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On the use of installed base information for spare parts logistics: a review of ideas and industry practice

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Abstract

Demand for spare parts is often difficult to forecast using historical data only. In this paper, we give an overview of installed based information and provide several ways in which installed base forecasting can be used. We discuss cases of installed based forecasting at four companies and list the issues involved. Moreover, we provide some models to assess the value of installed base information and conclude that forecasts of spare parts demand and return can be made considerably more timely and accurate by using installed base information.

Keywords: Installed base; spare parts; forecasting; inventory control; service logistics

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Introduction

It is well known that spare parts management is difficult because the parts can be expensive, their demand is highly erratic and intermittent, yet their shortage costs can be considerable (see e.g. Aberdeen Group, 2003). Moreover, spare parts typically carry high obsolescence risk due to their specific functionalities. Consequently, service logistics companies often have difficulties in striking the right balance between inventory holding, stockout and obsolescence costs while offering competitive service contracts.

Much could be gained if demand for spare parts could better be forecasted. Although there is a wide literature on time series forecasting these methods are not always successful. First of all, parts and products exhibit a lifecycle pattern with a initial growth, maturity and a final decline phase. Secondly, actual customer demand may depend on many local factors, very much depending on which systems the customer employs, which type of contracts he has, how they have been maintained, and what the actual states of his systems are. Accordingly, it makes sense to consider demand forecasting using all available information on the so-called installed base. Although this idea seems straightforward, it is not that easily realized in practice as much information needs to be maintained and often companies do not have access to it. Moreover, the scientific research on installed base forecasting is limited and the term is pretty scarce in the operations literature.

One could say that installed base forecasting is a kind of causal forecasting, in the sense that the forecast is not only made on the historic demand data but also on data about the installed base.

The idea to relate forecasts to the installed base was already mentioned in the forecasting of new product adoption by Brockhoff and Rao (1993) and later followed by marketing researchers. For spare parts it was mentioned shortly by Cohen et al. (1990), as a kind of updating of forecasting, however, without further analysis. Auramo and Ala-Risku (2005) discuss installed base information for service logistics, but the main focus is on getting the installed base information from various sources. Jin and Liao (2009) discuss inventory control in case of a stochastic growing installed base and assume the data is available. Jalil et al. (2010) highlight the potential economic value of installed base data for spare parts logistics. They also discuss various data quality issues that are associated with the use of installed base data and show that planning performance depends on the quality dimensions. They discuss an implementation with IBM. From these studies we conclude that the scientific literature lacks a good overview on what installed base forecasting is, how it can be used and what are its pros and cons. In this paper, we try to fill this gap by giving an overview of ideas and relating them to the industry practice.

The remainder of the paper is organized as follows. In section 2, we define the concept of installed base, indicate what kind of installed base data is relevant and how it can be collected. Moreover, we also discuss the actual practice of installed base forecasting, as observed with a number of companies which participated in a project on service logistics. We also discuss the obstacles with maintaining good quality data. In section 3, we indicate how installed base information can be used to make better forecasts and how that effects spare parts stocks. In section 4, we analyze the value of installed base forecasting in two cases, being an expected and a reported demand drop. Next we consider the effect of errors in the installed base data. We finish the paper with overall conclusions on installed base forecasting.

2. The installed base and the demand for spare parts

2.1 The installed base and the service network

Definition of Installed Base

The installed base is usually defined as the whole set of systems/products a company has sold and which are still in use (see Longman, 2007). Here we would like to elaborate on this definition and make explicit that the original equipment manufacturer (OEM) need not be the organization which provided the after sales services. Therefore, we define the installed base as the whole set of systems/products for which an organization provides after sales services.

Examples are the set of computers Dell has sold under its name, the airplanes manufactured by Airbus, the power plants positioned in remote locations by Wärtsilä, etc. The installed base of these systems/products is likely to need maintenance and spare parts in order to continue functioning. Thus, OEMs have maintenance or service contracts with the user either directly or through intermediary parties.

Although our exposition will be valid both for products sold in a consumer market (e.g. consumer electronics) and for equipment sold in an industrial market, in the sequel, we will only focus on the industrial equipment, as the cost of maintenance, repair and overhaul (MRO) services are highest in the industrial market.

Service Network

The installed base is served by means of a service network consisting of stock locations keeping inventory of spare parts to either directly serve the customer or to replenish the next tier of forward stock locations, i.e., stock locations nearer to the customer. Proximity to the customer is mainly driven by the requirement of short delivery lead times especially when equipment down time costs are substantial. Cohen et al. (1997) discuss general spare parts networks and state that usually two or three level networks are used, like continental distribution centers, regional distribution centers, and forward stock locations and/or also consignment stocks at customer sites.

Demand for spare parts at an individual customer is usually low and erratic, so pooling of stocks is economically attractive but also increases lead times. In the case when spare parts inventory is pooled, emergency transports are used to satisfy urgent demands. Typically, service contracts require 2h, 4h, 8h to next business day deliveries. To avoid high inventory costs, companies stock almost all parts at continental distribution centers, and use limited stock assortment at regional and forward stock locations. For a good stocking decision at a forward stock location, it is important to know exactly the installed base for the clients in the neighborhood. In the special case where stock locations dedicated to a particular customer, the assortment will be in agreement with customer requirements. For stock locations serving several customers, customer requirements may be less readily available.

Maintenance Concept

The demand for maintenance services will also depend on the deployed maintenance concept. We may distinguish reactive maintenance and various categories of proactive maintenance; for an overview see Murthy and Blischke (2005). Observe that the maintenance policy has an impact both on the demand for spare parts, e.g. peak demands due to periodic replacement, and the amount of information available from the installed base, e.g. detailed data about the state of products in the case of condition based maintenance.

