and 3 with a number of repair kits. These repair kits also contain parts and are carried to a jobsite by repairmen. We develop a policy for reducing the number of repair kits that contain a certain part towards the end of the final phase, that is similar to the aforementioned remaining time base-stock ordering policy.

In Chapter 5, we study the final order problem, if service is provided to many customers, as in the Philips case, or many machines. The main result is the derivation of a close to optimal final order-up-to level, given by an explicit formula. Furthermore, we also determine ‘remove-down-to’ levels for service parts. These levels are used to reduce cost by removing stock before all service contracts have expired. The effect of introducing remove-down-to levels on the expected cost and the optimal final order quantity are shown. At the end of Chapter 5, we discuss the implementation of the results derived in this chapter at LOPCS (Philips).

In Chapter 6, we study the final order problem if service is provided to a single customer or appliance. We encountered an example of this in practice at a company that sells gas turbines, reciprocating compressors, and centrifugal compressors. This equipment is highly specialized. Indeed, the same Gas Turbine is never sold to more than one customer, since the composition of the gas is never the same, and many customers buy only one piece of equipment. This company allows its customers to place a final order for service parts when it stops supplying service parts. Hence, we focus on one customer with one appliance. The customer plans to use this appliance up to a fixed horizon. In case of a shortage, two types of out-of-order cost are incurred. A fixed cost is incurred when the shortage occurs, and a variable cost rate is incurred during the remaining time up to the fixed horizon. We present a method for calculating nearly optimal final orders for problems with large out-of-order costs.