2.2 Main issues in spare parts logistics

Lead-times

We distinguish between the make to stock and make to (service) order situations, and as a consequence, between transport and manufacturing lead times. The transport lead time is the time needed to bring a part from a depot/stock location to a customer, and these lead times range from hours to weeks, depending on the transport characteristics and distance. The manufacturing lead time refers to the time it takes to source and produce a part according to the requirements, and bring it to the service network. Manufacturing lead times can be much longer (e.g., up to two years), as the manufacturing of a spare part might require production of new moulds or special set-ups to start production. The transport lead time is important for deciding on the stocking location of the spare part.

In Europe as well as in the US, there are efficient express companies, able to deliver parts to main cities within 24 hours (but not to all cities, and often not to islands). A single central stock location for the whole continent may be enough even when there are hundreds or thousands of customers. In this case of make to stock, the main concern is to determine the number of spare parts to be kept on stock to satisfy demand within the manufacturing lead time. Hence, a forecast of the spare parts demand within this lead time is needed.

However, if down time costs are high, spare part delivery lead times of a day are usually not acceptable. In that case one has to balance the stock out (downtime) costs with the inventory holding and obsolescence costs. When stock out costs prevails, one can store the parts close to the customer using regional depots or forward stock locations, or even at the site of the customer. These stocks can be re-supplied from a central stock. In this case forecasts are required only within a very short transportation lead time.

Demand Characteristics

The demand for spare parts is usually intermittent, erratic and slow moving. As a result, little data is available to perform forecasts based on time series analysis (Eaves and Kingsman, 2004), so demand is faced with a substantial level of uncertainty.

This issue is aggravated with a number of additional factors: First, hedging for uncertainty by means of safety stocks would often result in excessive costs, as parts can be very expensive; see for example Porras and Dekker (2008). Second, servicing an installed base may require several thousands of distinct parts (Van Jaarsveld and Dekker, 2010), so that investment in spare parts inventory is already costly given the sheer number of different items. Third, given the shorter life cycles of products and their parts, the spare parts inventory in the network also represents a substantial risk, due to high rates of obsolescence (Cohen et al., 1997).

Information Sharing

Another complicating factor is the fact that spare part inventories are not optimized. Although there are opportunities to pool spare parts inventories among different service providers and customers, usually, the service supply chain parties are not sharing information on installed base, inventories and demand (Veenstra et al., 2006). Reasons include competition between OEM and service providers, and the perceived strategic value of information about the installed base and spare parts demand.

Product Life Cycle Phase

Finally, we like to mention that demand for maintenance and spare parts goes through a number of phases. For instance, in the end-of-life phase, production of a part stops, because the demand has dropped or the manufacturer has switched to another technology. We will elaborate on product life cycle aspects in the next section.

2.3 The life cycle of products and parts

In order to identify installed base data elements which can be used as causal factors in spare parts demand, we need to model the demand for spare parts in a dynamic way.

First of all, the development of spare parts demand is related to the dynamics of market demand for products. The adoption of products in the market has been described by Bass (1969) in his seminal paper using a diffusion model, and in such a manner, it describes the growth and decline of the installed base. In our study of installed base data, we have observed this development, and we confirm the observations as displayed in Figure 1. Figure 1 shows that in the product life cycle, three phases can be discerned: initial phase, mature phase, and end-of-life phase. The unit of installed base size is number of items, the unit of demand for product, demand for spare parts, and for product returns is equal to number of items per time unit.

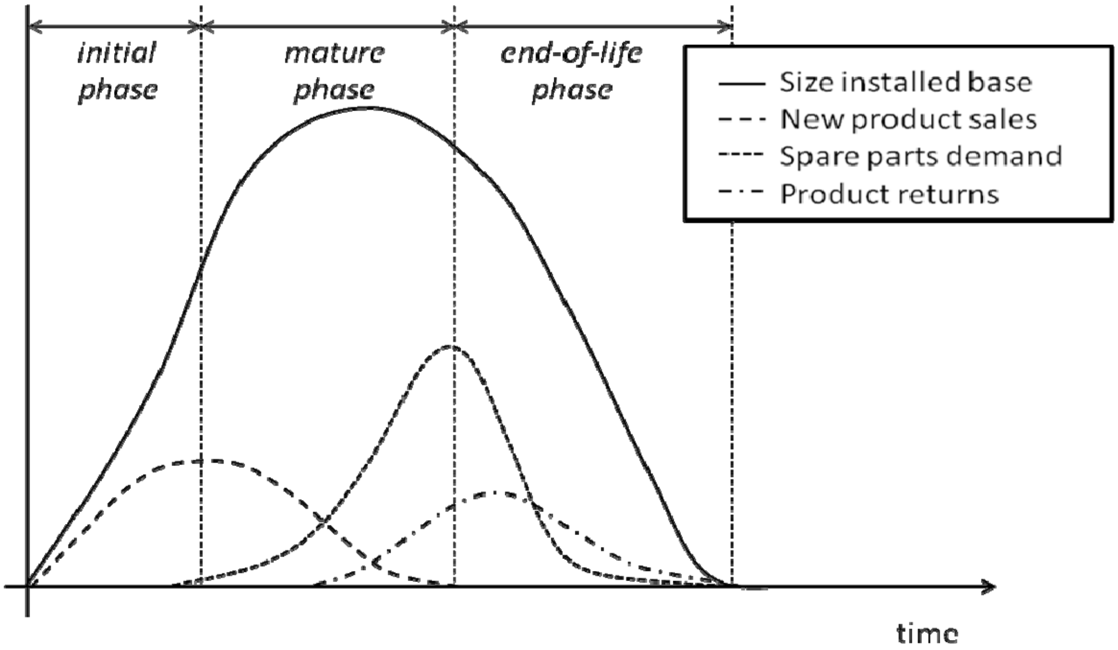

Figure 1. Installed base size, demand for product, demand for spare parts, and product returns (adapted from Inderfurth and Mukherjee, 2008).

By modeling the growth and decay of spare parts demand during its life cycle, (Moore, 1971) developed a forecast method. A stream of more recent contributions addressing the life cycle of service parts tend to focus on the final order or the last time buy; see for example Fortuin (1980); Spengler and Schröter (2003); Pourakbar et al. (2010) and references given there. These papers acknowledge the life cycle of spare parts demand, but do not describe it in a comprehensive way. Instead, the papers focus on the demand for spare parts after production of the spare parts has ceased. The "Life Cycle Mismatch" (Solomon et al., 2000), i.e. between product life cycle and demand for spare parts life cycle, occurs when one compares product sales and spare parts demand; see also Figure 1. We shall argue that the size of the installed base, together with the distribution of product or spare part life, provides a more comprehensive explanation of demand for spare parts.

As discussed above, the demand for spare parts will follow the demand for the complete product, but with a delay. Initial demand for spare parts may occur in a rather early stage, due to product quality problems in the beginning of the product life cycle. However, demand for spare parts due to the deterioration of the product while in use and random failure will occur throughout the life cycle of the product.

In the end-of-life phase, after production of the part has ceased, one has to estimate the spare parts demand over the remaining service period. This period can be up to decades for some equipment, like airplanes. Thus, a forecast on how many parts are needed is essential to determine the size of the final production run. One may also need to incorporate the availability of returned parts to meet the "last time buy" demand. High value of the parts may trigger quicker out-phasing of parts as compared to low value parts, because high maintenance cost will trigger new purchases. Therefore, the value of the spare parts has an impact on the product life cycle as well.

Secondly, demand for spare parts is triggered by the deterioration, and ultimately failure, of product performance. The deterioration of a product or its parts occurs during the use phase in the life cycle of an individual item. There is a substantial literature on forecasting deterioration and failure based on product monitoring and diagnostics, either during inspections and maintenance on site or from a remote location. For a review on maintenance policies for deteriorating systems, we refer the reader to the review paper (Wang, 2002). We may conclude that data about the technical state of the product has an impact on the demand for spare parts, and that such information can be used to forecast parts demand.

2.4 Management of installed base information

During the complete lifecycle of a product or service part, information is generated and used (Parlikad and McFarlane, 2007). Therefore, we follow the lifecycle of a product/system in order to categorize relevant installed base information: (a) the design/purchase phase; (b) the use/maintenance/upgrade phase; and (c) the end-of-life phase.

(a) Design/purchase phase

In this phase, product information is available from the design specifications, which include expected product life and time to failure of service parts (Hameri and Nihtilä, 1998). Purchase information is usually available in case of the first purchase from an OEM, unless the sale is done through a third party, like a reseller, or when the OEM is not involved in the recovery and sales of the used product. In case of aircrafts, aviation authorities typically require OEM involvement in declaring a plane safe to fly. In many other cases, where safety requirements are less dominant, the OEM may give warranties only under of the condition that the product is serviced exclusively by the OEM (Blischke and Murthy 1992).

(b) Use/maintenance/upgrade phase

The information about the location of a system is important in case of fast service delivery requirements, e.g., spare parts which have to be delivered in 2, 4 or 8 hours. Yet the customer may relocate his systems without informing the OEM. In that case, the information gets outdated with possibly negative consequences. Moreover, there is an important category of technical systems which are mobile, like ships, planes, trucks, trains and cars. They may need immediate maintenance on a remote site, which creates complex demand for spare parts. Airlines typically make agreements with local stockholders to provide spare parts. Truck manufacturers set up a whole network of dealers who can provide service in the areas trucks are used. This is usually a continent or a large island group.

The information about the usage of a system may be relevant for the need for spare parts, e.g. most airplane maintenance is fly hour driven. Yet the environment may also affect spare parts usage, e.g. military tanks operated in Iraq needed many more engine filters than the same tanks operated in the United States. Equipment suffered many more failures in desert areas of Afghanistan than in Europe.

Monitoring information can be obtained by electronic sensor and communication equipment which has reduced in price considerably. Remote monitoring allows identifying upcoming failures, or it may signal already occurred failures, with some kind of diagnosis, so that service engineers can be dispatched with the right parts to correct the failure. Modern airplanes employ this technology to shorten downtime while they are on the ground. The importance of this for spare parts demand is that one can anticipate demand for spare parts and adapt delivery planning accordingly.

Maintenance information is relevant when we try to predict parts needed for planned maintenance. Moreover, upgrades may change the part configuration of a system, with a consequence that other parts are needed for repairs. Also, customer requirements can be assessed through contract parameters and customer requests for upgrades etc.

(c) End-of-life/recovery phase

After abandonment of a system, spare parts are no longer needed and they can be disposed of. An OEM should however, receive information about such abandonment. The management of the installed base of older systems is complicated by the fact that the relevant installed base information may be scattered throughout different legacy information systems.

On the other hand, the returned product can be a source of information, providing input for new product releases. It also changes the parts yield if we would disassemble the system after abandonment. For example, IBM transports old computers to their remanufacturing plant in order to retrieve spare parts, but they often find out that these already had been replaced by other parts (Fleischmann et al. 2003). To support proper disposal of products and parts at the use by a customer, product information, including usage and maintenance history, can be logged and read upon return to product recovery centers (Parlikad and McFarlane, 2007).

2.5 Company Cases

During a project on service logistics, we were able to obtain information about several company practices. Below we present some company cases on storing and maintaining installed base information.

Fokker Services

After 1990, the Stork group took over the service for the Fokker planes (the turbo props F50, F60 and the jets F70 and F100) and created a new company, Fokker Services. It became type certificate holder and therefore responsible for the safety of the Fokker planes. Fokker is not doing maintenance itself, but provides spare parts, repairs of rotable spare parts and technical advice. It provides special service contracts, like the ABACUS program where participating companies get rotables (that are spare parts which can be repaired) against a fixed fee per flying hour. For this program it was essential to set-up installed base forecasting as the number of planes under contract and their location showed substantial changes over time. We contributed to this set-up.

We remark that although the Fokker install base consists of a mere 400 planes, this set-up of an installed base forecasting constituted a considerable effort, as the installed base was already 20 years old, yet for safety reasons proper data collection had taken place all the time. As the service period of a plane is very long (up to thirty years of which some twenty years after the end of production), there were many configuration changes to the equipment. Moreover, the equipment was not standardized and the relation between demand and flying hours had to be established, which complicated the analysis. So setting up installed base forecasting for an already existing installed base is difficult but it appeared possible if proper data has been collected. Moreover the introduction of install based forecasting pays off quickly if there are many changes in the installed base..

IBM Spare Parts Logistics

IBM is a large multinational fabricating high end computers. It offers service to its geographically dispersed customers in the form of various service contracts. To supply the parts it applies a sophisticated distribution structure with at the top continental DCs and at the lowest level forward stock locations. The latter is typically used to supply critical maintenance contracts with a very short response time.

Installed Base Data at IBM

IBM maintains installed base data to support forecasting, inventory planning, and execution in spare parts logistics for the customers that possess committed repair services (CRS) contracts from IBM. The CRS contracts are premium service level agreements that guarantee higher availability and repair time commitments (e.g. 2, 4 or 8 hours) for the installed machines. The primary source of installed base data are customer data collected by the IBM sales organization. Installed base data is maintained at machine level; information such as machine type, nearest stock location, installation date, type of service contract, customer location information, and spare parts delivery time is recorded for each machine serial number.

The part installed base data is deduced by combining machine installed base data with the machine's engineering bill of material (BOM), which contains the details of all installed parts on each specific machine serial number. In addition, machine's engineering BOM also lists the part criticality for the machine’s availability. The combination of these two data provides the complete list of the parts installed at each customer location and their criticality for the machine’s availability. Further combination with maintenance request handling data provides the maintenance and update history of each installed part at the customer location.

At IBM, installed base varies from a few hundred installs to more than 20,000 installs for various machine models. In the next sub-section, we discuss the use of installed base data for demand forecasting at IBM during the entire service life cycle. We should clarify that in addition to demand forecasting, installed base data is also used to derive other input parameters (such as transportation costs and possible delivery options) for spare parts inventory planning at IBM. During spare parts logistics execution, installed base data is used to determine customer entitlements for service delivery (Jalil et al. 2010; Draper and Suanet, 2005). Fleischmann et al. (2003) study the interaction of spare parts logistics and asset recovery at IBM and highlight the benefits of combining installed base data with extrapolation methods for product return forecasting.

Demand Forecasting at IBM

IBM offers after sales service as soon as a new machine model is introduced. A new machine model may consist of new and existing parts. During the machine’s introduction phase (initial load period), when no historical demand data is available for newly introduced parts, the decision to stock spare part types at a specific forward stock location is based on the estimated failure rates, spare part criticality, and projected installed base growth in the vicinity of the forward stock location (Draper and Suanet, 2005). For existing parts, the stocking decision is based on projected installed base growth and part demand rates of the comparable machine models.

Once the machine model enters the normal load (mature demand) phase, the historical demand data becomes available. Due to the slow moving and intermittent nature of demand, the available historical demand data is still not sufficient to forecast demand for each postal code - contract type. To counter this, IBM aggregates the entire country demand and utilizes extrapolation method to derive demand forecast at country - contract type level. The postal code level forecast is obtained by disaggregating the country level - contract type demand forecast according to each contract type installs present at each postal code. The details of this forecasting method are discussed in Jalil et al. (2010). The derived demand forecasts are used as an input for the spare parts inventory planning application that determines base stock levels for forward stock locations (Erke et al. 2003).

At IBM, the declining phase is defined as the period between end-of-manufacturing and end-of-service. It generally assumed to be seven years (although it may vary depending on the product type). During declining phase of the service life-cycle, installed base size decreases continuously due to service contract expirations. For demand forecasting during this phase, extrapolation based demand forecast is adjusted proportionally to the projected decrease in installed base size and potential spare parts harvesting and reuse opportunities from the reverse logistics operations (Draper and Suanet, 2005).

It is clear from the above discussion that IBM uses installed base data to support demand forecasting since its customer base is geographically dispersed, constantly changing due to short product life cycles, and requires responsive service. The higher level of detail provided by installed base data enables IBM to incorporate these aspects in demand forecasts and subsequently plan for responsive spare parts logistics services.

IHC Merwede

IHC Merwede is a worldwide leading shipyard for dredging ships. A dredging ship can be considered as a factory on a ship, because a lot of complex systems are required to do the dredging. Dredging sand usually induces a lot of wear out on equipment. As dredging projects are usually time constrained, there is a high emphasis on providing replacement parts on time. Yet the weight of these parts (up to 6,000 kg) often prohibits transportation by regular express companies.

Although IHC Merwede concentrated on building dredging ships in the past, it has made a move towards a more service oriented company in recent years. Hence it has set up a worldwide network of parts depots in order to serve the ships. Moreover, it has developed models to predict the amount of wear out as a function of the soil to be dredged, so depending on the state of the ships and the environment they operate in, IHC can give advice on pending failures and the need for parts. IHC also keeps track of the regions its ships move to in order to adapt their part stocking decisions in the depots in these regions. Yet not all customers cooperate as there is a fear on sharing data (Veenstra et al., 2006). We conclude from this case that even in case the install base is moving and failure rates depend on the environment, it is possible to set-up install base forecasting and also in this case it is worthwhile.

Voestalpine Railpro
Voestalpine Railpro is a railway service parts provider in the Netherlands. It works as intermediary for civil railway contractor to provide parts, as it has unique transport capabilities to move them (e.g. rail of 360 meters). The Dutch railway assets are state-owned, but management is done by an independent infrastructure manager, ProRail, a governmental company.

The problem with the railway assets is that it constitutes an asset base built up over more than 100 years, it lies all over the Netherlands and its maintenance has not well been recorded. Accordingly there are many problems with installed base information. For example, if a certain piece of track is to be maintained then Railpro may be faced with a large demand for specific parts, which is difficult to fulfill, because the demand for these parts is in other years very low. If it would have known which parts are installed in that piece of track, it could have predicted a higher demand for those parts and made sure there were enough stocks. Next Railpro also faces problems with supplying parts for unique objects, because these parts have a low turnover and high costs, so it is not economical for her to stock them. So if from monitoring information it could get indications that they should be replaced in the near future, then it would only need to stock them during a limited time, making it much more economical for her to provide timely service.

It will be clear that because of the complex organizational structure and a very old, distributed installed base, obtaining correct installed base information is very difficult. In fact it has been suggested that setting up an installed base information system for another railway, Deutsche Bahn, would costs tenths of millions. Moreover, in the split up of the Dutch railway company, some ten years ago, sophisticated maintenance contracts had been set-up, but one forgot to specify conditions on how to maintain the quality of installed base information. From this case we conclude that setting up installed base forecasting may be very difficult in case of an existing and old installed base even though there may be large potential for improvement.

2.6 Problems when keeping track of the installed base

We observed many problems with the aforementioned companies while keeping track of the installed base. Major issues are:

- Equipment is usually complex, consisting of several hierarchies, like subassemblies and parts. Hence one does not only need to keep track of the equipment, but also of its complete composition. So one has to apply configuration management, which is a difficult task, especially if installed base is of large size and consists of multiple equipment types. For example, IBM maintains installed base data at machine level for each machine model and combines it with specific machine's BOM to deduce part installed base data (see IBM case in Section 2.5).

- Although OEMs strive to make standard equipment, customization makes it specific. Next, equipment specifications are also likely to change in time due to technical improvements or maintenance. Consequently, OEMs need to keep track of all these changes (see end-of-life discussion on IBM in Section 2.4, Fokker Services and Voestalpine Railpro cases in Section 2.5).

- The level of control of an OEM on the equipment composition varies. In the airplane industry, safety is a dominant issue and changes can only be made if the OEM approves it. In other situations the OEM can maintain information by offering maintenance, but often third parties or the maintenance organization owned by the customer perform the maintenance. During maintenance the equipment composition may change. Third party maintenance providers do not always share that information with OEMs (see Voestalpine Railpro case in Section 2.5).

- OEMs do not have information on how and where the owner uses the product, unless the owner has a service contract. In many cases, owner moves the product from one place to another without informing the OEM. Therefore, the manufacturer OEM continues to forecast demand based on wrong installed base information until a product failure occurs (see IHC Merwede case and Jalil et al. 2010).

- Moving assets, like planes, ships and trucks need the spare parts at the locations where they currently are. This poses additional challenges since the installed base in a given geographical area is constantly changing (see Fokker Services and IHC Merwede cases in Section 2.5).

- Some OEMs do not sell their products to final customers but use wholesalers and resellers. As a result, OEMs often have no information on the final buyer, unless the buyer registers with them. This is especially valid for consumer products.

- Lack of communication between different organizational functions at OEM also leads to installed base tracking errors. For example, in many companies installed base data is collected during product sales by the company sales office. The sales office only records the owner's purchase office, whereas the product may not be ultimately installed at the same location by the owner (see Jalil et al. 2010).

The difficulties in acquisition and management of installed base data may result in a situation where there are data quality errors in acquired installed base data. The reasons for installed base data quality errors at IBM and their impact have been studied by Jalil et al. (2010). We shall discuss the results of their study in Section 4.

3. How to do installed base demand and return forecasting?

In order to position installed base forecasting, we would like to differentiate it from its basic alternative, vz. black-box forecasting solely based on historic demand data. That is, installed base forecasting uses historic demand data and combines it with relevant information about the installed base to make demand and return forecasts.

Installed base forecasting consists starts with the following step

Establishing demand and return for each piece of equipment

Given the installed base development and the history of failures and part demands, one establishes a statistical relation between the two. From the historic demands one should filter out the parts needed for preventive maintenance, as these can be planned separately. If the equipment is in its design stage, one can predict the spare parts demand through failure prediction models, like the parts count method. Such methods are not that accurate, but they do give some indication. Once the equipment has been installed, one can improve the failure rate estimation and then the spare parts need per product accordingly. An example of such a procedure is given in Aronis et al. (2004). So in this way one obtains an estimate of failures and demand for spare parts per installed base unit and per time unit. A more sophisticated forecasting can be made by relating the demand not only to calendar time, but also to the use and preventive maintenance of the systems, like flying hours or starts/stops, as that may be a more predictive measure. In this case one also needs registration of the use and maintenance of the installed base.

After having done this step, we consider three possible ways in which that information can be used. forecasting demand at aggregate level and at a customer (disaggregate) level and finally, forecasting parts retrieval from equipment returns.

Forecasting demand at aggregate level

Both in case of an increasing installed base (sales of new products) as well as in case of a decreasing installed base (abandonment) one may adapt parts stocks based on installed base information.

In case of an increasing installed base one can store increased amounts. Recall that the alternative is to use historical data on demands, but those estimates are likely to lag. In case of a decreasing installed base the opposite occurs. Although historical demand for parts may still be at a high level, the anticipated drop in the installed base may lead companies to lower parts stocks in order to avoid obsolescence. In case of an end-of-life production run one may estimate how long customers are likely to use the product as a base time horizon to predict spare parts demand over.

Forecasting demand at disaggregate level

Next we consider forecasting at a disaggregate level, viz. at the level of individual or groups of customers. These changes are likely to be more frequent and much larger (relatively) and thus have more impact on disaggregate parts stock levels.

In this case installed base information is often channeled through service contracts between the OEM and the customer(s). In case the service contract requires the stocking of parts close to the customer, it is important to know which and how many parts are needed. This can directly be derived from the customer installed base and the earlier derived relation with parts demand per item of the installed base. One often only stocks critical parts, as that is most cost-effective and this reduces the installed base information requirements.

Using installed base forecasting is especially worthwhile if there are changes in the installed base.

We distinguish two cases: changes in the installed base, planned and reported before they occur and changes in the installed base, reported only after their occurrence. The first case occurs when the customer announces the abandonment of his systems or when contracts are to expire. Krikke and Van der Laan (2009) present a case where a customer is planning the outphasing of so-called circuit boards. The dismantled circuit boards may be used as spare parts for the remaining ones. The authors develop a time-varying policy indicating how many stocks of spare circuit boards should be kept and whether the removed ones should be retained as spare. The advantage of install base forecasting in this case is that one can act before there is a change in demand. In the latter case one can only adapt quicker than in case of black-box forecasting based on historical demands.

Another way of using installed base information is the planning of spare parts in case of planned preventive maintenance. If for each piece of equipment in the installed base, maintenance packages have been defined and for each package the spare parts has been laid down, then from the planning of the maintenance and can also directly derive in an MRP-type of way the need for spare parts. Such an automatic way, however, seems seldom applied, as the parts need in preventive maintenance is often variable. The reason is that equipment is inspected and parts are not always replaced, but depending on their condition.

Another possible way of installed base information is in case of (remote) monitoring equipment performance. From such information one can derive whether failures are likely. From the installed base information we can next derive which parts may need replacement. This information may be used to stock parts closer to the equipment, but none of the companies we studied was systematically changing its stocking decision as a result of that information.

Forecasting part retrieval from equipment returns

The final use of installed base information is in parts retrieval in case of equipment abandonment. From the installed base information the OEM can predict which parts might be retrieved. These parts can then be used as spare for other systems. IBM is actively following such a policy according to Fleischmann et al. (2003). Railpro also uses returned parts as spares, e.g. in the case of relays, but again it has problems with predicting the returns in advance, with the consequence that they have to keep more stocks than needed in an ideal situation. The case reported by Krikke and Van der Laan (2009), which was mentioned in the previous paragraph, is also an example of return forecasting using installed base information.

4. Quantifying the value of installed base information for spare parts inventory control

From the previous sections it is clear that keeping track of installed base information can be difficult and a time-consuming task. So, the issue is whether it is worthwhile. We do not want to make a comprehensive model balancing the two, since that would depend too much on case specific aspects regarding collecting and maintaining installed base information but we want to give some insights and quantify the advantages of installed base forecasting for spare parts inventory control.

Although installed base information can also indicate an increasing need for spare parts, we will focus on decreases in demand, as it seems more difficult to get rid of stocks than to make or buy them.

We will consider three cases, viz.

1) A comparison of installed base forecasting in case of a demand drop compared to black-box forecasting with updates

2) A comparison of installed base forecasting inventory control in case of a planned drop of demand compared to a later reaction on lower demand rates.

3) An analysis of the consequences of errors in installed base on spare parts inventories.

Case 1

In the first case, installed base forecasting leads to a quicker adaptation to lower demand rates. Upon notification of installed base changes one can rerun the inventory models with the adapted demand rates. As a result one may obtain other inventory targets. Superfluous inventories may need to be removed, run-down or scrapped. In case of black-box forecasting with updating one will learn the new demand rates as well, but we like to remark that for slow movers this may take a considerable amount of time, with high overstocks as consequence. To illustrate this point, we provide the following example.

Example: Suppose that the demand of a slow moving item follows a Poisson process. Moreover, assume that the Poisson demand rate drops from λo=5 units per year to λ_1=0.5 units per year. Figure 2, shows approximately how much time it takes for exponential smoothing to converge to the mean interarrival time under the new demand rate.

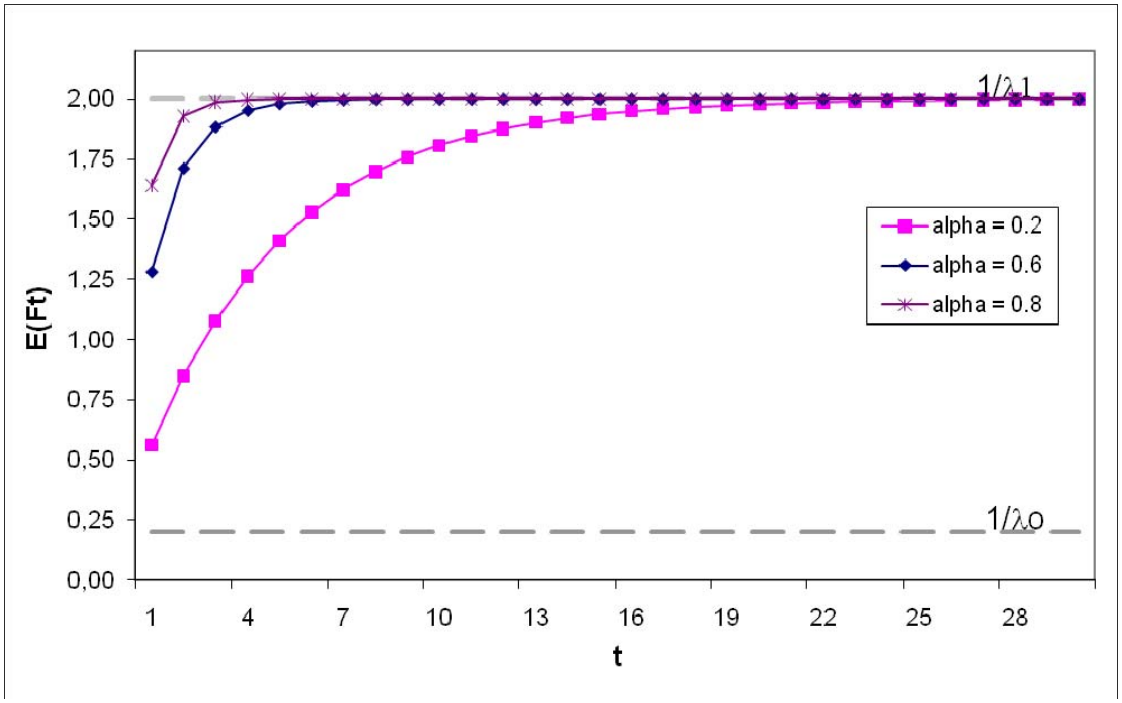

Figure 2. Convergence of mean forecasts to the real mean

We consider the following forecasting scenario: Whenever a demand occurs the interarrival time is smoothed. We assume simple exponential smoothing with the smoothing parameter α. Thus, t=1,2,3,… denotes the total number of demand arrivals to the system and F_t denotes the one step forecast of the interarrival time. Therefore, upon each arrival the demand rate can be updated base on the forecasts over the interarrival time history.

Moreover, we assume that the system is in steady state under the arrival rate λo before time t=0 and at t=0 the demand rate drops to λ_1. Thus, before t=0 forecasts has the mean 1/λo and we let F_0= 1/λo. We are interested in the convergence of the expected value of forecasts generated after the drop occurs to the new mean interarrival time $1/\lambda_1$.

Figure 2 presents different convergence behavior for different smoothing parameters. For example, for α=0.2 it takes 13 arrivals for exponential smoothing to generate forecasts having less than 5% deviation from the new mean interarrival time 2, i.e., $E(F_{13})$ = 1.901 and 100*(2-1.901)/2= 4.95%. Given that the arrival rate is λ_1=0.5 units per year this means that less than 5% error convergence takes on average 6.5 years. As expected, the convergence is faster as the smoothing parameter gets larger. For α=0.6, it takes on average 2 years ($E(F_4)$ = 1.954) to be within 5% error margin and for α=0.8 the same figure drops to 1 year ($E(F_2)$ = 1.928). We shall also mention that for α=1 $E(F_t)=1/\lambda_1$ and therefore, convergence is immediate. Yet the smoothing parameters we have encountered in industry are typically below 0.5!

Case 2

For the second case an investigation has been done by Pinçe and Dekker (2009). They consider a continuous review inventory system of a critical service part with Poisson demand where the demand rate drops to a lower level at a pre-determined time point in the future. This type of nonstationarity in demand process resembles *partial obsolescence* or *full obsolescence* scenarios in practice. Contract expirations, generation upgrades or relocations of installed base can cause this type of obsolescence. Using installed base information and installed base forecasting can be instrumental in foreseeing this kind of sudden changes in demand rate. Yet, as we discussed above obtaining installed base information can be an expensive and challenging task. Thus, it is natural to ask how this information can be used to make better decisions and when it is worthwhile to put efforts to foresee the future more precisely.

When there is a large drop in demand rate it results in excess inventories. Since most of the critical service parts are specific products, in general it is difficult to salvage the excess stock of these specific products. Consequently, most of the excess inventories end up as obsolete stocks increasing holding costs and waiting to be scrapped at a great expense. Therefore, often in practice, the logistics managers dealing with critical service parts complain about obsolescence problem and looking for methods that help to minimize obsolete stocks.

Under the assumptions of one-for-one replenishment, full backordering and fixed lead times, Pinçe and Dekker (2009) propose a policy where the base stock level is reduced to a lower level before the obsolescence time in order to let the demand take away the excess stocks. They derive heuristic expressions for the expected total cost incurred during the transient period and propose an approximate solution for the optimal time to reduce the base stock level.

They show that for pre-determined obsolescence time, advance adaptation of the base stock level can lead to important cost savings. For example, their numerical study reveals that when the demand rate of a slow moving item drops to a positive level (i.e., partial obsolescence), the expected transient period total cost increases on average by 60% as a result of postponing the base stock level adjustment after the obsolescence time. The transient period total cost is on average more than doubled (the average increase is 133.04%) when full obsolescence occurs, i.e., the demand drops to zero. In the partial obsolescence case, the increase in the total costs is due to the increase in inventory holding costs. That is, after the obsolescence occurs, natural attrition of the excess stocks takes a long time under the diminished demand and in return the holding costs increase. For the full obsolescence case, the total cost increase is due to obsolescence or relocation costs charged against per unit of remaining excess stock after the obsolescence time. These findings show that even when base stock levels are adjusted right after the drop in demand rate the costs can increase significantly due to the slow moving character of demand. Instead, by using installed base information one can try to foresee the time of the drop in demand rate and then take prior actions to run-down the stocks before the drop occurs.

Pinçe et al. (2010) conduct an exact analysis of the same inventory system under a more general policy and for infinite horizon case. In their model, the policy consists of not only the base stock reduction time but also pre- and post-obsolescence base stock levels. One of their main findings is that ignoring obsolescence in stocking decisions leads to substantial increase in costs. They report that the total discounted cost increases on average by 197.7% when the decision maker wrongly assumes a stationary demand and uses a steady state base stock level where in fact the demand rate drops at a certain time point. They show that the cost increase due to ignoring obsolescence is significant even when obsolescence is not expected in the near future, e.g., the total discounted cost increases on average by 50% when obsolescence is expected to happen in 5 years. Moreover, the costs increase on average by 56.5% if the demand drops by 75%. The practical implication of these findings is that installed base information can be used to make mid- to long-term forecasts on the timing and size of the drop in demand rate. For example, for the products passing their mature phase, an OEM can use information on contract expirations, location, size and technical condition of the installed base to make the forecasts about the contract renewals, generation upgrades or equipment relocations by customers. Once these forecasts are established they can be incorporated in proactive control policies to reduce obsolete stocks while balancing availability

Case 3

For the third case Jalil et al. (2010) study the value addition enabled by the use of installed base data and the impact of installed base data quality degradation for spare parts inventory planning at IBM. The authors highlight that by using installed base data, the calculated spare parts stocking decisions become more accurate. The higher accuracy results due to the higher levels of detail in installed base data and leads to value addition.

In any practical situation, the collected data contain some levels of data quality errors. Installed base data is no different. The authors classify the types of installed base data quality errors into homogeneous and heterogeneous error categories according to the geographical context of installed machines. Homogeneous errors in installed base data occur at random and are assumed to be uniformly distributed throughout the geographical region. For example, a certain numbers of installs are missing or incorrectly listed in installed base data. Such errors may occur due to human and system error during data collection and entry process. Heterogeneous errors are associated with the specific business context of spare parts logistics situation and are concentrated in a specific geographical region.

The analyses performed by Jalil et al. (2010) reveal that the spare parts inventory planning method at IBM is quite robust to the homogeneous errors in installed base data. The robustness is due to the synergy between spare parts inventory planning and installed base forecasting method. By combining installed base data with extrapolation based forecasting, IBM derives geographical proportionality of demand forecasts over the entire geographical region. Spare parts inventory planning method uses the geographical proportionality of demand forecasts and combines it with the transportation and holding costs to estimate the geographical equilibrium points for stock placement. The overall geographical proportionality of demand forecasts is not disturbed by having the error as homogeneously distributed. Therefore, the value addition induced by installed base data is not negated by the higher frequencies of homogeneously distributed error.

The robustness of the inventory planning method is not valid in the case of heterogeneously distributed error. The geographical proportionality of demand forecasts is disturbed by having the data quality error as heterogeneously distributed. Due to which, the value addition enabled by the usage of installed base data is negated.

The spare parts inventory planning method at IBM allows for flexible servicing in a sense that full and partial lateral transshipments are allowed and accounted for during inventory planning decision.

According to the authors, above data quality analysis results only hold for flexible inventory networks that allow for lateral transshipments, since the geographical distribution of data quality error becomes relevant for inventory planning decisions in such networks. For any inventory network configuration that does not allow for flexible servicing via lateral transshipments, the robustness of inventory planning method (for homogeneous data quality errors) may not hold.

Conclusions

Present Issues in Spare Parts Control and Demand Forecasting

We may conclude that spare parts control requires a level of reliability in forecasting which cannot be met by time series forecasting methods. Important causes are the lack of demand data due to slow moving and intermittent demand, the changes in demand over time caused by product life cycles, the relatively long lead times in make to order situations, and the need for very short delivery times in supply from stock situations. The large number of distinct parts and the criticality of components in the systems of the customer contribute to the financial consequences of poor forecast reliability.

Managing Installed Base Data

Managing installed base data is challenging for a variety of reasons. The sheer size of the installed base, autonomous changes of product configurations, heterogeneity of products and customers, aged installed based information scattered in legacy systems, and difficulties in acquisition of the data are some of the factors the authors have observed that cause deterioration of the installed base data quality. Some companies deal with these issues by seriously investing in their installed base data, and this is driven also by other reasons, such as safety. Other companies may focus on their installed base of new product only.

Benefits of Installed Base Forecasting

We have observed a number of economic benefits of managing the installed base information and using it to enhance the reliability of spare parts demand forecasts.

IBM uses installed base information to incorporate the geographic positions of their customer base and the dynamics of their product life cycles in their forecasts. This is enabled by the high level of detail provided by their installed base data. The enhanced forecasts further support IBM in planning for responsive spare parts logistics services. However, lower levels of data quality need not always result in performance degradation in spare parts inventory planning. Homogeneously distributed errors in the installed base data does not result in significant performance degradation in the robust spare parts inventory planning used by IBM, while heterogeneously distributed errors results in significant performance degradation.

There are other possibilities to use installed base data to improve the reliability of forecasts. When the time and the size of a drop in demand can be foreseen, taking this information into account in stocking decisions and using proactive policy can lead to significant cost savings.

The savings in inventory and obsolescence costs indicate that there is a great incentive for service logistics companies to increase their efforts to collect and use more installed base information in their stocking decisions, although the extent of the benefits depends on the situation. Installed base information is particularly useful in managing expensive slow moving service parts for which it is very difficult to balance stockout risk with obsolescence risk.

In general, factors that contribute to the benefits of installed base forecasting are the size of the installed base, the characteristics of spare parts demand, the value and salvage price of the spare parts, the life cycle of the product, and the type of maintenance policy.

We conclude that forecasts of spare parts demand and return can be made considerably more timely and accurate by using installed base information, compared with forecasts only based on historic demand.

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